Chapter 2
Meaningful Information

Abstract "Meaningful Information" is defined as a pattern of organized matter or energy that is detected by an animate or manufactured receptor and thereby triggers a change in the behavior, functioning, or organizational structure of the detecting entity—which may either be a macromolecule, a cell, an organism, a plant, an animal, or a fabricated device. A great deal of what is currently called "information" does not fit this definition, since it does not change or affect the recipients. The ability to detect and respond to meaningful information is essentially a biological phenomenon, since there are no inanimate information detectors in nature. Information and energy are both fundamental properties of organized matter that reflect the complexity of its organization, but while energy is a function of an entity's mass or substance, information is a function of its form (i.e., of the way its structure is organized and arranged in space or time).

The problem with offering yet another meaning to a word that already has several is not that people will not be able to understand it, but that they already think they do. The concept of meaningful information presented here represents a new way of looking at how cells and other living entities communicate with each other and how they detect, process, store, and respond to certain patterns of matter and energy. Its impact extends far beyond the word's associations with knowledge, language, and computers. Meaningful information is something that lights up the entire biosphere with a constant chatter of cellular signals that orchestrate how living organisms grow, adapt, and communicate with each other. It is the type of information that Oyama (2000, p. 1) refers to when she comments: "Information is what enables molecules, cells, and other entities to recognize, select, and instruct each other, to construct others and themselves, to regulate, control, induce, direct, and determine events of all kinds."

The basic idea is fairly simple. Meaningful information consists of patterns of matter or energy that have an effect of some kind on the entities that detect them—with the effect being either a behavioral response, a physiological change, or an

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alternation in their neuronal connectivity. A great deal of what is currently called "information" does not fit this definition, since it does not change or affect the recipients. Although their sensory systems can detect the patterns being conveyed, their brains cannot discern any meaningful information in them. This is because meaningful information, at least as envisioned here, is not a property of the patterns of matter or energy themselves, but something attributed to them by the recipient. The arrangement of the stars in the sky or the mating call of a Carolina Wren, for instance, represent meaningful information only to certain individuals, but not to others, since it has no effect on them. Meaningful information does not even have to be true; it just has to have an effect on the recipients—although they usually have to believe it is true in order to respond. Even having a sender is not essential, since naturally occurring phenomena can convey meaningful information without one, like fossils in a rock or the position of the sun in the sky.

Key Concepts

This book is about a particular way of conceptualizing information, the key elements of which are described below. As Gatlin (1972, p. 25) notes: "Information is an ultimately indefinable or intuitive first principle, like energy, whose precise definition always seems to slip through our fingers like a shadow. This does not mean that we cannot define information *operationally* as we do energy and understand a great deal about its nature and how it expresses itself in the world about us." This is why meaningful information is defined here by what it *does*, rather than what it is.[1]

Intrinsic information is a theoretical concept proposed by Wiener (1948) that refers to the way the various particles, atoms, molecules, and objects in the universe are organized and arranged. The amount of intrinsic information an entity contains is a measure of its organizational complexity, an expression of the degree to which the elements that comprise it are arranged in a nonrandom fashion. Although the amount of intrinsic information can be quantified in man-made devices that store or transmit data, it cannot be measured directly in naturally occurring entities, since we have no way of accessing it in them. As Goldstein and Goldstein (1993, p. 133) explain: "we can measure any changes of energy or information a body undergoes, but not how much energy or information there was in the body in the first place—since there are no instruments that can measure them, no energy-meters or entropy-scopes."

Meaningful information refers here to the minute fraction of intrinsic information that can be detected and can cause a change in some sort of recipient. It is defined operationally as a spatial or temporal pattern of organized matter or energy that is detected by an animate or manufactured receptor, which then triggers a change in the behavior, functioning, or structure of the detecting entity. The detecting entity can either be a macromolecule, a cell, an organism, a plant, an animal, or a fabricated device. If there is no effect on the detecting entity's behavior, functioning, or structure, the information is considered to be meaningless as far as that particular individual is concerned at that particular time. Meaning is the key that enables information to have an effect, the attribute that transforms detected patterns of matter and energy into signs, signals, and messages that *inform* the recipient. Patterns of organized matter or energy that *can* have an effect on an animate or human-made receptor, but are not currently doing so, are referred to here as *data*. They include the material stored in computer memories and libraries, the initial results of experiments, and messages in codes and foreign languages. Arrangements of matter or energy that can be detected but are not capable of generating an effect or change in a recipient are referred to here as *noise*.

Biological Information

Meaningful information is essentially a biological phenomenon, for there are no inanimate information detectors in nature. Although some fabricated devices can detect and transmit information, they are unable to do so on their own, since someone has to design them, someone has to encode them, and someone has to interpret their output. While both living and nonliving entities respond to the physical aspects of matter and energy, only living ones detect and respond to the *form* of the objects and events they constitute. The ability to detect and respond to information is, in fact, one of the defining attributes of living things, something that is lost when they eventually die. Form plays a central role in all of biology, since it is also expressed in the shapes of organisms, the arrangement of their cells, and the folding pattern of the protein molecules these contain, all of which serve adaptive functions that have been shaped by natural selection over the millennia. As Mayr (1982, p. 52) notes: "The explanatory equipment of the physical sciences is insufficient to explain complex living systems and, in particular, the interplay between historically acquired information and the responses of these genetic programs to the physical world. The phenomena of life have a much broader scope than the relatively simple phenomena dealt with by physics and chemistry."[2]

Dusenbery (1992, p. 19) points out, "Organisms obtain information about their environment to help solve a wide variety of problems—maintaining an appropriate environment, timing activities, locating resources or threats—and many organisms transmit information to other individuals in order to persuade them to do something." All living entities import information from the outside world to enable them to learn and adapt to their surroundings in much the same way as they import energy to fuel their various activities. While cells and unicellular organisms respond automatically to information patterns that are meaningful to them, more complex creatures develop neuronal structures that enable them to store and interpret what they perceive, and to vary their responses accordingly. According to Gatlin (1972, p. 1): "Life may be defined operationally as an information processing system—a structural hierarchy of functioning units—that has acquired through evolution the ability to store and process information necessary for its own accurate reproduction."

While *order* is a general property of nature, *organization* is an exclusive manifestation of living things, ranging across the entire spectrum from cells to organs to individuals, as well as to the devices and social systems they create. Order simply indicates that entities are arranged in a nonrandom fashion, like the furniture in a room, the bases in a strand of DNA, or the steel girders in a skyscraper. Organization, on the other hand, implies that entities are not only arranged in an orderly manner but that their component parts also interact with each other in ways that affect the entity's overall functioning. The essence of organization is that the entity's components communicate with one another by sending and receiving meaningful information. This is what enables them to coordinate their activities and function as an *ensemble*, rather than just a collection of parts. As Harold (2001, p. 108) notes: "Living things differ from non-living ones most pointedly in their capacity to maintain, reproduce, and multiply states of matter characterized by an extreme degree of organization."

Information and Energy

Energy is defined as the capacity to do work or cause physical change. The modern concept of energy was introduced in the eighteenth century in association with the emerging science of thermodynamics. As Dear (2006, p. 16) points out, it shares a number of attributes with information: "Energy was a very abstract concept, with no pure form that could be put in a bottle on the laboratory shelf, but its use as an accounting procedure for tracking changes in physical phenomena quickly made it indispensable." Virtually all of the available energy on our planet is derived from the sun. Plants capture energy from it through photosynthesis and store it for later use. Animals obtain their supply of energy by metabolizing plant substances (i.e., breaking down their organized structure), either directly or indirectly. Fossilized plant and animal matter, such as coal and oil, can also be broken down into less-complex substances when oxidized, thereby releasing energy that can be harnessed for work (Bryant et al. 2006).[3]

Information and energy are both fundamental properties of organized matter that express the complexity of its organization. But whereas energy is a function of an entity's *mass* or *substance*, information is a function of its *form*, of the way it is arranged in space and time. An entity with a repetitive pattern of structural elements, such as a crystal or a lattice, contains less information than a more intricately organized one, but not less energy. A 10-lb sack of potatoes, for instance, contains twice as much energy as a 5-lb one, but not twice as much information; nor do a dozen copies of the *Encyclopedia Britannica* contain more information than a single one, since the additional copies are just redundant. Because of the way redundancy reduces the amount of information in an entity, but not the amount of energy, the quantity of information a given object contains is not necessarily the same as the quantity of energy.[4]

The information and energy that are present in organized matter are only inactive potentials, however, until some process enables them to be realized. Most of the physical entities that make up the universe, such as atoms, mountains, and stars, are relatively stable and cannot easily be broken down to reveal either the energy or the information they contain. For energy to become available, an organized entity has to be transformed into a less-organized state, which is what happens when fossil fuel is burned or a nuclear reaction takes place. For information to become available, however, the object must interact with a receptor (or a set of receptors) that is capable of detecting the meaning it conveys. Thus, although the amount of energy in a source becomes depleted when some of it is released, the amount of information it contains is not changed by being detected. The words on this page, for instance, do not become degraded as you read them, but remain intact for others to read later on. Moreover, while energy cannot be destroyed, information can, as by burning a book, accidentally erasing a computer disc, or getting Alzheimer's disease.

Because a given amount of matter can exist in a number of different forms, the information each of them contains is not the same. Thus, although the arrows below contain the same amount of matter, they do not convey the same information. On the other hand, the squares adjacent to them convey the same information, even though they consist of different amounts of matter.

The amount of energy used to transmit information is unrelated to the amount of information being transmitted, which is why different energy substrates can be used to convey the same information—as long as they have comparable spatial and temporal patterns. This is the basis of the process of *transduction*, in which an information pattern in one energy medium is converted into an equivalent pattern in another. Transduction is the mechanism that enables electronic signals to be converted into radio and television shows, and sensory information to be represented in the brain as neuronal configurations. The key distinctions between energy and information are captured by Von Bayer (2004, p. 11): "Energy is located strictly within a physical system—metabolic energy in a jelly doughnut, electrical energy in a mobile-phone battery, chemical energy in a gas tank, kinetic energy in every puff of wind. Information, on the other hand, resides partly in the mind. A coded message may represent gibberish to one person, and valuable information to another. The smell of subjectivity, of dependence on a state of mind is the source of both the elusiveness and the power of the concept of information." This is why, as he sees it, "information stands poised to join the concept of *energy* as a unifying thread that runs through all of science, linking diverging branches and unifying the foundations of the whole enterprise" (p. 99). But first we need to be clear which sort of information we are talking about.[5]

Notes

[1]The everyday meaning of *information* emerged in the fourteenth century from roots in the Latin *informatio,* meaning to form, place in order, or arrange. It was something that gave *form* to the mind. Dr. Johnson's 1755 dictionary described it as the process of telling something to someone

and to the content being transmitted. The 1961 *Oxford English Dictionary* defined it as: (a) the action of informing, formation or molding of the mind or character, training, instruction, teaching, (b) the act of informing; communication of the knowledge or "news" of some fact or occurrence; the act of telling or the fact of being told of something, and (c) knowledge communicated concerning some particular fact, subject, or event; that of which one is appraised or told; intelligence, news (Cappuro 1985).

[2]Maynard Smith (2000) provides a lucid review of the unique role that information plays in the evolution and maintenance of biological systems, while Godfrey-Smith (2007) reviews the philosophical issues involved in the use of informational concepts in biology.

[3]The energy derived from nuclear reactions is an exception.

[4]The amounts of information and energy an entity contains are not necessarily identical, even though both are functions of the degree by which its organizational structure differs from randomness. The two of them thus entail somewhat different concepts of entropy, since this is an inverse measure of the amount of order and organization. *Entropy* refers to both the amount of disorder in a thermodynamic system as well as the process by which disorder occurs. According to the second law of thermodynamics, the total entropy of an isolated thermodynamic system tends to increase over time, so that organized systems tend to run down and become less organized unless external energy is supplied to them. This is why hot objects become cold, physical structures decay, and living things need to import energy to stay alive. As La Cerra (2003) notes: "Entropy is the primary adaptive problem that life forms must solve; consequently, evolutionary processes have crafted intelligence systems that are fundamentally designed to acquire, manage and direct energetic resources toward the maintenance of life processes and the attainment of life-stage specific goals." A review of the differing concepts of entropy can be found at http://entropysite.oxy.edu.

[5]Gitt (1996, p. 181) maintains that: "Energy and matter are considered to be basic universal quantities. However, the concept of information has become just as fundamental and far-reaching, justifying its categorization as the third fundamental quantity." As he sees it (Gitt 2006, p. 121): "Although matter and energy are necessary fundamental properties of life, they do not in themselves imply any basic differentiation between animate and inanimate systems."

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