Can Computers Create Meanings? A Cyber/Bio/Semiotic Perspective

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Biological evolution, having proceeded for a few million years and produced humans, has now entered a new stage. I adapt a useful phrase from Terrence Deacon, "complexity catastrophe," to denote the limits of human biological cognition in which further increases in capacity are constrained by the neuronal system's processing speed and memory storage.[1] The solution has been to invent computational media to extend and amplify human abilities. The result is biotechnoevolution, a hybrid process in which information, interpretations, and meanings circulate through flexible interactive human-computational collectivities or, in my terminology, cognitive assemblages.

Our understanding of how cognitive assemblages work has been impeded by views of computational media that position them as mere calculators without the ability to create, disseminate, or participate in meaning-making activities. This view, widely shared among philosophers and even some computer scientists, is undergirded by questionable assumptions that make humans the sole possessors of agency, value, and cognition. In addition to reinforcing a worldview in which humans have sole dominion over the earth, this perspective badly distorts the actual effects of cognitive assemblages in developed societies and obscures the ways in which biotechnoevolution presents us with urgent issues about our collective futures, human and nonhuman. Articulating a better framework through which to understand cognitive assemblages is this essay's work.

1. Terrence W. Deacon, *Incomplete Nature: How Mind Emerged from Matter* (New York, 2012), p. 473; hereafter abbreviated *IN*.

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To make the case for computer cognition, it is necessary first to trace the dynamic transitions that enabled humans to become cognitive; this in turn requires a brief account of how life arose from nonlife. Although such moves may seem to risk infinite regress, they are useful because they locate the central question of computer cognition within the larger and older context of biological evolution. In broad scope, the first evolutionary leap bootstrapped complexity from simpler mechanistic reactions; the second emerged from the first, bootstrapping meaning-making practices from complexity; the third emerged from the second, bootstrapping artificial cognition from biologically derived signs and meanings.

Two explanatory strategies will be used to trace these developments. The first I call intermediation, introduced in *My Mother Was a Computer* (2005).[2] The basic idea is that emergence proceeds through a pattern that repeats at multiple scale levels. To emphasize continuities between biological and computational cognition, I call each level of organization *media*; *intermediation*, on the other hand, refers to interactions between levels, both higher to lower and lower to higher. For example, a low level of dynamical organization, say subatomic particles, forms quasi-stable patterns captured by the next level up through the formation of new entities, atoms. Atoms in turn form quasi-stable patterns whose dynamics are captured by higher-level entities, molecules; molecules in turn form patterns captured by proteins, and so forth. The change of media in intermediation is crucial because it is what "locks in" lower-level dynamics and enables emergence to continue through successive levels of increasing complexity.

The second strategy draws on the work of Deacon. Deacon has his own scheme for evolutionary emergence, and his explanation shows how meaning-making practices develop, first in very simple organisms such as bacteria and then through progressively complex creatures up to and including humans. This way of thinking draws inspiration from the interdisciplinary field known as biosemiotics, *bio* connoting life and *semiotics* the science of signs. Biosemiotics develops from the semiotics of Charles

2. See N. Katherine Hayles, *My Mother Was a Computer: Digital Subjects and Literary Texts* (Chicago, 2005).

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Sanders Peirce, who used a triadic (rather than dyadic) view of signs. Writing from a biosemiotic perspective, Deacon enlarges its scope by arguing that signs in general become possible through the emergence of what he calls teleodynamics, end-directed processes that work by using something present to evoke or gesture toward something absent. The essential mechanisms enabling such gestures are constraints, and different forms of constraint function in his scheme similarly to different levels of intermediation in mine.

Powerful though Deacon's explanation is, it has a major blind spot shared by other theorists writing about biosemiotics such as Wendy Wheeler and Jesper Hoffmeyer.[3] Deacon argues that computers are not cognitive, engaging only in simple mechanical practices that are qualitatively different from cognition in biological organisms. Deacon and others fail to take into account, however, the possibility that computers evolve not through being autonomous (which clearly they are not) but precisely through their partnerships with humans. The assumption that beings must be autonomous to be cognitive is an example of what I call biologism, the faulty extrapolation of biological reasoning into computational media. Deacon and other biosemioticians are often deeply versed in biology but frequently manifest only a slight acquaintance with how computational media operate. Moreover, their focus on dynamics obscures the role that intermediation plays in the evolution of artificial cognition.

A principal contribution of this essay is to show that arguments based in biologistic assumptions misunderstand cognitive processes as they are manifested in computational media. On the positive side, the essay argues that a framework combining intermediation and constraints enables a deeper understanding of how computers generate meanings than either can by itself. It also illuminates how and why cognitive assemblages have become powerful actors in contemporary cognitive ecologies.

Intermediation and Teleodynamics

As I stated earlier, intermediation can be understood as an alternation between elements considered as individuals, which interact among themselves to create the quasi-stable patterns that are incorporated into the

3. See Wendy Wheeler, *The Whole Creature: Complexity, Biosemiotics and the Evolution of Culture* (London, 2006) and *Expecting the Earth: Life/Culture/Biosemiotics* (London, 2016); hereafter abbreviated *EE*. See also Jesper Hoffmeyer, *Biosemiotics: An Examination into the Signs of Life and the Life of Signs*, trans. Hoffmeyer and Donald Favareu, ed. Favareu (Scranton, Penn., 2008) and *Signs of Meaning in the Universe*, trans. Barbara J. Haveland (Bloomington, Ind., 1996).

emergence of individuals at a higher level of complexity, creating a process that results in increasingly complex patterns. As Harold Morowitz has argued, this kind of emergence is how the universe evolved after the big bang; as the superheated plasma cooled, subatomic particles appeared, then chemical elements, on up to the formation of planets and the emergence of life on earth.[4]

Intermediation, however, differs from Morowitz's account because it refers to elements at each level as media. And *media*, as John Guillory has reminded us, connotes both *materiality* and *mediation*; *mediation*, in turn, connotes communication through distance in time and space.[5] Technical media achieve this through different layers of code within a machine and networked functionalities between machines, but communication through distance can also be understood as the emergence of quasi-stable patterns as physicochemical entities "communicate" through their interacting dynamics. As noted earlier, intermediation denotes both bottom-up emergence, as new entities are formed from lower-level patterns, and also top-down emergence, as higher-level entities interact with and change lower-level dynamics. Intermediation thus describes a recursive organization that I call a dynamic heterarchy, in which lower-level media produce the higher-level media, and the higher-level media simultaneously affect the lower-level media.[6]

In informational terms, the specific levels formed by physicochemical media always contain more information within the level than they communicate upward or downward. Indeed, it is precisely this reserve of dynamic information that characterizes the levels as such. Subatomic particles, for example, manifest as probability distributions that get statistically "smoothed out" when incorporated into atoms, where they can be treated mathematically as point masses. However, the level-specific information is revealed through such phenomena as electron tunneling, explicable because there is a finite probability that an electron will appear on the other side of a barrier that it otherwise does not have enough energy to penetrate. Each level of physicochemical interactions has similarly specific dynamics in excess of its contributions to higher or lower levels.

A different strategy is at work in Deacon's scheme. His key terms involve dynamic patterns evolving through time (in this respect it overlaps with intermediation); in addition, he also introduces a novel component focusing

4. See Harold J. Morowitz, *The Emergence of Everything: How the World Became Complex* (New York, 2002).

5. See John Guillory, "Genesis of the Media Concept," *Critical Inquiry* 36 (Winter 2010): 355, 326, 331.

6. See Hayles, "Intermediation: The Pursuit of a Vision," *New Literary History* 38 (Winter 2007): 100.

on how constraints interact with structural organizations to produce emergent processes. He characterizes three different kinds of dynamics, which he calls homeodynamic, morphodynamic, and teleodynamic. Exploring this reasoning illuminates the contributions of his approach and the complementary ways in which it overlaps with intermediation.

Homeodynamics characterizes mechanistic physicochemical systems that tend to become more random and disorganized over time. The second law of thermodynamics expresses this as a tendency for closed systems spontaneously to move in the direction of increasing entropy (or randomness). Cream poured into a cup of coffee spontaneously tends to dissipate; a sugar cube dropped into water tends to dissolve. As a homey example, consider a dresser drawer full of socks and underwear. Over time, as the owner roots among these items, they tend to mix evenly throughout the drawer, which the owner may perceive as having become messy. Explanations of the second law frequently point out that what humans perceive as ordered represents only a small fraction of possible states; in this example, there are exponentially more ways for the items to mix together than there are ways for them to remain neatly separated.

A more rigorous way to state the second law, then, is to say that closed systems tend to move spontaneously toward more probable states, for example states that have lower potential energy than those that have higher potential energy. Because terms like *order* and *disorder* may have subjective implications (as in the dresser drawer example), Deacon usefully refines the terminology by calling processes that move in a direction consistent with what spontaneously happens as "orthograde," while processes that move against spontaneous tendencies are "contragrade" (*IN*, p. 21).

To characterize further the three kinds of dynamic systems, Deacon introduces the idea of constraints. The orthograde tendency of homeodynamic systems is to dissipate constraints. Consider, for example, a reservoir in which water is being held back by a dam. The system's spontaneous tendency is to let the water be distributed evenly over the ground (there are many more possible states in how this could be achieved than the few states in which it is contained), and the dam exerts a consistent pressure, or constraint, to prevent this from happening. If the dam is weakened by heavy rainfall or an earthquake, its constraint may not be sufficient to restrain the water, and in that case the system's orthograde tendencies take over and the water bursts through, cascading onto the ground.

So far these explanations do not go beyond a high-school physics textbook, but their explanatory power emerges when Deacon points out that constraints function as presences that point to what is absent, namely what is excluded by virtue of the constraints (see *IN*, p. 27). For example, a numerical system may be constructed using the constraint that the only integers allowed are odd numbers. This constraint becomes visible only through the absence of even integers, which are the phenomena gestured toward by the odd-number constraint. Deacon calls such exclusionary constraints "absential," phenomena that function by gesturing toward what is not present (*IN*, p. 323).

This view of constraints enables Deacon to distinguish further between homeodynamic systems and the next kind of system up the evolutionary ladder, which he calls morphodynamic. Morphodynamic systems are self-organizing phenomena such as the red eye of Jupiter, where storms circle continuously in consistent patterns that fluctuate within constrained dimensions of time and space. As Ilya Prigogine and Isabelle Stengers explain, dissipative systems are far-from-equilibrium phenomena in which the entropy production is so large that pockets of order can form without violating the second law.[7] Self-organizing systems are characterized, in Deacon's terminology, by the production of constraints, the spontaneous appearance of attractors that define the limits within which the system's phase-space trajectories move. A famous example is the Lorenz attractor characteristic of weather patterns, with its butterfly-wing shaped pattern traced by trajectories unpredictable as individual instances but nevertheless constrained by the attractor's parameters.[8]

Deacon argues that life could never have arisen directly from homeodynamic systems because life depends on the continuing existence of many different kinds of constraints, from cell membranes to energy and temperature requirements. Morphodynamic systems provide the necessary stepping-stone that allows constraints to be produced and preserved. Rephrasing Prigogine and Stengers's insight, we can say that morphodynamic systems are encapsulated within homeodynamic systems, whose strong entropy production serves to protect and buffer them against the constraint dissipation that is orthograde within the larger homeostatic system but contragrade within the morphodynamic system.

The next evolutionary step is the emergence of teleodynamic systems, systems directed toward some goal or endpoint. For living organisms, the foundational goal is survival and reproduction. Again, organizational dynamics and associated constraints are essential in understanding how such systems can emerge from self-organizing phenomena. When morphodynamic systems strongly couple together, as in chemical networks that produce the

7. See Ilya Prigogine and Isabelle Stengers, *Order Out of Chaos: Man's New Dialogue with Nature* (1984; New York, 2017).

8. See James Gleick, *Chaos: Making a New Science* (New York, 2008), p. ix.

catalysts that spark further reactions extending and strengthening the reactions, recursive patterns emerge in which the system's output becomes its input, leading to further catalysis as the input cycles through to produce more output.

Stuart Kauffman calls such systems autocatalytic networks and argues they are the immediate precursors to life.[9] In Deacon's terms, such systems connect and extend constraints in a complementary fashion, coevolving and cocreating through their mutual interactions. They recursively self-constitute one another and mutually reproduce a system of correlated constraints, leading to such complex organizations as a living cell. The cell as a whole is constituted through the constraints and organization of its parts, but the parts in turn are constituted through the constraints and organization of the whole.[10] Deacon explains:

> Life is characterized by the use of energy flowing in and out of an organism to generate the constraints that maintain its structural-functional integrity. . . . Organisms . . . additionally need to constantly impede certain forms of dissipation. Organisms take advantage of the flow of energy through them to do work to generate constraints that block some dissipative pathways as compared to others. . . . Organism[s don't] just block constraint[s, they generate new forms with] new constraints. [*IN*, p. 263]

Before proceeding to the next evolutionary development, in which constraints in living systems enable the emergence of signs, let us pause to consider the relationship between the two explanatory frameworks of intermediation versus dynamical organization and constraints. Both frameworks emphasize the existence of levels and the relations and transitions between them. Both identify mechanisms that lock in previous patterns and allow further reorganizations. Both emphasize recursive patterns of organization in which the whole produces the part and the parts simultaneously produce the whole.

There are also significant differences. Whereas the levels in intermediation are understood in terms of the patterns and entities forming them, Deacon's dynamical framework emphasizes the structural organizations and

9. See Stuart Kauffman, *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity* (New York, 1996), pp. 47–48.

10. There is an obvious parallel here with Humbert Maturana and Francisco Varela's idea of autopoiesis, which Deacon cites but does not in my view acknowledge sufficiently; see Humbert R. Maturana and Francisco J. Varela, *Autopoiesis and Cognition: The Realization of the Living* (Boston, 1980).

constraints that characterize the three different levels culminating in teleodynamic systems. Thus the two frameworks offer different explanations for the lock-in effect. In intermediation it is the change in media, whereas Deacon identifies it as a "polarity reversal" in how constraints operate: "the orthograde signature of thermodynamic change is constraint dissipation, the orthograde signature of morphodynamic change is constraint amplification, and the orthograde signature of teleodynamic change is constraint preservation and correlation [among constraints]" (*IN*, p. 324). In a sense, intermediation focuses on what is present, whereas the constraint framework emphasizes what is absent.

A related divergence appears when we consider what the two frameworks take to be the ultimate phenomena to be explained. For Deacon, it is not so much the emergence of life as the emergence of sign relations in living organisms. The framework's great strength, especially in relation to intermediation, is its explanation of how signs emerge from the absential phenomena already implicit in the formation of constraints. It thus builds in signs and meaning production from the beginning, whereas intermediation simply assumes that signs can operate through dynamics similar to the intermediating processes that brought the cosmos into existence.

This strength is also a limitation, however, because it ties emergence so strongly to dynamical organizations that it has little purchase when dynamics cease to be the important evolutionary driver in computational media, where intermediations between different levels of signs take center stage. Constraints do not need to evolve in computational media because they are programmed in at a foundational level through logic gates. Similarly, sign elations are also programed through bit (binary digit) patterns. However, such programming is possible only because constraints and signs had previously evolved in humans; computational media thus presuppose and depend upon biological emergence. In this sense, intermediation picks up the story of biotechnoevolution where the dynamical framework leaves off. Viewed as complementary rather than antagonistic, the two frameworks, with their different emphases, strengths, and limitations, provide an encompassing way to understand our present situation. Moreover, keeping both frameworks in view allows important distinctions between computers and humans to appear without needing to subsume one under the other, which is what occurs in computational models where brains are said to operate like computers. As humans continue evolving by implementing sign relations in computational media, design and purpose substitute for the biological imperatives of survival and reproduction; this is what I call the First Great Inversion. To explore further its implications, let us return to consider how signs evolved biologically.

The Emergence of Signs from Constraints

Once living cells emerge, natural selection operates to connect constraints and couple them with environmental signals of change. This gives the interrelating dynamics a forward motion in the form of anticipation. For example, as autumn temperatures drop, this environmental signal is interpreted by dynamic processes within a deciduous tree that set in motion a series of interrelated changes. Sap is withdrawn from branches, which causes fragility in the leaves so that they drop off the tree. We might say the tree anticipates winter, although obviously no such abstract conception is at work, only correlated changes that in the evolutionary history of the species have proven reliable indicators of future events. This exemplifies absential phenomena, where something that is not present (winter) causes something that is present (leaves on the tree) to undergo changes that otherwise could not be explained.

Wheeler elaborates on the idea of absential phenomena when she relates it to meaning. "The *meaning* of something is to be discovered in what it *does* in the world, in how it allows things to be and also to change. Thus we say that a biological meaning is a function. But this process, while certainly always carried by . . . material objects in fact involves something other than substances alone" (*EE*, p. 7). This "something other" is a relation between what is present and what is absent. "What happens is that a *relation* is established, and that relation has a value of one kind or another for the organisms which experience it" (*EE*, p. 8). In biosemiotic terms derived from Peircian triadic sign relations, the value for the organism is understood as emerging between a phenomenon in the world (a "representamen," in the above example, an autumn temperature drop), a function or process that responds to this event (the "interpretant," here the sap withdrawal), and the "object," absent but anticipated (the approach of winter).[11] "Expectations," Wheeler writes, "are relations to no-things which have real causal and shaping powers" (*EE*, p. 13).

This approach has proven fruitful in explaining how meaning-making practices emerge in the nonhuman as well as the human world, even for organisms with no central nervous system such as trees and for unicellular organisms such as bacteria. As humans initiate changes in our global ecology that have plunged the world into the sixth mass extinction and created epic levels of pollution and global warming, the calls to rethink anthropomorphic assumptions about how the world is organized and how it operates

11. For a summary of these terms, see Charles Sanders Peirce, "On a New List of Categories," in vol. 1 of *The Essential Peirce: Selected Philosophical Writings*, ed. Nathan Houser and Christian Kloesel (Bloomington, Ind., 1992), p. 6.

have become increasingly urgent. Accepting that meaning making is not an exclusively human prerogative is a crucial step in the right direction. Biosemiotics should be celebrated for its central contributions to this effort.

That these contributions are claimed to apply only to biological organisms is an unnecessary limitation based on flawed reasoning. The crucial point to be interrogated is the assumption that to be capable of meaning-making practices, an entity must be autonomous, self-organizing, self-maintaining, and self-encapsulated. While these assumptions are warranted in the biological realm—indeed, they collectively constitute the requirements for life to emerge—they do not necessarily apply to artificial cognition in networked and programmable machines. Cognitive media's evolutionary requirements include their necessary interactions with humans, already existent through biological evolution. These interactions do not preclude artificial media from being cognitive; they only indicate that biotechnoevolution now continues through a cognitive machine-human dynamic rather than through biological evolution alone.

Limitations of Biologistic Reasoning

As noted above, the major objection within biosemiotics to the proposition that computers participate in meaning making is their lack of autonomy. Wheeler makes this explicit in a footnote: "Of course, computers can be programmed to 'notice' relations. But 'programmed' is the point. A computer without a programme which originated from a human being is just an inert collection of metal, plastic and silicone" (*EE*, p. 25 n. 2). Deacon observes, "Today's computers are conduits through which people (programmers) express themselves. . . . Ultimately, then, software functions are human intentions to configure a machine to accomplish some specified task" (*IN*, p. 100). He uses this and similar statements to conclude that computation is only a "descriptive gloss" and that "*computation only transfers extrinsically imposed constraints from substrate to substrate, while cognition (semiosis) generates intrinsic constraints that have a capacity to propagate and self-organize*" (*IN*, p. 498).

It is of course true that computers are not autonomous in the ways that biological organisms are. What's missing, though, is the possibility that evolution, having produced life, may now proceed by different mechanisms that rely on human-computer interactions to form semiotic relationships that exceed the limits of biological cognition alone. If one uses only the criteria that enabled biological cognition to emerge—the interaction of constraints with dissipative dynamics—computers will of course come up lacking because they do not rely on attractors and dissipative systems to achieve cognition. But the requirement that this must be the only way through which cognition emerges is an arbitrary limitation that flies in the face of what computer-human interactions actually achieve.

The extraordinary blindness to which this kind of biologistic reasoning leads is illustrated in this passage from Deacon: "There is nothing additionally produced when a computation is completed, other than the physical rearrangement of matter and energy in the device that is performing this operation" (*IN*, p. 525). He is emboldened to make this claim because he has previously emphasized work as the output created when biological constraints operate on energy flows—work that moves things in the world and causes events to happen that would not otherwise be possible. His reasoning, however, assumes that the work must be done by an autonomous entity rather than a human-technical dyad. The fallacy here can be exposed if we ask instead what would be required for humans to do the cognitive labor performed by computers and use that measure to determine how much has changed in the world. Just to pose the question reveals how absurd Deacon's claim is, for the cognitive tasks now performed by computers would arguably require full-time labor by all 7.4 billion human inhabitants of the planet to produce equivalent results. Moreover, many tasks performed by computational media could not be done by humans no matter how long and hard they worked, for the scope of the data analyses, pattern recognitions, and correlations that networked and programmable machines routinely provide for their human partners are simply too vast, too fast, and too complex for human cognition alone to encompass.

Many of Deacon's arguments about the limitations of computation are aimed at critiquing the computational theory of mind, which argues that biological brains operate like computers, so that human cognition "is understood in terms of a rule-governed mapping of specific extrinsic properties or meanings to correspondingly specific machine states" (*IN*, p. 495). I agree wholeheartedly with this critique; a wide range of arguments by neuroscientists, cognitive scientists, and others has shown the importance of embodied and enworlded situatedness for human cognition.[12] However, an important asymmetry emerges here, for the fact that biological brains use input from their environments, sensory systems, and bodily functions

12. See Varela et al., *The Embodied Mind: Cognitive Science and Human Experience* (Cambridge, Mass., 1991); *Reclaiming Cognition: The Primacy of Action, Intention and Emotion*, ed. Rafael Núñez and Walter J. Freeman (Bowling Green, Ohio, 1999); Antonio Damasio, *The Feeling of What Happens: Body and Emotion in the Making of Consciousness* (New York, 1999); and Gerald M. Edelman and Giulio Tononi, *A Universe of Consciousness: How Matter Becomes Imagination* (New York, 2000).

to achieve cognition does not mean that computers must also be embodied and enworlded *in the same way* as humans to engage in meaning-making practices.

Wheeler uses a similar line of biologistic reasoning when she argues that "No human produced machine has any choice about its inputs; it has no body responding to its environment both nonconsciously and consciously. . . . In distinction, organisms, even the simplest, *do* make choices about their inputs and outputs, *do* have feeling bodies, *do* reproduce themselves and grow their themselves and environments" (*EE*, p. 139). But again, we see arbitrary limitations imposed here, in the stipulation that choice must pertain to "inputs and outputs" to serve a cognitive function and the assumption that feelings, reproduction, and growth are necessary for an entity to be cognitive. Computers do have bodies, just organized differently than biological ones; networked, programmable machines equipped with sensors and actuators do make choices about their inputs and outputs. Nevertheless, the thrust of Wheeler's comment is correct insofar as it points to the myriad differences between humans and computers; what is lacking is a willingness to explore what those differences might mean for computer cognition.

Both Deacon and Wheeler have moments when they come close to realizing that biologistic reasoning may not be appropriate for artificial cognition. Wheeler, following the passage above, remarks: "We should either be suspicious of the machine metaphor [used to describe biological brains] or radically rethink what we understand machines to be" (*EE*, p. 139). But the proffered alternative—"radically rethink[ing] what we understand machines to be"—remains a dead end in her text. Similarly, Deacon writes that "one fundamental difference" between biological cognition and machines is "obvious. The principles governing physical-chemical processes are different from those governing computation" (*IN*, p. 104); in another passage, he argues that "we need to think about the origin of organic mechanisms quite differently than designed mechanisms" (*IN*, p. 426). Like Wheeler, however, he fails to see how this might serve as a critique for his biologistic assumptions and rather uses it to further his argument against computational theories of mind.

If the emphasis in both Deacon and Wheeler is on biological organisms and the emergence of meaning-making practices in biota (succeeding brilliantly in this regard), why does it matter that they fall short when talking about computers? It matters because the frameworks they develop for interpretation, purpose, and meaning in the biological realm can become, with some necessary modifications, a powerful store of ideas to understand how computers achieve meanings and how computer-human interactions have dramatically transformed our potential to affect our world, for better and for worse. Showing how computational media create, communicate, and disseminate meanings is the next section's focus.

Intermediation and Constraints in Computational Media

The useful ideas emerging from biosemiotics that can be modified for computational media include the notion that interpretation (in Peirce's semiotics, the interpretant) consists of an action or behavior that has been consistently linked to an interior or external sign relation established through a historical connection, such as a young bird hearing the song characteristic of its species from its parents. The parental song, Hoffmeyer writes, serves as a "semiotic scaffolding" that allows the young bird to accomplish what it otherwise could not, and by learning the song, the young bird "interprets" an acoustic signal to initiate a new behavior, which in turn provides the basis for further interpretations.

In computational media, interpretation is ultimately based on the logic gates, which generate the constraints that in Deacon's scheme were accomplished through orthograde and contragrade dynamics. This signals one of the fundamental differences between biological and artificial cognition. Whereas with organisms the crucial point to explain is how they are able to generate and respond to sign relations, with computational media, designed to implement symbolic processes through their logic gates, the crucial point is how these deterministic operations can create a basis for flexibility, adaptability, and evolvability, the hallmark achievements of biological cognition.

This is the Second Great Inversion. Biological organisms, from the first stirrings of life on the planet, had to deal with unpredictable and fluctuating environments to survive. All lifeforms have developed ways to respond to environmental contingencies, from deciduous trees withdrawing sap to the coats that humans wear. Successfully adapting to the changes enabled lifeforms to develop increasingly sophisticated cognitive skills, culminating in symbolic abstractions by humans. But humans, in extending their cognitive capabilities through computational media, built symbolic abstraction into them at the foundational level of the logic gates. The challenge for computational media is to build up from this deterministic base to increasing capabilities for handling uncertainties and ambiguities, which they can achieve through a variety of means. Significant here are the time scales involved: while it took three million years for life to acquire the capacity for symbolic abstraction, it has taken computational media a mere half-century to achieve the hallmarks of biological cognition: flexibility, adaptability, and evolvability. To explore the implications of the First and Second Great Inversions, let us begin with how logic gates operate.[13]

Logic gates typically have either one or two inputs from transistors, which if switched on (accomplished through a voltage signal of five volts) register as a 1 (a bit) or, if switched off (accomplished through a voltage signal of zero), register as a 0. From the input combinations and the kinds of gates through which the inputs pass, various logical operators are generated. For example, the AND gate requires that both inputs be switched on to generate an output of 1; otherwise, the output is 0. The OR gate requires that either of the inputs be switched on to generate an output of 1; only if both are off does it output 0. The NOT gate, or inverter, has only one input and one output. It reverses whatever the input is and generates the opposite, so if the input is switched on, for example, it outputs a 0. Other kinds of gates include the XOR (exclusive OR), NAND (AND with outputs reversed), and so forth. These logical operators can be combined in many different ways, resulting in increasingly complex commands through the layers of code that sit on top of them. These include the machine and hardwired code that calls the machine's instructional set architecture, the system software that runs the specific hardware, the assembly language that encodes the operating system, up to high-level languages such as Python, Java, or C++ that encode the operating system software that runs the specific hardware processor and chipsets, on up to executable programs such as Microsoft Word, which is the level at which most users interact with the machine. Ultimately, however, all commands must be translated downward to the logic gates to be processed (either line by line as needed in interpreted languages, or in prepared batches in compiled languages) and then translated upward again to the high-level languages to communicate their results.

The distinctions between these different levels of code function as the different media in an intermediating dynamic heterarchy, with information communicated up from the logic gates to the higher code levels and down from the executable programs through the different code levels to the logic gates, in consistent patterns of interpretation that respond either to internal cues (endosemiosis) when the levels communicate with one another or external cues (exosemiosis) when a user inputs a command.

Biosemioticians writing about interpretation in a biological context often emphasize that interpretations can be wrong. A predator chasing a bird that

13. For a useful introduction to Boolean logic, logic gates, and switches, see Charles Petzold, *Code: The Hidden Language of Computer Hardware and Software* (Redmond, Wash., 2000), pp. 86–131.

appears to have a broken wing may discover, too late, that he was wrong when the bird flies away after drawing him away from the nest; the bacterium moving toward a presumed food source may discover it is a toxin instead. Such a requirement makes sense, for interpretation requires at least two choices to be pertinent; otherwise the situation can be parsed as a simple causal chain with no interpretation required.

In what contexts does interpretation operate within a computer, and how can it be wrong? Although the logic gates are deterministic, they can and do make mistakes. For example, the varying voltages that turn the transistor switches on and off typically manifest trail-off errors in which the signal decays over time, so at the end of the interval, the voltage may actually be, say, 4.7 volts rather than 5.0. As 4.7 is much closer to 5.0 than it is to 0, electronics are used to rectify the signal and interpret it as on rather than off and reinstate the 5.0. More significant voltage variations may cause an error in this rectification process.

Another source of uncertainty occurs when cosmic rays flip bits within a computer, analogous to when cosmic rays cause a mutation in a gene. Consequently, computer crashes are more frequent at thirty thousand feet than at sea level, because the cosmic rays are stronger there. A study of IBM in the 1990s suggested that such errors typically occur once every 256 megabytes per month, but as chips decrease in size, they need less voltage and less charge to set a bit and so are more at risk from cosmic rays.[14] An Intel patent application made this prediction: "Cosmic ray induced computer crashes have occurred and are expected to increase with frequency as devices (for example, transistors) decrease in size in chips. This problem is projected to become a major limiter of computer reliability in the next decade."[15] Routines such as parity checking and other programs able to check themselves may detect the flipped bit and correct it, rightly interpreting it as an error. Conversely, the flipped bit may cause certain commands to be misinterpreted, crashing the computer. Like mutations, it is possible (although extremely unlikely) that a flipped bit would actually improve the computer's performance, but if so, it would in all probability remain undetected.

These errors, however, are externally caused and do not undercut the deterministic quality of the logic gates. To arrive at interpretation understood as choices among options, it is necessary to move up to the level of

14. See "Cosmic Rays: What Is the Probability They Will Affect a Program?" *Stack Overflow*, stackoverflow.com/questions/2580933/cosmic-rays-what-is-the-probability-they-will-affect-a-program

15. Eric C. Hannah and Intel Corporation, "Cosmic Ray Detectors for Integrated Chips," US patent 7,309,866, filed 18 Dec. 2007.

executable programs, where complex interactions between logical operators combine with unpredictable inputs to create possibilities for interpretations. Unlike biological organisms immersed in unpredictable environments, computer-program contingencies have to be deliberately introduced to increase variability and flexibility. There are two basic strategies to accomplish this: recursivity and randomness.

Recursive dynamics are known to be powerful drivers of evolutionary processes in biological organisms, resulting in increased cognitive complexity.[16] In computational media, recursivity introduces contingencies because outputs are used as inputs, and in self-learning systems, the system itself determines how these inputs will be weighted for the next cycle, creating a kind of artificial evolution capable of proceeding in unpredictable directions. Randomness (more accurately, pseudorandomness) is produced when values are interjected into algorithms through contingent processes. For instance, one strategy takes a value from the computer's clock at a specified point, deterministic in the sense that the algorithm always operates the same way but unpredictable in a specific instance because the relation between the clock value and algorithm is uniquely established each time the algorithm runs.

In evolutionary programming, randomness is sometimes achieved by creating variations in algorithmic structures and then testing the variants against fitness criteria to discover which performs best. Since it is not known in advance which will succeed, this introduces unpredictability in the sense that the only way to determine the result is to run the program through hundreds or thousands of successive trials to see what emerges. An artistic implementation of this idea occurs in an evolutionary program designed by Swedish artists Johannes Heldén and Håkan Jonson to "evolve" Heldén's poetry through algorithmic variations. As with the clock example, the program consults various datasets to introduce pseudorandomness into the algorithms. In an amusingly eclectic mix, these include the "mass of exoplanetary systems detected by imaging," "GISS surface temperature" for various locations and dates, and "cups of coffee per episode of Twin Peaks."[17] Each time the program is run, it produces different results because of the injection of these pseudorandom values.[18]

16. Gerald Edelman and Joseph Gally have argued that recursive dynamics in humans are largely responsible for the emergence of consciousness through what they call "reentrant signaling" (Gerald M. Edelman and Joseph A. Gally, "Reentry: A Key Mechanism for Integration of Brain Function," *Frontiers in Integrative Neuroscience* 7 [Aug. 2013]: 1).

17. Johannes Heldén and Håkan Jonson, *Evolution* (2014), www.textevolution.net

18. See ibid. For an analysis of the work, see Hayles "Literary Texts as Cognitive Assemblages: The Case of Electronic Literature," *Electronic Book Review*, 5 Aug. 2018, electronicbookreview.com/essay/literary-texts-as-cognitive-assemblages-the-case-of-electronic-literature/

Anticipations are prominent in biosemiotics because they establish a relation between something present and something absent, which nevertheless has real causal powers. Deacon and Wheeler point to Peirce's definition of a sign as something "which is in a relation to its object on the one hand and to an interpretant on the other, in such a way as to bring the interpretant into a relation to the object, corresponding to its own relation to the object."[19] As a relational operator, a sign creates possibilities for meaning making because it brings a behavior (the interpretant) into relation with the object, the absential phenomenon for which the sign stands. It is this relation that invests the interpretant with aboutness, its meaningfulness in the context in which interpretation occurs. Each organism has its own semiotic niche, which in turn is coordinated with all the other niches operating in its environment. The sum total of all the semiotic niches comprises what Hoffmeyer calls the semiosphere, the dynamic interactions of sign relations enveloping the planet.

Anticipations also operate in computer codes. A basic structure in algorithms is the if/then construction: if A, do B; if C, do D. Even the simplest programs, such as the "Hello, World!" algorithm used to introduce programming, has an implicit if/then relation with the monitor, for the message will appear only if the algorithm completes its calculation and instructs the monitor to display the specified string. More complicated programs often require a result from a subroutine in order to proceed. In some complex programs, a supervening program needs a result from a subroutine, but, to save time, it anticipates the result and goes on to the next step. If the result is other than what it anticipated, it will back up and redo the calculation.

No one doubts that signs operate within computers, but the cogent objections have to do with aboutness, the computer's ability to recognize the absential phenomena so important for biosemiotics. In brief, a computer can manipulate signs, but does it know anything about what those signs signify? The classic challenge is John Searle's Chinese-room thought experiment, paraphrased as follows.[20] Imagine that a man who does not read, write, or speak Chinese sits in a room. There is slot in the door through which strings of Chinese letters are passed. The man uses a rule book and a basket of Chinese letters to compose a reply and slips it back through the door. His interlocutors are convinced that he knows Chinese, even

19. Peirce, "To Lady Welby," in *Reviews, Correspondence, and Bibliography*, in vol. 8 of *Collected Papers of Charles Sanders Peirce*, ed. Arthur W. Burks (Cambridge, Mass., 1958), p. 227.

20. See John Searle, *Minds, Brains and Science* (Cambridge, Mass., 1984) and, more concisely restated, "Chinese Room Argument," in *The MIT Encyclopedia of Cognitive Science*, ed. Robert A. Wilson and Frank C. Keil (Cambridge, Mass. 1999), pp. 115–16.

though all his replies are incomprehensible to him. The man, of course, represents the computer, and Searle's point is that the computer achieves its results simply by matching patterns and understands nothing about what it does. There have been hundreds of replies to this challenge, including ones pointing out that the computer is not simply the man but the rule book and characters as well as the room itself; other replies imagine that an embodied robot takes the man's place, capable of connecting input and output through embodied interactions. As rebuttals have proliferated, Searle has elaborated the challenge in ways that he claims effectively answer these.[21]

Suppose that we pose the question differently, adapting from Jakob von Uexküll the idea that every organism has an *umwelt* (a world-horizon) through which it makes sense of the world.[22] Then we may ask what the computer has knowledge about in its internal milieu—in effect, what the computer's *umwelt* is. This shifts the ground from whether the computer "understands" as a human would to the internal states of the computer and its capacities for sensing and responding to these states. Here a brief reflection on "knowledge" in the context of biological organisms may be helpful. Many organisms have information about ("know") how to interpret environmental cues, but this information is not necessarily present in every part of the organism. For example, like many people I have the ability to set my internal alarm clock to wake me at a specified time, say 5 a.m. Invariably I will wake within a minute or two of the set time, but how does my body "know" what the time is? It would not be difficult to figure this out: simply count how many times my heart beats per minute, multiply by the minutes that need to pass, count that many beats, then send a wake-up signal. But who is counting? Obviously not my consciousness, as I am asleep.

Nevertheless, something in my body accomplishes this task, no doubt with nonconscious cognition. *I* might not know, but somewhere in my body, as an integrated system, this information exists.

Similarly, a computer has many interacting parts, so a better way to ask what it "knows" is to ask what information exists somewhere within the computer's integrated system, although not necessarily in every part. A computer has information about time through its internal clock, and it has information about how many clock cycles have passed for any given operation. It has information about the different layers of its codes and

21. For a summary of the various responses and counterresponses by Searle, see David Cole, "The Chinese Room Argument," *Stanford Encyclopedia of Philosophy*, 19 Mar. 2004, plato.stanford.edu/entries/chinese-room/

22. See Jakob von Uexküll, "*A Foray into the Worlds of Animals and Humans*" *with* "*A Theory of Meaning*," trans. Joseph D. O'Neil (Minneapolis, 2010).

how they interrelate. It has information about how to interpret the algorithms it uses to solve problems, and it is able to anticipate the next steps in those algorithms and construct the proper sequences that a given program requires. It may also have a program able to discern when it is infected with a virus, and it has information about how to cure itself by deleting the malicious software. All this implies that instead of the biological imperative to survive and reproduce, the computer is designed for certain purposes (or self-designed, for computers that have evolved on their own beyond their initial design parameters), and its *umwelt* consists of the functions, architectures, and procedures that enable these purposes to be achieved.

Returning to Searle's thought experiment, I want to make explicit the anthropomorphic assumption embedded in his claim that the man "understands" nothing, an assumption underscored by figuring the interlocutor in the room as a human being. Perhaps the single most important contribution of biosemiotics is its challenge to anthropocentrism and its reconceptualization of meaning as a response to an environmental cue that benefits the organism in some way. Wheeler writes, "meaning is always a kind of doing. The meaning of a sign is to be found in the changes . . . which it brings about" (*EE*, p. 121). With design and purpose displacing biological imperatives in the First Great Inversion, a computer achieves meaning in this behavioral sense when it processes an algorithm, reads a data set, performs the calculations indicated, and produces results that it "understands" through its anticipations, interpretations, and information flows.

Of course, this is not all that computational media do, because humans have designed them to perform useful work in the context of hybrid human-computer assemblages. Rather than a stand-along computer, used above to explore the ground-state capacities of logic gates, contemporary computational media are networked with each other and connected to a wide variety of sensors and actuators, permeating contemporary infrastructures in ways that are often invisible to the humans who rely on them, as they work toward the Second Great Inversion of attaining flexibility, adaptability, and evolvability. As soon as a computational system includes sensors, it is exposed to the kinds of contingencies that organisms evolved to cope with; similarly, the system's algorithms must also be able to cope with uncertain or ambiguous data. The results of these computational systems are unquestionably teleodynamic—end-directed toward purposes that their designs enable and that (presumably) benefit the humans interacting with them. Granted, these computational media do not understand in the same sense as do humans; nevertheless, they are capable of meaning-making practices within their *umwelten*, performing actions in response to internal and external cues, making interpretations, and constructing relations between what is present and what is absent through their anticipations and operating constraints. As von Uexküll emphasized, *umwelten* between different species may overlap, but they are never completely coincident with one another. Similarly, computational systems have information about their internal and external milieux, which overlap with but do not coincide with what the humans know. Moreover, in self-designing programs such as evolutionary computations, genetic algorithms, and neural-net architectures, it is extremely difficult, if not impossible, for humans to reconstruct after the fact everything that has happened within the computational processes, so in this sense the computer "knows" more than humans.

Including more complex forms of artificial cognition into the conversation returns us to the issue of biotechnoevolution. As we have seen, the next evolutionary leap after the emergence of human cognition has been achieved through the development of artificial cognizers, communicating with each other and with humans through planet-wide networks of information flows, interpretations, and meaning-making practices. This strategy has resulted in a corresponding explosion of sign exchanges, extending the scope from the semiosphere, used to denote sign relations in the biological realm, to the cognisphere, which includes all these as well as all the sign relations created and communicated through computational media.[23] To explore this development, I turn now to cognitive assemblages and their implications for our human and nonhuman futures.

Cognitive Assemblages: Cyber/Bio/Semiotic Perspectives

As I have argued, cognitive assemblages are everywhere in our contemporary world, from satellite-imaging software to railroad-switching controllers to electrical-grid components and operators.[24] Perhaps the most obvious and visible is the internet and the web it hosts, facilitating worldwide traffic of enormous reach and complexity. Assuming that only the human participants in these assemblages are capable of meaning-making practices is as erroneous and anthropocentric as believing that the only species in the biosphere capable of making meanings are humans, a viewpoint that has become not only untenable but dangerously skewed in its implicit acceptance of human domination. Urgently needed are alternate

23. See Hayles, "Unfinished Work: From Cyborg to Cognisphere," *Theory, Culture and Society* 23, no. 7–8 (2006): 159–66.

24. See Hayles, "Literary Texts as Cognitive Assemblages."

perspectives that recognize the contributions of other species to our planetary semiosphere, as well as theoretical frameworks that underscore the importance of cognitive media in creating the meanings that guide hybrid human-technical action, perception, and decision-making in the contemporary world-horizon of the cognisphere.[25]

The evidence supporting this claim for the meaning-making capabilities of cognitive media is pervasive. Choosing one example out of thousands, I instance this proposal for a cognitive vision system for robotic docking with a free-flying space satellite. Here is the authors' description:

> Our system functions as follows: First, captured images are processed to estimate the current position and orientation of the satellite. Second, behavior-based perception and memory units use contextual information to construct a symbolic description of the scene. Third, the cognitive module uses knowledge about scene dynamics encoded using *situation calculus* to construct a scene interpretation. Finally, the cognitive module formulates a plan to achieve the current goal. The scene description constructed in the third step provides a mechanism to verify the findings of the vision system. The ability to plan allows the system to handle unforeseen situations.[26]

Interpretation, cognition, knowledge, planning, and flexibility characterize the design parameters for this system, designed, implemented, and overseen by humans but with the autonomy necessary to operate on its own in a space environment. The researchers make clear that this system does have an *umwelt*, an experiential horizon encompassing the perceptions, actions, and anticipations created by its sensors, actuators, and cognizing modules. Within its *umwelt*, it acts as a teleodynamical system with the end-directed goal of successful docking with a free-flying satellite. Within the larger human-technical assemblage, it serves the purpose of freeing astronauts from hazardous forays outside spacecraft required by manual docking or conversely from the risks of automated docking that follow detailed control scripts, which are error-prone and inflexible, without the ability to cope with unexpected developments.

25. A notable attempt in this regard is the Søren Brier's concept of cybersemiosis, which unites four different frameworks into an integrated framework: cosmology/physics; evolution/biology; historical/sociology and linguistics; and personal life history/phenomenology. See Søren Brier, *Cybersemiosis: Why Information is Not Enough!* (Toronto, 2008).

26. Qureshi et al., "Cognitive Vision for Autonomous Satellite Rendezvous and Docking," *Proceedings of the 9th IAPR Conference on Machine Vision Applications* (2005), web.cs.ucla.edu/~dt/papers/mva05/mva05.pdf

As Bruno Latour and Peter-Paul Verbeek have argued, such cognitive systems are much more than neutral tools, for they alter the horizon of what can be known and thereby have far-reaching consequences for social, cultural, and economic practices.[27] Louise Amoore highlights these implications in her work on cloud computing, especially ICITE (pronounced "eyesight"), the Amazon Web Services six hundred million dollar contract for data security and intelligence infrastructure. She writes, "the cloud promises to transform not only what kinds of data can be stored, where, and by whom, but most significantly what can be discovered and analysed of the world. The cloud's capacity to extend 'big data' to a horizon of 'infinite data' opens new spaces of what I have elsewhere called the politics of possibility, where security practices act upon future possible horizons."[28] Among ICITE's platforms is Digital Reasoning software, a machine-learning program for "analysing and deriving meaning from information." She quotes from the software's description, which touts the program's ability to extract "'value from complex, often opaque data . . . [empowering] the analyst with advanced situational awareness, enhancing cognitive clarity for decision-making'" ("CG," pp. 12, 13). As she demonstrates, such programs make "possible the distributed analysis of big data across data forms," for example, human language in emails and social media sites ("CG," p. 13). The upshot, as one analyst she cites observed, is that "'it allows us to say correlation is enough'" ("CG," p. 13). Enough, that is, for actionable intelligence in a variety of surveillance contexts, ranging from detaining "persons of interest" suspected of terrorism to spotting insider trading in the financial industry.

This example, and many others, raises troubling questions about the ethics of employing such hybrid human-technical systems when they threaten long-standing traditional values, such as the right to be free from surveillance and to opt out of having one's data analyzed without one's permission or knowledge. To tackle these complex issues, we must recognize that computational media act as ethical agents in our contemporary world, although the locus for ethical responsibility remains with the humans who design, implement, and maintain the systems. What we can no longer afford is the illusion that computational media simply perform calculations, devoid of interpretations, anticipations, and meaning making.

27. See Bruno Latour, "Morality and Technology: The End of the Means," trans. Couze Venn, *Theory, Culture and Society* 19, no. 5–6 (2002): 247–60, and Peter-Paul Verbeek *Moralizing Technology: Understanding and Designing the Morality of Things* (Chicago, 2011).

28. Louise Amoore, "Cloud Geographies: Computing, Data, Sovereignty," *Progress in Human Geography* 42, no. 1 (2018): 7; hereafter abbreviated "CG."

It seems obvious to me, and to many who write about our human futures, that (short of environmental collapse or catastrophic global war) our journey into symbiosis with computational media, which has already begun, is likely to accelerate in the coming decades. Kauffman has written about the "'adjacent possible'" within biological evolution.[29] When there is a very large space of possibility, he argues, the relevant issue is not the space's theoretical size but the strong likelihood that pathways adjacent to the existing one will be followed, giving a teleological impetus to evolutionary developments. Through this reasoning, he demonstrates that it was not a statistical freak that life evolved on earth but rather a probable outcome produced by following a series of adjacent possibles.

Given where we are now, the adjacent possibles include increasing use of intelligence augmentation, in which the cognitive capacities of humans are enlarged and enhanced by computational media as in the examples above, which will sit side by side with the development of more powerful, flexible, and pervasive forms of artificial intelligence. Among these are neural-net architectures and deep-learning algorithms, already mentioned above as programs that, by making extensive use of recursive dynamics, are able to adapt and evolve. The potential of neural-net architecture is exemplified in the development of AlphaGo by DeepMind.[30] I previously have discussed this instance as follows:

> Go is considered more "intuitive" than chess, having exponentially more possible moves, with a possibility space vastly greater than the number of atoms in the universe (10^{240} moves vs. 10^{74} atoms). With numbers this unimaginably large, brute computational methods simply will not work—but neural nets, working iteratively through successive rounds of inputs and outputs with a hidden layer that adjusts how the connections are weighted, can learn in ways that are flexible and adaptive, much as biological brains learn.
>
> Now DeepMind, the company that developed AlphaGo (recently acquired by Google), has developed a new version that "learns from scratch," AlphaGoZero. AlphaGoZero combines neural net architecture with a powerful search algorithm designed to explore the Go possibility space in ways that are computationally tractable. Whereas AlphaGo was trained on many human-played games as examples, its successor uses no human input at all, starting only with the basic rules

29. Kauffman, *Investigations* (New York, 2000), p. 22.

30. See David Silver et al., "AlphaGo Zero: Learning from Scratch," *DeepMind*, 18 Oct. 2017, deepmind.com/blog/alphago-zero-learning-scratch/

> of the game. Then it plays against itself and learns strategies through trial and error. At three hours, AlphaGoZero was at the level of a beginning player, focusing on immediate advances rather than long-term strategies; at 19 hours it had advanced to an intermediate level, able to evolve and pursue long-term goals; and at 70 hours, it was playing at a superhuman level, able to beat AlphaGo 100 games to 0, and arguably becoming the best Go player on the planet.[31]

There are utopian as well as dystopian possibilities in developments like these. Our best hope for navigating these tricky waters is to start with a clear-eyed view of how human *umwelten* overlap with and differ from the nonhuman others with whom we share the planet, including both biological organisms and computational media. The cognisphere in which we all interact grows ever denser and more complex, a sure sign that biotechnoevolution continues to accelerate towards an unknown future. It is up to us to anticipate risks and dangers in our continuing biotechnoevolution and use the two Great Inversions to create livable environments for us and our nonhuman symbionts, biological and technological.

31. Hayles, "Literary Texts as Cognitive Assemblages."