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Heinz von Foerster's Demons

The Emergence of Second-Order Systems Theory

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At its inception the discourse of cybernetics centered on the cluster of topics given by the initial title of the famed Macy Conferences, ten of which occurred between 1946 through 1953, "Circular Causality and Feedback Mechanisms in Biological and Social Systems." The interdisciplinary group here assembled brought together philosophically minded scientific polymaths and pioneers of electronic computation and information theory, such as Warren McCulloch, Norbert Wiener, John von Neumann, and Claude Shannon, with anthropological social scientists such as Margaret Mead and Gregory Bateson. A student of the Vienna circle trained in mathematics, physics, and electrical engineering, Heinz von Foerster in 1949 landed newly arrived in the United States and somewhat miraculously in the midst of this uncommon aggregation, in the middle of its run, and, despite minimal proficiency in English, was appointed (by McCulloch) the secretary of the Macy Conference proceedings. A year later and in the influential wake of Norbert Wiener's 1948 book, *Cybernetics, or Control and Communication in the Animal and Machine*, von Foerster suggested changing the name of the Macy Conferences to simply "Cybernetics," and his suggestion was adopted.[1]

The Macy Conferences represent the high point of the first interdisciplinary synthesis through which cybernetics came forward as a metadiscipline, bringing physical, mathematical, and engineering concepts of entropy, information, and feedback toward an integrated study of complex mechanical, computational, biological, psychic, and social systems. However, in the years after the Macy Conferences closed up shop, this cybernetic synthesis gradually splintered into noncommunicating specializations. Broadly considered, it diverged sharply back into subject/object dichotomy and Cartesian dualism—what could be called "hard" and "soft" camps. The former monopolized its resources, hoarded its grants, and redirected the mathematical and engineering sides of cybernetics

toward Artificial Intelligence (AI), robotics, computer science, and command-control-communications technologies. To its credit, this is why you now have a computer on your desk and an iPhone in your pocket. The latter camp, often loosely identified with the work of Gregory Bateson, gradually gathered up the cognitive and philosophical insights of cybernetics toward matters of managerial and social systems, psychotherapy, and epistemology. Few persons besides von Foerster could be said to have had a foot in both camps, and no other vision of a holistic cybernetics was forthcoming to split the difference between them. Instead, the abandoned middle ground was eventually filled up with a multifarious cultural mythology centered on celebratory and cautionary images of the cyborg, a theoretical figure built up from variously real and imaginary mergers of biological bodies and electronic brains.

Twenty years after the lapse of the Macy Conferences, however, von Foerster would consolidate these alternative cybernetic trends with the turn toward what he called "second-order cybernetics." In a cluster of papers written by the mid-1970s—"Notes on an Epistemology for Living Things," "On Constructing a Reality," "Cybernetics of Epistemology," and "Objects: Tokens for (Eigen-) Behaviors"—von Foerster catalyzed new thinking about the deeper cognitive implications of "circular causality." Essentially, von Foerster tweaked the engineering discourse of positive and negative feedback toward the recognition of self-reference as an ineluctable form of operation in systems in general, and particularly at the basis of anything worthy of being called cognition, whether the system at hand was natural or technical. The crucial conceptual shift was a movement from first-order cybernetics' attention to homeostasis as a mode of autonomous self-regulation in mechanical and informatic systems to concepts of self-organization—especially as that notion captured the apparent self-ordering and self-regulation of bodies and minds—and to self-reference and autology as the abstract logical counterparts of recursive operations in concrete and worldly systems.

Befitting his adolescent apprenticeship as an amateur magician, Heinz von Foerster's professional papers, many of them reading texts for conference audiences, in addition to the usual scientific diagrams and mathematical equations, are consistently peppered with amusements, puzzles, and paradoxes.[2] Delivered by a mildly manic discursive persona—at times one almost sees the baggy sleeves of the sorcerer's cloak flapping—these papers are intensely focused on entertaining audiences often assumed to be skeptical about their propositions. For scientific papers they are remarkably high rhetorical performances. Serious arguments about matters of biological computation, system/environment interrelation, and perceptual and cognitive construction typically turn on a

presentational rhetoric that places them, as it were, on a magician's stage and presto! turns them into visible shapes. Yet the discursive style of this prestidigitating persona is more than a mannerism. It embodies the "natural magic" of cybernetics itself.

With von Foerster's writings, cybernetic discourse begins in earnest the project of taking itself as its own object. With his second-order turn, matters of circular form and operation break out of philosophical and literary treatment (as "reflexivity") and into scientific discussion (as "recursion"). Amazing though it may seem, one discovers that whereas circularity is death (by infinite regress) to *structures*, it is life (by autonomous self-regulation) to *systems*. Von Foerster's work renders paradoxical propositions, recursive forms, and self-referential operations available at once to rational and aesthetic, scientific and literary view. A major and early instance of von Foerster's rhetorical persona discursively embodying cybernetic tenets regarding recursion, epistemological paradox, and self-reference is "On Self-Organizing Systems and Their Environments," delivered in 1959 and first published in 1960. This important paper figures prominently in the work of systems thinkers as disparate as Henri Atlan, Francisco Varela, and Niklas Luhmann and anticipates chaos theory by two decades with its seminal and exhilarating presentation of the "order-from-noise" principle.

Written a decade before the self-referential or neocybernetic turn in his own work, however, this essay still resides in the milieu of first-order cybernetics. It is still large with the heuristic extension of Shannon's information theory as a relay between energy and information; physics and biology; thermodynamical, living, and computational systems. Nevertheless, "On Self-Organizing Systems and Their Environments" prefigures von Foerster's later papers' epistemological turn toward matters of cognitive recursion, in synch with the simultaneous emergence of the concept of biological autopoiesis in the early 1970s, for which discursive event von Foerster was literally the institutional midwife.[3] "On Self-Organizing Systems and Their Environments" is centered on a pre-autopoietic concept of self-organization and the possibility of conceptualizing it through the mathematical theory of communication as the emergence of order from noise.

But to get to this exposition, its audience must first process at some length two conceptual paradoxes, two "fallacies" concerning the definition of self-organizing systems, both of which are subjected to mock deployments of *reductio ad absurdam* arguments. Tying these propaedeutic rhetorical paradoxes together with the essay's subsequent work-up of entropy, information, and redundancy in the interrelations of self-organizing systems and their environments is Maxwell's Demon, a scientific thought-experimental entity custom-made for von Foerster's conceptual whimsy. A preliminary review of the demon's development from its creation in 1867 to its return performance in von Foerster's 1959 paper will allow us to measure the aptness of von Foerster's appropriation of the demon for systems theory, as well as the poetic justice of this collaboration of scientific pranksters. The "magical" or daemonic side of von Foerster's rhetoric—the significance of the paradoxes and other meta-logical performances through which he utters his arguments—can then be more clearly factored into the neocybernetic concepts and methods of his later cognitive papers. Von Foerster's importance for and imprint on the social systems theory of Niklas Luhmann will then emerge with particular clarity.

Protocybernetics in Maxwell's Demon

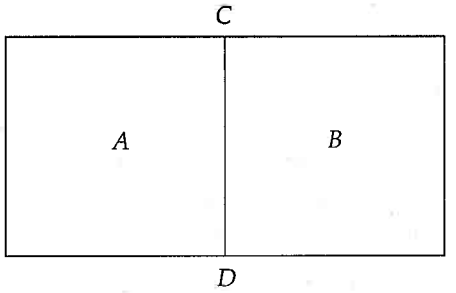
At a conference entitled "Self-Organizing Systems," von Foerster begins a paper entitled "On Self-Organizing Systems and Their Environments" with the following thesis: "There are no such things as self-organizing systems!"[4] As we noted above, this is the first of the two paradoxes or, more precisely, mock fallacies in this paper. With an obvious allusion to the classical role of Maxwell's Demon as a challenge to the "rule of entropy" in closed physical systems, he asks, ironically, whether "there is not a secret purpose behind this meeting to promote a conspiracy to dispose of the Second Law of Thermodynamics."[5] Maintaining ironical posture, with this remark von Foerster implicitly plays devil's advocate to Maxwell's Demon, as the demon's scientific fame was first established as a successful conceptual antagonist to the "heat death" scenarios spun off from the second law by William Thomson, Hermann von Helmholtz, and many others. Classical thermodynamics declared that physical organization, the orderliness of material/energetic systems, spontaneously deteriorates over time (the rule of entropy) and that its restoration must always be paid for with new contributions of energy. If autonomous self-organization can occur without energic input from or entropic output to the environment, in Maxwell's famous words, this would indeed "pick a hole in the 2nd law." So von Foerster sets up his first paradox by placing the notion of self-organizing systems within a thermodynamic frame, ostensibly like the hermetic enclosure Maxwell used in 1867 to circumscribe the environmental relations of the abstract or hypothetical system into which he first placed his thought-experimental demon.

Maxwell's Demon began as a practical conceit. In this scientific allegory, the daemonic agent personifies the conceptual manipulation of scientific models of physical systems. Viewed historically, the demon began as a scientific fiction

but has evolved into a supple theoretical fact with real consequences for the development of modern science. The demon's successful run has rested on its conducting thought experiments in fruitful directions. And few heuristic entities from the annals of scientific modeling have been as thoroughly anthropomorphized—not just brought to conceptual life but also endowed with a narrative career—as Maxwell's Demon. For instance, for several decades around the mid-twentieth century, the demon was declared to be dead—that is, to be a dead scientific metaphor, no longer able to generate plausible challenges to the second law of thermodynamics. Fortunately for the demon, cybernetics revived it for heuristic duty in information theory and computer science, and it can still be sighted today in odd corners of both scientific and popular culture.[6] The demon is clearly more than an academic curiosity or cultural antique: it is the Elvis of Victorian thermodynamics.

On December 11, 1867, Maxwell wrote to fellow physicist Peter Guthrie Tait with a way "to pick a hole" in the second law of thermodynamics, that "if two things are in contact the hotter cannot take heat from the colder without external agency." That is, when physical systems are left to themselves, one always observes heat to move (thermo-dynamics) from hotter to colder bodies. Maxwell invented the demon to reverse, in theory at least, this entropic drift of things. To restore energy to a closed system is potentially to restore it, if the system is then opened, to the environment of that system as well.[7] As first materialized in Maxwell's letter to Tait, the demon takes the form of an *internal* agency within a sealed and partitioned chamber containing a gas: "Now let *A* & *B* be two vessels divided by a diaphragm and let them contain elastic molecules in a state of agitation."

Despite their temperature differential, among the molecules in both chambers "there will be velocities of all magnitudes." It is the random distribution of molecular velocities, together with the partitioning (*CD*) of the total system, that provides the opening for an intelligent agent to fix the molecular lottery. "Now conceive a finite being who knows the paths and velocities of all the molecules by simple inspection but who can do no work, except to open and close a hole in the diaphragm by means of a slide without mass." Supplementing the dynamical system at the microlevel, the demon famously lets only hotter molecules from *B* go into *A*, where it is already hot, and only colder ones from *A* go into *B*, where it is already cold, by which stratagem the second law is violated in that *the hotter vessel takes heat from the colder without external agency*. The demon works on the *inside* of the system but (according to the total conceit of the thought experiment) without adding any energy to the system. Merely by the intelligent sorting of statistical variations in already energetic particles,



Maxwell's Sketch for a Thermodynamic Thought-Experiment.

the demon reverses the probable drift toward thermal equilibrium and, so the legend goes, saves the world from the specter of entropy.

The demon's career has taken it from the closed systems abstracted from environmental contingencies idealized by classical thermodynamics to the models of self-organizing and autopoietic systems founded on variably open and closed boundaries and structural couplings of systems to each other and to their environments, relationships crucial in cybernetic models of the interfaces among physical, technological, biological, and social systems. As a figure accompanying the postclassical development of the entropy concept, Maxwell's Demon now mediates between the realms of energy and information—classical thermodynamics, quantum physics, and cybernetics. As a broader figure of system functions, as an observer and operator of inner and outer boundaries, the demon can also mediate the distinctions *among* systems, a matter increasingly important to systems theory in a postclassical conceptual milieu where measures of energy (*E*), thermodynamic entropy (*S*), and "information entropy" (*H*) are differentiated and coordinated.

In particular, in its progress from Victorian thermodynamics to contemporary systems theory, one of the demon's signal accomplishments has been to conduct the classical entropy concept from the absolute bondage of thermodynamic closure in material-energetic systems to the contingent liberation of an informatic or statistical virtuality, in which environmental openness to energies and signs is coupled to the operational or organizational closure of self-organizing and autopoietic systems. In Maxwell's original conception, the demon is the internal observer of an isolated physical system, an idealized thermodynamical system with a closed or "adiabatic" outer boundary. By definition, such systems perfectly exclude their environments. In the original case, prior to the arrival of the demon, this exclusion also ensured the eventual thermal equilibration of vessels *A* and *B*, the slurring of their heat differential, and thus the system's submission to the second law. What openness this model

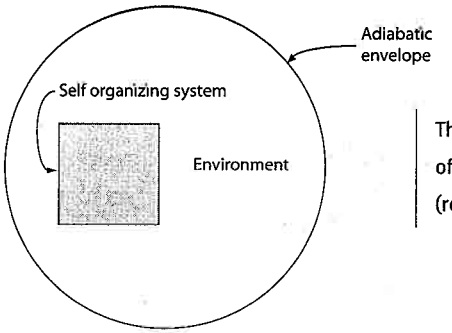
possessed was strictly internal: the hole in the partition, which the demon opened or closed to allow selected molecules to pass from one vessel to the other. Yet it was precisely *by partitioning the chamber with a diaphragm and then poking a hole in it*, and so providing the demon with an internal passage point to operate on the basis of its observations, that Maxwell "picked a hole" in the classical idea of thermodynamic entropy in closed systems. In Maxwell's original demon scenario, that is, the external closure of the physical system is countered by the demon's capacity to open and shut the membrane between the vessels. Thus the demon's operations already anticipated the "open closure" of complex systems that go beyond thermodynamical enclosure and use their boundaries to regulate commerce (input/output ratios or perturbation/compensation relations) with their environments.

"On Self-Organizing Systems and Their Environments"

Mock Fallacy 1: There Is Such a Thing as a Self-Organizing System

With his allusion to the second law at the beginning of "On Self-Organizing Systems and Their Environments," von Foerster sets up his first paradox—"I shall now prove the non-existence of self-organizing systems by *reductio ad absurdam* of the assumption that there is such a thing as a self-organizing system"—by placing the notion of self-organizing systems within the frame of classical thermodynamic constraints. These include the "adiabatic shell" (see below), across which no energy may pass. The hermetic closure of this universe from any other universe underscores the importance of *environmental closure* in the classical thermodynamic milieu. The universe of classical thermodynamics is closed not only at the (ideally) sealed outer boundaries of thermodynamical systems, such as heat engines, but also insofar as that universe itself, the environment of all environments, is envisioned as a closed system. Von Foerster framed his model of a self-organizing system with these classical thermodynamic allusions to closed partitionings of *energy*, it seems, precisely to elicit certain systemic *alternatives* to this form of closure. That is, his essay unfolds the repercussions for self-organization for systems that process *information* as well.

> Assume a finite universe, U_0, as small or as large as you wish, which is enclosed in an adiabatic shell which separates this finite universe from any "meta-universe" in which it may be immersed. Assume, furthermore, that in this universe, U_0, there is a closed surface which divides this universe into



The Environmental Closure of a Self-Organizing System (redrawn).

> two mutually exclusive parts: the one part is completely occupied with a self-organizing system S_0, while the other part we may call the environment E_0 of this self-organizing system: $S_0 \& E_0 = U_0 \ldots$.
>
> Undoubtedly, if this self-organizing system is permitted to do its job of organizing itself for a little while, its entropy must have decreased during this time . . . otherwise we would not call it a self-organizing system, but just a mechanical . . . or a thermodynamical . . . system. In order to accomplish this, the entropy in the remaining part of our finite universe, i.e. the entropy in the environment must have increased . . . otherwise the Second Law of Thermodynamics is violated. . . . Hence the state of the universe will be more disorganized than before . . . , in other words the activity of the system was a disorganizing one, and we may justly call such a system a "disorganizing system."[8]

In this passage von Foerster plays fast and loose with, or rather mocks, (1) the noncoincidence of the system S_0's *self*-organization with its "disorganizing" of its *other*, the environment E_0, and (2) the distinction between energy and information. That is, for the moment he equivocates between, on the one hand, thermodynamic entropy as the measure of some real reduction in the sum of usable energy within a material system and, on the other hand, entropy as redefined in Shannon's information theory as a measure of the (dis)order or formal (dis)organization of any system, but particularly of message structures (information) transmitted within communication systems. But the equivocations embedded in this supposed proof bring out the paradoxical punch line of von Foerster's mock fallacy: distinctions are also inclusive of what they exclude. From the holistic perspective that stays attentive to both system *and* environment, the universe U_0 is comprised by the *mutual inclusion* of these "two mutually exclusive parts": "In spite of this suggested proof of the

non-existence of self-organizing systems, I propose to continue the use of the term 'self-organizing system,' whilst being aware of the fact that this term becomes meaningless, unless the system is in close contact with an environment, *which possesses available energy and order*, and with which our system is in a state of perpetual interaction, such that it somehow manages to 'live' on the expenses of this environment."[9]

Von Foerster administers these bracing doses of classical thermodynamics and first-order cybernetics, then, to put his audience's material-energetic feet on the ground. To balance the bias toward information and the valorization of order taken as forms *internal* to self-organizing systems, he insists on maintaining conceptual hold on the environment, what Cary Wolfe calls "the pragmatics of the 'outside.'"[10] "Energy and order" are characteristics particularly plain in living systems and in the environments that sustain them, and the metaphorics of this latter passage are more biological than physical. Before the emergence of far-from-equilibrium thermodynamics and dynamical systems theory, considerations of self-organization were typically centered on *living* systems and then extended, not so much to physical or chemical systems as to the biotic and metabiotic natural systems—nervous, psychic, and social—that ramify from the evolution of cells and organisms within material-energetic, thermodynamical environments. Von Foerster's serious point remains indispensable: No system of any stripe can be adequately treated in the absence of the environment it constitutes for itself by emerging as a system. The inseparability of the system/environment dyad is a primary and pivotal premise of cybernetic thought, separating cybernetics per se from the late-classical paradigms of Victorian thermodynamics. To characterize the argument so far, "There is such a thing as a self-organizing system" is a *mock fallacy*—strictly speaking, a paradox. Although certain systems *do* self-organize, or decrease their internal entropy, they do so only in the presence of conditions provided for elsewhere, by environments that lend a necessary other to the self of self-organization.

Mock Fallacy 2: This World Is Only in Our Imagination

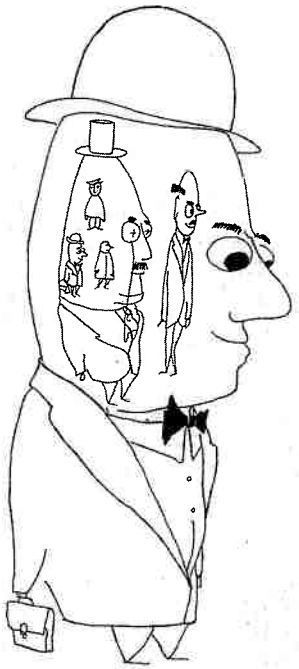
The inseparability of the system/environment dyad is also the point of von Foerster's second gambit at the beginning of "On Self-Organizing Systems and Their Environments." But this time he approaches it from a philosophical rather than biophysical vantage. From the side of the "subject" rather than that of the "object," he arranges a kind of Cartesian litmus test for the reality of the environment.[11] For in its first moment, all the Cogito can cognize is its *own* existence, precisely as a *system* capable of *self*-observation: "Perhaps one of the oldest philosophical problems with which mankind has had to live . . .

arises when we, men, consider ourselves to be self-organizing systems. We may insist that introspection does not permit us to decide whether the world as we see it is 'real,' or just a phantasmagory, a dream, an illusion of our fancy."[12] What if the only reality is in fact the self in terms of which the mind carries out its self-organization? If that were the case, "my original thesis asserting the nonsensicality of the conception of an isolated self-organizing system would pitiably collapse. I shall now proceed to show the reality of the world as we see it, by *reductio ad absurdum* of the thesis: this world is only in our imagination and the only reality is the imagining 'I.'"[13] Or again (says von Foerster, honorary cousin of Ludwig Wittgenstein) I shall now make a superannuated philosophical conundrum—disappear![14]

With this buildup, von Foerster musters up one of the more famous icons in the visual rhetoric of cybernetic discourse. In order to problematize the solipsistic notion of the *mind* as "an isolated self-organizing system," von Foerster diagrams a situation of self-referential selves within selves—the Man with the Bowler Hat (MBH). The MBH imagines that he is a self-organizing system *without an environment*:

> Assume for the moment that I am the successful business man with the bowler hat . . ., and I insist that I am the sole reality, while everything else appears only in my imagination. I cannot deny that in my imagination there will appear people, scientists, other successful businessmen, etc., as for instance in this conference. Since I find these apparitions in many respects similar to myself, I have to grant them the privilege that they themselves may insist that they are the sole reality and everything else is only a concoction of their imagination. On the other hand, they cannot deny that their fantasies will be populated by people—and one of them may be I, with bowler hat and everything!
>
> With this we have closed the circle of our contradiction: If I assume that I am the sole reality, it turns out that I am the imagination of somebody else, who in turn assumes that *he* is the sole reality. Of course, [since either of these propositions is "absurd"] this paradox is easily resolved, by postulating the reality of the world in which we happily thrive.[15]

The X-ray image of the Man with the Bowler Hat ostensibly depicts the classical solipsist—one who asserts that whatever they perceive (here, those two gentlemen over there) exists only inside their own mind and that, therefore, *they* are the only thing in existence. Even if idealist philosophies of the transcendental subject do not rule such notions out, however, according to the primary premise of systems theory rehearsed in the first paradox, in the world of



The Man with the Bowler Hat (drawn by Gordon Pask).

real systems the nonexistence of an environment is simply not forthcoming. So solipsism is not the real problem but rather a metaphor for a real propensity to concentrate on the system concept without maintaining sufficient consideration of its necessary counterpart, its environment. Or again—to be adequate to its object, systems thought has to proceed from the full situation constituted by the system and its environment and the dynamic maintenance of the boundary that distinguishes them.

In the 1959 paper, then, von Foerster uses the MBH to reaffirm the proposition just established, to underscore again, from the side of the subject, the real existence of the environment over against a too narrow interest in the system concept per se. Von Foerster deconstructs the paradox of solipsistic self-descriptions by reframing it within a world created by the mutual observations of two or more (mock) solipsists. To state the moral of this parable in second-order systems parlance: if autopoietic systems can *not* be environmentally closed systems (as thermodynamic systems ideally can) and if the mind is an autopoietic system (the psychic system), then solipsism—"pure" self-reference—has no way to even begin to operate. Solipsism is thus dismissed as cognitive repression of the environment.

Still, the paradox is so easily resolved that we almost fail to notice that what we have just been presented is another bit of conceptual sleight of hand, a mock

proof, a rhetorical argument masquerading as a logical *reductio*. As Katherine Hayles has noted, although without, I think, appreciating the full significance of her observation, "Von Foerster himself seemed to recognize that the argument was the philosophical equivalent to pulling a rabbit from a hat."[16] But the worldly environment within which all cognitive systems are embedded was not really in serious doubt, only the rigor with which it got itself factored into systems thinking. What von Foerster implies with his magical fallacy is that we still have a hard time taking for real that all *knowledge* of the environment depends upon the specific realities of the systems that observe it. The *systemic* reality of the environment is to be both the precondition *and* the product of an observing system. This is the self-reference bound up in any presentation of something beyond the self. The MBH conveys an ironic message to those who would affirm that when they observe the world and state their truths about it, they are *not* a part of the reality they are describing, that they are not embedded within their own descriptions. *This* denial would be the sort of reverse solipsism of the epistemological positivist that posits a contextless context of knowledge—as if the world could be known without the existence of local and embodied knowers to carry out the knowing. So the "subjective" self/other difference of the second paradox doubles the "objective" system/environment coupling developed in the first paradox, allowing for the different, environmental reality of the other to arise a second time, this time out of the self-reference of the self as observing system.

In the 1959 paper, von Foerster concludes the bowler hat interlude with a methodological proposition in the form of a discursive aside: "Having reestablished reality, it may be interesting to note that reality appears as a consistent reference frame for at least two observers."[17] And if we examine the MBH carefully, we see that he constructs in imagination *two* observers, one of which confirms his reality by imagining *him*. The total figure, then, prefigures what second-order cybernetics will call the observation of observation. Through a reticulation of levels of observation, it presents a second-order view of the epistemological situation, which reveals that the solipsist, in turn, exists both as the figment of its own figments and as the observation of another observer.

For the solipsist to confess that its own existence depends on the reality of an other in its environment is a parable of the overcoming of ontological idealism by epistemological constructivism. Taken as a diagram of recursive cognition, then, the MBH is not a sterile *mise-en-abyme*, hall of mirrors, or vicious circle of the same all over again. Literally considered, the MBH does not simply self-reiterate in a mode of infinite regress; rather, an other is interposed between the self and its reflection. This is better understood as a productive

oscillation, as the image of a mutual embedding of the other within the self and the self within the other. The message is that the reality one can know depends on the communication of reality from one observer to another, which depends on "a consistent reference frame" within which "at least two observers" are embedded so as to construct a conversation about that reality.

Two Maxwell's Demons and the "Order-from-Noise" Principle

As we have just seen, "On Self-Organizing Systems and Their Environments" adumbrates the explicit epistemological constructivism of von Foerster's later essays with a systems theory built on the premises of recursively structured system/environment couples. A multiplicity of mutually reinforcing observers maintains relationships and states of stable cross-systemic resonance von Foerster will come to call "eigenbehaviors," at both the biological and the social level. Thus it is fitting that when Maxwell's Demon makes a literal entrance later in the paper, it does its self-organizing not as a solo act within a closed system, but instead as a duo of demons collaborating to self-organize within a system/environment dyad under their mutual observation.

This time, the matter of entropy is treated cybernetically, in its information-theoretic redescription as a measure of the relative order or disorder of an information source: "Order has a relative connotation, rather than an absolute one, namely, with respect to the maximum disorder the elements of the set may be able to display." Von Foerster advances Claude Shannon's definition of redundancy (R) as a measure of the order of a system, derived by subtracting from unity or maximum order the relative entropy, "the ratio of the entropy H of an information source to the maximum value, H_m, it could have while still restricted to the same symbols."[18]

Von Foerster works through further mathematical models that would obtain for a system whose self-organization is observed in these terms. The self-organizing operations of the system, it turns out, can be viewed from either side of the ratio. For instance, if the maximum entropy H_m is held constant, then the system will be self-organizing if the entropy H can be decreased. This represents the "internal" view of the situation, and von Foerster slips the first demon into the demonstration to underscore its boundedness on the inside of the system: "Since all these changes take place internally I'm going to make an 'internal demon' responsible for . . . shifting conditional probabilities by establishing ties between elements such that H is going to decrease."[19] However, if instead of the maximum entropy H_m, the given entropy of the system H is held constant, "we obtain the peculiar result that . . . we may have a self-organizing system

$$R = 1 - \frac{H}{H_m}$$

Claude Shannon's Definition of Redundancy.

before us, if its possible maximum disorder is increasing."[20] In other words, it is also possible to increase the order of a system *by maintaining its entropy while increasing its complexity*: "Clearly, this task of increasing H_m by keeping H constant asks for superhuman skills and thus we may employ another demon whom I shall call the 'external demon,' and whose business it is to admit to the system only those elements, the state of which complies with the conditions of, at least, constant internal entropy."[21]

However, in both of these limit cases one demon is chained while the other does all the work. The more common situation will be one "where both demons are free to move"[22] or—translating this mathematical allegory of self-organization into somewhat plainer terms—one where systematic processes and environmental resources are structurally coupled to each other in a way that maintains the system and under favorable conditions enables it to reduce its entropy and/or increase its complexity. The paradoxical boundary where system and environment meet is marked by the "greater than" sign indicating the higher order of the system relative to the lesser order but greater complexity of its environment. In this parable of productive mutuality, what I also like to read as a fable of academic interdisciplinarity, "if the two demons are permitted to work together, they will have a disproportionately easier life compared to when they were forced to work alone."[23]

Now von Foerster makes a famous final move that synthesizes the energic and informatic potentials of his system-theoretical demons and derives the *order-from-noise* principle from "the double linkage between the internal and external demon which makes them entropically (H) and energetically (E) interdependent." It is not just a matter of "negentropy," as that term was used at the time to identify informational order with negative entropy. Self-organizing systems can also translate the *external noise* of their environments into systemic gain: "Thus, in my restaurant self-organizing systems do not only feed upon order, they also find noise on the menu."[24] With the formulations that "reality appears as a consistent reference frame for at least two observers" and "a self-organizing system feeds upon noise," von Foerster both shapes and integrates the future courses of second-order and self-organizing systems theory. Citing Ilya Prigogine's work on dissipative structures in the discussion that followed his 1959 presentation,[25] he inspires the theoretical bioinformatics of Henri Atlan, taken up by Michel Serres, and anticipates broad future developments in chaos

$$H \times \frac{\delta H_m}{\delta t} > H_m \times \frac{\delta H}{\delta t}$$

Internal demon's results

External demon's efforts

External demon's results

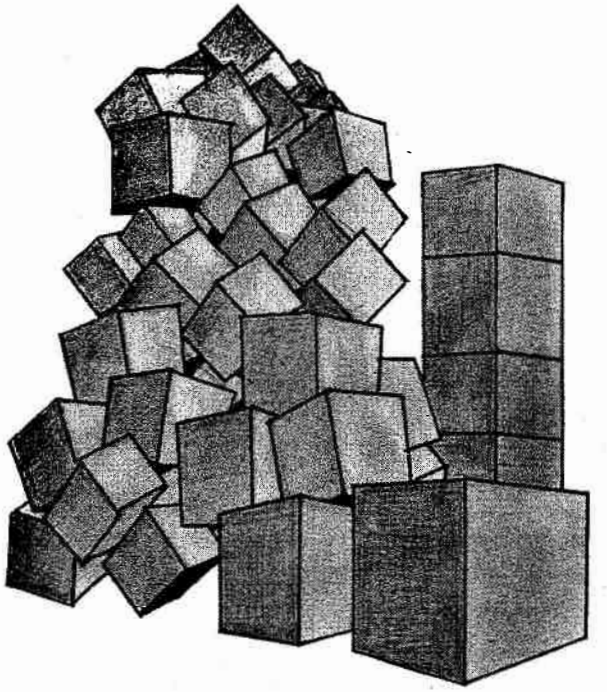
Internal demon's efforts

Heinz von Foerster's Internal and External Demons.

theory, the actor-network theory of Bruno Latour, and the autopoietic systems theories of Maturana and Varela and Niklas Luhmann.[26]

To demonstrate the order-from-noise principle, von Foerster plays a sophisticated game of stacking blocks. Conjured up to probe Shannon's mathematics of information in light of a dual system-and-environment approach to the self-organization concept, the exposition of the order-from-noise principle is done up with magnetic cubes reminiscent of Charles Howard Hinton's tesseracts or hypercubes.[27] The blocks are prepared by gluing to their faces magnetized squares with either the north or south pole of the magnetization facing outward. Out of the ten possible arrangements, various cubes will have more or less propensity to couple as their surfaces present opposite or the same magnetic poles. The probability is high that attracted surfaces will indeed fasten to each other. If a large number of cubes other than those that offer all north or all south poles, so only repel each other, is placed in a box in a jumble and given a vigorous shake, the cubes will assume a more ordered formation. "The entropy of the system has gone down, hence we have more order after the shaking than before." Indeed, if one works with a population of cubes with a particularly favorable arrangement of facet polarities, von Foerster proclaims, "you may not believe your eyes, but an incredibly ordered structure will emerge, which, I fancy, may pass the grade to be displayed in an exhibition of surrealistic art."[28]

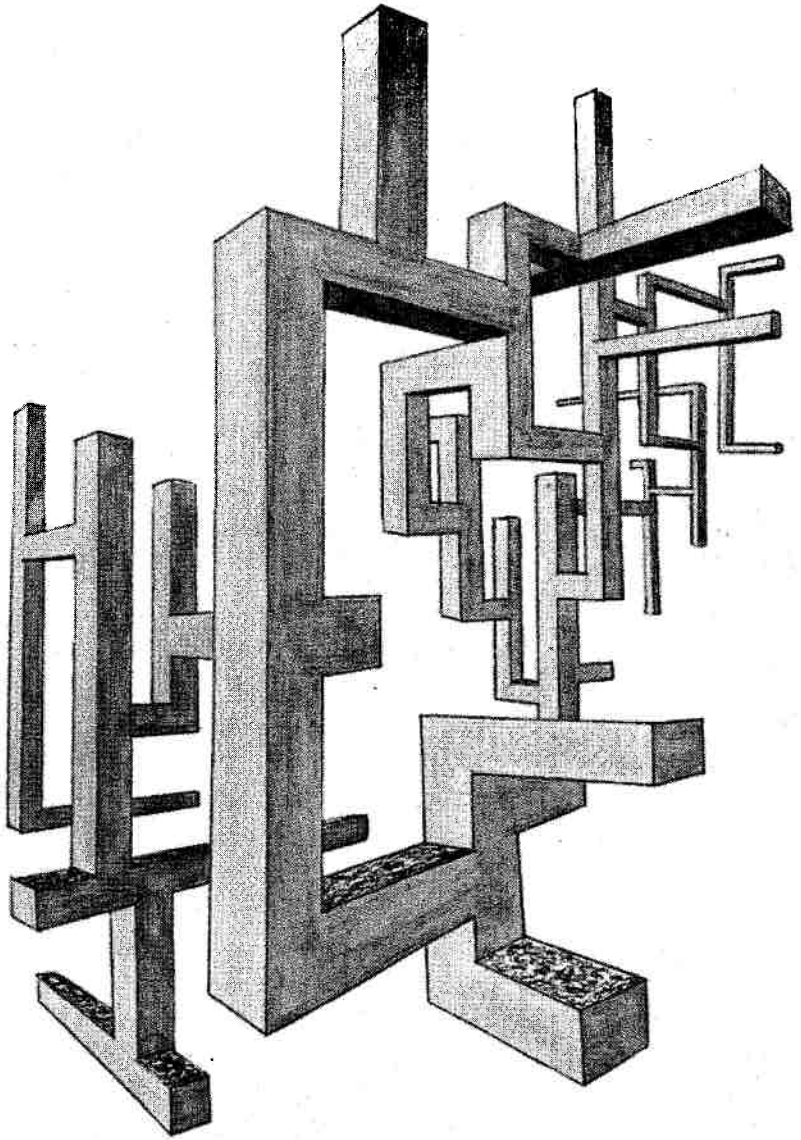
How could this happen? "The shaking, of course—and some little demons in the box." Von Foerster's daemonic duo outdo Maxwell's Demon, as, flashlight or no, it had to sort by detecting particles, calculating their trajectories, selecting and rejecting candidates for transfer, then opening and closing the "slide without mass" over the aperture in the diaphragm. In von Foerster's self-organization scenario, the environment donates its energies to the processes increasing the system's order. As with the minds of children, for instance, ordering can emerge when random energies are distributed among relatable elements such as building blocks and given enough time to play. Just as no additional



Jumbled Boxes (drawn by Gordon Pask).

energy was imported into Maxwell's Demon's system, "No order was fed to the system [of the blocks], just cheap undirected energy; however, thanks to the little demons in the box, in the long run only those components of the noise were selected which contributed to the increase of order in the system."[29]

Best of all, in this scenario these offspring of Maxwell's Demon are not entirely imaginary: "The co-operation of our demons" is guaranteed because they are not interlopers from elsewhere, but are themselves "created along with the elements of our system, being manifest in some of the intrinsic structural properties of these elements."[30] Von Foerster's self-organizing demons are as allegorical as Maxwell's, but they are not merely thought-experimental. Rather, they are pragmatic personifications of the structural attributes of material-energetic elements, the building blocks of systems and their theories. Whereas Maxwell's Demon was first envisioned as an idealized supplement to the description of a closed entropic system, von Foerster's demons derive from cybernetic models of the radical distinction yet operational coupling between energy and information in complex systems. Thus, with von Foerster, the demon may be seen to have entered a further, post-computational phase of his career, now as a messenger of deterministic chaos and as a mediator between information theory and cybernetic systems theory.



Self-Organization from Noise (drawn by Gordon Pask).

Neocybernetics of Social Systems Theory

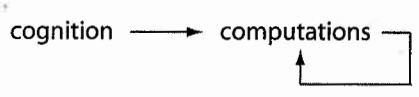
We may take it that the world undoubtedly is itself (i.e. is indistinct from itself), but, in any attempt to see itself as an object, it must, equally undoubtedly, act so as to make itself distinct from, and therefore false to, itself. In this condition it will always partially elude itself.—George Spencer-Brown, *Laws of Form*

From one paper to the next in *Understanding Understanding*, a certain reshuffling of the same deck occurs as need arises. But von Foerster's discursive recursions are not merely repetitive or perfunctory: his discourse evolves, and recurrent elements take on new roles and bear new meanings. Take perhaps the most accessible and broadly disseminated rendering of von Foerster's insights into recursive neural computation and what Maturana and Varela would soon call the "organizational closure" of autopoietic systems, the 1973 paper "On Constructing a Reality." In keeping with the rhetorical pattern I described above, it begins with a humorous and erudite literary allusion, then segues to a series of perceptual puzzles eliciting "blind spots" in the sensorium before settling into its central arguments regarding neural computation and the "double closure" of cognitive systems.

"On Constructing a Reality" is a seminal annunciation of second-order cybernetics, precisely as a constructivist theory of cognition. As one now says in the vocabulary of George Spencer-Brown, "On Constructing a Reality" *reenters* the form of cybernetic observation into its own form. Von Foerster later coins the slogan "the observation of observation" for this mode of cybernetic self-reference, and "On Constructing a Reality" prefigures this slogan with its logical derivation of cognition as recursive computation.

Computation is generalized to mean any process or algorithm that transforms or recodes stimuli or data presented to it: "Computing (from *com-putare*) literally means to reflect, to contemplate (*putare*) things in concert (*com*), without any explicit reference to numerical properties. Indeed, I shall use this term in this most general sense to indicate any operation (not necessarily numerical) that transforms, modifies, rearranges, orders, and so on, observed physical entities ('objects') or their representations ('symbols')."[31] Although the term "autopoiesis" does not appear in it, several of Humberto Maturana's works, preliminary to that coinage co-authored with Varela, are cited in it, and the form of the concept of autopoiesis—self-referential recursion bounded by operational closure—is limned throughout the essay.

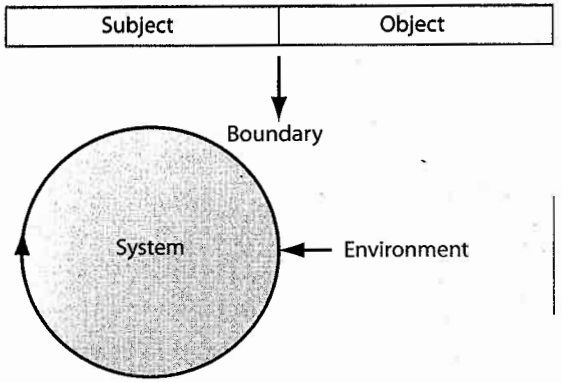
Using recursion as a skeleton key to unlock a range of complex self-referential systems, von Foerster's second-order cybernetics arrived at a general discourse



Cognition as Recursive Computation.

of operational circularity by turning cybernetic thinking upon itself. Luhmann has written about cybernetics in general that "the first innovation was the rediscovery of the circle as, at the same moment, a natural and technical form."[32] When viewed in this wider context, much of Luhmann's social systems theory extends directly from von Foerster's contributions to the recuperation of self-reference.[33] In "Notes on an Epistemology for Living Things" von Foerster sketches the ways that, for most of a century, hard scientific thought has been forced to acknowledge the paradoxes of observation.[34] Forcing the epistemological issue of second-order cybernetics, Luhmann puts the paradox point blank in "The Cognitive Program of Constructivism": "It is only non-knowing systems that can know; or, one can only see because one cannot see."[35] However, how *can* a discourse of knowledge founded on a concept of self-reference, which implies the operational closure of subjects of knowledge reconceptualized as "observing systems" cut out from their surrounding environments, result in anything but a short circuit or an infinite regress?

To shift epistemology to an explicitly recursive system/environment paradigm forces a cascade of repercussions. This cognitive regime bars any traditional form of empirical or realist representationalism, any simplistic notion of knowledge as a mechanics of linear inputs and outputs. Redescribed as the production of an observing system, cognition is rendered as a contingent operational effect rather than assumed as a free-floating or even disembodied agency. The boundary between "subject" and "object" is re-cognized as both an ongoing product of and an impassable limit to the operation of the system. A system boundary never just is, ontologically, but is always coming into being as part and parcel of the system's total autopoiesis. As a self-referential product of the system's operational enclosure, the boundary guarantees that the system is autonomous, or "information-tight." The environment as "object" cannot enter into the system in the mode of its own being, cannot dictate to the system. What it can do is perturb its observer in such a way that the system reorganizes its own elements to compensate, which compensation must then count for the system's cognition of the object. One of the more scandalous ways to express this situation appears as Proposition 11 in von Foerster's "Notes on an Epistemology for Living Things": "*The environment contains no information; the environment is as it is.*"[36] That is to say, it is only self-referential observing systems that can construct environments in the mode of information; the construction of these

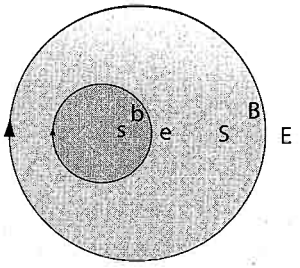


From Subject/Object to System/Environment Epistemology.

descriptions is solely the system's affair. "*The environment is as it is.*" However, there is always more than one observing system; or again, cognition is always also a social affair. Observing systems in communication may be observed to arrive at *eigenbehaviors*—that is, mutually to stabilize and reinforce perceptions autonomously achieved.[37]

The virtual boundaries of social and psychic systems are produced and reproduced by the forms of distinction those same systems construct in the medium of meaning—say, between self and other, between inclusion and exclusion—that render those systems operable at any given moment, maintainable from one moment to the next, and sufficiently distinct from their environment and other systems to maintain operations. Luhmann writes: "Boundaries can be differentiated as specific mechanisms with the specific purpose of separating yet connecting. They assume this function via particular performances of selection."[38] Psychic and social identities coalesce around a system's probable reiteration of the same selections from a given repertoire of possible distinctions and may be transformed when different selections ramify into a new norm or new options enter the repertoire of possible distinctions. But because the inevitable effect of a system's history of self-bounding through cognitive selections is to have excluded, at least for the time being, other forms of possibility, Luhmann goes on to note that "a contact mediated by boundaries cannot convey to any system the full complexity of another, even if its capacity for processing information would otherwise be sufficient."[39]

The figure on page 54 diagrams the operation of reentry as a model of recursive cognition in the second-order cybernetic description of observing systems. This is how one constructs a reality: an observing system **S**, a necessarily self-referential form, creates epistemological space for itself by reentering the virtual form of its own bounded distinction from the environment **B/E** into itself as



Reentry as a Model of Recursive Cognition.

the virtual border **b/e**, which it can then use to make distinctions between self and other. It can then, at any given moment, construct its selective knowledge **e** as a reduction of the complexity of the environment **E** rendered through its own repertoire of distinctions. We see that our knowledge of **E** will always be a somewhat lesser version, **e**. But that's still saying something, and **S** can also proceed to test its knowledge, its internal model **e**, against other versions constructed at other moments. In this way we see that **e** is not a static production but an ongoing, recursively refreshed computation. And recursive processes, like rolling hoops or gyroscopes, are self-stabilizing—they tend to find their own balance.

In "On Constructing a Reality," focused on a comparable model of "double closure," von Foerster draws from his discussion of neural computation a conclusion that we can also apply to the model in figure 10. According to "the postulate of cognitive homeostasis," our self-referential constructions of the world are rendered relatively stable (and not merely arbitrary) because as a result of its own recursive self-corrections, "The nervous system is organized (or organizes itself) so that it computes a stable reality."[40] But still, how does this self-referential construction of epistemological constructivism differ from traditional notions of idealism, in which the world of objects was also presented as a product of the mind's own activities? As Luhmann observed at the outset of "The Cognitive Program of Constructivism," "It is only in our century that the name 'idealism' has been replaced by 'constructivism.' . . . Insofar as constructivism maintains nothing more than the inapproachability of the external world 'in itself' and the closure of knowing—without yielding, at any rate, to the old skeptical or 'solipsistic' doubt that an external world exists at all—there is nothing new to be found in it."[41] To earn its epistemological spurs as a true and pivotal redescription of our knowledge of knowledge, that is, neocybernetic constructivism must demonstrate its actual operationality, its *social* productivity beyond any singular mind's phenomenality.

This is one reason why von Foerster concludes "On Constructing a Reality" with a coda acknowledging that his foregoing discussion could plausibly be dismissed as a plea for solipsism, if it were to be delimited by old philosophical habits, "the view that this world is only in my imagination and the only reality is the imagining 'I.' Indeed, that was precisely what I was saying before, but I was talking only about a single organism. The situation is quite different when there are two."[42] We see that the fallacy of solipsism always was an aberration but not a paradox: it was an inference logically induced by the idealization of singularity, the residual monotheologism that allowed the conception of disembodied observations—that is, the conception of the possibility of systems without environments, and thus the possibility of a system unaccompanied by other systems. The real paradox is that we could have gone so long imagining that there could be not just minds without bodies or worlds, but also minds in the absence of other minds.

As we recall, in "On Self-Organizing Systems and Their Environments," the Man with the Bowler Hat prefigured but did not unfold the matter of cognitive self-reproduction, or the autopoiesis of the psychic system. The main thrust of that essay was self-organization as the emergence of order from noise in material-energetic systems. When the MBH makes an encore fourteen years later, it is no longer put to work to support the reality of the environment per se, but rather to support a view of that reality that now rests solely and explicitly on its cognitive co-construction by multiple observing systems. Misreadings of the MBH are more likely to occur in the context of this paper, however, because here its epistemological exposition is relatively compressed. Having just spent an entire paper formulating the recursive nature and operational closure of the nervous system, in a way now directly (if still implicitly) tied to the propositions of second-order cybernetics, von Foerster has less interest in using the MBH to satirize and deconstruct the architecture of solipsism. Rather, "solipsism" is morphed into "irresponsibility" and blasted into a systems dimension that provides for its self-overcoming. Whereas in the 1959 paper the mantra of the solipsist had been, "I insist that I am the sole reality,"[43] the entire 1973 paper revolves around an initial constructivist postulate—"The Environment as We Perceive It Is Our Invention"[44]—that would seem considerably to up the solipsist's ante.

Instead, from here we can see more clearly why the second paradox in "On Self-Organizing Systems and Their Environments" was a *mock* fallacy, a statement that only seems to oscillate between true and false. Rather, it *is* true, just not true enough. Once again, as in the first paradox regarding systems without

environments, *it captures something true but not sufficient about reality.* Namely, *what is true* (that is, as true as possible under constructivist constraints on the concept of "truth") is that we do have to construct reality—"the environment as we perceive it *is* our invention." But *what is insufficient* is the implication that when we do so, we are in the solipsistic situation of going it alone. In "On Constructing a Reality," the grammatical doubling of the constructivist postulate ("the environment as *we* perceive it") carries the epistemological weight. Whereas solipsism proceeds in the singular, constructivism proceeds in the plural. Solipsism is transcended not by negating its proposition but by forcing the complexity of the multiple out of its unitary simplicity. Epistemology proceeds from classical capture by the singularity of the knowing mind to multiple knowledges in social contexts.

Second-order cybernetics sees instead a world so constructed that any single observer's observations may be rendered stable from moment to moment by the structural couplings and recursive conversations of *its* multiple observers. Just as all nervous systems and all organisms that possess them within themselves are virtual consortiums of multiple autopoietic systems, so are all observers bound into (what Varela calls) "observer-communities" within which (what Luhmann calls) *social* autopoiesis—the ongoing self-production of and self-maintenance of communication—produces (what von Foerster calls) *eigenvalues*—that is, stable yet mobile and multiple recursive consensuses about shared environments.

By way of conclusion, let us read some of Luhmann's opening moves in *Social Systems* to appreciate the force with which von Foerster's text inflects Luhmann's systems theory, as well as the extent to which Luhmann's theory represents one of the most important ways that von Foerster's pioneering work has come to further fruition. Luhmann's "Introduction: Paradigm Change in Systems Theory" states the following:

> The theory of self-referential systems maintains that systems can differentiate only by self-reference, which is to say, only insofar as systems refer to themselves (be this to elements of the same system, to operations of the same system, or to the unity of the same system) in constituting their elements and their elemental operations. To make this possible, systems must create and employ a description of themselves; they must at least be able to use the difference between system and environment within themselves, for orientation and as a principle for creating information. Therefore self-referential closure is possible only in an environment, only under ecological conditions.[45]

The footnote here is to von Foerster's "On Self-Organizing Systems and Their Environments," one of the essential points of which was that in the vogue for notions of self-organization then abroad at the turn of the 1960s, systems theory also had to discipline itself against traditional biases toward the singular *self* of self-organization at the expense of its multiple and heterogeneous other, its environment. Luhmann's phrase "ecological conditions," then, is neatly parsed to mean "environmental contingencies."

Luhmann continues: "The environment is a necessary correlate of self-referential operations because these out of all operations cannot operate under the premise of solipsism."[46] The footnote here is to von Foerster's "On Constructing a Reality," implicitly to the coda we were just discussing, where the treatment of solipsism is itself a compressed version of a longer passage from the earlier "On Self-Organizing Systems." This compounds the extent to which Luhmann is leaning on von Foerster's provision of systems-theoretical premises that predate the explicit turn toward second-order recursions. But Luhmann's passage goes right on to reinvoke matters of distinction and reentry that we can appreciate as the Spencer-Brownian side of von Foerster's legacy: ". . . cannot operate under the premise of solipsism (one could even say because everything that is seen playing a role in the environment must be introduced by means of distinction). The (subsequently classical) distinction between 'closed' and 'open' systems is replaced by the question of *how self-referential closure can create openness.*"[47] This conceptual framework of a paradoxical yet recursively operational *open closure* spanning the autopoietic spectrum from biotic to metabiotic instances is the crux of the radical neocybernetic reorientation of systems thinking around a paradoxical "sublation" of the classical polarity between "closed" and "open" systems, over which thinkers as astute as Hayles continue, for whatever reasons, to stumble. Polarities aligning humanism with openness and antihumanism with closure shift to strategies for an adequate conceptual grasp of the complex *posthumanism* of neocybernetic thought.[48]

In the immediate continuation of this passage, Luhmann offers his posthumanist formulation of the epistemological boundaries or observational constraints Hansen in this volume foregrounds in Varela's "ethico-ontological" precept respecting the autonomy of autopoietic observing systems: "Here too one comes to a 'sublation' of the older basic difference [between system and environment] into a more complex theory, which now enables one to speak about the introduction of self-descriptions, self-observations, and self-simplifications within systems. One can now distinguish the system/environment difference as seen from the perspective of an observer (e.g., that of a scientist)

from the system/environment difference as it is used within the system itself, the observer, in turn, being conceivable himself only as a self-referential system."[49]

In "On Constructing a Reality" von Foerster presents his own "ethico-ontological" understanding of neocybernetic co-constructivism by forcing the social issue out of the biological and neurological factors of operational closure, wringing from the MBH the cognitive confession that "reality = community." He unfolds from the pair of internal observers in the MBH a pair of co-constructing social imperatives—two performative utterances bound together by a feedback loop. The "*ethical imperative*" is "Act always so as to increase the number of choices"; the "*aesthetical imperative*" is "If you desire to see, learn how to act."[50] If ethics concerns the *operations* systems select for themselves, especially insofar as these systems may be considered as self-referential or "reflective" entities, aesthetics concerns the role of *observations* in guiding those operations. To shift into the conceptual mode of second-order systems theory, then, is to reform classical dyads such as part/whole divisions or subject/object dichotomies, in order to reobserve and grasp the complexly supplementary rather than merely exclusionary relations of system/environment couples and to re-cognize the borders that self-organizing, now *autopoietic*, systems must use in order to operate.

Simply put, taking systemic self-reference seriously subverts the notion of "objective" material or philosophical foundations. And those who believe in the actual or possible possession of "objective truth" can only see in such a deconstruction an occasion for its flip side, that other mirage called "subjective relativism." This negative oscillation of universal truth and individual falsity is the infinite regress one enters by *avoiding* the productive encounter with paradox. On the plus side, observers can now choose to construct themselves as inside and a part of, as well as outside and detached from, the systems and environments they observe. And if we were to convince ourselves that the whole show—the virtual integration of all biotic and metabiotic systems into a global environment stretching out to the boundless cosmos—is at all times *collectively* self-bootstrapping—that is, held up by the self-maintenance and complex interlocking of all of its strange loops—we might start to behave in less merely selfish ways. Who knows, we might even begin to overcome the larger *social* solipsisms that are currently wreaking destruction on social systems and their natural environments. While Luhmann himself remained skeptical of such a recuperative reading of systems theory, von Foerster did not.

Notes

1. Firsthand accounts of these events are given in von Foerster with Poerksen, *Understanding Systems*, 135–40, and Brand, "For God's Sake, Margaret."
2. See his family reminiscence, "Introduction to Natural Magic." An illustrated biography of von Foerster (in German) is Grössung, Hartman, Korn, and Müller, *Heinz von Foerster 90*; p. 16 shows a snapshot of von Foerster and his cousin as teenaged magicians.
3. In "The Early Days of Autopoiesis" in this volume, Varela narrates the history of the first appearance of "autopoiesis" in a 1973 Chilean publication by Maturana and Varela, *De máquinas y seres vivos*, and von Foerster's vetting of its first appearance in English; Varela, Maturana, and Uribe, "Autopoiesis." Von Foerster then publishes as Biological Computer Laboratory Report 9.4 (September 1, 1975) their extended treatment, *Autopoietic Systems*, which eventually appears as *Autopoiesis and Cognition*. See also Zeleny, "Autopoiesis."
4. Von Foerster, "On Self-Organizing Systems," 1. The article was first published in Yovits and Cameron, *On Self-Organizing Systems*, 31–50.
5. Von Foerster, "On Self-Organizing Systems," 1.
6. In the standard anthropomorphic idiom, the editors of a compendium of scientific papers on Maxwell's Demon write: "The life of Maxwell's demon can be viewed usefully in terms of three major phases" (Leff and Rex, *Maxwell's Demon*, 2). The Beatles' "Maxwell's Silver Hammer" is a likely atavism; cf. "Maxwell's Demon" as Brian Slade's (Jonathan Rhys-Meyers) glam persona in *Velvet Goldmine*.
7. Because of the notion of using a demon to *generate* energy out of thin air rather than, with Maxwell, to restore extant energy (by the first law) from unusable to usable form, the demon is sometimes simplistically presented as the operator of a perpetual motion machine. For more on Maxwell and his demon from a literature and science perspective, see Clarke, *Energy Forms*, ch. 4; and Hayles, "Self-Reflexive Metaphors." For more on the culture of thermodynamics, see Prigogine and Stengers, *Order Out of Chaos*; Stengers, *Power and Invention*, esp. "Turtles All the Way Down" (60–74); and Clarke and Henderson, *From Energy to Information*, part 1. A new theory of thermodynamics in its cosmic and biospheric contexts is given in Schneider and Sagan, *Into the Cool*.
8. Von Foerster, "On Self-Organizing Systems," 1–2; my elisions of the mathematical notation in the original.
9. Ibid., 3.
10. Wolfe, *Critical Environments*, subtitle.
11. "You remember René Descartes. . . . 'Am I, or am I not?' He answered this rhetorical question with the solipsistic monologue, 'Je pense, donc je suis'" (von Foerster, "Ethics and Second-Order Cybernetics," 297).
12. Von Foerster, "On Self-Organizing Systems," 3–4.
13. Ibid., 4.

14. See von Foerster with Poerksen, *Understanding Systems*, where von Foerster states about Ludwig Wittgenstein, "He was an honorary uncle, a *Nennonkel*, as they say in Vienna, not a relative, but a very good friend. My mother and his sister, Margarethe, were good friends" (122).
15. Von Foerster, "On Self-Organizing Systems," 4.
16. Cf. Hayles, *How We Became Posthuman*, 133. I am suggesting that Hayles misses the point when she comments, "Although charmingly posed, the argument is logically nonsensical" (133).
17. Von Foerster, "On Self-Organizing Systems," 4.
18. Ibid., 7.
19. Ibid., 8.
20. Ibid., 9.
21. Ibid.
22. Ibid., 10.
23. Ibid.
24. Ibid., 11.
25. Von Foerster, *Understanding Understanding*, 19.
26. Atlan treats von Foerster's order-from-noise principle in "Hierarchical Self-Organization in Living Systems"; see also Dupuy, *The Mechanization of the Mind*, ix, 120.
27. For von Foerster's own exposition of the tesseract, see "Cybernetics of Epistemology," 237–41. On the wider culture of ideas since the nineteenth century regarding the *spatial* construction of the fourth dimension, see Henderson, *The Fourth Dimension*. I am grateful to Professor Henderson for sharing with me her correspondence from von Foerster, a fan letter on the publication of her text cited above.
28. Von Foerster, "On Self-Organizing Systems," 13.
29. Ibid.
30. Ibid.
31. Von Foerster, "On Constructing a Reality," 216.
32. Luhmann, "The Control of Intransparency," 361.
33. On Luhmann's relation to von Foerster, see the apparatus of his work for pervasive references to numerous von Foerster articles. For instance, the very late, fairly short paper cited above, "The Control of Intransparency," mentions four von Foerster texts: "On Self-Organizing Systems" (in note 4); *Observing Systems* (in note 8); "Principles of Self-Organization" (in note 9); and the highly obscure 1948 text, von Foerster's calling card when first visiting the United States, *Das Gedächtnis* (in note 21). See also Baecker, "Knowledge and Ignorance."
34. "In the first quarter of [the twentieth] century physicists and cosmologists were forced to revise the basic notions that govern the natural sciences. . . . It was clear that the classical concept of an 'ultimate science,' that is an objective description of the world in which there are no subjects (a 'subjectless universe'), contains contradictions. To remove these one had to account for an 'observer' (that is at least for one subject): (i) Observations are not absolute but relative to an observer's point of view (i.e. his coordinate system: Einstein); (ii) Observations affect the observed so as to obliterate the observer's hope for prediction (i.e. his uncertainty is absolute: Heisenberg)" (von Foerster, "Notes on an Epistemology for Living Things," 247).
35. Luhmann, "The Cognitive Program of Constructivism," 132.
36. Von Foerster, *Understanding Understanding*, 252. Original emphasis.
37. The problematics of communication under a second-order cybernetic constructivist regime, as those have been developed and variously resolved by von Foerster, Maturana, Varela, and Luhmann, are further addressed, in synthetic relation to C. S. Peirce, Jakob von Uexküll, and the conceptual program of biosemiotics, in Brier, "The Construction of Information and Communication."
38. Luhmann, *Social Systems*, 29.
39. Ibid.
40. Von Foerster, "On Constructing a Reality," 225.
41. Luhmann, "The Cognitive Program of Constructivism," 129.
42. Von Foerster, "On Constructing a Reality," 226.
43. Von Foerster, *Understanding Understanding*, 4.
44. Von Foerster, "On Constructing a Reality," 212.
45. Luhmann, *Social Systems*, 9.
46. Ibid.
47. Ibid. My emphasis.
48. On this point, see my *Posthuman Metamorphosis*.
49. Luhmann, *Social Systems*, 9.
50. Von Foerster, "On Constructing a Reality," 227.