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Infodynamics, a Review

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Abstract

A review of studies on the interaction of information with the physical world found no fundamental contradiction between the eighth authors promoting Infodynamics. Each one emphasizes different aspects. The fact that free energy and useful work require information, and that new information requires energy, may favor synergistic chain reactions producing increases of negentropy (increases in Useful Information or decreases in Information Entropy) in living systems. Infodynamics searches for feasible balances between energy and information using empirical studies of the effect of information on Free Energy and vice-versa. 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 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 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. However, intuitively, it seems to be understood by humans in all cultures. Information can be reproduced, transmitted, stored, but it is not in itself a physical reality although it requires a physical substrate in order to become a reality. It does not follow the laws of thermodynamics but it does follow some 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 kind of information.

Consciousness means being aware of possessing a given information.

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, or DNA, which perdure 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 de 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 in a superposition of the states 0 and 1, which means 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.

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

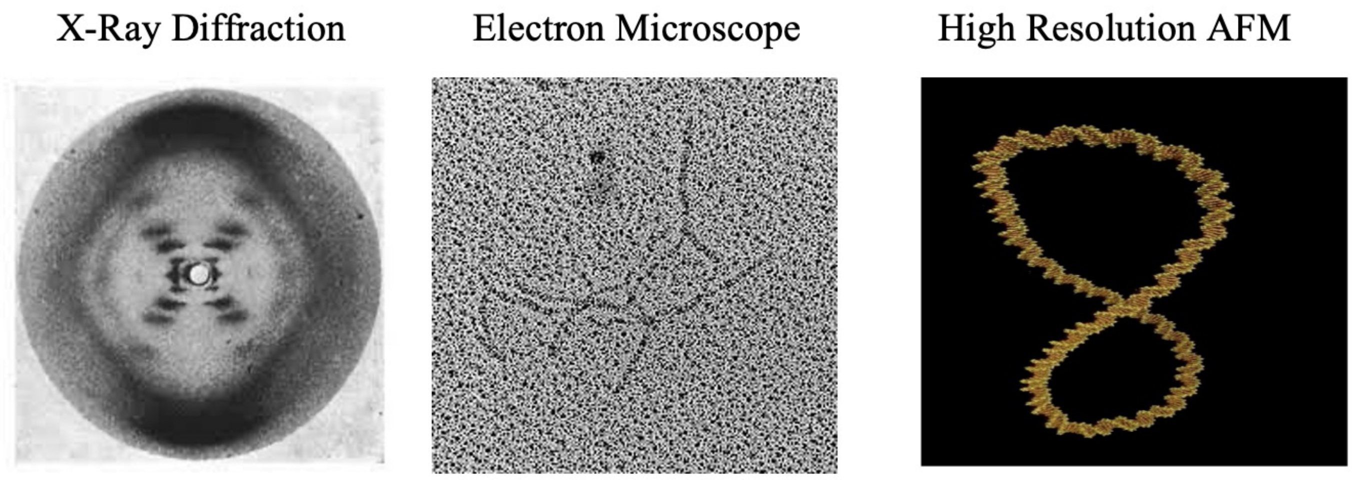
Or the question of how much information is stored in the DNA of a human compared to that of a mouse is answered as follows by Bard:

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 nor always directly comparable, specially 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.



X-Ray Diffraction

Electron Microscope

High Resolution AFM

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 information? 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.

Information is a fuzzy concept that is relevant when assessing interactions between systems and between systems and their environments. Information has many dimensions as it appears 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. We must find empirical ways[4] 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 canalize 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.

What is Infodynamics?

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

R. Ridl

Rupet Riedl[5] 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"[6] 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[7] 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[8]. 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[9] 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[10] edits a book that “*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[11] 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[12] 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 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".*

Synthesis and Propositions

Interestingly, no fundamental contradiction exists between the eighth 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 by 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[13].

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[14]. "..*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[15]. 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[16]. 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[17]. 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 exist. 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, 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), **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 has 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 nor 0 at 0 degrees Kelvin! Thus the relation between entropy and information is not direct!

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 of these two concepts with that of Clausius, lead to regard them 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[18]. Energy follows the laws of thermodynamics whereas interchanges of information do not. The concept Entropy, even as a descriptor of phenomena of information in the same field, i.e ecology, has several meanings[19].

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 to 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 to live longer. The difference depends on the information used to make a decision[20]. The usefulness of information depends on the time window we are assessing the effect of a given 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.

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 reveal the history of each other without need of 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 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[21]; or in quantum physics 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 obliterates 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 of 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 in 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 that 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[22] and Shannon lower bound[23], 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

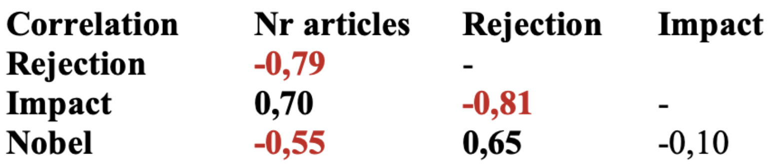
Empirically research in Infodynamics regarding the quantification of different types of information is possible[24]. Here I provide three examples of how written useful-information is selected in academia; and one example of how life solved the problem in selecting and improving useful genetic information.

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 journal, based on data from Bard for 2022 are:

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 Praise. Interestingly, the lower the rejection rate, the more articles were published in the journal. More articles correlated positively with impact factor. High number of articles published did correlate negatively with work leading to Nobel Praises.



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 shows that the cost of separating information based on its acceptance in the community is very high but not necessarily very successful in picking up the best works as it correlates negatively with impact. But 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 is 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

The average number of comments articles posted on Qeios receive is 3.2 (Data from Bard October 2023). This number is based on a sample of 10,000 articles posted on Qeios between January 1, 2023 and November 1, 2023. Although the rejection rate at Qeios is not publicly available, the journal is very new and has jet to produce statistics (I hope the editors might provide them to me eventually) is seems to be very low. As of October 2023, Qeios has published over 2,000 articles, and these articles have been cited over 6,000 times. This gives Qeios an average citation rate of over 3 citations per article. The impact of articles however is still respectable considering the very short time span allowed for the accumulation of citations. Data on comments to the published articles is available.

Comment Nr	0	1	2	3	4-9	> 9
% of Articles	45	25	15	10	5	5

The table provides the distribution of articles according to the number of comments they receive. That is 10 percent receive over 3 comments which is normally the maximum in standard academic journals. Half (50%) receive the same number of comments as they would receive reviews (1-3), if the paper were submitted to a classical peer-reviewed journal. The data show that the effort made by Qeios to separate information from noise is much lower than in Wikipedia and Academic Journals. Despite this, its results are interesting taking into account its very short existence.

These 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 successfully very complex information 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 diploid 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[25], two copies of DNA, assortative mating[26] and Natural Selection[27] are the optimal combination of features that possess the best balance between innovation and conservation of genetic information[28] to promote life with continuous improvement of useful information.

The examples presented here show that empirical studies as to the working of methods to select useful information and separate it from noise are feasible. Different ways to do this work are in development in academia. 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.

Conclusions

The dynamics of information and its relation to the material world is fundamental for understanding simple and highly complex systems. For example, Infodynamics is being applied to studies of the biosphere and the human knowledge sphere, but is relevant in most areas of science. In order to have a coherent and general view on information, we also need to understand the most simple interactions of matter and information we know to occur in physical quantum physics.

If we achieve this, we might bridge the intermediate levels of complexity regarding our understanding of the interactions between information and physical reality. 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. Thus, total information and useful information can be empirically quantified independently. 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 that follow different laws of nature. The challenge to find the missing elements referred to by Einstein, Podolsky, and Rosen [29] 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 relate to the distinct nature between energy and information. It is astonishing the lack of knowledge we have about the detailed mechanisms of their interactions. In quantum physics, memory of the particle's history is not explicit. In complex system science, the exact mechanism by which information creates free energy is still nebulose. 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 might teach us some lessons.

Acknowledgments

I acknowledge that this is a preliminary version of this review. I have not been able to read all that has been published on the subject, not even all the publications of the main authors mentioned. I invite potential coauthors to add to this review, and commentators to scrutinize it.

References

1. ^*J. B. Anderson; R. Johnnesson (1996). Understanding Information Transmission. Ieee Press. ISBN.*
2. ^*Shannon, C. E. (1951). Prediction and entropy of printed English. Bell system technical journal, 30(1), 50-64.*
3. ^*Parrondo, J., Horowitz, J. & Sagawa, T. Thermodynamics of information. Nature Phys 11, 131–139 (2015). https://doi.org/10.1038/nphys3230*

4. ^K Jaffe (2009). *What is Science? An interdisciplinary perspective. University Press of America*
5. ^*R. Riedl (1986) Die Strategie der Genesis. Naturgeschichte der realen Welt. 5. Auflage, Neuausgabe, 12. - 19. Tausend. München, Zürich: Piper, 1986. 381 Seiten mit 106 Zeichnungen, Literaturverzeichnis und Register. Pappband (gebunden) mit Schutzumschlag. ISBN: 349200590X (ISBN-13: 9783492005906)*
6. ^*Salthe, S.N. (2001). What is Infodynamics?. In: Ragsdell, G., Wilby, J. (eds) Understanding Complexity. Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-1313-1_5*
7. ^*R. E. Ulanowicz. (2001) Information theory in ecology, Computers & Chemistry, Volume 25, Issue 4, 393-399, ISSN 0097-8485*
8. ^*J. Kåhre (2002). Infodynamics. In: The Mathematical Theory of Information. The Springer International Series in Engineering and Computer Science, vol 684. Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-0975-2_6*
9. ^*M. G. Ceruti, S. H. Rubin (2007). Infodynamics: Analogical analysis of states of matter and information. Information Sciences, Volume 177, Issue 4, Pages 969-987. https://doi.org/10.1016/j.ins.2006.07.006*
10. ^*KK Dompere. The Theory of Info-Dynamics: Rational Foundations of Information-Knowledge Dynamics. Book series: Studies in Systems, Decision and Control (SSDC, volume 114) 2018 - Springer*
11. ^*Melvin M. Vopson (2023). The second law of infodynamics and its implications for the simulated universe hypothesis AIP Advances 13, 105308.*
12. ^*Jaffe K. (2023). Thermodynamics, Infodynamics and Emergence. Qeios. doi:10.32388/S90ADN.6.*
13. ^*Maturana, H. R., & Varela, F. J. (1991). Autopoiesis and cognition: The realization of the living (Vol. 42). Springer Science & Business Media.*
14. ^*Schrödinger, E. (1944). What is life? The physical aspect of the living cell and mind. Cambridge: Cambridge university press.*
15. ^*Maxwell, J. C. (1867). On the dynamical theory of gases. Proceedings of the Royal Society of London, (15).*
16. ^*Wendong Wang et al. Order and information in the patterns of spinning magnetic micro-disks at the air-water interface.Sci. Adv.8,eabk0685(2022).DOI:10.1126/sciadv.abk0685*
17. ^*Jaffe, K., & Febres, G. (2016). Defining synergy thermodynamically using quantitative measurements of entropy and free energy. Complexity, 21(S2), 235-242.*
18. ^*https://physics.stackexchange.com/questions/263197/is-information-entropy-the-same-as-thermodynamic-entropy*
19. ^*Søren Nors Nielsen and Felix Müller (2023). Review: The Entropy of Entropy: Are We Talking about the Same Thing? Entropy 25, 1288. https://doi.org/10.3390/e25091288)*
20. ^*Jaffe, K. (2002). An economic analysis of altruism: Who benefits from altruistic acts?. Journal of Artificial Societies and Social Simulation, 5(3)*
21. ^*Gershenson, C. (2012). Self-Organizing Urban Transportation Systems. In: Portugali, J., Meyer, H., Stolk, E., Tan, E. (eds) Complexity Theories of Cities Have Come of Age. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-24544-2_15*
22. ^*A.N. Kolmogorov. Combinatorial foundations of information theory and the calculus of probabilities. Russian Math. Surveys, 38(4):29–40, 1983.*
23. ^*C.E. Shannon. The mathematical theory of communication. Bell System Tech. J., 27:379–423, 623–656, 1948.*

24. ^*Jaffe K (2023). A Law for Irreversible Thermodynamics? Synergy Increases Free Energy by Decreasing Entropy. Qeios. doi:10.32388/2VWCJG.5.*
25. ^*Jaffe, K. (1996). The dynamics of the evolution of sex: Why the sexes are, in fact, always two?. INTERCIENCIA-CARACAS-, 21, 259-267.*
26. ^*Jaffe, K. (2002). On sex, mate selection, and evolution: An exploration. Comments® on Theoretical Biology, 7(2), 91-107.*
27. ^*Darwin, C., & Wallace, A. R. (1958). Evolution by natural selection. Evolution by natural selection.*
28. ^*Jaffe, K. (2018). Synergy from reproductive division of labor and genetic complexity drive the evolution of sex. Journal of Biological Physics, 44(3), 317-329.*
29. ^*A. Einstein, B. Podolsky, and N. Rosen (1935). Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?". Physical Review. 47: 777–780. doi:10.1103/physrev.47.777*