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FROM ENERGY TO INFORMATION

REPRESENTATION IN SCIENCE AND TECHNOLOGY, ART, AND LITERATURE

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From Thermodynamics to Virtuality

BRUCE CLARKE

One can trace the movement from energy to information regimes by following the sequence of events that has channeled thermodynamics and electromagnetics into computation and media technology, the merger of life and information sciences, and the virtualization of matter and energy. Energy and information, two prime concepts in the history of science and technology, are also crucial discursive operators in the fields of aesthetics and critical theory.[1] The coupling between energy and information has overcome the prior divisiveness of modern thought by wiring physics into communications and replotting the interrelations between natural objects and cultural subjects. Science and technology are no longer ontologically disjoined from the discursive disciplines of the humanities and social sciences. The conceptual merger of energy and information has opened a new interdisciplinary space for a complex reintegration of natural and cultural multiplicities.

THE CULTURES OF ENERGY

Energy has perennially signified the power to affect observers. The classical sense of energy as a signifier of perceptual effects or psychological impressions inflects the connotative value of energy as a physical term. Obsolete as well as active extrascientific meanings of energy can reveal much about the term's cultural provenance over the last two centuries.[2] The prescientific concept of energy had not yet been abstracted from its social and psychological import as a measure of the intensity of an event's reception. Classical energy is "impressive" and "efficacious": it creates something *for* and *within* its recipient, but on the basis of powers exercised at its *source*. This expression-impression model of aesthetic energy is strikingly conveyed in its long-standing rhetorical and poetic usages.

The *Oxford English Dictionary's* (*OED*) first definition of the concept of energy is "with reference to speech or writing: force or vigour of expression," which is "originally derived from an imperfect understanding of Aristotle's use of ἐνέργεια (*Rhet.* iii. xi. §2) for the species of metaphor which calls up a mental picture of something 'acting' or moving." Here it is precisely literary efficacy that is in question, a power distributed between authors and readers of creating and receiving mental effects. The semantic history of the term implicates it in a texture of aesthetic meanings: energy informs both the expression and the reception of effective tropes and figures. Its force binds poetic and visual images to the broader arena of material and physical powers and products. In its classical provenance, the aesthetic senses of *energeia* are not strongly divided from the physical sense of *dynamis*, the force or dynamism possessed by material objects. Its premodern usages do not distinguish between the natural and the spiritual senses of the term, because the prescientific concept of energy did not bear a primary reference to physical operations. Rather, it was indifferently divided between physical and cultural effects.

FORCE AND MECHANICAL ENERGY

Newton's laws of motion took shape two centuries prior to the consolidation of the modern energy concept. Mechanics is now defined as the branch of physics that deals with the energies of bodies in motion, but Newton's principles were elaborated in terms of the concept of *force*, the product of mass times acceleration. Thermal properties were not yet factored into classical dynamical systems, for which motion is the sole parameter of change and process, and momentum or *vis viva* is the conserved quality.[3] The physical concept of energy was gradually detached from these mechanical precursors—force and *vis viva*, or "living force."[4]

British physician and physicist Thomas Young is credited with the first use (in 1805) of the term *energy* in its modern sense, to "denote what is now called actual, kinetic, or motive energy, i.e., the power of doing work possessed by a moving body by virtue of its motion" (*OED*). In modern mechanics the physical sense of energy emerges as the *power of doing work*, the capacity to move material masses by transferring energy from one form to another.[5] In this new frame of conservation throughout conversion, the classical mechanical concepts of force and momentum could be extended to include *potential* forms, that is, "energy of position, . . . the power of doing work possessed by a body in virtue of the stresses which result from its position relatively to other bodies" (*OED*). No gross motions need be in evidence for potential energy to be present. A stone at rest but elevated above the earth possesses a quantity of potential energy by virtue of its position within a gravitational field. Upon falling that potential energy will be converted into an equal sum of kinetic energy calculated as one half its mass times the square of its velocity. This reconceptualization of mechanical force in terms of the conversion of kinetic and potential energies prepared scientists for understanding the more complex interchanges of energic potentiality and actuality exhibited by electromagnetic fields and chemical and atomic structures.

Newton's physics of forces described vectors, quantities determined by the specific trajectories of material bodies in spatial motion. With the emergence of thermodynamics in the mid-nineteenth century, physical attention was enlarged from vectorial forces to scalar energies, quantities described by their magnitude irrespective of their motions. In thermodynamics, the perceptible trajectories of singular bodies—planets and projectiles—give way to the quantifiable intensities of molecular populations, and the motions defined by classical mechanics become relative to the averaged behaviors of thermodynamic ensembles.

THE LAWS OF THERMODYNAMICS

The emergence of energy as a physical concept forced a transition from the orderly world of classical mechanics to the chaotic phenomena marshaled by the laws of thermodynamics. In the first half of the nineteenth century, the movement of heat was accounted for by the theory of *caloric*, a hypothetical fluid presumed to carry heat and to be conserved throughout its cycles. By mid-century caloric had been largely discarded and heat reconceived under the broader principle that *energy* was both conserved and interconvertible among thermal, mechanical, and other forms. This conceptual development led to the first law of thermodynamics: Within a closed system the sum of energy is conserved throughout its transformations; the sum of energy in the universe is constant.[6] The first law marks the continuity between classical dynamics and classical thermodynamics. It extends to the energy concept a conservation principle previously accorded other substances and processes: the conservation of matter recognized by chemistry, the conservation of *vis viva* in classical dynamics.

In contrast, the second law of thermodynamics is discontinuous with classical dynamics. This law introduced an irreversible parameter into the time-reversible mathematics of mechanical forces in the Newtonian scheme. The physics of heat engines forced this fateful confrontation with the temporality of real systems. It became necessary to measure the actual losses of usable energy involved in their operations, specifically, the amount of heat unrecoverable for conversion into work within the cycle of a steam engine's operation. This increment of inefficiency, the inexorable falling away from perfectly reversible performance, led to the initial formulation of the second law as the *dissipation* of mechanical energy. Whereas work may be completely converted into heat, in the process of converting heat into work some fraction always remains as heat. This practical observation on the necessary functioning of heat engines was submitted to a dramatic global extension in William Thomson's seminal paper of 1852, "On a Universal Tendency in Nature to the Dissipation of Mechanical Energy."[7]

Thomson (Lord Kelvin) began by noting that, as only God can augment or diminish the sum of universal energy, the "absolute waste of mechanical energy" in a real heat engine must be conserved in some fashion. But the first law's hoarding is subsumed by the second law's theft. The fraction of thermal energy that eludes conversion into work is not annihilated, but it is left in a form from which it cannot be returned to potential energy or further seized by any human agency or instrumentality. Thomson drew out of these thermodynamic considerations a litany of cosmological consequences whose chilling tones would reverberate for the next century:

1. There is at present in the material world a universal tendency to the dissipation of mechanical energy.
2. Any *restoration* of mechanical energy, without more than an equivalent of dissipation, is impossible in inanimate material processes, and is probably never effected by means of organized matter, either endowed with vegetable life or subjected to the will of an animated creature.
3. Within a finite period of time past, the earth must have been, and within a finite period of time to come the earth must again be, unfit for the habitation of man as at present constituted, unless operations have been, or are to be performed, which are impossible under the laws to which the known operations going on at present in the material world are subject.[8]

Conceptual purchase on this irreversibly wasting aspect of worldly dynamical systems was physically if not culturally stabilized in 1865 when Rudolf Clausius coined the neologism *entropy* or "transformation-content" by analogy with the Greek root of the term energy or "work-content" (*en* in + *ergon* work). Thermodynamic entropy provides a measure of the energy unavailable for work within a closed physical system. Clausius then reformulated the second law to match the cosmic extension of the first law and of the principle of mechanical dissipation: the entropy of the universe tends to a maximum.

The formulation of entropy complicated the physical idea of energy in an unpredicted and unpredictable way. The scientific concept of energy was preceded by the notion of mechanical force, but nothing in classical mechanics anticipated the concept of entropy.[9] Energy had no sooner been delivered to the world of science as a primary physical concept on a par with matter than it was shadowed by its evil twin entropy, the demonic underside of energy's divine potency. As these florid metaphors may indicate, the twinned physical concepts of energy and entropy immediately began to generate both conceptual and analogical surpluses. Although these twins may look alike, as was Clausius's intention, they have very different natures.

Although energy is multivalent, its sign (except under extreme conditions such as a "squeezed state") is mathematically stable.[10] Thermodynamic entropy is unitary but with an unstable sign: "Whether entropy be called positive or negative is a mere convention."[11] And this is the case not just mathematically but also with regard to the discursive career of the entropy concept. Throughout much of the modern period, however, the notion of entropy has been broadly accorded a negative valence. It has been played out as a proof of the inevitable degradation of energies, of the exhaustion of material and vital resources, as a synonym for melancholy reflections on the devolution of biological and human achievements, on the arrival of a world "unfit for the habitation of man as at present constituted," and ultimately, on the "heat death" of the universe itself. It is difficult to overestimate the extent to which the second law and its avatar entropy have been extended and culturally elaborated, used and abused in the form of deterministic scenarios of local and universal waste.[12]

WAVE THEORY: ETHER AND FIELD

During the nineteenth century, the attention of physics shifted from material bodies and mechanical forces to the imponderable phenomena of heat and radiation. The laws of thermodynamics were unfolded at the same time as the modern understanding of light and electromagnetism. In the first half of the century, Thomas Young and Augustin-Jean Fresnel revived Christiaan Huyghens's late-seventeenth-century wave theory of light, suppressed until then by the authority of Newton's corpuscular model of optical phenomena. Nevertheless, the resuscitated undulatory theory of light still functioned within a late-classical milieu that demanded mechanical explanations—visualizable models of material contact—for all phenomena, including radiant and electromagnetic energies. Although he was far from regarding it as an established fact, Newton himself had speculated at times about the existence of a gravitational ether—an imponderable physical medium that would account for the spatial transmission of gravitational forces. On the same mechanical model, the refashioned theory of a *luminiferous* ether was elaborated to serve as a material and vibratory medium for the propagation of light.

The theory of the ether ran alongside the rise of the energy concept as the stationary but undulating spatial foundation upon which the mobile contents of radiant energies were propped. Developed into a comprehensive explanatory cornerstone of late-classical physics, the luminiferous ether enjoyed a tremendous vogue both within scientific circles and broadly across the popular consciousness. An important agent in the popularization of the ether concept was physicist John Tyndall, the director of London's Royal Institution from the 1850s to the 1880s. In the following passage from the sixth edition (1880) of *Heat: A Mode of Motion*, Tyndall sets the theory of the ether into a comprehensive atomo-mechanical frame of optical explanation:

> According to the theory now universally received, light consists of a vibratory motion of the atoms and molecules of the luminous body; but how is this motion transmitted to our organs of sight? Sound has the air as its medium, and a close examination of the phenomena of light has led philosophers to the conclusion, that space is occupied by a substance almost infinitely elastic, through which the pulses of light make their way. Here your conceptions must be perfectly clear. It is just as easy to picture a vibrating atom as to picture a vibrating cannon-ball; and there is no more difficulty in conceiving of this *ether*, as it is called, which fills space, than in imagining all space filled with jelly. The atoms of luminous bodies vibrate, and you must figure their vibrations, as communicated to the ether, being propagated through it in pulses or waves; these waves enter the pupil of the eye, cross the ball, and impinge upon the retina, at the back of the eye. The motion thus communicated to the retina, is transmitted thence along the optic nerve to the brain, and there announces itself to consciousness, as light.[13]

In the mid-nineteenth century, there were still several ethers at large in theoretical physics, the luminiferous version just described and various other hypothetical media posited to bear the operations of electricity and magnetism. In the 1850s and 1860s, James Clerk Maxwell recast Michael Faraday's early field conceptions into an ether theory of electromagnetism in which "lines of force" are conducted through some form of rotatory and elastic medium. In order to interrelate the phenomena of electricity and magnetism, and then of electromagnetism and light, Maxwell developed a series of ether hypotheses, the most important being the vortex-and-idle-wheel model elaborated in his essay, "On Physical Lines of Force" (1860–61).

Maxwell's mechanical models of energy propagation were remarkable not just for their ingenuity but also for their heuristic power.[14] Most famously, Maxwell used the mathematical relations of this ether model to specify the identity of electromagnetic and optical radiation.[15] Maxwell would go on to formulate mathematically a dynamical theory of the electromagnetic field independent of the details of any particular ether model. Bruce Hunt's essay reminds us, however, that Maxwell and his successors would continue to tinker earnestly with mechanical ether-models for several more decades.[16] And as Linda Henderson's work has shown, the general public continued to embrace the notion of the ether well into the twentieth century.

The eventual confirmation of inferences Maxwell drew from the heuristic manipulation of his ether fictions marks an important threshold in the development of contemporary science and in its convergence with symbolic processes at large in literary and artistic production. In the early study of energies, physical science was explicitly and significantly enhanced by investigating figurative representations of hypothetical entities—virtual artifacts rather than real or palpable objects. Like Sadi Carnot's ideal heat engine, Maxwell's diagram of the impalpable and elusive ether was the model of a fiction invented to reify a factual process—a heuristic construction or work of intellectual scaffolding representing something complex and invisible. Almost a century later, mathematical physicist John von Neumann would affirm: "The sciences do not try to explain, they hardly even try to interpret, they mainly make models."[17] Maxwell's science grasped what we now take to be a methodological truism: Scientific models are conceptual instruments that constitute as well as simulate the world.[18]

STATISTICAL MECHANICS AND MAXWELL'S DEMON

The phenomena of heat enforce a macroscopic focus on whole populations whose constituents are too minute to be observed or dealt with one by one. The kinetic theory of gases explains macroscopic properties—pressure, volume, density, and temperature—on the basis of the mechanical energies distributed within a population of perfectly elastic, constantly moving and colliding molecular particles. Statistical mechanics combined with the kinetic theory of gases to model thermal behaviors by treating the mathematical probabilities of the various distributions of kinetic energies among the freely mobile molecules in a sealed vessel of gas. The Demon came about as a thought-experiment using a form of statistical mechanics to contradict the seeming inexorability of the entropy law, the determined tendency of environmentally closed systems to dissipate thermal energies through the complete leveling off of kinetic differentials among the constituents of the system.[19]

"To pick a hole" in the seeming inexorability of the entropy law, Maxwell imagined an active agent and thus an *animated* mechanism, a thermodynamic engine supplemented and inhabited by a microscopic observer-operator, which sentient entity Maxwell nevertheless thought replaceable with an automatic mechanism.[20] An 1870 letter to J. W. Strutt (later Lord Rayleigh) set forth the operation and physical significance of the heuristic being soon to be immortalized by Lord Kelvin as Maxwell's Demon:

> If there is any truth in the dynamical theory of gases the different molecules in a gas at uniform temperature are moving with very different velocities. Put

> such a gas into a vessel with two compartments and make a small hole in the wall about the right size to let one molecule through. Provide a lid or stopper for this hole and appoint a doorkeeper, very intelligent and exceedingly quick, with microscopic eyes, but still an essentially finite being.
>
> Whenever he sees a molecule of great velocity coming against the door from A into B he is to let it through, but if the molecule happens to be going slow, he is to keep the door shut. He is also to let slow molecules pass from B to A but not fast ones. . . .
>
> In this way, the temperature of B may be raised and that of A lowered without any expenditure of work, but only by the intelligent action of a mere guiding agent (like a pointsman on a railway with perfectly acting switches who should send the express along one line and the goods along another).
>
> I do not see why even intelligence might not be dispensed with and the thing made self-acting.
>
> *Moral.* The 2nd law of thermodynamics has the same degree of truth as the statement that if you throw a tumblerful of water into the sea you cannot get the same tumblerful of water out again.[21]

In theory, in performing its duties on the inside, the sorting Demon is neither adding energy to nor subtracting it from the system. There is to be no breach of the hermetic enclosure. The second law is to be abrogated strictly by internally arranging for the system to be *reshuffled* back into a state of higher thermal difference. The Demon's benevolent mechanical guidance reverses the irreversible drift of dissipation; it could as easily part the waters and reassemble the contents of the tumbler from the jumble of the sea. The Demon's effect is virtually to make systems go backwards in time to a point of lower entropy, lesser randomness. In the bipartite vessel of gas, the total amount of energy will be the same, as mandated by the first law, but the point is that it will be restored to a *usable form*. For instance, by replacing the partition between compartments with a piston, work could be extracted from the fall of heat from B to A. Ideally, such a Demon could operate the system as a perpetual motion machine, creating infinite amounts of mechanical work from a fixed quantity of energy.

But no Demons were literally forthcoming to restore the dissipated energies of industrial cultures firing up ever more grandiose heat-based technologies of physical power. Within this framework, however, an important advance was made when the Austrian physicist Ludwig Boltzmann developed some of Maxwell's heuristic suggestions into a statistical analysis of thermal entropy. Boltzmann followed Maxwell in treating energic relations of order and disorder with the mathematics of probability. His innovation was to define the entropy (S) of a physical system in terms of its possible energic complexions (P)—that is, the number of different possible ways to distribute its particles. Ordered complexions are relatively rare. There are many more complexions that yield a random distribution in which thermal differences are reduced to a minimum. It is more likely to find a system in a state of relative disorder, and disorder is likely to increase over time toward a maximum state of equilibrium in which the evolution of the system slows to a minimum. This is the probabilistic restatement of the second law: in a closed system left to itself molecular disorder is most likely to increase. In its simplest form, Boltzmann's quantification of the entropy law is:

$$S = k \log P.$$

As the number of possible complexions P of a system increases, so does the likelihood of a random rather than ordered distribution, and so (logarithmically) does the entropy S.

Translated into these terms, the Demon uses the microscopic information it gathers to counteract the probable randomization of thermal energies among the molecules, which reveal themselves at the macroscopic level as an increase in entropy. The Demon extracts a less probable state of differentiation out of a more probable state of chaos. And "to think of entropy as a statistical measure of disorder allows its extension to systems that have nothing to do with heat engines."[22] Boltzmann's statistical analysis of entropy joined with Maxwell's Demon to move thermodynamic concepts beyond energic applications and into the information age.

INFORMATION AND ENTROPY

Explicit attention to Boltzmann's statistical analysis of thermodynamics is writ large in the founding documents of information theory and cybernetics. In 1948, John von Neumann noted concerning the mathematical logic of automata that "thermodynamics, primarily in the form it was received from Boltzmann . . . is that part of theoretical physics which comes nearest in some of its aspects to manipulating and measuring information."[23] Two years later, Norbert Wiener commented that the conceptual alignment of information with the probabilities associated with a set of related patterns "was already familiar in the branch of physics known as statistical mechanics, and which was associated with the famous second law of thermodynamics."[24] At the beginning of his general introduction to *The Mathematical Theory of Communication* (1949), the first great formalization of modern information theory, Warren Weaver outlined the set of thinkers most responsible for connecting energy to information, thermodynamics to cybernetics: Boltzmann, von Neumann, Wiener, and Claude Shannon. He stated, "Dr. Shannon's work roots back, as von Neumann has pointed out, to Boltzmann's observation, in some of his work on statistical physics (1894), that entropy is related to 'missing information.'"[25]

In order to exploit the link with statistical mechanics, Shannon defined information mathematically on the basis of the probabilistic distribution of a finite ensemble of message elements. This set of possible messages posits an informatic ensemble analogous to a thermodynamic ensemble having a set of possible complexions with various degrees of probability. Within this framework, information is quantified as a measure of the unpredictability of a message, specifically as an inverse function (the negative logarithm) of the probability of a particular message being chosen from a set of finite options. For Shannon, "information is a measure of one's freedom of choice when one selects a message."[26] For instance, making a selection from a binary set of choices (yes/no, on/off) yields one bit of information—some but not a great deal—because the options available at the information source are relatively constrained. The larger the ensemble of choices, however, the less probable any particular choice. In this decidedly "liberal" approach to calculating the value of information, the more choices offered a sender by a set of possible messages, the more information the message chosen will contain. Shannon's mathematical formalization of information (H) on the basis of such "probabilities of choice" yielded an "entropy-like expression," an equation strikingly analogous to Boltzmann's logarithmic formula for thermodynamic entropy:

$$H = -\Sigma p_i \log p_i$$

In linking physics directly to communications theory, the mathematical analogy between thermodynamic and information entropy has reconnected the natural sciences to the arts, humanities, and social sciences. Michel Serres celebrates that marriage in these terms: "Henceforth, the theoretical reconciliation between information theory and thermodynamics favors and advocates the practical reconciliation between those funds of knowledge which exploited signs and those which exploited energy displacements."[27] But this connection has also "been much debated, largely because Shannon's definition of information as a quantity directly related to disorder and multiple possibility is counterintuitive, going against an everyday notion of information as something singular and determinate."[28] For instance, information can also be measured on the other side of the communications circuit as a function of the *receiver's knowledge*, by the degree to which the receiver's uncertainty is diminished by the arrival of a message. Uncertainty in this sense is the state of a receiver with regard to the content of a message yet to arrive. If a recipient's uncertainty is great, the message that resolves it will

have a correspondingly high information value. As Shannon was developing his particular version of information theory, Norbert Wiener and many others were operating on the equally reasonable assumption that the quantity of information is greater as the probability of *receiving* the order or pattern that conveys it grows less. In this case, information is conceived as the *opposite* of thermodynamic entropy and so merits an opposite mathematical sign. Léon Brillouin would coin the term *negentropy* on this basis as a synonym for information.

Following the mathematical analogy of his formula for information to Boltzmann's formula for thermodynamic entropy, however, Shannon chose to name his information-measure the *entropy* of the message, and thereby to give entropy the same sign as information. Katherine Hayles has shown that the crucial distinction between Shannon's approach and those of Wiener and Brillouin is that the latter are still looking at informatic ensembles as thermodynamicists, for whom the statistical probability of disordered states makes the entropy of the ensemble analogous to a measure of the energic degradation of the system. The thermodynamic approach to entropy—a statistical measure of a macrostate in ignorance of the individual microstates—concentrates on uncertainty at the *destination*, that is, on the observer's ignorance of the particular microscopic "choices" a system makes as it evolves in time. Shannon's informatic redefinition of entropy—as the function of a choice among a set of probabilities that *resolves* the ignorance of a receiver—locates uncertainty at the information *source*. In other words, Shannon analyzes an informatic ensemble from a communication-engineering perspective, in which case the relative "disorder" of an ensemble, the greater entropy of a randomized set of probabilities, provides the agent of a message with a greater number of selection opportunities.[29] Shannon's "message entropy" is thus, relative to thermodynamic dissipation, a counter-entropic phenomenon.

One could say that Shannon's "information source" reenacts Maxwell's Demon. In the movement from energy to information, the concept of entropy initiated an ongoing shift away from the vision of a simple or homogeneous universe reducible to a reversible and predictable calculus, toward a cognition of complexity that offers to reunify nature and the human mind in terms of a shared order of multiplicity and irreversible time, random processes and unpredictable influxes of creative reorganizations. A sender of information creates order and so reverses the sign of entropy by assessing the largest possible array of informatic options, then choosing what fits the communicational situation. Systems that lack options are relatively predictable, low in information. Extreme order is as destructive of information as extreme chaos. Through this seemingly counterintuitive restatement of information as entropy, as a function of disorder or "surprise" rather than order and predictability, Shannon helped to open the door for a cascade of conceptual developments leading to the contemporary sciences of general systems and theories of self-organization, autopoiesis, chaos, complexity, and their discursive analogues in the current critical focus on the contingent materialities of signs and communication.

The far-from-equilibrium thermodynamics developed by Ilya Prigogine and his coworkers is also linked to the statistical mechanics descending from Maxwell and Boltzmann. Here, thermal dissipation is studied as a potentially creative process that can drive the temporal organization of open dynamical systems: "Once we have dissipative structures, we can speak of self-organization. Even if we know the initial values and boundary constraints, there are still many states available to the system among which it 'chooses' as a result of fluctuations. Such conclusions are of interest beyond the realms of physics and chemistry. Indeed, bifurcations can be considered the source of diversification and innovation."[30] Classical dynamics allowed time to arbitrarily reverse its direction. For Prigogine, the infinite amount of information necessary for such temporal reversal is irrecoverable from dissipative or energy-consuming systems. What dissipative systems *can* do is bootstrap their physical entropy into form, self-organize on the basis of their own noise. Non-universal but nonetheless pervasive, "irreversibility is the mechanism that brings order out of chaos."[31]

CYBERNETIC COUPLINGS

The new relations forged at mid-twentieth century between information and entropy highlighted not only the potential positivities of randomness and disorder, but also the crucial difference between environmental isolation and openness. Even given the assumption of a universal tendency toward maximal entropy, organisms maintain their local organizations through *operational* closure structurally coupled to environmental perturbation by energy and data sources, and modern electronic systems process energy through informatic feedback. The classical emphasis on the equilibrium of sealed systems now begins to shift to the non-equilibrium operation of open and multiply coupled biological and technological ensembles.[32]

Boltzmann's work enabled Maxwell's Demon scenario to be reconceived according to the different kinds of information that can be extracted from the different levels of a system. The Demon anticipates the further development of information theory by positing an interactive observer that views the thermodynamic "channel." In hindsight, we now appreciate the Demon as a statistical operator whose tracking of the velocities and trajectories of individual molecules performs an information-gathering and data-processing function. Maxwell's intuition that the Demon could be replaced by a mechanism was correct: in terms of contemporary computer architecture, the Demon is tantamount to a logic gate, a digital switch operating a binary aperture, and the Demon's sorting function can be realized as a string of algorithmic code that mechanizes a sequence of sensory and computational tasks.[33] Maxwell's Demon joins Charles Babbage's Difference Engine as one of the earliest intimations of the eventual development of artificial or machine intelligences that simulate and extend human perceptive, mnemonic, and calculative capacities.[34]

Norbert Wiener channeled his interest in information theory toward his effort to construct a science of *cybernetics*, which he defined as the "study of messages, and in particular of the effective messages of control."[35] Although the militaristic origins and imperial intellectual ambitions of cybernetics have invited a variety of skeptical reactions, Wiener's immediate aim was to advance early computer technology by investigating the informatic circuits that allow one to draw functional analogies between organisms and machines. Biological nervous systems and modern electronic devices both feed information from certain parts of their structures back into a processing network, and these internal messages enable both the organism and the machine to track and regulate their respective performances.[36]

John von Neumann also used analogies with biological and nervous processes and organs as a means to guide the design of computers and other electronic devices. In these early heuristic moves for the splicing of the biological and the technological, Wiener and von Neumann worked on conceptual and technological foundations laid in the previous century by the scientific and aesthetic development of inscription technologies. In his "General and Logical Theory of Automata," von Neumann traced structural parallels between living organisms and computational machines and other "artificial automata." He compared the differences between analogue and digital computers to the distinction between humoral and neural processes, and seized the human central nervous system as a model for the construction of digital processors. In particular, von Neumann proposed an analogy between the function of the organic neuron and the electronic vacuum tube.

The transmission of signals through communication channels, nerves or phone lines, is analogous to the temporal behavior of closed thermodynamic systems: In both cases, disorder tends to increase over time. In informatics this increment of systemic evolution is called *noise*. In the informatic situation, "the statistical nature of *messages* is entirely determined by the character of the source. But the statistical character of the *signal* as actually transmitted by a channel, and hence the entropy in the channel, is determined both by what one attempts to feed into the channel and by the capabilities of the channel to handle different signal situations."[37] The amount of "entropy in the channel," as opposed to the entropy of a message before it is sent, is determined by the degree of noise that impinges on the signal—"anything that arrives as part of a message, but that was not part of the message when sent out."[38] No real-world channel can be made entirely free of some level of random fluctuation that introduces noise into the received message, and this circumstance introduces another level of uncertainty into the communication process. By the same token, the process of electronic computation is analogous to the transmission of a message. Here, the emergence of *error* represents the noise of computational transmission. In computation as well as communication, the margin of error as well as the increment of noise is counteracted by the injection of *redundancy* into coding protocols. With some sacrifice of efficiency, redundant coding provides a repetition of crucial calculative steps or message elements and so ensures a reliable if not impeccable level of accuracy at the end of the process.

At this point we reach a significant threshold in the development of contemporary technoscience out of these foundational mid twentieth-century documents. It is now broadly accepted that, just as the sign of entropy was reversed by information theory, so, too, the sign of noise has been reversed by the subsequent and pervasive extensions of informatic concepts, especially in physics and biology.[39] Yet at the moment of its informatic inception, much as thermodynamic entropy had been a century before, the concept of noise was treated only as a regrettable impediment to perfect efficiency. At the same time that Shannon and Weaver appropriated entropy into their informatic vernacular as a positive quantity, noise emerged in the old role of thermodynamic entropy as an uneradicable friction of communication. As entropy had begun as a measure of the loss of "usable energy," noise was immediately stipulated as a negative or destructive interference, the cause of a loss of "useful information."

But just as entropy is not properly conceived merely as energy's antithesis, by the very terms of Shannon's mathematicization of information, noise is not simply "anti-information." In a situation as pregnant with futurity as the unfolding of entropy, the productive ambiguity of noise emerged from the consideration that it, too, *is* information. Noise is precisely *unexpected* information, an uncanny increment that rolls the dice of randomness within every communicative and calculative transmission. In this volume, Doug Kahn discusses the modernist discovery, within the otherwise "pure" tones of an earlier musical acoustics, of noise: timbre is a musical noise that does not physically corrupt, but rather, informatically enhances the sound it inhabits. Similarly, much of the most exciting critical work of the past five decades has derived from the informatic integration of the disciplines of knowledge made possible by reversing the sign of noise.

VIRTUALITY

The mathematicization of information in communication theory established it as a scientific entity on a par with the physical concepts of matter and energy. The advent of information as a fundamental category also accompanied the relativization of matter and energy, which no longer possess the absolute existence implied by traditional laws of conservation. Both *can* be created and destroyed, but only (as quantified by Einstein's famous equation $e = mc^2$) by expending or producing the other. Thus a higher form of conservation law still determines, with relativistic adjustments, our understanding of the limits of material and energic phenomena; moreover, they are interconvertible only under what to us are extreme conditions. In contrast, information is inherently hyperbolic at all scales; more precisely, it has no proper scale.[40] As with entropy, conservation laws do not apply. Information can be endlessly replicated, multiplied, reproduced, piled up, and disseminated; conversely, it can be grievously deteriorated or utterly annihilated, expunged, defaced, or erased without any trace of compensatory vestige or remainder.

Although any medium and its messages can be lost, as long as traditional media are preserved, the scripts they bear are relatively hard to erase. "Carving is the prototypical kind of inscription," Marcos Novak writes, "though every other kind of writing partakes in this modification of one substance by another."[41] As a result, and in constant struggle against the entropic drift toward informatic as well as thermal disorganization, geologists, biologists, archaeologists, and historians have been able to salvage and interpret traces of the planetary, evolutionary, and cultural past. In contrast, information preserved in the form of electromagnetic coding, although equally material, breeds endless copies indistinguishable from any "original," yet if deleted and overwritten, leaves no scratch on any surface. For some, this ephemeralization of abiding fixation forebodes a disappearance and derealization of human efforts and accomplishments. Novak has no time for such obituaries: physical disembodiment "is the loss of inscription," but virtual "dis/embodiment" is "the agile shedding of one inscription in favor of another. . . . Digital writing celebrates the loss of inscription by removing the trace from acts of erasure."[42] What the virtual loses in place and permanence, it gains in velocity and transformativity.

The implosion of the mode of information within our technoscientific culture has produced a collective effort to bring forth the metaphysics of a new cosmos somewhere off to the side of the old universe of matter and energy. The nonplace of cyberspace underscores again that the mode of information and the modes of matter and energy are not immediately commensurate. Information both forms and takes form from the interplay of the real and the possible, but in its own realm it plays out in the reversible dynamics of virtualization and actualization.[43] For example, consider as an instance of informatic virtuality the ontology of a hypertext located on the World Wide Web: "Deterritorialized, fully present in all its existing versions, copies, and projections, deprived of inertia, ubiquitous inhabitant of cyberspace, hypertext helps produce events of textual actualization, navigation, and reading. Only such events can be said to be truly situated. And although it requires a real physical substrate for its subsistence and actualization, the imponderable hypertext has no place."[44] For our "selves" as well, to enter the realm of cyberspace is to be informatically transformed into a hypertext and dispersed into digital patterns.

Informatic virtuality puts into question the traditional categories of conservation, identity, substance, and situated presence, by referring any ontological differences, especially those between the organic and the mechanical, to the common currency of information—significant traces and unpredictable swerves within immense but finite signifying ensembles. Technosublimity and techno-angst play over this border where, as Novak argues in his essay in this volume, fixed phases break down and previously incommensurable realms are set into fluid intercommunication. Donna Haraway's discourse on the cyborg makes clear that such boundary breakdowns can assist as well as subvert hegemonic practices. Haraway grasps both the potential eros of these monstrous syntheses and the political aggression that could be activated by the virtual transparency of informatics: "Communications sciences and modern biologies are constructed by a common move—*the translation of the world into a problem of coding*, a search for a common language in which all resistance to instrumental control disappears and all heterogeneity can be submitted to disassembly, reassembly, investment, and exchange."[45]

This instrumental dream of a "common language" that eliminates the resistant noise of materiality altogether has recently been treated in a way that underscores how the opening onto the virtual has also, not so paradoxically, reinforced the persistence of the Real, that residue of bodies "which escapes the net, the point of excess that breaks through symbolic forms of reality."[46] In "Lingua ex Machina: Computer-Mediated Communication and the Tower of Babel," David J. Gunkel surveys the long-standing quest to fashion a universal language capable of transcending the static of translation among the multiplicity of natural languages.[47] With the advent of modern computers, it was hoped that research in machine translation (MT) would succeed in automating translation through an intermediate language or *interlingua* that might ultimately serve as a new lingua franca obviating the need for translation altogether. Gunkel's critique of this effort persuasively shows that, "ironically, universal MT is possible only if it is ultimately superfluous, and necessary only if it is fundamentally impossible."[48]

The virtual analog of MT research is the fantasy enacted by William Gibson's cyberpunk classic *Neuromancer* and pursued ever since by virtual reality (VR) technology. In the dream of "postsymbolic communication" through an immediate neural interface between the mind and the computer that eliminates the drag of translation from the velocity of thought, the virtual agent ascends to the disembodied state of Thomas Aquinas's angels, who converse from spirit to spirit without need of any material medium. The desire to see virtuality as a leap beyond organic contingency draws in its train a corollary wish to dispense with the encumbrances of language. However, "far from escaping the limitations of symbolic description, Virtual Reality is necessarily produced in and by the manipulation of descriptive signs," that is, the very coding protocols that enable computers to generate virtual worlds. "The apparent flight of VR away from the symbolic is ironically produced and substantiated in and by that from which it flees."[49]

Gunkel demonstrates how many of these computer-mediated quests for transcendent modes of universal communicative immediacy are based on a particular mythology, a culturally-specific reading of the Tower of Babel (Genesis 11:1–9) that posits an original (linguistic) unity from which humanity fell away and which we thus ought to be able to recover. If, however, there was never any such primal unity, if the origins and ontology of language were and remain irreducibly multiple, then we can never transcend the materialities of translation. The most considered responses to the technoculture of the virtual have also come to similar conclusions about the "materiality of informatics" altogether, and about the reckoning our real and virtual manufacturing cultures need to make with the living forms of individual and ecological embodiment.[50]

The transit from energy to information brings us back to the body, in particular the human body at the complex threshold of a rupture with and redoubling upon its material conditions. "The virtualization of the body is . . . not a form of disembodiment but a re-creation, a reincarnation, a multiplication, vectorization, and heterogenesis of the human. However, the boundary between heterogenesis and alienation, actualization and commodity reification, virtualization and amputation, is never clearly defined."[51] By clarifying the developments in science and technology and the literary and artistic productions that have spurred and responded to the cultural changes enacted by the historical movement from energy to information regimes, the essays in this volume can assist the thoughtful demarcation of this crucial but permeable boundary between subject and object, agency and commodity, form and medium, at the threshold of the virtual community.