As If They Were Thinking:
New Aesthetics of “Thought” in Machine Intelligence

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Abstract

The present century has seen a boom in both artificial intelligence (AI) and biotechnology research, but it is mainly in the past decade that machine learning (ML) has been explored as a form of artistic expression. These art practices run in parallel with an emerging paradigm shift that problematizes default models of intelligence (the human brain, neuron structures, and abstract and representational thinking). How do artists manifest these shifts in computational media art, and how does art as a cultural institution reflect these transformations in technology and culture? We examine (1) the shifting cultural discourse concerning the nature of “intelligence”; (2) the diversity of computational models that challenge processes and values associated with the human brain; (3) scientific examples of sophisticated self-organization, from the molecular level to the super organismal; and (4) the aesthetic tendencies of eco-hybrid computational artworks engaging with new concepts of “thinking” and AI. To conclude, we propose an aesthetic and conceptual framework for artists working at the intersection of ecology, biotechnology, and AI, and call for an open ecology of machine intelligence that incorporates reciprocal aesthetics and planetary thinking into AI and ML.

Keywords

Aesthetics, Contemporary Art, Artificial Intelligence, Self-Organization, Biosemiotics, Unconventional Computing

Introduction

Artist and critic Jack Burnham declared in *Systems Esthetics* (1968) that the culture of his time was transitioning from object-oriented to system-oriented, arguing for art as an adaptive mechanism and cybernetic system that produces new information, rather than objects. Like cybernetics in the 1960s, research in artificial intelligence (AI) has inspired artistic exploration since the 1990s (Stephen Wilson 2002). The late 20th century witnessed biological research and computational living systems expanding from hardware and software into the realm of wetware, as the convergence of art and technology “has imagined, represented and mimicked, then simulated and manipulated living beings and systems” (Jens Hauser 2017, 264). In *Edge Life: Technoetic Structures and Moist Media* (2000), Roy Ascott stated that moist media, where bits, atoms, neurons and genes converge, will be the substrate for art of the 21st century. Ascott argued that this radical restructuring requires new intelligent architectures that function at the “planetary level of self-organising, self-aware systems,” in which the artist’s role is “to plant, grow and cultivate new forms, new structures, and new meanings.”

The 21st century has seen an unprecedented boom in AI and biotechnology research, especially machine learning (ML), a sub-field of AI that has attracted growing interest from the technological and cultural industries, but it is predominantly in the past decade that ML has been explored as a form of artistic expression. Echoing Ascott's statement, we ask: What new thinking models and architectures can be built by today's artists in relation to the convergence of biotechnology and ML? As we examine the underlying politics and assumptions around intelligence, what can be gained from expanding our human-centric, neuro-centric notions and better understanding diverse natural phenomena *as if they were thinking*? Beyond expanding artistic expression, we believe these investigations are philosophically and scientifically imperative, as they open more inclusive and ecological ways of thinking about the world and interacting in it.

It is largely in the past decade that ML has been explored through generative algorithms and opened new territory for AI applications in the creative industries. Artistic interest in ML took off after the development of generative adversarial networks (GANs) by computer scientist Ian Goodfellow in 2014. Shortly after his research was published, raw, untrained GANs and general ML toolboxes were made open source by different companies, including TensorFlow by Google, Torch by Facebook, and pix2pix by the Dutch NPO radio broadcaster (Artnet News 2018). The invention of new tools like Artbreeder and Runway ML have continually lowered the technical barriers, making GANs and other machine learning models accessible for artistic exploration (Fritz AI 2019).

We identified two major types of artworks that use ML: (1) Generative ML works: These works synthesize general classes of objects, images and textures (Refik Anadol, Robbie Barrat, Mario Klingemann, Trevor Paglen, Jason Salavon, Helena Sarin, Mike Tyka); musical composition (Hao-Wen Dong, et. al. 2017); literature with the advanced NLP techniques and language models such as GPT2 by OpenAI (Fritz AI 2018); and machine poems (Bei Liu et.al 2018) with NLP-aided network generation of poems from images. (2) Agent-based works with other ML models: These works create autonomous systems with artificial agents that manifest AI-based behavioral evolution. Ruairi Glynn's *Performative Ecologies* (2006–2010), Stephen Kelly's *Open Ended Ensemble* (2016), Sofian Audry's *For the sleepers in that quiet earth* (2019), and Ian Cheng's *Emissaries* (2015–17) and *Bag Of Beliefs* (2018–19). Artist and media theorist Simon Penny calls these works "embodied cultural agents" or "agents as artworks" and frames them as a "new aesthetic field opened up by the possibility of cultural interaction with machine systems" (Penny 1997).

The aesthetics of GANs, in particular, are best-acknowledged for their "visual indeterminacy" (Hertzmann 2020) and famous GAN-generated artworks, which have been auctioned by Christie's and Sotheby's. However, the aesthetics of GANs are often criticised as homogeneous and without artistic intention. Some artists, such as Sougwen Chung, Anna Ridler, and Helena Sarin, have reintroduced elements of analog art production by training GANs with their own drawings and paintings, but they are still limited by the arbitrariness of their training and execution. Agent-based, adaptive computational artworks represent an "aesthetics of adaptive behaviours" (Sofian 2019). However, by simulating or mimicking living systems, these artworks are based on algorithmic generative processes. In both types of artworks mentioned above, we recognize the lack of biological or organic living elements involved in ML processes.

Among the most prominent ML approaches, artificial neural networks are inspired by the structure and functional aspects of biological neural networks, and reinforcement learning is influenced by behaviorist psychology (Aguilar et al. 2014). However, are there interesting approaches to understanding information processing that does not emerge only in neurons? Can we broaden our artistic and aesthetic experience by introducing new strata of complex behavior that might not result from the process of "learning" as it is conventionally defined? In "An Outside View of Ourselves as a Toy Model AGI" (2020), philosopher Reza Negarestani questions whether the "human" is a sufficient model for conceptualizing intelligence. In order to surpass the transcendental structure of human experience that artificial general intelligence (AGI) is modelling on, there needs to be an outside view of humans that resets our collective notion of intelligence.

In the following sections, we examine the problems concerning the current definitions and models of AI and ML, and offer alternative information architectures for "thinking" and "learning". We note an increasing number of artistic practices from artists such as Evelina Domnitch and Dmitry Gelfand, Jenna Sutela, Saša Spačal, Michael Sedbon and Tega Brain that combine AI and ML with biological systems, not as a simulation or representation, but by engaging organic living entities, from microscopic organisms to whole ecosystems. We believe artists can and should participate in a cultural dialogue that recognizes the diverse information processing unfolding at every level of the material world. Reframing diverse natural phenomena "as if they were thinking" can help us acknowledge the full complexity and sophistication of these processes.

Shifting Cultural Discourse

P. W. Anderson famously claimed, "more is different" (1972). Although we are not particle physicists, we believe this principle can be applied to the question we are engaged with in this essay. In *Resisting Reduction: A Manifesto* (2017), Ito Joichi urges us to "embrace the unknowability—the irreducibility—of the real world that artists, biologists and those who work in the messy world of liberal arts and the humanities are familiar with." He acutely points out that we are all participants in multiple, complex adaptive systems, in which individuals are composed of interwoven systems of different scale. Therefore, instead of thinking of machine intelligence in the framework of humans vs. machines, it is the system that *integrates* humans and machines that needs to be studied, from the perspective of "Extended Intelligence (EI), understanding intelligence as a fundamentally distributed phenomenon."

We argue that focusing only on the brain, neurons and the traditional concept of "thinking," centred around abstract symbolic thought excludes many sophisticated behaviors and self-organizational capacities that may be characterized as "intelligent." In her talk, *Questioning the Cranial Paradigm,* art historian Caroline A. Jones and her colleagues playfully refer to these brain-centric tendencies as "neuron supremacy" and "representation fetishism." Jones provokes her colleagues to rethink the traditional neuro-cognitive concept of intelligence, pushing towards a notion of distribution, or "homeostatic surfing" along worldly engagements. Jones cites the incredible intricacy of the mammalian gut and the immune system and their engagement with non-representational processes analogous to memory (creation of antibodies) and recognition (immune cells' ability to distinguish between self and nonself).

Anthropologist Eduardo Kohn proposes that non-human living entities participate in sign-making, a type of 'living logic' that can be seen in natural phenomena, from tropical forests to the logistical dances of bees. Kohn relates his work to the field of *biosemiotics* and believes symbolic thought is emergent from other kinds of semiotic thinking, which always remains "open." Kohn aims to "break down the Cartesian divide that still relegates all of mind and thought to the human," but warns that we should not "see these other kinds of minds as human minds." While we agree that it is important to distinguish between diverse modes of "thinking," Kohn's framework risks the reinforcement of restrictive binaries. Kohn argues that "thinking" is present only in biological life, and is not apparent in geological or mineral life, and warns us not to reduce human and nonhuman thought to "effect and vibration" (2014). To drive his point home, he bluntly states that "life thinks; stones don't" (Kohn 2013, 100).

To go beyond the Western analytical mode of binary thinking, animism may provide a useful lens as a "relational epistemology. . . a way of understanding relatedness from a related point of view within the shifting horizons of the related viewer" (Nurit Bird-David 1999). Robin Wall Kimmerer, botanist and member of the

Citizen Potawatomi Nation, outlines the question of animacy as a problem of grammar, noting the "arrogance" of the English language, with its preponderance of nouns and severe lack of verbs (only 30%), compared to that of her indigenous language (70%). Describing the liveliness of water, Kimmerer writes that "a bay is a noun only if water is dead. When bay is a noun, it is defined by humans, trapped between its shores and contained by the word. But the verb *wiikwegamaa*—to *be* a bay—releases the water from bondage and lets it live" (116).

Pursuing Robin Wall Kimmer's consideration of the liveliness of water, what might be gained from viewing the interactions between these water molecules as a type of "thought?" Is thought a phenomenon that can be extended into the most minute of scales—the microscopic and molecular? Within contemporary Western academic discourse, materials and entities once neglected or dismissed as "inert, inanimate, without moral or political will or relations" (Astor-Aguilera 2018, 4) are now becoming subjects of multidisciplinary interest, for example, agential particles (Barad 2007), living water (Kimmerer 2017), molecular assemblages (Parisi and Terranova 2000), "vibrant matter" such as metal, toxins and stem cells (Bennett 2010), and microbes as Shamanic beings (Herrera 2018). When we consider the "training" and "learning" of machines, what lessons might be gathered from these lively materials and their diverse modes of information processing?

We note that Ito's proposal for "extended intelligence" is still narrowly anthropocentric by emphasizing *human* participants. Indigenous communities worldwide open new lines of non-anthropocentric discussion, proposing an "extended circle of relationship", which includes AI and machines as non-human kin (Lewis et al. 2018). In *Making Kin with Machines*, the authors highlight three core concepts in Indigenous Epistemologies from Hawaiian, Cree, and Lakota cultural knowledge: *Hāloa*, the long breath that nourishes people and their surroundings, guiding them to privilege balance (*pono*) as an ethical stance to achieve "good growth;" *wahkohtawin*, the state of being related to others; and *wakȟáŋ*—that which cannot be understood. These ontologies illuminate possible paths of recognizing non-human beings, and privileging reciprocal and respectful relationships, instead of the default Western "epistemology of control," in cultural philosopher Jim Cheney's term. As alternative world views, they offer resistance to the capitalist model of extraction and exploitation, as well as the singularitarian's belief in the world being fully "knowable" and computable.

In contrast to the universal mono-technology and unified global system of the modern age, philosopher Yuk Hui suggests the notion of *cosmotechnics*. Hui's concept describes "the unification of the cosmos and the moral through technical activities, whether craft-making or art-making." Hui emphasizes the urgency of envisioning alternative possibilities, bifurcations and fragmentations by conceiving different cosmotechnics (Hui 2017). His book *The Question Concerning Technology in China: An Essay in Cosmotechnics* interrogates Chinese cosmotechnics through the inseparable unity, yet dynamic relationship between *Dao* (the ethereal life force that circulates among all things, commonly referred to as "the way", the soul) and *Qi* (tool or utensil; the machine), and relational sensibility (*ganying*) as "correlative thinking" that resonates between the subject and the cosmos based on morality (*de*, virtue) (2019, 27).

Emerging Technical Developments

In tandem with this shifting cultural discourse, in the past few years we have noted a renewed interest in computational models that challenge processes and values associated with the human brain. Drawing further from the work of Yuk Hui, we examine these models from the standpoint of *technodiversity*, the idea that technologies are not anthropologically universal, but expressive of specific ontologies and epistemologies. In other words, technologies are *shaped by* and *expressive of* specific world views. Hui identifies a narrow anthropocentrism in the Western history of technology, a reductionist stance that resonates with Caroline Jones's critique of "neuron supremacy" and "representation fetishism." Hui describes a dangerous convergence of Western modernist technologies into a universal and totalizing mode, an "anthropological machine, the victory of a humanism that aspires to reinvent *homo sapiens* as *homo deus* through technological acceleration" (Hui 2019).

The focus on the processes of the brain, specifically the cognitive abilities of the human brain, permeates AI discourse. In the beginning of his 1950 paper *Computing Machinery and Intelligence*, Alan Turing famously posed the question, "Can machines think?" Turing didn't originally offer a definition of "thinking." Rather, the Turing Test was proposed simply as an operational definition of intelligence. However, the question regarding "thinking machines" continued to fascinate his successors in the following 70 years. Most of these discussions centred around the "brain." From the functional machine consciousness model, which sees the brain as a central information exchange or "global workspace" within a distributed system, to phenomenal consciousness models, which identify all thoughts and experience as statuses in the brain, to the emphasis on intentionality, which would necessarily require neuroprotein for intelligence (Boden 2018).

ML suffers from a similar reductivist problem, as many of its modern network architectures are structured to mimic those aspects of the brain that are considered virtuous in Western culture: speed, efficiency, abstraction, and autonomy. This approach assumes that for everything the brain does well, we can and *should* build a model (although we do not even have a very clear idea of how the brain itself functions). Additionally, there is a common assumption that the conclusions drawn from limited datasets are objective and converge on truth. Yet just because the data used to drive ML originates in the physical world, it does necessarily mean that the results are communicated back to the origin. Similarly, the psychology theories related to learning and reinforcement that initially inspired the ML field are quite far from the mathematical techniques that drive ML today. Gary Marcus, professor of cognitive psychology at NYU, has identified the fragility and limitations of ML, summarizing that they are "greedy, brittle, opaque, and shallow" (2018). This is not to criticize ML on the whole as a field of study, but to clarify that it is in no way representative of different modes of "learning" and is in actuality only loosely connected to traditional ideas of "thought."

Artificial Life (ALife) and Swarm Intelligence are two historically related fields that emphasize decentralized organization and a relational mode of "intelligence." Eric Bonabeau and Guy Theraulaz, early members of both the ALife and swarm intelligence communities, define ALife as a method for "generating at a macroscopic level, from microscopic, generally simple, interacting components, behaviors that are *interpretable as lifelike*" (1994, 303, emphasis in original). Similarly, Swarm Intelligence describes the collective behavior that emerges from decentralized systems, both natural and artificial (Beni et al. 1993). These systems are composed of many, usually very simple agents, which interact locally with one another and with the environment, leading to emergent "intelligent" global behaviors. Models of swarm intelligence include numerous distributed phenomena, such as flocks of birds, the social behavior of insect colonies, bacterial growth, and schools of fish.

Unconventional computing is an emerging field, which explores alternative models of both computation and thinking at the practical level. British computer scientist Andrew Adamatzky has been a consistent champion of this field, strongly urging practitioners to move beyond theorizing "natural computing" and into the production of artworks and laboratory prototypes. Adamatzky has made significant strides in developing real applications for liquid computing (2019), fungal computing (2018), and slime-mold based "physarum machines" (2010). Unconventional computing expresses alternative modes of intelligence and demonstrates that a nervous system is not necessary to fuse sensorial inputs, process information, and make decisions. This field creates alternative models of learning by slime mould, and morphogenetic and spatial computing, distributed information processing in plant organs, and neuron-like activity of bacterial biofilms (Adamatzky 2019).

Adamatzky admits that fungal computers will never be as fast as silicone-based computers, but argues that they offer new ecological insights—forest-sized networks of mycelium can collect and analyze information about the environment, including the health and well-being of other forest inhabitants.

Challenging the human brain from another angle, Katherine Hayles argues that humans have awarded ourselves too much credit, often imagining that we are the "sole possessors of agency, value, and cognition," and that our technologies are not capable of participating in human activities such as meaning-making. According to Hayles, the human brain is biologically limited by the speed and memory capacity of its neuronal system and expands this capacity by engaging in "cognitive assemblages." Hayles states that there is a continuity between biological and computational cognition, progressing through levels of dynamic organization from the subatomic scale to atoms, and onwards. She names this evolving spectrum *biotechnoevolution*, a "hybrid process in which information, interpretations, and meanings circulate through flexible interactive human-computational collectivities" or "cognitive assemblages" (2019, 32–55). Expanding the notion of biosemiotics, Hayles identifies her perspective as one of *cyber/bio/semiotics*.

In her consideration of the "smart forest," media theorist Jennifer Gabrys introduces what we might characterize as an ecosystem-level cognitive assemblage (2020). If, as posited by Eduardo Kohn, forests can think, how does a "smart forest" think through all of its many cognitive connections, both with humans and our technologies, and other organisms? Gabrys suggests that these hybrid forests, with sensor networks attached to tree trunks and embedded in soil, are transforming into technologies for managing environmental change. She identifies the contested nature of the term "smart" in these environmental contexts, as it is often used as a marketing ploy, rather than given serious consideration. What are the implications of fully embracing this term and imagining smart forests as something possessing a technologically assembled "intelligence" beyond simple augmentation through a collection of sensors? Extending this line of questioning to the planetary level, Gabrys outlines the varying scales of environmental sensing and effects in the "becoming environmental of computation" (2016).

Material Insights - Self-organization from molecular to super organismal

Many of our computational models still fall under the "cranial paradigm" and justify or demonstrate their sophistication by appealing to many of the qualities of brains as virtues. But perplexingly, many descriptions of biological systems, particularly within the synthetic biology community, are rife with terms originating in computer science: genes are turned "on" and "off" in digital fashion, these genes operate in "circuits," which organisms use to "compute" information about their environment, and they can be "programmed" to the will of bioengineers. We believe that broadening the language and thinking around "thinking" might make the tension between these two frameworks productive: what happens if we think about bodies and bacteria, or even "simpler" forms of matter, *as if they were thinking* in a similar way?

We can ground this line of reasoning by examining and extending Kohn's arguments about symbol-making, first, by showing that even very simple living things without a brain or even a nervous system at all perform symbolic "thought," then showing how symbol use is also not actually required for complex behaviours in organisms that *do* have brains, and finally by arguing that this complexity, and perhaps even the complexity and sophistication of "higher level" thought may be grounded in, or at least intimately related to, physical principles involving self-assembly and reductions in local entropy.

Symbol use and abstraction in nature

There are numerous examples of what might be called "abstract, symbolic" thought that occur in nature. Although often methodologically problematic, there exist several known cases of primates using hand symbols or touchpads to communicate, and at least one case in which a primate may have deliberately lied to its trainers about making a mess (Patterson 1981, 181–182). Beyond the admittedly convoluted cases of trained primate behaviors, both primates and birds may use similarly sophisticated behavior as part of feeding strategies. Capuchin monkeys, for instance, may use fake warning calls to frighten other individuals away from food, and some birds may do the same even to non-bird animals, sounding fake warning calls near other animals feeding on a tasty morsel, inducing those competitors to flee (Wheeler 2009; Flower 2010). These behaviors seem to be symbolic: using hand or image symbols to represent something other than themselves, and also abstract: they rest on the understanding that the symbol is subject to interpretation, and is therefore more complex than a raw, uninterpretable statement of reality.

Pure symbolic "thought," as Kohn has suggested, also appears to be widespread. Those same warning calls, when used as an actual warning, for instance, are the encapsulation of a concept into a communication channel in a way that does not rely on similarities between the information ("Predator!"), the channel medium (sound), or any direct representational model, as warning calls do not typically mimic, for example, the sounds the predator makes. Such thinking behavior extends to those organisms that we do not conventionally think capable of symbolic thought. Bees, for instance, perform a "dance" after returning to the hive, which communicates the direction (encoded representationally in that the bee may dance along a line oriented relative to the sun and the nectar source in real space, and the length of that danced line is proportional to the distance to the nectar source), and communicates symbolically (modulating a "waggle" behavior and sound production to indicate how rich the nectar source is) (von Frisch 1967). Our lack of recognition reflects the over-emphasis we place on brains like ours, while we underestimate the power of brains much smaller than ours, as bees seem to be able to count, and can potentially understand the concept of zero or nothingness (Howard et al. 2018).

Brainless symbolic thought

In fact, brains are not a prerequisite for this type of "thinking." Plants, for instance, use representational communication, in the form of volatile organic compounds that act both as defense compounds to repel insects and signals to neighboring trees of insect attack (which insects, in turn, have successfully learned to interpret and use as guides to vulnerable plants). They also use what appears to be pure symbolic messaging, communicating with neighbors about stressful conditions like drought, sometimes even with the help of other species, like the dense fungal networks present in soil (Engelberth et al. 2004; Halitschke et al. 2008; Falik et al. 2011; Gorzelak et al. 2015). Bacteria also utilize small molecules ubiquitously to organize density dependent functions like biofilm formation using a system called quorum sensing (Abisado *et al.* 2018). In a prototypical quorum sensing system, bacteria produce small molecules, called acyl homoserine lactones, that signal their presence to nearby individuals. When enough individuals are present together, the build-up of this signal can induce changes in morphology and behaviour that help stabilize and/or defend the bacterial community.

Sophisticated non-symbolic behaviors and emergence

However, symbolic thought is not a prerequisite for behavioral complexity, even among organisms with brains. In fact, in some cases it is precisely the absence of the typical virtues of brains and symbolic thought that allow sophisticated behavior to occur. For instance, ant larval sorting appears to *require* short term memory loss (Parunak 1997). Models of ant behavior using simple rule sets can recapitulate the ability of ants to move larvae from chamber to chamber within nests, but only if the ants are sufficiently (but not overly) forgetful: too short and the ants will not be able to move around enough to successfully separate larvae from eggs before dropping larvae, and too long and the ants will see egg and larvae storage areas as part of the same "location" and will not differentiate where to place the larvae. Nowhere in this process are the ants performing symbolic representation; the sophistication appears somehow displaced from the cognitive process as we might think of it, even with the broad definition of thought that Kohn espouses, and is an emergent function *of* behavior, rather than *a behavior*.

Slime molds, the best-studied of which are *Physarum polycephalum* and *Dictyostelium discoideum*, can exhibit similarly sophisticated behaviors despite not having a nervous system, much less a brain (Reid and Latty 2016). The true slime mold *P. polycephalum*, for instance, can solve mazes and allocate resources spatially, as demonstrated by its ability to recapitulate the shape of human-made transportation networks like the Tokyo subway when food sources are positioned on a growing plate of *P. polycephalum*, as if they were real locations on an actual map (Nakagaki et al. 2000; Tero et al. 2010). *P. polycephalum* also appears to have a kind of memory and is able to anticipate coming stresses, like changes in temperature if it has been conditioned by repeated experience with the same stressor (Saigusa et al. 2008). *D. discoideum*, on the other hand, spends a significant part of its life cycle in a single-cell state, but when reproducing, it coalesces into a single "slug" with differentiated multicellular organ-like structures and moves as a unit until it finds a suitable place to develop into its final reproductive form, producing a single-celled amoebae as its solitary offspring. As with *P. polycephalum*, the organizing signal that brings these organisms together into the "slug" is both symbolic and emergent, taking the form of self-organizing pulses of the signalling molecule cyclic adenosine monophosphate, which eventually coalesce into spiral waves of signals that draw the individual *D. discoideum* amoeba together to a single point, forming the slug (Tyson et al. 1989).

Thinking close to the metal

These spiral waves of signals are strikingly similar to those observed in some non-linear thin-layer chemical reactions, most familiarly the Belousov-Zhabotinskii reaction, and may be driven by the same underlying chemical processes (Tyson et al. 1989). With tongue in cheek, this raises the question: why not extend the principle of *as if it were thinking* to similarly complex, but non-living systems? After all, the "complexity" of all these systems is, ultimately, a product of their underlying physics, differing more by degree than quality. Does the tool of "symbolic" thought, broad as it can be, go far enough to extend our thinking, or just recapitulate the same old mind-body dualisms, arbitrary hierarchies, and appeals to the supposed virtue of brains, conveniently exemplified by our own? At the risk of just playing a semantic game, let us consider what might be included if we broadened the definition of "thought" to something closer to "complexity", or simply the organized properties of a system that result from interactions between the system's parts. The bacterial quorum communication described above, for instance, already falls well within this definition, even as it remains symbolic, with most of the biochemical mechanisms underlying the quorum-sensing molecular function being relatively well understood. One order of magnitude in scaled-down, bare biochemical systems have also already been coaxed to "think." Microtubules, part of the superstructural system that gives mammalian cells, including our own, their physical shape, can be used to run mazes that physically encode difficult computational problems (Nicolau et al. 2016). Similarly, the folding behavior of DNA has been used to solve difficult problems, and even to construct the famous fractal Sierpiński triangle structures that appear in some Alife models, like Conway's Life (Adleman 1994; Rothemund et al. 2004). While convoluted, these examples may hint at deep connections between self-assembly, complexity, and "thought."

In the early 20th century, the physicist Alfred Lotka proposed a kind of informal fifth law of thermodynamics, which he believed might help explain how locally complex systems, more specifically life, have come to exist in the face of the ever-increasing global entropy described by the second law (Chen 2006). The "maximum power principle", as it is now known, roughly states that in open systems (like living ones), configurations that maximize efficient intake and transformation will prevail over time. Recent more rigorous work has lent support to this idea, showing that in certain cases, systems of interconnected chemical reactions will stabilize those reactions that most effectively dissipate energy, effectively selecting more complex reactions in the process, and offering a tantalizing glimpse of a coherent, physically grounded story of the origin of life (Horowitz and England 2017). Similarly, admittedly probably unfalsifiable arguments have been proposed, controversially, as explanatory models for cognition itself in the form of the "free energy principle", which formally relates cognition to a process by which agents minimize differences between their beliefs about the world and their observations of it—a discrepancy which can be calculated using the same principles of entropy that govern thermodynamics and information theory (Friston 2010). Another way of articulating the proposed connection between "thinking" and the basic principles of order-generation exhibited by such systems might be to articulate *thinking of self-organization as thinking*.

Self-organization can itself be broadly divided into two classes: dissipative structures, which must pass energy through them to maintain their organization, and structures existing at thermodynamic equilibrium (Whitesides and Grzybowski 2002). Both classes are subject to ongoing study, often adjacent to studies in unconventional computing. As well as probably being central to every example presented above, self-organization extends to much simpler structures like a sink drain whirlpool, which is a particularly ordered form of water (compared to the same sink at rest), which emerges from the properties of the sink, the water, and the drain, and is stabilized by the dissipation of energy in the form of water flow. More provocatively, something as simple as crystallization, probably known most familiarly through the freezing of water into ice, is an example of a self-organizing system operating at equilibrium. As water freezes, molecules spontaneously organize themselves into the ordered crystalline form we know as ice, each finding a properly oriented set of partners and settling into a locally ordered structure.

So what if we thought of something as calm as our draining sinks (as wild as Charybdis?) or familiar as ice *as if it were thinking*? The fundamental processes of dissipative and equilibrium self-assembly are clearly important to nearly every biological process, and the statistical physics that underlie them may even lie at the heart of thought and life themselves. But a draining sink is also clearly not "thinking" in the way we typically think about thinking. Given that the fundamental differences and lines between these systems seem to get slippery as one looks closer, perhaps such a framework holds a productive tension for questioning existing paradigms, zeitgeists and epistemologies.

New Aesthetics

In parallel with the shifting cultural paradigm regarding the nature of intelligence, as well as the computational developments and scientific insights that challenge neuro-cognitive defaults, we identify emerging artistic practices that engage with the diverse information processing unfolding at every level of the material world. The next section introduces some of these artworks that we believe contribute to reframing diverse natural phenomena *as if they were thinkin*g and acknowledge the full complexity and sophistication of these processes. By emphasizing these works, we hope to create an alternative artistic genealogy of artificial intelligent systems.

Artist duo Dmitry Gelfand and Evelina Domnitch are known for creating multisensory environments and pursuing philosophical inquiries in their installations, which function as "phenomenological investigations" (2014). Resonating with our speculations above on the organizing principles of whirlpools and sink drains, Gelfand and Domnitch explore the energetics, memory, and cognitive capacities of turbulent matter at the particle level, forgoing the use of "solid, fixative and recording media in favour of liquids, gases and plasmas permeated by acoustic vibrations and light emissions" (Domnitch and Gelfand 2019). *Memory Vapor* (2011) transforms a thread of condensation droplets into a dynamic prism with a particle accelerator and a scanning white laser sheet. *Luminiferous Drift* (2016) speculates on the ambiguous planetary transition from lifeless to living matter by tracing bioluminescent protocells (fig. 1). As the artists state, their works describe an “emergent cognisphere” and explore “the non-rigid, morphing structures of consciousness itself.”

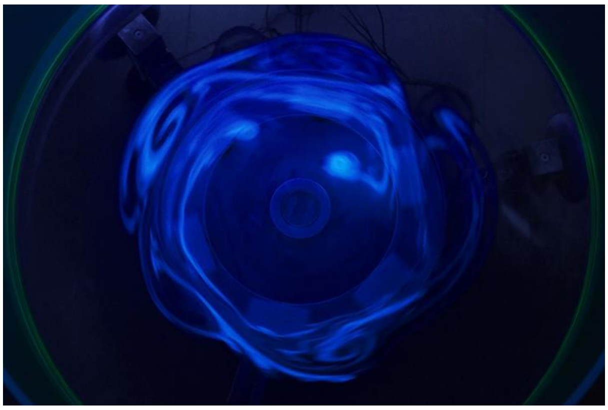

Fig. 1. *Luminiferous Drift,* 2016. Dmitry Gelfand and Evelina Domnitch. Installation.© Domnitch Gelfand.

Berlin-based artist Jenna Sutela performs an experimental survey of slime mold *Physarum polycephalum* in her project *Orgs* (2016), which consists of layered organizational and spiritual charts, networking diagrams, architectural mazes, and installation. The “many-headed, no brain” *Physarum* becomes not only a collection of “abstract machines generating alternate realities” (Sutela 2017, 26), but also a soft machine that encodes its own instructions through spatial, non-human intelligence. In an experimental performance of the publication, Sutela ingested *Physarum polycephalum* and imagined that the organism might be able to program the artist (fig. 2). *nimiia cétiï* (2018) deals with another kind of intelligence—*Bacillus subtilis*, a bacterium gathered from fermented soybeans, which according to recent spaceflight experiments, can survive on Mars (Cortesão et al. 2019). Sutela uses ML to generate a new written and spoken language, based on the computer's interpretation of a Martian tongue. Using the generated alien language, the computer observes and details the movements of a *Bacillus subtilis nattō* culture under a microscope, generating a script to be recited in the machine language. Sutela’s work de-emphasizes neuro-centric human intelligence, highlighting how humans are convenient earthly vessels for “brainless” microbial collectives, which may manipulate human behaviour in order to spread them to other planets.

Fig. 2. *Many-Headed Reading, 2016.* Jenna Sutela. Decentralized performance featuring a Physarum polycephalum (slime mold) trip report. Photo by Mikko Gaestrel. © Jenna Sutela.

Saša Spačal is a postmedia artist with a similar interest in decentralized, networked intelligence, who often juxtaposes both biological and technological living systems in her immersive installations. Her *MycoMythologies* (2020) is a speculative artistic investigation of ontogenetic mythological stories, video essays and machines that taps into the underground flow of the mycelium network (fig. 3). She points out that the “wood wide web” metaphor used to describe mycorrhizal networks (connections between plants and fungi) treats fungi as merely wires, rather than organisms with their own agency. To highlight the thought processes of fungi, Spačal developed her own language and protocol, the *Fungal Network Traits Protocol*, in collaboration with fungal agents. Using her protocol, Spačal channelled fungal messages through machines and performed their decision-making processes. In the installation, the microscopic node in the *World Networks Entanglement* programmed with the *Fungal Network Traits Protocol* is experiencing an overflow of sonic data. One single sentence with numerous languages is computed by the *Entanglement* and repeatedly uttered by the machine, creating an intense, distant and glitched machinic murmuring, "We can't return to normal because the normal that we had was precisely the problem." The machine failed to compute the immense breaching across the feedback looping of the planetary networks, rendering a rupture of the entanglement of the world.

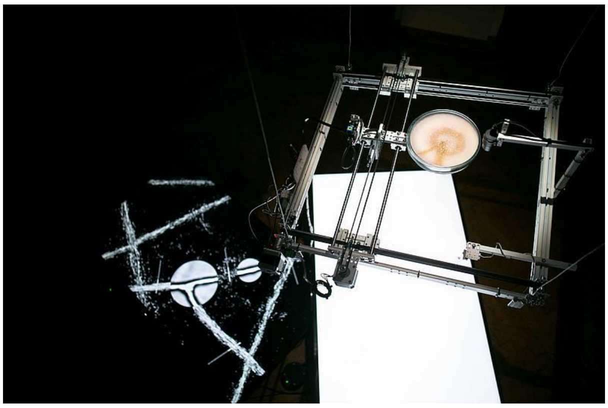

Fig. 3. *MycoMythologies: Rupture, 2020.* Saša Spačal. Installation. © *Saša Spačal.*

Michael Sedbon, a French artist and interaction designer, explores digital networked technologies and systems through their convergence with non-human intelligence. *CMD* (2019) is a juxtaposition of an artificial intelligence and two artificial ecosystems of Cyanobacteria that are competing for the same light source (fig. 4). Each colony of photosynthetic bacteria can claim access to light as its reward earned from its oxygen production. The distribution of the light source is managed by a market, whose rules are constantly optimized by a genetic algorithm. The computer and the photosynthetic cells experiment with various political and economic systems granting access to the resource, which can also be tested at the macroscopic scale. As Sedbon noted, a new status quo granting non-human entities agency over political economic and ecological systems at an unprecedented speed marks a cultural paradigm shift regarding the notion of living and nonliving, and reconsidering "intelligence" and agency provides a good prism to assess these transitions (Cao 2020).

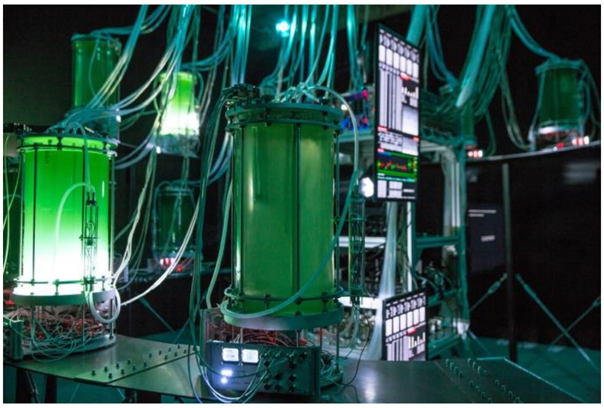

Fig. 4. *CMD*, 2019. Michael Sedbon. Mixed media installation (installation view). © Michael Sedbon.

However, some of these initiatives remain human-centered. *terra0* is a blockchain-based project, whose aim is to turn a forest into a technologically augmented self-owning ecosystem by providing technical infrastructure such as remote sensing, machine learning, and smart contract. Instead of extending our economic and political structures into the non-human realm, which seems to be rather an attempt to reinforce the existing hierarchy, we should be more open to the possible emergent properties of such technological or algorithmic systems regarding decision-making processes by incorporating our systems into the complex ecology.

The problematics underlying the application of engineering metaphors to complex environments is also addressed by Australian artist and environmental engineer Tega Brain, who argues that the term "ecosystem" enmeshes ecology with systems theory, framing interspecies relations as functional and controllable. With her installations and extended writing, she brings up concerns regarding ecosystem optimization and manipulation in the context of increasing human impacts on climate change, mass extinction, and paradoxically, the unprecedented surplus of computing used to manage ecological processes (Brain 2018). *Deep Swamp* (2018) is a triptych of semi-inundated environments, where wetland life forms and artificially intelligent software agents converge (fig. 5). The swamp territories are under the management, engineering and strategic intervention of three AI agents, whose responsibilities are modifying the wetland conditions—floods, melting, dehydration and erosion—to achieve optimal conservation. Each agent possesses different engineering goals and gains increasing understanding of its tasks through a deep-learning approach with data collected online, which guide them to experiment with new combinations of settings in order to achieve their programmatic goals. This piece raises the question of the goal and means of optimization concerning environmental engineering, whether by machine or human intelligence.

Fig. 5. *Deep Swamp,* 2018. Tega Brain. Glass tanks, wetland plant species, gravel, sand, acrylic pipes, shade balls, electronics, misters, lighting, pumps, custom software, 3 channel sound (installation and detail view). © Tega Brain.

With the examples above we have identified an emerging tendency towards ecohybridized computational artworks. These works often involve "biologized" machine (Yi, 2020) and nonhuman intelligence, and interrogate the limitations and possibilities of computational models involving complex living systems and planetary ecology. By engaging with organic living entities, the artists expand the conversations around critical issues in AI-related artworks and offer new understandings for notions such as "intelligence," and "living vs. nonliving."

Conclusion

Within the context of AI-related computational media arts, this paper outlines the cultural paradigm shift around the notion of "intelligence" and "thinking," and examines some technical developments and scientific insights associated with such transitions. By presenting the emerging artistic practices involving eco-hybrid computation, we propose a new aesthetic and conceptual framework for contemporary artmaking to be engaged with the increasing convergence of biotechnology and machine learning. Artists have an important role to play in expanding our cultural notions of intelligence and our corresponding appreciation for the diversity and sophistication of non-human lifeforms and phenomena.

We want to emphasize the importance of not confusing blindness with absence. We advocate an extended practice of "noticing" (Tsing, Bubandt, Gan, and Heather 2017) when it comes to computational models that challenge processes and values associated with the human brain. The limiting focus on traditional concepts of "thinking" excludes many types of sophisticated behaviors and self-organizational capacities that may be characterized as "intelligent." What new models of AI and ML might be developed that privilege slow, gradual, collective, embodied, emergent intelligence? What can we and our machines learn from cognitive complexity, diverse informational processing, an emergent cognisphere, cognitive assemblages, vibrant matter, living water, and living logics?

We call for artists to engage with an open ecology of machine intelligence that incorporates non-human cognition, reciprocal aesthetics, and entangled planetary thinking into AI and ML. We also urge an increased awareness of the gravity of utilization—think twice before instrumentalizing something that may also be thinking.

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