Review Article

# Infodynamics, a Review

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**A review of studies on the interaction of information with the physical world found no fundamental contradiction between the eight authors promoting Infodynamics. Each one emphasizes different aspects. The fact that energy requires information in order to produce work and that the acquisition of new information requires energy triggers synergistic chain reactions producing increases in negentropy (increases in Useful Information or decreases in Information Entropy) in living systems. Infodynamics aims to study feasible balances between energy and information using empirical methods. Getting information requires energy, and so does separating useful information from noise. Producing energy requires information, but there is no direct proportionality between the energy required to produce the information and the energy unleashed by this information. Energy and information are parts of two separate realms of reality that are intimately entangled but follow different laws of nature. Infodynamics recognizes multiple forms and dimensions of information. Information can be the opposite of thermodynamic entropy (Negentropy), a trigger of Free Energy (Useful or Potentially Useful), a reserve (Redundant Information), Structural, Enformation, Intropy, Entangled, Encrypted Information, Synergic, or Noise. These are overlapping functional properties focusing on different aspects of Information. Studies on information entropy normally quantify only one of these dimensions. The challenge of Infodynamics is to design empirical studies to overcome these limitations. The working of sexual reproduction and its evolution through natural selection and its role in powering the continuous increase in information and energy in living systems might teach us how.**

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## Content

## What is Information

**Information** is an abstract concept with divergent meanings. No precise quantifiable definition of information can be applied to all realms where the concept is used. Intuitively, it is understood by humans in all cultures. Information can be reproduced, transmitted, and stored, but it is not in itself a material reality: it requires a physical substrate or interactions between matter and energy in order to become "visible". It does not obey the laws of thermodynamics, but it does follow laws that mirror them. Some related concepts help in understanding the concept "Information".

**Knowledge** is information that allows an agent to predict behaviors or features of a system even if it has access to only partial information of the system. It is a form of awareness or familiarity, practical skills, or other kinds of information.

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**Consciousness** means being aware of possessing information about oneself and its relations with others and the environment. It is a tool for living beings to model the world, including the self.

**Understanding** is knowing information so as to be able to teach it.

**Intelligence** is the ability to manage and process information.

**Meaning** may be derived from a representation through interpretation of information[1].

**Memory** is the information stored in a physical substrate, such as a brain, electronic devices, books and libraries, or DNA and biomes, which perdure with some changes over time.

**Complexity** is an abstraction related to the amount and diversity of information in a system.

**Information entropy**, coined by Claude Shannon[2], tells us how much information there is in an event or a system. It is measured in bits. In general, the more certain or deterministic the event is, the less information it will contain. It indicates the degree to which the content of the message is surprising. Confusingly, this kind of entropy has nothing to do with the entropy concept used in thermodynamics, which is measured in calories[3].

**Information in thermodynamics** is needed for the production of Free Energy or useful work.

**Negentropy,** or the opposite of entropy (negative entropy), refers to more order that contains more information.

**Medium** or substrate upon which information is encoded or transmitted.

**Structural information:** Information that describes the spatiotemporal arrangements of the physical parts of a system. For example, the structural information of an enzyme (protein) to catalyze a given chemical reaction, or the structure of a cannon that allows a projectile to accelerate at maximum speed.

**Encrypted information**: Human Languages, Animal Communication systems, Mathematics, Computer Languages, DNA, Proteins, Ecosystems...

**Language** is a symbolic system used to describe us and the world around us. It can be mathematical, figurative, linguistic, chemical, or structural,

**Information in quantum physics** is the information that is encoded in the state of a quantum system. Quantum systems can be in superposition states, meaning that they can be in multiple states at the same time. This allows quantum information to be encoded in a different way than classical information, which can only be in one state at a time. The basic unit of quantum information is the qubit, which can be


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in a superposition of the states 0 and 1, meaning that it can represent both values at the same time. This is in contrast to a classical bit, which can only be in one state at a time, either 0 or 1.

**Information in Biology vs Physics** differs due to contradictory conceptions of entropy[[4]]. For a biologist, it is irrefutable that all information stored in the brain cells and organs of an animal disappears with death, whereas many physicists believe that information contained in matter remains even when collapsed inside a black hole[5]. This belief seems to originate from a confusion in the meaning of entropy[6].

**Quantifying information** Shannon Information Entropy is widely used to quantify information. However, it is limited to encrypted information. Yet, a good description of information must allow its quantification even if not encrypted in a simple format. For example, the question of how much information is contained in Wikipedia, and if it is more than that stored in New York City telephone books, seems to be answerable even by modern AI platforms (Data in Table from Bard Nov 2023 in this case). Care must be taken to select the appropriate data, which is not always possible.

| Source | Number of Articles | Number of Words | Estimated Size |
|---|---|---|---|
| **Wikipedia** | 6.7 million (English) | 29 billion (all languages) | 30 terabytes |
| **NY City Tele. Book** | 8 million | N/A | 1 gigabyte |

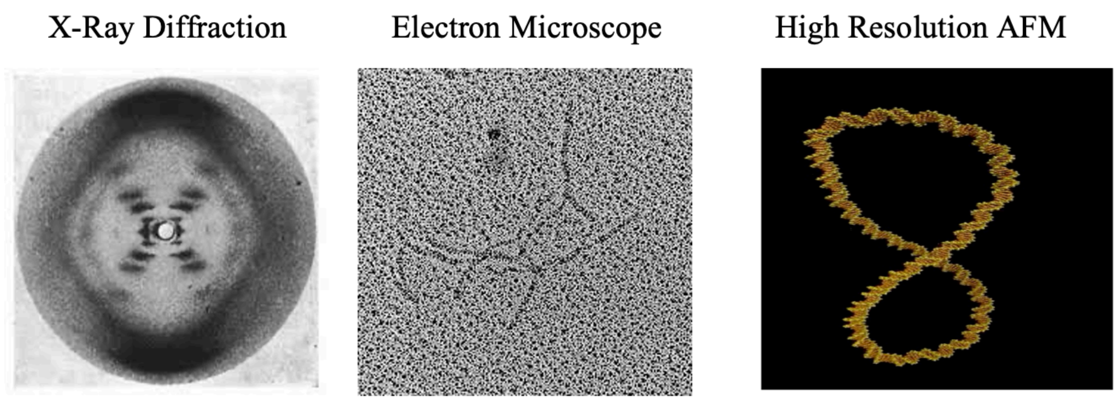
Or the question of how much information is stored in the DNA of a human compared to that of a mouse is answered as follows by Bard:

| DNA | Number of Books | Estimated Size |
|---|---|---|
| **Human** | 1500 | 6.4 gigabytes |
| **Mouse** | 750 | 3.2 gigabytes |

This data does not consider that much of the information in DNA and Wikipedia is redundant.

The type of information quantified in each table is different and describes two different dimensions of reality, but we can use bit units to compare them. Different ways to encrypt information produce information that is not always directly comparable, especially if we use different levels of resolution and dimensions.

**Resolution.** The more resolution our empirical sciences achieve, the more information becomes visible. The Table shows the advances in our capacity to view a DNA molecule in the last decades.




The limits given by possible resolutions are those of quantum physics.

**Information dimensions.** Two proteins with the same number of nucleotides have the same amount of information as measured in bytes but may differ widely in their function. The function of a protein is determined by its three-dimensional structure, which has practically infinite possible configurations. Thus, the coded information in the amino-acid sequence does not provide the full spectrum of information of the protein. The environment is also relevant in determining its information content. One protein might be a structural protein in a membrane, and the other might be an enzyme, thus encoding very different information that is responsible for very different functions and behavior. How do we measure the difference between these informations? The qualitative differences in the amino-acid sequence can account for part of this difference and can be quantified; but it provides only a partial description of the information relevant to the system.

**Fuzzy Information** is a concept that is relevant when assessing interactions between systems and between systems and their environments. For example, non-verbal communication in humans[7] transmits qualitative information related to emotions. Facial and corporal signals are fast to transmit but do not provide details about the elicitor of the emotions. They get meaning from the context in which they are transmitted. The context of the emitter and receiver may differ, creating fuzzy

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information causing fuzzy communication[8] or even misinformation. Misinformation related to emotions, values, and religion is often a source of conflict and even war. Fuzziness also appears because information has many dimensions in different levels of physical, chemical, and biological complexity and in different aspects or manifestations of nature. So, an enzyme has information about its chemical composition, about the isotopic nature of its constituent atoms, about the amino-acid sequence of its protein, about the three-dimensional structure of its molecule, about the solvent and solutes in its environment, about the pressure and temperature it is exposed to, about the electromagnetic radiation it receives, about the pressure waves that act upon it… All these different kinds of information will determine its effectiveness in catalyzing a specific reaction. It is the interactions that allow us to measure aspects of physical phenomena related to information exchanges and changes of information over time in a given system. We need more precise descriptions of information to understand natural processes in greater depth and find empirical ways[9] to study and measure these different kinds of information.

We could ask questions like:

- What type of information is used by different living organisms?
- How much information can be transmitted per time unit in different media?
- What information is needed by an enzyme to efficiently catalyze a specific chemical reaction?
- What information about ancient civilization can be revealed by archaeological artifacts?
- What information is revealed by your face when you speak?
- What part of the information is junk or noise?
- What lack of information is critical in natural processes?
- What information is contained in a physical structure or in a complex system?

Different ways to study information exist. Whereas digital signals and other data use discrete signs, and signal coding conveys easily measurable information, other phenomena and artifacts such as analogue signals, poems, pictures, music or other sounds, and currents convey information in a more continuous form. Infodynamics studies the dynamics of information to get insights into its relevance in physical systems. It analyzes information related to its effect or action on physical processes and its changes in time. Different flavors of Infodynamics have been proposed; the most important (according to Google Scholar) are presented here.


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## What is Infodynamics?

Eight of the most relevant works on Infodynamics, presented in chronological order, are:

### *R. Ridl*

Rupet Riedl[10] wrote in German and thus did not use the term info-dynamics and is widely ignored in the English literature. He wrote about the dynamics of information in the biosphere triggered by biological evolution. He presents life as a mechanism that, through evolution, produces increases in non-redundant (or non-repetitive) information. Life is thus linked to increases in information, but not any kind of information increase is relevant for living systems, especially not repetitive information.

### *SN Salthe*

Stanley Salthe is the first name that appears in Google Scholar in historical searches for the word Infodynamics. In "What is Infodynamics"[11] he writes "*Infodynamics is the study of the accumulation of informational constraints during system development. This is driven by the Second Law of Thermodynamics because (a) macroscopic configurations provide increased opportunities for enhanced external production of physical entropy, and (b) energetic exchanges tend to give rise to mutated forms, increasing the number of constraints in a system, as well as providing more opportunities for entropy production. So, increased amounts of information (I) generate potential increases in informational entropy (H) as well as facilitating physical entropy (S) production. We can identify two kinds of system information -- that which characterizes a system as the kind of system it is (**enformation**), also informing its constitutive changes, and information acquired as a result of a system's experiences in the world (historical information, or **intropy**). Intropic constraints can become integrated with system enformation, the final form of which emerges gradually. The emergence of system developmental reorganization requires information, not only from the system itself, but from its environment, as boundary conditions. This raises the question of structural attractors influencing system development as final causes*."

### *R. E. Ulanowicz*

Robert E Ulanovicz[12] explores the possibility that ecosystem behavior is the most palpable example of a purely natural 'Infodynamics' that transcends classical dynamics, but remains well within the realm of quantitative description. He writes that "*The application of information theory (IT) to ecology has occurred along two separate lines: (1) It has been used to quantify the distribution of stocks and numbers of organisms; and (2) it has been employed to quantify the pattern of interactions of trophic processes. By and large, the first* *endeavor has resulted in relatively few insights into ecosystem dynamics and has generated much ambiguity and disappointment, so that most ecologists remain highly skeptical about the advisability of applying IT to ecology. By contrast, the second, and less well- known application has shed light on the possibility that ecosystem behavior is the most palpable example of a purely natural "infodynamics" that transcends classical dynamics, but remains well within the realm of quantitative description.*\".

### *J Kåhre*

Jan Kåhre makes a precise mathematical description of changes in information[13]. He describes that "The state of a dynamic system changes from one instant of time to another. There is a transition rule, according to which the state at a given instant is generated by the state at the preceding instant. Mathematically, it is the question of handling long chains, or blocks in series. The length of the chain can grow without limit." This description is only applicable to information defined in precise and simple units.

### *MG Ceruti, SH Rubin*

Marion G. Ceruti, Stuart H. Rubin[14] expand the concept of Infodynamics, embracing physico-chemical theories on thermodynamics. "*The analogy spans the range of information systems to include databases, knowledge bases, and model bases. It includes but is not limited to pressure, expressiveness, temperature, tractability, degrees of order, systems of liquid–liquid equilibrium, and disjunction in information-systems integration. By taking advantage of the isomorphism that exists between states of matter and states of information, we can understand new ways to characterize and measure information systems*." The authors introduce the concept of "*states of information as similar to states of matter using analogical reasoning. The difficulty in defining the various states of information is seen as a natural consequence of the isomorphism between states of matter and states of information. Taking advantage of this isomorphism, the paper examines the possibility of predicting properties and characteristics of information systems using analogs of well-established equations of state and other thermodynamic equations.*"

### *KK Dompere*

Kofi K. Dompere[15] explores a philosophical theory of knowing as human decision-choice actions. He defines Information as "*a set of characteristics that provide signaling evidence regarding the existence and identity of the elements in the universe in an objective sense from the ontological space. It is also a set of* *relations that create awareness of possibilities among objects in a subjective sense in the epistemological space*". In several books, he "*promotes a theory of info-dynamics to support the theory of info-statics in the general theory of information. It establishes the rational foundations of information dynamics and how these foundations relate to the general socio-natural dynamics from the primary to the derived categories in the universal existence and from the potential to the actual in the ontological space. The value of the theory of info-dynamics is demonstrated in the explanatory and prescriptive structures of the transformations of varieties and categorial varieties at each point of time and over time from parent–offspring sequences. It constitutes a general explanation of dynamics of information-knowledge production through info-processes and info-processors induced by a socio-natural infinite set of technologies in the construction–destruction space*."

### *MM Vopson*

Melvin M. Vopson[16] presents the Simulation Hypothesis which "..*is a philosophical theory, in which the entire universe and our objective reality are just simulated constructs*". In 2022, he proposed a second law of information dynamics (Infodynamics) that facilitates new research tools at the intersection between physics and information. He applied this **second law of Infodynamics** to digital information, genetic information, atomic physics, mathematical symmetries, and cosmology, providing scientific evidence for his law. His *second law of Infodynamics requires that information entropy remains constant or decreases over time*. Less entropy in thermodynamics relates to more order and complexity, which implies more total information. This law applies to living systems or to products of living systems.

### *K Jaffe*

Klaus Jaffe explored the relation between Thermodynamics, Infodynamics, and Emergence[4] proposing that emergence is the consequence of the interaction between information and energy: "..*it takes free energy (energy that produces work, designed as F) to acquire information, and it takes information to increment free energy.* ***Useful information*** *(Φ), is the one that increases free energy, and differs from information not producing free energy or producing entropy. Energy obeys all laws of thermodynamics, while information may not. When energy and information of systems interact, novel properties or levels of energy and information may emerge. Information can reveal itself in different forms (as entropy, order, complexity, physically encoded, mechanical, biological, structural, in neural or social networks, etc.). Information may increase free energy by reducing entropy in an open system, or by capturing free energy from the surroundings. The dynamics of information and energy has been studied mostly in physical chemistry and engineering. Now we find it*


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*everywhere, including in computer sciences, genetics, biotechnology, experimental social sciences, and experimental law. In emergent systems, new possibilities of increasing free energy and useful information appear. A characteristic of energy and matter is that more information is required to produce more Free Energy to generate more useful work, and more Free Energy requires more information in its creation. The dynamic changes of information and its action on matter is called Infodynamics".*

### *Luppi et al.*

Andrea I. Luppi, E. Rosas, Pedro A.M. Mediano, David K. Menon, and Emmanuel A. Stamatakis [17] analyze information in the context of the information architecture of the brain. "*As an illustrative example, consider humans' sources of visual information: the eyes. Unique information is exemplified by the peripheral information that is lost when one eye is closed: information that cannot be obtained from the remaining eye. Redundant information is the information that you still have when closing either eye: it is carried equally by both sources. This provides robustness: despite losing peripheral vision, you can still see what is in front of you even after losing one eye. However, closing either eye also deprives you of stereoscopic information about depth. This information does not come from either eye alone: you need both to perceive the third dimension. This is synergistic information: the extra advantage that is derived from combining different sources.*"

## Synthesis and Propositions

Interestingly, no fundamental contradiction exists between the eight authors promoting Infodynamics. Each one emphasizes different aspects. For example, the Second law of Infodynamics (Vopson) requires that information entropy remains constant or decreases over time. This is no different from the strategy of genesis described by Ridl or the views of Salthe, Ulanowicz, and Jaffe on increases of information in the biosphere driven by evolution through natural selection. Some of the approaches embrace more specifically physico-chemical views of thermodynamics, such as the works of Ceruti, Rubin, and Jaffe. But calling the tendency for living systems to increase their information content a law (Vopson) is misleading, as this characteristic is part of the definition of a living system or of autopoiesis[18].

A law is a rule given certain preconditions. It is the fact that free energy producing useful work requires information, and that new information requires energy, that produces the rule for increases of negentropy (i.e., increases in Useful Information, decrease in Information Entropy) in living systems. In the words of Schrödinger[19]. "*..contrary to the general tendency dictated by the second law of thermodynamics, which states that the entropy of an isolated system tends to increase, life decreases or keeps* *constant its entropy by feeding on negative entropy*". But new information requires Free Energy for its emergence. That is the law proposed by Jaffe, which is the mirror image of Maxwell's Demon[20]. The information used to produce Free Energy can have multiple forms. The most common in living organisms is structural information embedded in the food they eat. Think of vitamins, for example. The relation between structure (order) and information can be studied in much detail and can be precisely quantified[21]. Living beings eat (both energy and information), breathe, and breed! But many other forms of information exist and should be studied by Infodynamics.

The important point here is that the energy required to produce information has no direct proportionality to the energy produced[22]. This allows synergies to emerge and diverse forms of memory storage to exist. The energy to produce information is expended in searching details and changes in the structure of physical entities and encoding them. Whereas the energy produced by these changes depends on the energies stored or controlled by the system. No direct proportionality between both exists. A single click on a button can release the energy of an atomic bomb. Or a cheap altruistic act by a social organism can release a cascade of energies, so that altruism may become an important social investment in the long term. Or a decades-long expensive research can find a simple molecule that cures a trivial illness.

The challenge for handling various different types of information is assumed by Salthe, Dompere, Jaffe, Luppi et al., Ceruti, and Rubin. Clearly, not all information is the same. Information can be just the opposite of thermodynamic entropy (**Negentropy**), serving to produce Free Energy (**Useful or Potentially** Useful, Synergic), **Redundant** information, **Enformation** (a kind of structural information), **Intropy** (a kind of entangled information), or **Noise.** These are all overlapping functional properties focusing on different aspects of Information. We might need a better classification of types of information. Infodynamics also includes a highly developed field recognized as "**Informatics**" as indicated by Kåhre. This overlap might create some confusion and may favor some oversimplifications.

**Information and Entropy in thermodynamics** have been mixed without compassion for the accuracy of the concepts. Entropy is a measure of energy, which is a physical entity related to energy and that follows the laws of thermodynamics. Information is an abstraction that has no clear relation to thermodynamics. For example, the third law of thermodynamics states that at the temperature of 0 degrees Kelvin, the entropy of a system is 0. But clearly, the information content of a system does not depend on temperature. It is not 0 at 0 degrees Kelvin! Thus, the relation between entropy and information is not direct!


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**Entropy in Infodynamics.** An expansion or re-formulation of the meaning of entropy has its origins in the late 19th and early 20th centuries when, in 1872, the Austrian physicist Ludwig Boltzmann developed a statistical theory of thermodynamics. This effort uses the concept of entropy as a descriptor of information. He used “entropy” to explain a measure of the number of possible microstates of a system. The more microstates a system has, the higher its entropy. In 1948, the American electrical engineer Claude Shannon developed a mathematical theory of information, which defined information entropy as a measure of the uncertainty associated with a random variable. The higher the uncertainty, the higher the information entropy. Shannon was not initially aware of the close relationship between his concept of information entropy and Boltzmann's concept of thermodynamic entropy. This confusion and the discrepancy between these two concepts and that of Clausius led to their being regarded by many as mathematically equivalent. Different concepts use similar wording to describe three different phenomena. Measuring energy is different from measuring disorder and uncertainty. Thermodynamic entropy, as defined by Clausius, characterizes macroscopic observations of a system based on phenomenological quantities such as temperature and heat. In contrast, information-theoretic entropy, introduced by Shannon, is a measure of uncertainty. Entropy in quantum physics refers to the information entropy rather than thermodynamic entropy. This confusion is common in many other sciences, but clearly, entropy as energy and entropy as information are not the same[23]. Energy follows the laws of thermodynamics, whereas interchanges of information do not·. The concept of entropy, even as a descriptor of phenomena of information in the same field, i.e., ecology, has several meanings[24].

**Information senescence:** Rather than using the term entropy in Infodynamics, we might refer to Information Senescence. The battle between new information, loss of old information, reordering of new and old information, and accumulation of noise makes it efficient for information systems to reboot or anneal. This makes forgetting have evolutionary adaptive advantages, and for life and death to be efficient evolutionary algorithms.

**Temporal Perspective:** The effect on Free Energy of useful information depends on the time scale analyzed. Certain acts seem costly to an individual in the short term (altruism) but may become a social investment (synergy) in the long run, making generous individuals live longer. The difference depends on the information used to make a decision[25]. The usefulness of information depends on the time window in which we are assessing the effect of a given piece of information. Redundant information might be useless in the short term but highly useful in the long term as it increases the likelihood of preserving important information.


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**Entanglement** is a concept from quantum physics indicating that information may disperse so as not to be limited by the speed of light. Thus, two particles that are entangled and separate can reveal the information of the entangled couple without any need to interchange energy, as their history is embedded in the "memory" of both particles and reveals the history of each other without the need for any exchange of energy between them. The term means that information might be wrapped, twisted, confused, or ensnared by something physical in such a way that they share the same fate. If you measure the state of one entangled system, you will instantly know the state of the other systems, even if they are separated by a large distance. Entanglement has no direct remote influence as it does not imply direct communication between the parts after they are entangled. But it can influence events in interacting elements that depend on specific information in their memory. Examples are coordinated behavior in social insects, where individuals that have never seen each other coordinate their action instinctively because the information in their genes is entangled; or emergent order in human city traffic, as local constraints and limitations in the movement of cars affect the behavior of individual drivers coordinating their movement without direct communication between them[26]; or in quantum physics, where entangled electrons or photons are known to exist. We can thus speak of historic memory (Intropy), entanglement, or information empathy, referring to the phenomena where information stored in a given memory is shared due to a common memory. Examples are organisms of the same species with the same information stored in their DNA, or individuals of the same culture with the same information received through education. The phenomenon of entanglement can be extrapolated from quantum physics to the macroscopic world.

**Multiple Dimensions.** Studies on information entropy normally quantify information in only one of its dimensions. This is a very serious limitation, as no single dimension can compare a spider with an elephant. Traditional studies using Shannon information obliterate the increase of novel information dimensions in an evolving system. For example, information may be present in the description in a given language or in a specific characteristic of a system. It might be described in terms of qubits of a subatomic particle, or it might be the description of the complete genetic characteristics in terms of bits or nucleotide sequences of a human being. Emotions carry information, and so do images. This diversity of information dimensions represents a challenge for future studies in Infodynamics. Dompere and co-workers propose views on information in transformations of varieties and categorical varieties at each point in time. This takes into account information on different substrates and emerging at different levels of physical complexity. Ceruti and Rubin explore states of information similar to states of matter in physics using analogical reasoning, detecting different entities of information. This is congruent with Jaffe's exploration of different levels of physical complexity (emergence) where information manifests itself in different forms. This field remains largely unexplored as it demands deep interdisciplinary research.

**Properties of information** describing a system include quantity or **Amount** of information, which in turn requires encryption of the information in order to be quantified; **Complexity** , where several indicators of complexity are available, such as the amount of information that is necessary to solve a computational problem. Several solutions are available. Popular ones include Kolmogorov complexity[27] and the Shannon lower bound[28], which states that the information complexity of any two-party protocol for solving the set disjointness problem is at least the logarithm of the size of the sets. A series of properties have been assigned to information. **Novelty-Redundancy**: **Context dependency**: **Specificity, Fine Graininess, Value** , which is equivalent to usefulness.

## Examples of Empirical Data

Empirical research in Infodynamics regarding the quantification of different types of information is possible [29]. Here, I provide three examples of how written useful information is selected in academia, and one example of how life solved the problem in selecting and improving useful genetic information.

### *Academic Journals*

Academic journals are an old device to separate good and important information from less good, less important ones, and even from noise. The rejection rate of most highly ranked journals, based on data from Bard for 2022, is:

| Journal | Nr Papers | Rejection Rate | Impact Factor | Nobel work |
|---|---|---|---|---|
| **Nature** | 814 | 96 | 49.8 | 41 |
| **Science** | 1388 | 95 | 46.1 | 28 |
| **PNAS** | 1572 | 94 | 10.1 | 15 |
| **Cell** | 1068 | 93 | 51,9 | 17 |
| **NEJM** | 1816 | 92 | 176.1 | 27 |
| **Lancet** | 1939 | 91 | 202.7 | 17 |

On the other hand, only about 30% of Nobel Prize-winning works are published in Science, Nature, and PNAS, the three journals with the highest rejection rates. Correlation between these variables showed that high rejection rates correlated negatively with impact factor and with the number of articles published but correlated positively with work leading to a Nobel Prize. Interestingly, the lower the rejection rate, the more articles were published in the journal. More articles correlated positively with impact factor. A high number of articles published did correlate negatively with work leading to Nobel Prizes.

| Correlation | Nr articles | Rejection | Impact |
|---|---|---|---|
| **Rejection** | **-0,79** | - | |
| **Impact** | **0,70** | **-0,81** | - |
| **Nobel** | **-0,55** | **0,65** | -0,10 |

These data show that a large effort is made by the academic community to select information based on its importance in science, relevance to the actual interest of the community, and other various criteria. The data seem to indicate that this effort produces mixed results. High rejection rates show that the cost of separating information based on its acceptance in the community is very high but not necessarily very


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successful in picking up the best works, as it correlates negatively with impact. However, it correlates positively with Nobel work. Clearly, other issues are at play here. This exercise serves to show the feasibility of quantitative analysis. More and better data are required to investigate this issue in detail!

### *Wikipedia*

Wikipedia works on a more participatory platform, where rejection rates do not influence rankings nor importance. But the effort in weeding out relevant information is still very great. The amount of new content added to Wikipedia has been steadily growing over the past 10 years. In 2013, there were approximately 1.5 million new articles added to Wikipedia. By 2022, this number had grown to over 5.5 million. The amount of deleted content has also been growing, but at a much slower rate. In 2013, there were approximately 500,000 articles deleted from Wikipedia. By 2022, this number had grown to over 1 million. That is, over 60% of new articles are deleted. This rate is high even if compared to medium-ranked academic journals.

### *Qeios*

Data for 2023 provided by Qeios publisher report 1,875 submissions received, 1,109 articles approved by peers (i.e., "published" in traditional terms), and 27,139 peer reviews posted. This is equivalent to 14.5 reviews per paper and a rejection rate of 40.9%.

These data show that the effort made by Qeios to separate information from noise is much higher than that for traditional journals, but at a much lower economic expenditure. It shows a higher rejection rate compared to most for-profit academic journals, but lower than that of top scientific journals, at a speed and transparency unequaled by either academic journals or Wikipedia. Qeios′ model is more comparable to the effort made by Wikipedia but is more transparent about authors′ responsibility for the information. The very short existence of Qeios means that these results might change in the future.

These very crude and preliminary examples show that quantitative studies in Infodynamics can improve our methods in managing and selecting useful information, but they remain challenging. An example of how to manage very complex information successfully is provided by life.

### *Biological Sex*

Over a billion years ago, natural selection invented sexual reproduction (two individuals interchange genetic information to produce a new individual) and diploidy (genetic information is stored in two copies of DNA, one from the father, the other from the mother). This is now the most popular, widespread, and efficient mechanism, decanted in eons of biological evolution, to manage information needs and constraints in living organisms. Thus, diploids and bisexuals must have advantages in maintaining and increasing genetic information that other mechanisms lack. Extensive empirical evidence and computer simulations show that random mutations, two sexes[30], two copies of DNA, assortative mating[31] and Natural Selection[32] are the optimal combination of features that possess the best balance between innovation and conservation of genetic information[33] to promote life with continuous improvement of useful information.

### *Creation of information*

The examples presented above show that empirical studies on the working of methods to select useful information and separate it from noise in academia are feasible. Different ways to do this are in development, but none seems to have found a perfect balance between costs and results. However, rejecting information based on the opinion of "experts" does not seem to be the way forward. The lesson from biology is that no silver bullet seems to be available for predicting the usefulness of information and that any successful mechanism to find useful information will need to implement empirical selection methods that include exploiting serendipity. A neat example comes from the study of the evolution of organismality and society [34].

Life and its evolution are good examples of how genetic information can be created [35]. Information has adaptive value[36] and is accumulated and produced among living beings by random mutations, reproduction, and selection [[31]]. In this sense, information is regarded as the basis for the forms and structures that allow their function. Physiologist Albrecht von Haller[37] was one of the first to use vivisection and other methods to directly observe and analyze information in organ anatomy and functions, showing that information encoded in form and structures produces work.

The creation of art and science in human society is based on new information selected for the ability to elicit emotions or useful work. This is not solely based on serendipity. Dogma and religion can hinder this creativity[38], while tolerance and respect seem to favor it[39].

Information is an entity derived from interactions between matter and energy. Its creation is a fundamental element of nature and is relevant beyond biological evolution [[10][4]][40]. The challenge of


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Infodynamics is to tame the fuzzy concepts and poor mathematical instruments available to study the dynamics of information and unveil more secrets as to its creation.

## Conclusions

**Aristotle** distinguished between form (morphê) and function (ergon), emphasizing that organs have specific purposes and that their structure reflects their function. This teleological perspective can be substituted by a more general one where information substitutes form and energy stands in the stead of function. The abstraction of information (contained in form) and the concept of Free Energy that produces Useful Work perceived as function may bridge the conceptual gap between different disciplines to understand our "Elephant" better when we describe its different sides with different words. Information (stored in some cases in form) allows energy to perform work. The dynamics of information and its relation to the material world are essential for understanding natural processes. Infodynamics allows the study of the biosphere and the human knowledge sphere and is relevant in most areas of science. Although philosophical studies have explored Infodynamics, it is empirical physical science that can make it a useful science. We need a coherent and general view of information that explains the simplest interactions of matter and information we know to occur in physics. But this is not enough to understand interactions between information and physical reality at intermediate levels of complexity, and much less so for highly complex systems. I suggest that the degree of energetic synergy achieved in a given system after useful information is accessed is a measure of the degree of the usefulness of the information. Total information and useful information can be empirically quantified independently. This allows us to quantify the interactions between information and energy. Inroads have been made, but more tools to address these problems in different instances remain to be developed.

Getting information requires energy, and so does separating useful information from noise. At the quantum level, when energy is used to gather information, this energy is transformed, and the properties of the physical state are changed. But energy is not information. Nor is information necessarily quantized, although it could be, definitively so if time is also shown to be quantized. Energy and information are parts of two separate realms of reality that are intimately entangled and follow different laws of nature. The challenge to find the missing elements referred to by Einstein, Podolsky, and Rosen [41] continues. When assuming local causality, it is not only quantum mechanics that is an incomplete description of a physical state of a single system. The insight gained in this review suggests that the incompleteness in these physical descriptions relates to the distinct nature between energy and


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information. It is astonishing the lack of knowledge we have about the detailed mechanisms of their interactions. In quantum physics, the memory of the particle's history is not explicit. In complex system science, the exact mechanism by which information creates free energy is still nebulous. It is experimental studies in Infodynamics that might unveil these relationships.

Infodynamics will help us gain a better understanding of the complex relations in the human knowledge sphere. There are some lessons for AI: All information management by any mechanism, be it with natural or artificial intelligence, requires empirical reliability tests and quality control using the scientific method. Only empirical evidence can help us increase our understanding of reality and differentiate between useful information and noise. Truth is a religious concept and has no place in science. Empirically tested hypotheses might lead to an ever more solid understanding of our surrounding reality. The way biological evolution manages improvements in genetic information by inventing sexual reproduction teaches us some lessons: Maintain low mutation rates (allow a certain level of error), keep information always in duplicate (two sexes, two copies of the genome, or diploidy), mix information (sexual reproduction with genetic recombination and crossover), look for novel information using random mutations and taming disruptions of high mutation rates and complex information aggregates with assortation[42] (exogamy with assortative mating), maintain different testers of the usefulness of information (different sexes, morphs, or life-stages), never stop improving information (continuous evolution through random mutations), and discard what does not work (selection) and eventually start anew (no life without death).

## Statements and Declarations

### *Author Contributions*

Conceptualization, K.J.; writing—original draft preparation, K.J.; writing—review and editing, K.J.

### *Data Availability*

No new data were created or analyzed in this study. Data sharing is not applicable to this article as all information discussed is derived from publicly available sources cited within the text.

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