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11 :: INFORMATION

BRUCE CLARKE

Everything that is, is information.
Pirate Pugg, in *The Cyberiad* by STANISLAW LEM

The environment contains no information. The environment is as it is.
HEINZ VON FOERSTER

Virtuality

Information is now established as a scientific entity on a par with matter and energy. However, unlike matter and energy, which are reliably conserved under normal physical conditions, information can be created or destroyed at will. And if matter and energy are (more or less) *real* physical quantities, information is *virtual*. This is what Heinz von Foerster means when he says, "The environment contains no information." Information does not exist until an observing system (such as a mind) *constructs* it—renders it as a "virtual reality" for a cognitive process—in response to the *noise* of environmental perturbations. Thus, enthusiastic ontological proclamations, such as Stanislaw Lem put in the mouth of his character Pirate Pugg in *The Cyberiad*, merit satire for the *fallacy of misplaced concreteness* (in Alfred North Whitehead's phrase). Information has no concreteness.

Stated more technically, information is a virtual structure dependent upon distributed coding/decoding regimes within which it can function. As we will detail later, the quantification of information depends upon a set of probabilities that differ relative to the position from which they are observed. That is, the "central explanatory quantity" of cybernetics—information—rests on a shifting measure of "probability," which is "a ratio between quantities which have similar dimensions" but "is itself of zero dimensions" (Bateson 1972, 403). On the plus side, "The advantage of working with information structures is that information has no intrinsic size" (Langton 1989, 39). This means that any *material* thing that can bear and preserve a coded difference, from magnetized molecules to carved granite mountain sides, can serve as a medium for the transmission of information.

Although any medium and its messages can be lost, the scripts borne by traditional media are relatively hard to erase as long as the media themselves are preserved. 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 or reconstruct traces of the planetary, evolutionary, and cultural past. In contrast, information preserved in the mediums of printed texts or electromagnetic coding, although equally material, breeds endless copies indistinguishable from any "original," yet if discarded, deleted, or overwritten, leaves no scratch on any surface. But what the virtuality of information 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 prior 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. For a practical example, consider as an instance of informatic virtuality the ontology of a hypertext located on the 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" (Levy 1998, 28).

Language

The canonical popularization of Claude Shannon's information theory, Warren Weaver's "Recent Contributions to the Mathematical Theory of Communication," parallels the canonical presentation of structural linguistics in Ferdinand de Saussure's *Course in General Linguistics*. Saussure already elaborates a *systemic* orientation focusing on the relations between the totality of the linguistic system as a social collectivity (*langue*) and any particular linguistic message (*parole*). The possibility of an individual message in the medium of language bearing significance for its addressee derives from its ability to link its sender and recipient to a collective external structure. Thus, for Saussure, the "integral and concrete object of linguistics," *langue*, "is a system of interdependent terms in which the value of each term results solely from the simultaneous presence of the others" (1966, 7, 114). Compare Weaver: "The concept of information applies not to the individual messages (as the concept of meaning would), but rather to the situation as a whole" (1949, 9). Just as the object of linguistics in its systematic and grammatical dimensions precedes matters of semantics, so information in its practical dimension (in particular, as an electromagnetic signal bearing an increment of message-load carried by a communications system) precedes the matter of *meaning*. Weaver cites Shannon on this point: "the semantic aspects of communication are irrelevant to the engineering aspects" (1949, 8). Information, in Shannon's mathematical treatment, is a matter of quantity—the amount to be transmitted relative to the capacity of a channel—rather than quality.

Similarly, in Shannon as in Saussure, matters of *value* are systemic rather than elemental. Informatic as well as linguistic values derive from "the situation as a whole"—the possibility of making specific selections from finite ensembles of variously probable options—rather than from anything intrinsic to what is selected. Saussure famously remarks, "Signs function . . . not through their intrinsic value but through their relative position. . . . In language there are only differences *without positive terms*" (1966, 118, 120). Compare Weaver (referring to Shannon's diagram, reproduced in chapter 9) on what amounts to informatic *parole* and on the determination of its value: "The *information source* selects a desired *message* out of a set of possible messages. . . . Information is a measure of one's freedom of choice when one selects a message" (1949, 7, 9).

However, just as in language there are finite amounts of paradigmatic difference from which to choose, so in the informatic situation one's "freedom of choice" will be contingent upon the finite statistical structure of a given system. Norbert Wiener clarifies this point in relation to the telegraphic medium: "A pattern which is conceived to convey information . . . is not taken as an isolated phenomenon. To telegraph . . . it is necessary that these dots and dashes be a selection from among a set which contains other possibilities as well" (1950, 4). Our positions as subjects of language, and more broadly, as subjects of information systems, bind our communicative behaviors to ratios of freedom and necessity determined in the first instance by social and technological collectivities: "It is most interesting to note that the redundancy of English is just about 50 per cent, so that about half of the letters or words we choose in writing or speaking are under our free choice, and about half (although we are not ordinarily aware of it) are really controlled by the statistical structure of the language" (Weaver 1949, 13).

Energy and Entropy

To further locate the modern discourse of information and *its* statistical structure, one must consult the history of the science of energy. Shannon quantified information through a calculus of message-probabilities modeled on statistical mechanics, a branch of physics. Statistical mechanics was developed in the late nineteenth century when Ludwig Boltzmann, transferring the mathematics of probabilities James Clerk Maxwell applied in his kinetic theory of gases, produced a measure of the energic disorder, or thermodynamic *entropy*, of physical systems. In all physical processes involving the conversion of energy from one form to another, some of the energy is dissipated in the form of heat: thermodynamic entropy is, at one level of its application, a measure of this "waste" (see Clarke 2002). A famous phrasing of the second law of thermodynamics is: In a closed system, entropy tends to a maximum. That is, observed over time, one can expect a physical or mechanical system—say, a pendulum or a steam engine—to go from order to disorder. Thermodynamically, the more unlikely the energy differentials, the lower the entropy—and so, informatically, the greater the information. Ordered or low-entropy physical systems with highly differentiated energies are relatively improbable; their lesser entropy equates to more information, just as finding a hot cup of coffee on a table in a cool room (a low-entropy scenario) would give you more information about its environment (someone is likely nearby) than the more typical circumstance of finding a cup at room temperature.

Boltzmann's statistical mechanics followed Maxwell in treating energic relations of order and disorder, work and waste, with the mathematics of probability (see Prigogine and Stengers 1984). His innovation was to define the entropy of a physical system as a function of its possible energic complexions—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 (high-entropy) distribution in which thermal differences are reduced to a minimum. One is more likely to find a system in a state of relative disorder, and disorder is likely to increase over time toward a state of maximum equilibrium in which the evolution of the system slows to a minimum. This, then, is the probabilistic restatement of the second law: In a closed physical system left to itself, molecular disorder is most likely to increase. Boltzmann's quantification of the entropy law is

$$S = k \log P.$$

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

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, with reference to 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." (1963, 5:304). Wiener commented that the conceptual alignment of information with the probabilities associated with a set of related informational patterns "was already familiar in the branch of physics known as statistical mechanics, and . . . associated with the famous second law of thermodynamics" (1950, 7). Weaver acknowledged this lineup—to whom he added Claude Shannon—as the set of thinkers most responsible for connecting energy to information, thermodynamics to cybernetics: "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'" (1949, 3).

Informatic Entropy

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, arriving at a measure he termed "the entropy of the message." The 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 improbability 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. As noted above, "information is a measure of one's freedom of choice when one selects a message." 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 severely constrained. The larger the ensemble of choices, however, the less probable is any particular choice. In this decidedly "liberal" approach to calculating the value of information, the more choices a sender has, 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," analogous to Boltzmann's logarithmic formula for thermodynamic entropy:

$$H = -\sum p_i \log p_i.$$

Information theory translates the ratios or improbable order to probable disorder in physical systems into a distinction between signal and noise, or "useful" and "waste" information, in communication systems. In the development of this transposition, information, or "message-entropy," becomes a variably complex measure of message-probabilities, a measure *dependent upon the position of the observer of the communication system.* The observer can, for instance, assess the value of a message at its source by increase of order, *or* at its destination by decrease of disorder.

To summarize: In physical systems doing work by converting energy from one form to another, the *thermodynamic* entropy of the system is the amount of energy unavailable for further work, or "wasted," usually in the form of heat. In communication systems, the *informatic* entropy of the message is a measure of message-probabilities relative to one of several vantage points:

- at the *source*, where one observes the ratio of *actual* selections to *possible* selections;
- in the *channel*, considering the ratio of *signal* ("useful information") to *noise* ("waste information"); or
- at the *destination*, based on the ratio of *surprise* (improbability) to *expectation* (probability).

At the source, informatic value is a function of the probability or improbability of a message's selection from a repertoire of possible messages: the smaller that ensemble, the fewer the available choices and the less information any given selection will carry. However, selection at the source only initiates a communication event and cannot determine the informatic value of its outcome. For instance, the order of the signal can be lost in transit due to noise in the channel. Finally, the value of information can also be defined by its effect on the receiver: "The amount of information received is the degree to which the receiver's uncertainty . . . has been diminished" (Paulson 1988, 55). Considering matters at the receiving end of informatic transmission underwrites many later twentieth-century developments in reception theory, reader response theory, and

cognitive sciences that have focused on the constitutive or constructivist moment for the audience of communications.

Noise

Norbert Wiener channeled information theory toward the science of cybernetics, which he defined as the "study of messages, and in particular of the effective messages of control" (1950, 8). His immediate aim was to advance computer technology by investigating the informatic circuits that allow 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 performance. The transmission of signals through communication channels, whether nerves or phone lines, is analogous to the temporal behavior of closed thermodynamic systems: in each case, disorder tends to increase over time. In informatics this increment of systemic evolution over the time of transmission is called *noise*. "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" (Weaver 1949, 17–18).

The amount of "entropy in the channel," as opposed to the entropy of a message before it is sent, is determined by the level of noise—"anything that arrives as part of a message, but that was not part of the message when sent out" (Paulson 1988, 67)—that impinges on the signal. No real-world channel can be made entirely free of random fluctuations that introduce noise, and this introduces another level of uncertainty into the communication process. This is analogous to the emergence of *error* in the process of electronic computation. In both computation and communication, the margin of error is counteracted through *redundancy*. 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 integrity at the end of the process.

The concept of noise was at first treated only as a regrettable impediment to perfect efficiency, much as thermodynamic entropy had been a century before. Yet entropy, which had begun as a measure of the loss of "usable energy," is not properly conceived merely as energy's antithesis. Similarly, noise was initially stipulated as a negative or destructive interference, the cause of a loss of "useful information." As Shannon and Weaver appropriated entropy into their informatic vernacular as a *positive* quantity, noise emerged as an ineradicable friction affecting communication. But by the very terms of Shannon's mathematizing of information, noise is not simply "anti-information." Rather, the productive ambiguity of noise emerged from the consideration that it too *is* information—and precisely *unexpected* information, an uncanny increment that rolls the dice of randomness within every communicative and calculative transmission. 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 (see Serres 2007).

The significance of noise for the discourse of information becomes clearer if we switch focus from communications systems (the milieu of Shannon's Bell Labs) to media systems (Manovich's "representational technologies")—that is, from information systems centered on *transmission* (such as the telegraph and telephone) to those centered on *inscription and storage* (the photograph and phonograph and their progeny). Graphic and digital systems do both, of course, but it is important nonetheless to bear in mind this distinction in system functions. We tend to envision information as perpetually in transit, in social circulation, but in equal degree, information accumulates, gets stored, and sits there, in some actual or virtual location, awaiting retrieval. What the inscription and storage of information also allows is its *manipulation*, an opening beyond its utilitarian functions to creative uses. Stored information becomes a medium out of which—by editing, cutting, reframing, resequencing, and so forth—new orders of form can be produced.

From the standpoint of transmission, any such meddling with stored information amounts to the mixing of noise into its signal. But from the standpoint of art forms instantiated in informatic media (aural sounds, visual images, linguistic signs), the noise *is* the art. For instance, the advent of phonography enabled the discovery, within the otherwise "pure" (Pythagorean) tones of an earlier musical acoustics, of noise. Timbre itself is a musical noise derived in the first instance from the material specifics of a given instrument. The noise of timbre does not physically corrupt but, rather, informatically enhances the sound it inhabits (see Kahn 2002), allowing for instrumental differentiations which then become part of the musical orchestration. For another example, with the advent of audiotape, time-axis manipulation (TAM) of the recorded signal became feasible. The Beatles and Jimi Hendrix famously crafted segments of their recordings by replaying pieces of studio tape backward. Media arts remediate information in forms of meaningful noise.

The Informatic and the Material

One of the more problematic legacies of the cybernetic discussion is the pervasive oversimplification of its distinction of information from matter. This is not so much the fault of the original expositors, who made a necessary effort—especially in light of the profound analogies between thermodynamics and informatics—to distinguish the object of cybernetics from the object of physics. Rather, the tendency to set matter and information into dialectical antithesis follows the engrained dualistic trends of Western thought, intellectual habits that persist despite the efforts of key cyberneticists to cultivate new ways of thinking, for instance, about the emergent productions of system/environment ensembles. A case in point is Gregory Bateson's seminal discourse on information, summed up in his famous observation that "what we mean by information—the elementary unit of information—is a *difference which makes a difference*" (1972, 453).

Bateson, who brought about a significant relay of cybernetic discourse from the natural to the social sciences, offers the following comment on "the ancient dichotomy between form and substance" in the context of a protest about the misleading scientism in "the metaphoric use of 'energy' in the behavioral sciences" to schematize psychological events: "The conservative laws for energy and matter concern substance rather than form. But mental process, ideas, communication, organization, differentiation, pattern, and so on, are matters of form rather than substance" (1972, xxv). Bateson's points are entirely congruent with Saussure's "in language there are only differences *without positive terms*": the concept of difference is a formal or relational one. It is *abstract*, in the way that mathematics is an abstraction from the world of things enumerated. But seldom does one find consternation over the "immateriality" of language or the "disembodiment" of mathematics. Bateson's point is precisely that information, under its "cybernetic explanation," crosses the form of linguistic differentiation with the form of mathematical probability.

The tendency, however, has been to read Bateson's *heuristic* exclusion of physical quantities from information theory as an *ontological* exclusion on the mind/nature model that licenses either the pseudo-utopian rhetoric of information as liberation from physical constraints, or alternatively, the materialist counterpolemic against information as a discourse of domination. For a sample of the latter tendency, let us briefly unpack a short passage early in Friedrich Kittler's brilliant work of media discourse theory, *Gramophone, Film, Typewriter*:

> The technological differentiation of optics, acoustics, and writing exploded Gutenberg's writing monopoly around 1880. . . . And with this differentiation—and not with steam engines and railroads—a clear division occurs between matter and information, the real and the symbolic. (1999, 16)

Kittler argues provocatively that the "writing monopoly"—print technology as the dominant means of archiving cultural production—broke down in the nineteenth century due to photography and phonography, the new graphic media of that time. In this passage he aligns literature, information, and the (Lacanian) symbolic. All three involve the imposition of a *code* by which the world is rearticulated for storage and transmission—and also by which information about the world is rendered into a coded *signal*. "To record the sound sequences of speech, literature had to arrest them in a system of 26 letters, thereby categorically excluding all noise sequences" (1999, 3)—excluding them, that is, from the *signal*, if not the *channel*. But no such transcriptive process is needed when the phonograph records "the sound sequences of speech" or of anything else; the "continuous undulations recorded by the gramophone and the audiotape" are, in contrast, "signatures of the real" (1999, 118). If the symbolic is pure signal (and so decipherable by definition), the real is pure noise and always already beyond intelligibility, no matter how "recognizable" a particular sound sequence may be.

For Kittler, the arrival of analog media technologies made possible a "reproduction authenticated by the object itself . . . . It refers to the bodily real, which of necessity escapes all symbolic grids" (1999, 12). In this and like remarks Kittler continues the dualistic discussion of information, rendering the "clear division . . . between matter and information, the real and the symbolic," as an absolute opposition on the Lacanian, if not indeed on the Cartesian, model. Here again the crucial analytical distinction between matter and information is reified, with information becoming the technoid signifier for "the *soul* of a new machine"—for immateriality, dematerialization, or disembodiment. In this way, the concept of information remains available for stigmatization by the spectrum of philosophical and political moralizations attached for millennia to ontological disputes over soul, form, essence, spirit, and their sundry historical avatars (see Terranova 2004).

However, if noise is *also* information—noise is a "signature of the real" just as signal is a signature of the symbolic—then the concept of information incorporates the unity of the difference between signal and noise. Signal *or* noise, it's all information. Or again, the bodies of the technological infrastructures of information systems are always part of the message—"the medium is the massage." The student of media can get the kinks out of the concept of information by reentering media environments into the whole picture, whatever transmissions come across the system. This prescription is a restatement of the contextual or "holistic" impetus in the best cybernetic thinking—the imperative always to think "organism plus environment," system *and* environment, message *and* medium. To do so is simply to be methodical about factoring into informatic transactions the matter of their material couplings and their systemic contexts. Bateson goes to the heart of this "relationship between *context* and its content," again with an analogy drawn from linguistics:

> A phoneme exists as such only in combination with other phonemes which make up a word. The word is the *context* of the phoneme. But the word only exists as such—only has "meaning"—in the larger context of the utterance, which again has meaning only in a relationship.
>
> This hierarchy of contexts within contexts is universal for the communicational (or "emic") aspect of phenomena and drives the scientist always to seek for information in the ever larger units. It may (perhaps) be true in physics that the explanation of the macroscopic is to be sought in the microscopic. The opposite is usually true in cybernetics: without context, there is no communication. (1972, 402)

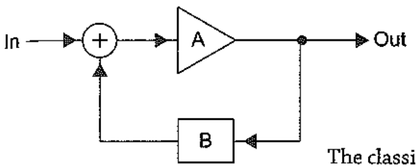
Feedback

The new relations and distinctions forged in the mid-twentieth century between energy and information highlight the crucial difference for systems of all kinds between isolation from, and openness to, their environments. In the cybernetic era the classical thermodynamic emphasis on the tendency of closed systems toward equilibrium shifts to the nonequilibrium operation of open and multiply coupled biotic and metabiotic ensembles. Even given the assumption of a universal drift toward entropy, biological, psychic, and social systems maintain their organizational autonomies through *operational* closure hand in hand with *environmental* openness (see Clarke 2008). For such autopoietic systems worldly perturbations are variously construed as signals or noises—a distinction whose meaning rests on the self-referential binary of meaning/nonmeaning. The point here is that informatic noise always bears "meaning" for the system that construes it, even if for that observer its meaning is to be meaningless, or unintelligble with reference to presently available codes.

If we shift now to an operational orientation, considering the role of information for systems that do not simply store it or transmit it but *use* it to maintain or steer their own functions, we encounter the concept of feedback. As we have noted, information theory defines information mathematically as an inverse function of the probability or predictability of a message. From the receiver's perspective, the less certain a message, the more information it delivers once it arrives. Because the noise of transmission intrudes randomly or unpredictably into signals, the shape it will take in any given communicative situation remains unknown until it is received. By introducing greater uncertainty into the message, noise can thus be thought of not as mere static, a loss of efficiency or clarity, but as a form of information about the media environment, a gain in communicative unpredictability with at least the potential to introduce other information of value into the transmission. As Bateson famously summed up this situation, using "information" as a synecdoche for *signal*: "All that is not information, not redundancy, not form, and not restraints—is noise, the only possible source of *new* patterns" (1972, 410).

The concept of feedback can also be regarded in the light of information theory. At the same moment in the 1940s when electronic computers were first being designed, feedback emerged as a key concept for the science of control mechanisms. In certain systems, output or behavior can be controlled—say, maintained within an effective range—by introducing information about the output back into the system as input. This circle of information, as seen in the figure, is called a feedback loop. In this classical feedback model, the feedback is *negative* if B < 0. The effect of negative feedback is to stabilize the output. This is the desired function in the case of servomechanisms such as thermostats, whose aim is to render the system homeostatic, fixing its operational parameters within an acceptable range. In the case of *positive* feedback, the fed-back signal adds rather than subtracts itself, compounding rather than dampening the output of the system. In either case, when output is fed back as input, the distinction between them breaks down and a looping circularity overtakes a strictly linear flow.

Let's consider feedback within electronic audio amplification in the wider context of its exploitation within popular music. Here the message is a source signal—say, from a guitar pickup—that the audio system registers, codes, decodes, and boosts into speakers. Audio feedback in an amplified circuit is produced when some of the output signal from an amplifier reenters the input signal by way of a microphone or instrument. This can generate unwanted noise, a fraying or distortion of the signal; one common manifestation is the horrible screech of runaway positive feedback that results when a microphone is placed too close to its speakers. However, when audio feedback is properly calibrated by an operator balancing the amount of output fed back into the system, a kind of harmonic equilibrium can evolve. Sound crystals emerge and condense to reveal the angularities of overtones and chord harmonics. It's a sort of fragile audio homeostasis, an island of order emerging in the chaos of amplified noise. This momentary system effect can itself be modulated within various limits and sustained to form a beam of sound.



The classical feedback model. Wikimedia Commons.

Rock feedback is a musical medium created by rodeo-riding a cascade of noise. Emerging full-blown in the mid-1960s, guitar feedback unleashed a new world of previously unheard-of sounds. A natural consequence of pushing an amplifier to fill a room too big for it, feedback was recognized as a sonic resource that could be both tonally and melodically controlled. Its use in rock was anticipated by Chicago-style electrified blues guitarists exploiting the pleasingly gritty sound of overdriven vacuum-tube amplifiers. That electric-blues signature was reprocessed by British guitar heroes such as Eric Clapton, Jeff Beck, and Jimmy Page, who in the mid-1960s found wavery feedback tones effective for signifying the mind-bending effects of pot and LSD. But one performer literally embodies the feedback of feedback—its cultural reentry into the States as the sound of psychedelia. The London-incubated American rocker Jimi Hendrix raised blues-based rock-guitar feedback to an art form, playing feedback like a violin. At the beginning of "Foxey Lady" (1967), for instance, he lays down a classic signature, rattling a string on his Fender Stratocaster into a stack of Marshall amplifiers until it generates enough input/output to loop into a feedback beam.

Hendrix especially perfected the "spacey" feel of psychedelic rock by developing ingenious ways of looping and relayering the noisy feedback signal to produce a sonic density or depth effect. He made guitar feedback sing using, in addition to guitar and amplifiers, a repertoire of newly created effects pedals, especially the fuzztone, which jacked up the volume of the guitar and made sustained feedback tones available at the punch of a floor pedal. To this, Hendrix added the wah-wah pedal, the Octavia octave-splitter, and the Uni-Vibe, which simulated the tremolo effect of the revolving tweeters in the sound box of a Hammond B3 electric organ—giving his feedback sounds a further range of stunning effects.

In "Third Stone from the Sun" (Hendrix 1967), for instance, he comes out of a spacey jam with his band and reasserts the head of the tune by capturing a feedback beam and using it to sing the melody, while rippling the aural solidity of the beam with the guitar's whammy bar. A few years later Hendrix distilled this form of guitar attack in his monumental performance—on New Year's Eve 1969, the night the '60s turned into the '70s—of "Machine Gun" (Hendrix 1970). Here, after the first set of verses, at the beginning of the main instrumental break, the dire horror of jungle warfare is condensed into a long-sustained, perfectly tuned scream of feedback, its octaves split by the Octavia and eerily lashed by the helicopterlike rotations of the Uni-Vibe.

In this example art is formed out of noise by reprocessing not a stored signal but one produced on the fly, in the moment of improvisation. Whereas the pioneers of cybernetics and information theory studied the formal parallels between electronic circuitry and the nervous system, Hendrix showed how to couple the electric guitar and its amplification and sound-processing technologies to the nervous system, communicating his own cybernetic fusion to his live and virtual audiences. Playing on the cutting edge of this human/machine interface, Jimi's rock persona embodied the "Body electric" sighted in the poetic ether a century earlier by America's first rock prophet, Walt Whitman: in Jimi's performance, Whitman's romantic body was transformed into a cybernetic body sustained by the potentially infinite looping of a feedback signal.

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