



Appendix A



# Information

Information is the fundamental metaphysical connection between *idealism* and *materialism*.

Information is the *form* in all concrete objects as well as the *content* in non-existent, merely possible, *abstract entities*. It is the disembodied, de-materialized *essence* of anything.

Information philosophy goes beyond *a priori* logic and its puzzles, beyond *analytic* language and its games and paradoxes, beyond philosophical claims of *necessary* truths, to a *contingent* physical world that is best represented as made of dynamic, interacting *information structures*. Models of these structures can best represent the fundamental metaphysical nature of reality.

Knowledge begins with information structures in minds that are partial *isomorphisms* (mappings) of the information structures in the external world. Information philosophy is the ultimate *correspondence* theory.

But I-Phi shows that there is no isomorphism, no information in common, no necessary connection, between *words and objects*. Although language is an excellent tool for human communication, its arbitrary and ambiguous nature makes it ill-suited to represent the world directly. Language does not picture reality. Is is not the best tool for solving philosophical problems.

The extraordinarily sophisticated connection between words and objects is made in human minds, mediated by the brain's experience recorder and reproducer (ERR).<sup>1</sup> Words stimulate neurons to start firing and to play back relevant experiences that include the objects.

By contrast, a dynamic information model of an information structure in the world is presented immediately to the mind as a look-alike and act-alike simulation, which is experienced for itself, not mediated through words.

<sup>1</sup> See appendix E on the experience recorder and reproducer..



Without words and related experiences previously recorded in your mental experience recorder, you could not comprehend spoken or written words. They would be mere noise, with no meaning. Compare these two representations of a cat.

CAT



Compared to a spoken or printed word, a photograph or a moving picture with sound can be seen and mostly understood by human beings, independent of their native tongue.

The elements of information philosophy, *dynamical models of information structures*, go far beyond logic and language as a representation of the fundamental, metaphysical, nature of reality.

Models “write” directly into our mental experience recorders. They are not *mediated* through ambiguous language.

Computer animated models must incorporate all the laws of nature, from the differential equations of quantum physics to the myriad processes of biology. At their best, simulations are not only our most accurate knowledge of the physical world, they are the best teaching tools ever devised. We can transfer knowledge non-verbally to coming generations and most of the world’s population via the Internet and ubiquitous smartphones.

If you think about it, everything you know is pure abstract information. Everything you are is an “information structure,” a combination of matter and energy that embodies and communicates your information. And everything that you value contains information.

You are a creator of information, part of a cosmic creation process. Your free will depends on your unique ability to create alternative possibilities for your willed decisions and responsible actions.

The simple definition of information is the act of informing - the communication of knowledge from a sender to a receiver that informs (literally shapes) the receiver.



By information we mean a quantity that can be understood mathematically and physically. It corresponds to the common-sense meaning of information, in the sense of communicating or informing. It is like the information stored in books and computers. But it also measures the information in any physical object, like a snow crystal or a star like our sun, as well as the information in biological systems, including the genetic code, the cell structure, and the developmental learning of the phenotype.

Although some commentators would like to limit the term “information” to messages sent with an *intended* purpose, physical scientists have long included the structure in physical objects as something that can be measured by an observer and thus is also information. Information philosophy recognizes material objects as “information structures,” from which pure information content can be abstracted as meaningful knowledge, even though the object itself may have no purpose.

The sender of information need not be a person, an animal, or even a living thing. It might be a purely material object, a rainbow, for example, sending color information to your eye.

The receiver, too, might be merely physical, a molecule of water in that rainbow that receives too few photons and cools to join the formation of a crystal snowflake, increasing its information content.

Information theory, the mathematical theory of the communication of information, says little about meaning in a message, which is roughly the use to which the information received is put. Information philosophy extends the information flows in human communications systems and digital computers to the natural information carried in the energy and material flows between all the information structures in the observable universe.

A message that is certain to tell you something you already know contains no new information. It does not increase your knowledge, or reduce the uncertainty in what you know, as information theorists put it.



## Information in the Universe

Information in physical systems was connected to a measure of the structural order in a system as early as the nineteenth century by WILLIAM THOMSON (later Lord Kelvin) and LUDWIG BOLTZMANN, who described an increase in the thermodynamic entropy as “lost information.”

In 1877, Boltzmann proved his “*H*-Theorem” that the entropy or disorder in the universe always increases.<sup>2</sup>

He defined entropy  $S$  as the logarithm of the number  $W$  of possible microscopic states of a physical system, an equation now known as Boltzmann’s Principle,

$$S = k \log W.$$

In 1929, LEO SZILARD showed the mean value of the quantity of information produced by a 1-bit, two-possibility (“yes/no”) measurement as  $S = k \log 2$ , where  $k$  is Boltzmann’s constant, connecting information directly to entropy.

Following Szilard, LUDWIG VON BERTALANFFY, ERWIN SCHRÖDINGER, NORBERT WIENER, CLAUDE SHANNON, WARREN WEAVER, JOHN VON NEUMANN, and LEON BRILLOUIN, all expressed similar views on the connection between physical entropy and abstract “bits” of information.

Schrödinger said the information in a living organism is the result of “feeding on negative entropy” from the sun. Wiener said “The quantity we define as amount of information is the negative of the quantity usually defined as entropy in similar situations.”

Brillouin created the term “negentropy” because he said, “One of the most interesting parts in Wiener’s *Cybernetics* is the discussion on “Time series, information, and communication,” in which he specifies that a certain “amount of information is the negative of the quantity usually defined as entropy in similar situations.”

Shannon, with a nudge from von Neumann, used the term entropy to describe his estimate of the amount of information that can be

<sup>2</sup> Boltzmann’s critics objected to his proof, but we have shown how to overcome their objections in chapters 24 and 25.



communicated over a channel, because his mathematical theory of the communication of information produced a mathematical formula identical to Boltzmann's equation for entropy, except for a minus sign (the negative in negative entropy).

Shannon described a set of  $i$  messages, each with probability  $p_i$ . He then defined a quantity  $H$ ,

$$H = k \sum p_i \log p_i$$

where  $k$  is a positive constant. Since  $H$  looked like the  $H$  in Boltzmann's  $H$ -Theorem, Shannon called it the entropy of the set of probabilities  $p_1, p_2, \dots, p_n$ .

To see the connection, we can note that Boltzmann assumed that all his probabilities were equal. For  $n$  equal states, the probability of each state is  $p = 1/n$ . The sum over  $n$  states,  $\sum p_i \log p_i$ , is then  $n \times 1/n \times \log(1/n) = \log(1/n) = -\log n$ . If we set  $n = W$ , we get Boltzmann's entropy with a minus sign,

$$H = -k \log W.$$

Shannon's entropy  $H$  is simply the negative of Boltzmann's  $S$ .

Shannon showed that a communication that is certain to tell you something you already know (one of the messages has probability unity) contains no new information. The logarithm of 1 is 0.

If everything that happens was certain to happen, as determinist philosophers claim, no new information would ever enter the universe. Information would be a universal constant. There would be "nothing new under the sun." Every past and future event could in principle be known (as PIERRE-SIMON LAPLACE suggested<sup>3</sup>) by a super-intelligence with access to such a fixed totality of information.

It is of the deepest philosophical significance that information is based on the mathematics of probability. If all outcomes were certain, there would be no "surprises" in the universe. Information would be conserved and a universal constant, as some mathematicians mistakenly believe it is. Information philosophy requires the ontological chance and probabilistic outcomes of modern quantum physics to create new information structures.

3 See "Laplace's Demon" on page 28

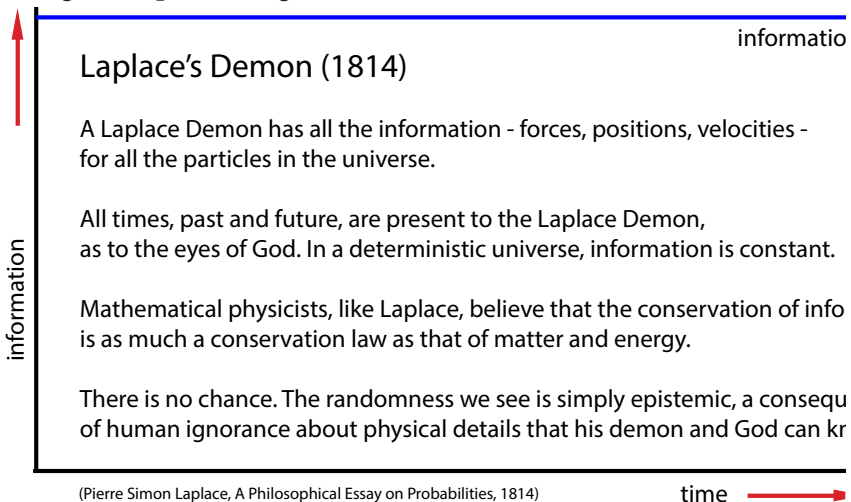


But at the same time, without the extraordinary stability of quantized information structures over cosmological time scales, life and the universe we know would not be possible. Quantum mechanics reveals the architecture of the universe to be *discrete* rather than continuous, to be digital rather than analog. And digital provides extraordinary stability.

Creation of information structures means that in parts of the universe local entropy is actually going down. Creation of a low-entropy system is always accompanied by radiation of energy and entropy away from the local structure to the night sky and the cosmic background radiation.

From Newton's time to the start of the 19th century, the Laplacian view coincided with the notion of the divine foreknowledge of an omniscient God. On this view, complete, perfect and constant information exists at all times that describes the designed evolution of the universe and of the creatures inhabiting the world.

In this God's-eye view, information is a constant of nature. Some mathematicians argue that information must be a conserved quantity, like matter and energy. They are wrong. In Laplace's view, information would be a constant straight line over all time, as shown along the top of the figure.



**Figure 29-1. Constant information in a deterministic universe**



If information were a universal constant, there would be “nothing new under the sun.” Every past and future event can in principle be known by Laplace’s super-intelligent demon, with its access to such a fixed totality of information.

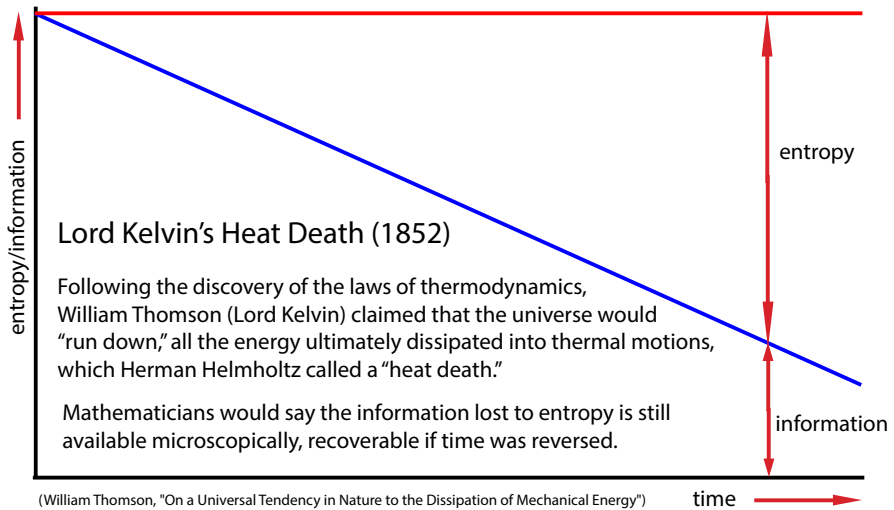


Figure 29-2. The second law predicts a heat death of the universe

But midway through the nineteenth century, Lord Kelvin (William Thomson) realized that the newly discovered second law of thermodynamics required that information could not be constant, but would be destroyed as the entropy (disorder) increased. HERMANN HELMHOLTZ described this as the “heat death” of the universe.

Mathematicians who are convinced that information is always conserved argue that macroscopic order is disappearing into microscopic order, but the information could in principle be recovered, if time could only be reversed.

This raises the possibility of some connection between the increasing entropy and what ARTHUR STANLEY EDDINGTON called “Time’s Arrow.”<sup>4</sup>

Kelvin’s claim that information must be destroyed when entropy increases would be correct if the universe were a closed system. But in our open and expanding universe, my Harvard colleague DAVID LAYZER showed that the maximum possible entropy is increasing

4 See chapter 24.





faster than the actual entropy. The difference between maximum possible entropy and the current entropy is called negative entropy, opening the possibility for complex and stable information structures to develop.

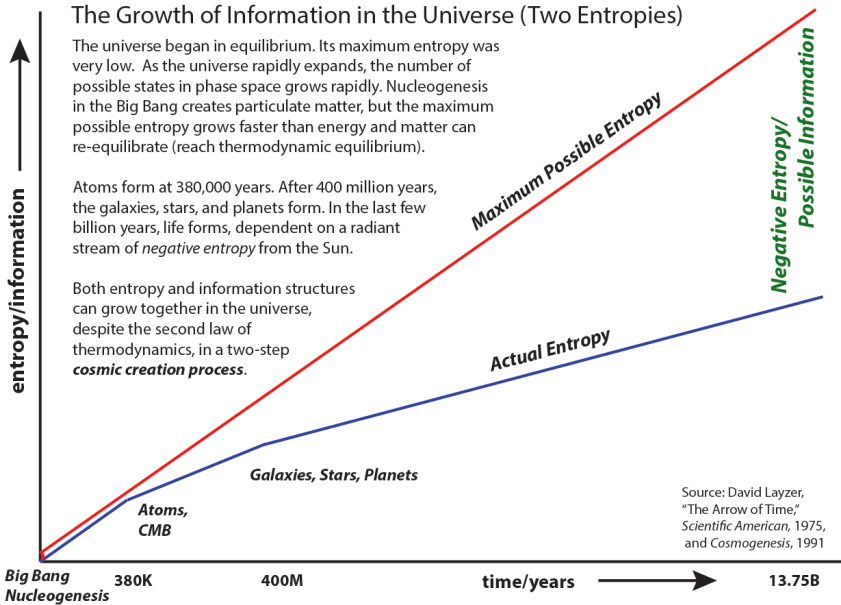


Figure 29-3. Growth of information and entropy in the universe

We can see from the figure that it is not only entropy that increases in the direction of the arrow of time, but also the information content of the universe. We can describe the new information as “*emerging*.”<sup>5</sup>

*The expanding universe is the source of possibilities*

Despite the second law of thermodynamics, stable and lawlike information structures evolved out of the initial chaos. First, quantum processes formed microscopic particulate matter – baryons, nuclei - from the fundamental quarks and electrons. Eventually these became atoms. Later, under the influence of gravitation, they coalesced into macroscopic galaxies, stars, and planets.

5 See chapter 27.



Every new information structure reduces the entropy locally, so the second law requires an equal (or generally much greater) amount of entropy to be carried away. Without the expansion of the universe, this would be impossible.

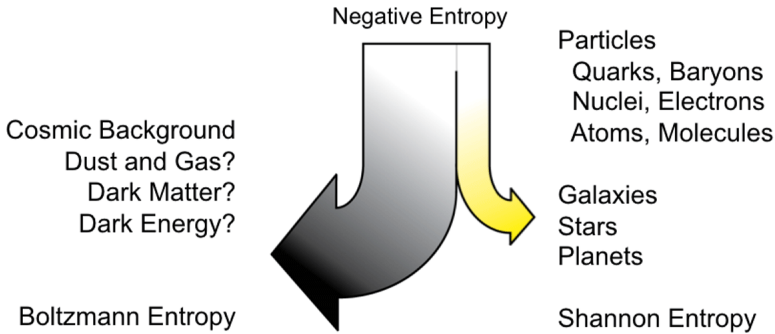


Figure 29-4. Two entropy flows

The positive entropy carried away (the big dark arrow on the left) is always greater than and generally orders of magnitude larger than the negative entropy in the created information structure (the smaller light arrow on the right).

See appendix B for the other negative entropy flows that ultimately lead to human life.

Information is *emergent*, because the universe began with minimal, essentially zero, information. It was in a state of thermodynamic equilibrium, maximum disorder.

And there are three distinct kinds of information emergence:

- the “order out of chaos” when the matter in the universe formed cosmic information structures. This is also ILYA PRIGOGINE’s chaos and complexity theory.
- the “order out of order” when the material information structures form self-replicating biological information processing systems. This is what ERWIN SCHRÖDINGER described as life “feeding on negative entropy.”



- the pure “information out of order” when organisms with minds create, process, and externalize information, communicating it to other minds and storing it in the environment, sharing it with all humanity as the *Sum* of human knowledge.

*Information philosophy* explains how new information is constantly being created, by nature and by humanity. We are co-creators of our universe.

*Information theory* is the mathematical quantification of communication to describe how information is transmitted and received, in human language, for example.

*Information science* is the study of the categorization, classification, manipulation, storage, and retrieval of information.

Cognitive science is the study of the mental acquisition, retention, and utilization of knowledge, which we can describe as the recording and reproduction of experiences as guides for action.

Information philosophy is an attempt to examine some classic problems in philosophy from the standpoint of information.

What is information that merits its use as the foundation of a new philosophical method of inquiry?

Abstract information is neither matter nor energy, yet it needs matter for its concrete embodiment and energy for its communication. Information is immaterial.

*Information is the modern spirit, the ghost in the machine.*

Immaterial information is perhaps as close as a physical or biological scientist can get to the idea of a soul or spirit that departs the body at death. When a living being dies, it is the maintenance of biological information that ceases. The matter remains.

Biological systems are different from purely physical systems primarily because they create, store, and communicate information. Living things store information in a memory of the past that they use to shape their future. Fundamental physical objects like atoms have no history.



And when human beings export some of their personal information to make it a part of human culture, that information moves closer to becoming immortal.

Human beings differ from other animals in their extraordinary ability to communicate information and store it in external artifacts. In the last decade the amount of external information per person may have grown to exceed an individual's purely biological information.

Information is an excellent basis for philosophy, and for science as well, capable of answering questions about metaphysics (the ontology of things themselves), epistemology (the existential status of ideas and how we know them), idealism (pure information), the mind-body problem, the problem of free will, and the "hard" problem of consciousness.

Actionable information has pragmatic value.

In our information philosophy, knowledge is the sum of all the information created and preserved by humanity. It is all the information in human minds and in artifacts of every kind - from books and internetworked computers to our dwellings and managed environment.

We shall see that all information in the universe is created by a single two-part cosmic creation process, the only one capable of generating and maintaining information in spite of the dread second law of thermodynamics, which describes the irresistible increase in disorder or entropy. We call this anti-entropic process ergodic. It should be appreciated as the creative source of everything we can possibly value, and of everything distinguishable from chaos and therefore interesting.

Enabled by the general relativistic expansion of the universe, the cosmic creative process has formed the macrocosmos of galaxies, stars, and planets. It has also generated the particular forms of microscopic matter - atoms, molecules, and the complex macromolecules that support biological organisms. It includes all quantum cooperative phenomena.



Quantum phenomena control the evolution of life and human knowledge. They help bring new information into the universe in a fundamentally unpredictable way. They drive biological speciation. They facilitate human creativity and free will.

Although information philosophy looks at the universe, life, and intelligence through the single lens of information, it is far from mechanical and reducible to a deterministic physics. The growth of information over time - our principle of increasing information - is the essential reason why time matters and individuals are distinguishable.

Information is the principal reason that biology is not reducible to chemistry and physics. Increasing information (a combination of perfect replication with occasional copying errors) explains all emergent phenomena.”

In information philosophy, the future is unpredictable for two basic reasons. First, quantum mechanics shows that some events are not predictable. The world is causal, but not pre-determined. Second, the early universe does not contain the information of later times, just as early primates do not contain the information structures for intelligence and verbal communication, and infants do not contain the knowledge and remembered experience they will have as adults.

In the naive world of Laplace’s demon and strict determinism, all the information in the universe is constant at all times. But “determinism” itself is an emergent idea, realized only when large numbers of particles assemble into bodies that can average over the irreducible microscopic indeterminacy of their component atoms.

### Information and Entropy

In our open and expanding universe, the maximum possible entropy is increasing faster than the actual entropy. The difference between maximum possible entropy and the current entropy is called negative entropy. There is an intimate connection between the physical quantity negative entropy and information.<sup>6</sup>

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6 See appendix B for more on entropy and the second law.



To give this very positive quantity of “negative” entropy a positive name, we call it “Ergo” and describe processes capable of generating negative entropy “ergodic.”

Ergodic processes provide room to increase the information structures in the universe. As pointed out by David Layzer, the Arrow of Time<sup>7</sup> points not only to increasing disorder but also to increasing information.

The increase of biological information is primarily by perfect replication of prior existing information, but it is critically important that replication errors occur from time to time. They are the source of new species and creative new ideas.

The universe is creative. Information structures and processes are emergent. Some laws of nature are emergent. Adequately deterministic phenomena are emergent. The very idea of determinism is emergent.<sup>8</sup> Knowledge of the present did not all exist in the past. We have only a rough idea of the exact future.

The creative process continues. Life and humanity are a part of the process. What gets created is in part our responsibility. We can choose to help create and preserve information. Or we can choose to destroy it. We are free to create our own futures.

Why Information? Information is neither Matter nor Energy,

But it needs Matter for its Embodiment,  
And it needs Energy for its Communication.

Information is the modern Spirit.

It is the Ghost in the Machine.

It is the Mind in the Body.

It is the Soul, and when we Die,

It is our Information that Perishes,

unless we Publish it to the World and Posterity.

Therefore, we publish this book and the accompanying website, whose contents are freely usable according to a Creative Commons license, because *information wants to be free*.

7 See chapter 24 for the arrow of time.

8 See chapter 27 on emergence.

