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Roman Krzanowski

INFORMATION – MODERN THEORIES

Abstract *This review deviates from the usual approach to the topic of information by not focusing on Shannon's Theory of Communication (TOC) and the related or derived concepts. In addition, we do not talk at length about information in relation to knowledge, data, communication, information processing, or similar concepts. Instead, we endeavor to reappraise our understanding of information without favoring any specific perspective. We know a lot about information, and the various conceptualizations of information presented in this paper are proof of this. Nevertheless, we also show that some lingering unresolved questions remain about the nature of information. To somewhat stem the appearance of further new concepts of information, we consider two perspectives, namely ontological and epistemic, and posit that we can potentially reduce all information variants to just these concepts. We then look at two general theories of information: the General Definition of Information (GDI) and the General Theory of Information (GTI), arguing that the GTI appears to be the better of these two options because it is more fundamental and comprehensive with deep metaphysical roots. Finally, we review some recent studies about information's physical nature, such as for information and mass, meaningful physical information, and the persistence of information. This review, like all reviews, is selective and synthetic, but the extensive reference list provides the necessary resources to explore the discussed ideas in greater detail, as well as study the recent works on the nature of information.*

Keywords information, physical information, information in nature, concepts of information, quantifications of information, GDI, GTI, information and mass, persistence of information

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1. Introduction

Some 70 years ago, Shannon introduced the concept of information in science and technology [166], with this later being followed up by Shannon and Weaver [168] and Weaver [201] and a flood of research publications on this topic (e.g. [164]). Nevertheless, we still have a rather vague understanding of what information is, although such feelings of insufficiency are not shared by everyone in the field. Thus, we see a few perspectives to consider here[1].

We may claim that (1) information is what we define it to be and accept the multiple past, current, and future definitions as reflecting the multifaceted nature of information, thus escaping the pressure of Platonic essence. The numerous existing definitions for information (see the following section) certainly supports this perspective[2]. (2) A somewhat related option that seems to excuse option (1) is to claim that information is just an empty word, one that means what we want it to mean in any given context, implying that there is nothing more to information that what we already know. We could (3) perform some reductive analysis and narrow down the possible concepts to just a few or perhaps even (4) propose a single fundamental, all-encompassing concept. Such a fundamental definition would obviously be metaphysical, something abstract and conceptual, with this Platonic attitude being shared by few despite seeming to be the right approach. The choice from these options may reflect someone's philosophical worldview and tastes, as is always the case in philosophy, but each choice comes with a price.

We certainly know more about information now than we did in the 1940s, but we have no clear vision of it, as expressed by these questions that were posed in a recent conference on information[3]:

1. If information is represented by a physical structure, it means that information is not a physical structure. So, what is information in this context, given that a structure without energy does not exist?
2. What is the dependence relation between matter and structure? Information has both structure and an implementation in some substrate (i.e., matter).
3. Some researchers believe that information is physical (material), while others believe that it is not physical (i.e., a structure). On the other hand, we know that matter without structure and structure without matter cannot exist. How can we explain this contradiction?

[1] Shannon never defined information but rather information entropy. Still, he is regarded as the Columbus of information, with him discovering what had been known before his time. Indeed, information had a much older heritage dating well back to before Shannon's paper (See, for example, the historical notes on the concept of information by Vreeken [198], Adriaans [1], or Gleick [68]).

[2] This flood of conceptualizations for information among the philosophical commons is reflected in the Wikipedia entry for Information [204].

[3] Information and computing in nature – philosophical perspectives. On–line conference. December 1–2, 2022. Commission for Philosophy of Science, Polish Academy of Arts and Sciences (Polska Akademia Umiejętności) – Unpublished notes from the online discussion.

4. What do we mean when we say, ‰ooInformation constitutes a structure comprising the differences in one system that cause differences in another system"?
5. If information has mass/energy, can we then just as well ask under what circumstances we should assign mass/energy to our knowledge?
6. A lot of the confusion about the definitions for fundamental terms like information derives from the transfer of terms found at a higher (human) level of complexity to a lower (fundamental) level of complexity. At the lower level, these terms become synonymous because less differentiation is needed. In the case of information, does it then follow that that the terms information, form, feature, structure, object, and anything else that can be distinguished are all synonymous?
7. Suppose that there no longer existed any organisms in the world (or universe) capable of perceiving and exploiting information. Can we say that information still exists in such a world? I would say not. In the absence of organisms to somehow detect and exploit the different forms, structures, regularities of physical events, properties, and objects, all that remained would be matter and energy, together with whatever else the physicists might add to the mix.
8. If structure and matter are mutually dependent on each other for their existence, and if information belongs to, or is an instance of, one of them, then it would follow that information also depends on the other element. Nevertheless, A being existentially dependent on B does not imply that A is identical to B.

With such unanswered questions, it is hard to agree with anyone who claims to really know what information is, so it seems that much research remains to be done. The root of the divergent views may lie in the nature of information itself, which is an all–permeating but elusive concept. There is also a lack of studies that try to bring together and synthesize what is already known and agreed upon.

The following more systematic list from Krzanowski [99,100] proposes some open research problems to be investigated. On reading both the previous and this list, nobody could claim that our work with information is complete. Indeed, both lists could no doubt be greatly expanded upon.

The specific research questions are:

Question 1. Do laws for the conservation of information exist, and if they do, what do they claim? Is the total amount of information in the universe therefore constant? This question probes the problem of "the conservation of information". If information is fundamental to whatever exists in the physical world, does it follow laws for its preservation, much like energy? (Suggested by the writings of Sean Carroll [29], for example).

Question 2. Can we claim that whatever exists must contain information? Can we defend the paninformatism claim that information is everything that exists? What is more, is paninformatism related to panpsychism? This question probes the claim that information is in everything that exists. Can such a claim be justified? And does such a claim amount to some kind of paninformatism or panpsychism? If so, what precisely would this entail? Would such a claim trivialize the concept of information? (Suggested by the writings of Tom Stonier [179], Krzysztof Turek [190, 191], and Sean Carroll [29], for example).

Question 3. Can we interpret information as a causal factor, and how could such a claim be verified? This question probes the alleged causal role of information in the physical world. It amounts to the question of whether information is a passive or active element in nature and what the nature of this activity would be. (Suggested by the writings of Sean Carroll [29] and Carl von Weizsäcker [203], for example).

Question 4. Information is foundational to the physical universe, but in what sense can this statement be made? This question probes the claim that information is fundamental to nature, but what exactly would this mean? Should such a claim be interpreted along the lines of the proposed information–matter–energy complex? Or should it be interpreted more metaphysically like the Logos of The Bible or the Tao of Tao-Te-Ching as an all-pervading and primordial element of existence? (Suggested by the writings of Michal Heller [78], Gordana Dodig Crnkovic [46–51], and Tom Stonier [179], for example).

Question 5. Can we say that highly complex and chaotic (i.e. non-linear, dynamic) systems have no information C? This concerns the problems of chaos and non-linear, dynamic systems. Does information play a role in such systems? Quite often, chaos is associated with a lack of information, which seems to be a questionable interpretation of a physical phenomenon. (This issue was indicated by Bates [14]).

Question 6. Does information imply some form of modern hylemorphism? This question seeks to identify the similarities between information and hylemorphism in its modern interpretations. The problem of the nature of information and matter and energy has resurfaced in the works of many authors (see the references in this paper), and they all seem to echo Aristotelian metaphysics (Suggested by the writings of John Polkinghorne [139], Krzysztof Turek [190, 191], Roman Krzanowski [99, 100], and Sean Carroll [29], for example).

Question 7. Does the fact that information is physical change the meaning of computation from one of symbolic processing to processing physical information? We associate computation with symbolic processing, but computation in computers is, in fact, a highly structured, pure physical process (e.g., as Searle said, "computation is in the eye of the beholder"). Could we extend the concept of computation to any physical process involving changes in physical organization without trivializing the concept of computing? Do we even care? (Suggested by the writings of Charles Seife [163], Gordana Dodig Crnkovic [46–51], and Gordana Dodig Crnkovic and Vincent Mueller [52], for example).

Question 8. Can information be equated to some kind of structure, and what would this mean for the concept of structure? This question proposes explaining the concept of information through the concepts of structure and structural realism. (Suggested by the writings of Michal Heller [78] and Marcin Schroeder [156,157], for example).

Nevertheless, we are not going to resolve the above questions in this paper. Our objective in listing them here is to demonstrate that the problem of information is far from solved. Instead, we attempt to review the current state of the art for the concept of information and point to some new research that explored some of above questions. Of course, our review is selective and partial, and it may miss some critical studies, but we have attempted to be as complete and comprehensive as possible.

This paper is structured as follows: After this introduction, we discuss the various conceptualizations of information before then presenting the concepts of ontological and epistemic information and discussing the ideas of infons and data vs. information, which are frequently connected topics. Next, we present two unifying theories of information, namely the General Definition of Information (GDI) and the General Theory of Information (GTI). The final section focuses on selected advanced topics, such as the question of information and mass, the meaning of physical information, and the perdurance of information. The references provide an ample resource for exploring the discussed ideas for information in greater detail.

2. Varieties of information

The profusion of various definitions of information reflects the trend of creating new definitions for information based on new shades or aspects of meaning (see option (1) above). This process has not added any value but rather served to further obfuscate an already muddled concept by creating the impression that there are numerous types of information. Needless to say, this practice conflicts with Occam's razor [56], common sense, and reality itself, or so it seems.

The varieties of information are too numerous to be listed in their entirety, so we focus instead on a selected few that have gained prominence in the literature, under the proviso that such a selection will inevitably be subjective and incomplete. We discuss several classes of information, including biological information, natural information, pragmatic information, quantum information, quantified information, relative information, semantic information, semiotic information, and syntactic information, together with some of their variants that have been mentioned in publications. For the sake of brevity, the descriptions for each class of information have been compressed, so they are therefore devoid of nuanced interpretations and details. In addition, the references for each concept have been limited to a few representative examples, although each referenced paper usually contains several references to work on the same or similar concepts. We have differentiated a variety of biological information, natural information, pragmatic information, quantum information, semiotic information, semantic information, syntactic and quantified information, several of them with multiple variants.

2.1. Biological information

Biological information refers to information within the context of biological systems. Biological information describes processes related to genetic processes, cellular functions, or other biochemical processes in organisms. We denote this class of information as $information_B$. To be more specific about types of $information_B$, we denote genetic information as $information_{BG}$, semiotic biological information as $information_{BSmi}$, and semantic biological information as $information_{BSma}$. There are also other proposed conceptualizations of biological systems as information-processing units.

Conceptualizations of biological information have been discussed by scholars such as Maynard Smith [121], Schneider [154], Griffiths [72], Godfrey-Smith [70], Jablonka [85], Roederer [143,144], Stegmann [177], Yockey [207], Terzis and Arp [185], Godfrey-Smith and Sterelny [71], and Moffat [125].

Definition $\mathbf{I}_B$. Biological information, or $information_B$, describes the properties of biological systems as they relate to their organization, structure, and interaction, as opposed to purely physical and chemical properties.

Definition $\mathbf{I}_B$1. Genetic information ($information_{BG}$) denotes the concept of information that is responsible for the biological form of an organism [121].

Definition $\mathbf{I}_B$2. Organic information ($information_{BO}$) refers to the specific sequence of a molecule produced by a (biological) copying process [13].

Definition $\mathbf{I}_B$3. Semiotic biological information ($information_{BSmi}$) denotes the concept of information when it is perceived as an exchange between biological systems, such that the exchange process is interpreted as a signaling process between these biological systems, which could be cells, plants, animals, and so on [27].

Definition $\mathbf{I}_B$4. Semantic biological information ($information_{BSma}$) denotes information that can be attributed to a source when a receiver of this information reacts to it in a particular way, when both the source and the receiver are biological systems [85].

Definition $\mathbf{I}_B$5. In biological systems, Pragmatic information ($information_{BPb}$) refers to patterns and univocally corresponding changes that are mediated by some biological processes [145].

2.2. Natural information

Natural information is information conveyed by natural signals in a communication process. Natural information is a certain message that has a meaning, or a meaning can be inferred by a cognitive agent, which can be human or non-human. The source of this message may be a natural phenomenon like a fire (a natural root sign), or it can be a human agent communicating through language, a map, a diagram, and so on. In all these cases, however, the message piggybacks on some kind of natural phenomenon, a physical carrier, and this medium can be considered an infosign. Millikan's natural information is connected to the concept of teleosemantics in a theory for the meaningfulness of representation in terms of biological functions. Millikan's concept of natural information is based on Dretske's work on semantic information. Baker later extended Dretske's work by proposing concepts like nomic factive information (denoted as $information_{Nf}$), the counterfactual theory of information (denoted as $information_{Ncf}$), and even exemplar thermometer information (denoted as $information_{Nt}$). There are also other definitions of natural information unrelated to Dretske, however. Sweller, for example, defines natural information (denoted as $information_{Nm}$) as information that governs activities in natural entities, and this relates to the concepts of morphological computing and biological information processing. We will refer to this class of information as $information_N$.

Conceptualizations of natural information have been discussed by scholars such as Dretske [53], Sweller [181], Scarantino and Piccinini [153], Piccinini and Scarantino [137], Kraemer [98], Symons [182], Millikan [124], and Baker [9].

Definition $\mathbf{I}_N$. Natural information in Millikan's and Symons' interpretations ($information_N$) denotes information that is associated with natural processes or natural phenomena. It may be conceptualized as a message riding on some kind of physical carrier, and this medium (carrier) can be regarded as an *infosign*.

Definition $\mathbf{I}_N$1. Nomic factive information (denoted as $information_{Nfn}$) is defined as b's being in state N carries the information that s is F if and only if (i) s is F, and (ii) the covariation of b's being in state N with s's being in state F is nomic [9], where nomic means physically necessary. Thermometer information ($information_{Nt}$) is an example of nomic factive information (see definition $\mathbf{I}_N$**4**).

Definition $\mathbf{I}_N$2. Factive information ($information_{Nf}$) denotes "information that pertains to actually existing states or properties, or in other words [factive information is] information that indicates what, in fact, happens" [9].

Definition $\mathbf{I}_N$3. Natural probabilistic information or probabilistic information ($information_{NPI}$) denotes information such that if it is the case that when a signal carries the information that there is a certain probability that s is F, there truly is such a probability that s is F [98].

Definition $\mathbf{I}_N$4. Thermometer information ($information_{Nt}$) denotes information carried in the same way that a standard thermometer carries about the temperature [9].

Definition $\mathbf{I}_N$5. Natural information may also denote information that governs processes in natural entities, and this relates to the concepts of morphological computing and biological information processing [181]. We denote this interpretation of information as $information_{NBIP}$.

Definition $\mathbf{I}_N$6a. Environmental information ($information_{NE}$) denotes information that biological systems receive from their natural environment [182].

Definition $\mathbf{I}_N$6b. Environmental information can be alternatively defined as information where two systems a and b are coupled in such a way that a's being (of type, or in state) F is correlated to b's being (of type, or in state) G, thus carrying for the agent the information that b is G [62].

Definition $\mathbf{I}_N$7. Correlation (or correlational) information (*information*$_{NC}$) denotes information carried by patterns created by cognitive systems to represent reality. *Information*$_{NC}$ therefore represents the correlation between these representations and the state of the world [182].

Definition $\mathbf{I}_N$8. Locally recurrent natural information (*information*$_{Nlrni}$) denotes information contained in, or associated with, repeated patterns of natural processes [123, 182].

Definition $\mathbf{I}_N$9. Incremental natural information (*information*$_{Nini}$) is defined as when b's being in state N carries information about s's being in state F, relative to background data d, if and only if $Pr(s\ is\ F|b\ is\ N) \neq Pr(s\ is\ F|D)$ [9].

Definition $\mathbf{I}_N$10. Counterfactual information (*information*$_{NCTI}$) is defined as when b's being N carries information about s's being F if and only if the counterfactual "if s were not F, then b would not be N" is non-vacuously true, as quoted by Baker [9].

Definition $\mathbf{I}_N$11. Dretske's natural information (*information*$_{NDr}$) has been defined more formally by Baker [9] as a signal that b's being in state N carries the information that s is in state F if and only if (i) the conditional probability that s is in state F, given that b is in state N, is equal to 1; and (ii) this conditional probability relation is fixed by some Law(s) of Nature.

2.3. Pragmatic information

Pragmatic information represents the impact of a message on a system. This is considered a perspective–based notion, so it requires an explicit description of the context. The definition of pragmatic information depends on concepts of meaning, structure, complexity, and similarity or dissimilarity. Pragmatic information also covers other concepts of information, such as negative information, information on the way, structural information, latent information, potential information, and active information. We also have a quantified definition for pragmatic information as the information gained through the probability distributions of the receiver's actions, both before and after receiving a message in some pre–defined form. Another definition asserts that pragmatic information is what determines the decision context. With these definitions, we may surmise that pragmatic information generally represents the impact of a message on a system's pattern or patterns of behaviors, such that the implied intention of the transmitting system is not explicitly stated. Some claim that pragmatic information is a purely biological concept (e.g. [145]). We will label this class of information as *information*$_{Pr}$.

Conceptualizations of pragmatic information have been discussed by the likes of Bar-Hillel and Carnap [12], Kornwachs [97], Weinberger [202], Andrew [63], Gernert [67], Roederer [145], Chen [35], Bielecki, and Schmittel [16], and Bielecki and Stocki [17].

Definition $\mathbf{I}_{Pr}$. Pragmatic information (*information*$_{Pr}$) is a message that may have an impact, whether realized or not, on another system, with the impact and the system being defined differently by different authors. Pragmatic information is strongly associated with a generalized concept for the meaning of information.

Definition $\mathbf{I}_{Pr}$1. Information–on–the–way ($\mathbf{I}_{Pr-iw}$) is a transmitted sequence of signals that is addressed to the potential receiver(s) [67].

Definition $\mathbf{I}_{Pr}$2. Structural information ($\mathbf{I}_{Pr-st}$) is a preserved, quasi–permanent, natural structure that can be interpreted by a human agent [67]. This is not the only definition of structural information cited in research. Bielecki and Stocki [17] and Bielecki and Schmittel [16] point out that depending on the context structural definition may have different meaning. Yet, it is always related to some form of structure: abstract, mathematical, or physical.

Definition $\mathbf{I}_{Pr}$3. For latent information ($\mathbf{I}_{Pr-stL}$), see the work of [67].

Definition $\mathbf{I}_{Pr}$4. For potential information ($\mathbf{I}_{Pr-stP}$), see the work of [67].

Definition $\mathbf{I}_{Pr}$5. Active information ($\mathbf{I}_{Pr-stA}$) is information received by a physical system from its physical environment. Active information is used in the context of quantum physical processes, and it has also been proposed within neuro-cognitive processes (Hiley & Pylkkanen [81]; also see referenced publications, as well as those referenced by Gernert [67]).

2.4. Quantum information

Quantum information is defined as information about the state of a quantum system, where the quantum system (e.g., electron, photon) is a carrier of information. Some deny that quantum information exists at all, while others claim that it is not qualitatively different from classical (i.e., non-quantum) information. Nevertheless, quantum information is expressed in qubits, and two-state systems encode information in two quantum states: $|0\rangle$ and $|1\rangle$. A quantum bit, or qubit, can be in a superposition of different states at the same time, so a qubit can be both in the $|0\rangle$ state and the $|1\rangle$ state simultaneously. The state of a qubit can be manipulated by quantum gates, which are unitary physical operators that can be represented as rotations on the Bloch sphere, with a qubit often being expressed as a vector in the Bloch sphere.

Quantum information may be seen as a generalization of classical information to quantum systems, so many measures from classical information theory could also be generalized for quantum information, such as Shannon's entropy, which is represented in quantum systems as Von Neumann entropy. We label this class of information as *information*$_Q$.

Conceptualizations of quantum information have been discussed by among others by Nielsen and Chuang [133], Le Bellac [107], Jaeger [86], Reifeel and Polak [141], Harshman [73], Lombardi et al. [113], Timpson [187–189], and Zygelman [212].

Definition $\mathbf{I}_Q$. Quantum information (*information*$_Q$) is defined as information about the state of a quantum system, such that the quantum system is interpreted as a carrier of information.

2.5. Relative information

Relative information was proposed by Rovelli [147, 148] as information that expresses the number of possible states in which two physical systems can be together relative to the hypothetical number of states that is logically possible for these two systems. Rovelli claimed that relative information is purely physical, so it does not refer to subjectivity or semantics, but this does not seem to be entirely true. Relative information expresses a relation between hypothetical (i.e., nonexistent) states and factual (i.e., that which exists) states. Relative information expresses what-if situations or nonexistent conditions, so it clearly expresses conceptual situations and abstract ideas rather than real ones. We label this class of information as $information_{Rl}$.

The conceptualization of relative information has been discussed by Rovelli [147, 148].

Definition $\mathbf{I}_{RI}$. Relative information ($information_{Rl}$) is information that A and B have about one another, with this being defined as $S = log_2(NA \times NB) - log_2 NAB$, where A and B are physical systems with NA and NB distinct states and the pair of the systems (A, B) can be in $NA \times NB$ (NAB) states. Thus, we may say that A and B have information about one another if NAB is strictly smaller than the product $NA \times NB$ [147].

2.6. Semantic information

Semantic information is closely related to the concept of communication and the meaning of a message. (In some definitions, message is replaced with data [55]). A comprehensive definition of semantic information was formulated by Floridi in his General Definition of Information (GDI). In the GDI, semantic information is "meaningful and well-formed data". Semantic information may be instructional or factual, and it needs the presence of a cognitive agent, whether artificial or natural, for whom the information has meaning. Semantic information may also refer to a subset of the syntactic statistical correlations between systems, one that has some meaning or significance for a given system. We label this class of information and its variants as $information_{Sm}$.

Conceptualizations of semantic information have been discussed by the likes of Bar-Hillel and Carnap [12], Brilluion [20], Duch [55], Dretske [53], Floridi [60–62], Johannsen [88], Zhong [210], and Kolchynski and Wolpert [94].

Definition Sm. Semantic information denotes information with meaning for a particular artificial or natural cognitive agent. The particular interpretation of the term "meaning" may broaden or narrow the concept of semantic information.

Definition $Sm1$. Semantic system information ($information_{Sms}$) is information that a physical (biological) system has about its environment that is causally necessary for the system to maintain its own existence over time [94].

Definition $Sm2$. Semantic factual information ($information_{Smsf}$) represents a fact [62].

Definition $Sm3$**.** Semantic instructional information ($information_{Smsi}$) conveys a need for a particular action [62].

Definition $Sm4$**.** Semantic biological information ($information_{Smsb}$) is defined as a quality of energy. It depends on a biological receiver to classify and process received energy as informationally structured or not. Semantic information is biological, and it is exclusively created and used by biological evolution (see Johannsen [88]).

2.7. Semiotic information

Semiotic information refers to interpreting information under the theory of signs or semiotics, particularly biosemiotics. It assumes that information is an implicit semiotic term, and this contrasts with Shannon's communication theory for the use of information. Semiotic information is a sign that can be interpreted by an agent. A sign carrying information is known as passive information (i.e., it exists objectively), while an interpreted sign is active information (i.e., it carries valuable epistemic knowledge). In general, information is regarded in biosemiotics as "a difference that makes the difference" [14]. In the semiotic view, information is seen as either reducing "entropy and favoring adaptation and survival with regard to living entities" (the determinate view) or always being indeterminate due to the "abductive nature of information" (the indeterminate view). The first type of semiotic information above is also referred to as functional information [27]. We label this class of information as $information_{So}$.

Conceptualizations of semiotic information have been discussed by various scholars, such as Batenson [14], Sharov [169], Cannizzarro [27], and Thellefsen, Thellefsen, and Sørensen [186].

Definition $\mathbf{I}_{So}$**.** Semiotic information conceptualizes information under the theory of signs or semiotics, particularly biosemiotics. This view assumes that information is an implicit semiotic term, so under this assumption, information is a sign.

Definition $\mathbf{I}_{So}1$**.** Functional information ($information_{Sof}$) denotes a set of signs that encode and control the functions of organisms [169].

Definition $\mathbf{I}_{So}2$**.** Batenson semiotic information ($information_{SoB}$) denotes any difference which makes a difference in some later event. However, the difference that makes the difference is an idea, not a thing. A single difference is a unit of information, a kind of bit [14].

Definition $\mathbf{I}_{So}3$**.** Passive/active information ($information_{SoPA}$) is where passive information denotes something being real and thus not dependent on any active interpreter. For passive information to become active, interpretational signs must carry it; in this case, the signs are either rheme, dicent sign (dicisign), or arguments [186].

2.8. Syntantic information

The term syntactic information has been used to refer to different ideas connected by the concept of the structure (syntax) of a message. Syntactic information therefore expresses the amount of statistical correlation between systems, so from this perspective, information is seen as it is expressed in Shannon's theory of communication. Syntactic information also relates to the grammatical features of a message, assuming that the message is coded in some language or other coding system with a set of rules. In this context, syntactic information can also be referred to as grammatical information. Syntactic information may also refer to the meaning of a sentence as derived from its syntactic structure. Related terms used in the context of syntactic information are morphosyntactic information [89] or case-marking information. We label this class of information as $information_{Syn}$.

Conceptualizations of syntactic information have been discussed by the likes of Sells [165], Kamide et al. [89], and Kolchynski and Wolpert [94].

Definition $\mathbf{I}_{Sy}$. Syntactic information ($information_{Syn}$) expresses the concept of the structure of a message and its role in forming the meaning.

Definition $\mathbf{I}_{Sy}$1. Syntactic information represents the number of bits needed to store a certain data structure [55].

2.9. Digital information

Digital information refers to information processed in digital computer systems, where "information" denotes a physical signal interpreted as binary symbols (0s and 1s) by these systems. Processing encompasses the acquisition, storage, transmission, and collation of information. In general terms, a "signal" is a modulated medium or medium with imposed variations. A digital signal is a modulated analog signal interpreted as a sequence of binary symbols by a computer system. Here, "digital" signifies binary encoding. Physical signals are inherently analog, meaning their time–varying features (frequency, amplitude, phase, or their combinations) represent other time–varying quantities (e.g., a modulated electromagnetic wave conveying binary data). In digital systems, these analog signals are carried as modulated electric waves (LAN and MAN networks, electronic circuits), electromagnetic waves (wireless networks), or modulated light (optical networks in LAN, MAN and WAN systems)[4]. Computer systems convert these modulated signals into binary form through analog-to-digital (A/D) or optical–to–digital (O/D) converters. Digital computer systems–computers, telecommunication networks, and digital storage systems–are the sole environments where digital information exists. Since digital information is an interpreted physical signal, it qualifies as epistemic information, meaning its syntactic and semantic structures are imposed by an external system and are interpretable by other systems (more details about epistemic information can be found in other sections in this paper). Unlike analog signals, digital signal cannot be directly interpreted by humans but can be presented in an analog format as text, image, sound, or video or combination of these through user interfaces using digital to analog converters (D/A) such as displays, printers, or speakers.

[4]LAN denotes Local Area Networks, MAN denotes Metro Area Network, WAN denotes Wide Area Networks [176].

Digital information is often referred to by terms such as numerical information, digital data, digitized data, numerical data, electronic data, computer data, binary data, computerized information, machine–readable data, encoded information, digital signals, bitstream data, digital content, electronic records or computerized format. Each term may have slightly different connotations depending on the context, but they all broadly relate to the concept of information represented in digital form.

Note: Quantum computing, a form of digital computing, uses quantum phenomena for encoding digital information and is discussed separately.

Digital information, telecommunication networks, digital information systems and digital information processing have been discussed by the likes of Clark [37], Gelinas et al. [66], Watson [200], Moore [126], Kurose and Ross [101], Balakrishnan et al. [11]. Stair and Reynolds [176] or newer editions on similar topics. On analog signals in nature see Yong [208].

Definition $\mathbf{D}_{in}$1. Digital Information denotes organized/structured collections of binary symbols (processed, acquired, stored, transmitted, collated, etc.) in digital computer systems.

2.10. Infons

The infon is a concept described by Stonier [179], Devlin [45], Floridi [61], and [120]. Infons are positioned as elemental (natural) units of information, not as something like binary bits but rather in the sense of the elementary constituents of matter, much like quarks. In other words, they are elements that are fundamental to the construction of information[5]. Thus, much like how nothing is smaller than a quark, at least with our current knowledge, no information is smaller (whatever that may mean) than an infon.

Stonier claims that there may exist "a class of hypothetical particles which consist of only information. Such 'infons' might not show up in traditional physical experiments since such particles would possess neither mass nor energy–they could, however, manifest their effect by changes in organization" [179, p. 126]. The physical interpretation of an infon provided by Stonier is just conjecture, however. He does not propose how we could conduct an experiment that could prove the existence of infons. After all, if they exist, we should be able to detect them. Thus, Stonier's infons are not like bosons in the way they were conceptualized (in terms of their properties) before they were detected. Indeed, Stonier's infons have been conceptualized without a chance of ever being detected.

Floridi [61, p. 84] uses the term infon in his General Definition of Information (GDI) stating, "GDI σ (an infon) is an instance of information, understood as semantic content". He also explains that an infon "refers to the discrete item of information, irrespective of its semiotic code and physical implementation". Furthermore, he also

[5]We compare infons to bits because a bit is the smallest unit of data in digital computer information systems. But what is the smallest processing unit in analogous systems?

says that "the term 'infon' and the symbol refer to discrete items of factual semantic information quantifiable in principle as either true or false, irrespective of their semiotic code and physical implementation" [61, p. 110] and that "infons are messages formulated by a source" [61, p. 111]. Floridi's infons are clearly elemental units of semantic information, so they are foundational to the semantic conceptualization of information. Thus, Floridi's infon is the smallest form of an interpretable something, and it is not physical, so it must be abstract.

Infons have been also defined by Devlin [45, p. 35] in many ways. For example, infons are not physical objects. It is an "item of information" that is theory absolute or representation-independent; it is like real numbers and independent of the form they are in. Infons are semantic objects within the theory they are in. Their nature is that of numbers. For Devlin, information comes in infons, elementary bits of information for a specific agent. Infon information essentially comprises propositions about the state of the world, or facts if you will. The source of this information is perceived stimuli processed by a cognitive system, and each cognitive system may have its own infon–based ontology that suits its needs. (Note that ontology here refers to preexisting information/knowledge that enables the interpretation of stimuli.) For example, a cat will have a different infon–based ontology from a bee, as would a fish and an autonomous car.

Yet another definition of infons is proposed by Martinez and Sequoiah–Grayson [120]. They define an infon as "informational issues that may or may not be supported by particular situations; what is expressed as $s \models \sigma.$, with s being a situation and σ being an infon". This definition is developed in the context of the situation theory of information [120].

The lesson to take from this discussion is that the infon is clearly an attractive concept, as many people seek to define it. Indeed, the infon seems to enable the quantification or discretization of information, thus making it measurable. Yet the infon is not a clearly defined concept like electrons and protons, assuming we regard them as being clearly defined. It is not elemental in the sense that an elementary particle is in physics, nor is it sufficiently well–defined to use it without qualification. The infons of Stonier, Martinez and Sequoiah-Grayson, and Devlin are clearly not the same, even if they all seek to play the role of "elementary units of information".

From the perspective of this study, an infon must be smallest quantity of identifiable information, much like today's opinion that quarks are the smallest identifiable form of matter. From the perspective of epistemic information[6], an infon appears to be a unit of thought, so it is a unit of epistemic information. We do not know what this unit is, though. For example, what is an elementary thought? But what

[6] As the smallest amount of matter that we know of today, this complex object is somewhat reflected in the combinatorial ontology of Perzanowski [136], where objects appear only after reaching some level and some structural complexity from the fundamental ontology realm. In other words, the simplest objects that exist are already complexes.

is elementary thought? Is it a simple Humean impression? The search for it seems rather pointless.

From the perspective of ontological information, though, we may see the infon in a different light. With ontological information, we assume that information is always embedded in a physical carrier, so the simplest ontological information relates to the simplest organizations of nature or to the fundamental elements of nature, much like elementary particles do. As we recall, some authors in the reviewed publications do mention that matter and information cannot be considered separately, with there being no priority between matter and information. Thus, if information is always carried by a physical phenomenon, the smallest physical element, elementary particles like the muon, may be also the smallest "quanta" of ontological information, although this is just conjecture.

2.11. Quantified information

Quantified information refers to mathematical measures of some form of physical phenomenon that has been designated as either being information or a carrier of information. This category of information encompasses Shannon's entropy of information, Chaitin's and Kolmogorov's algorithmic complexity metrics [33, 95] and Fisher's and Klir's information metrics.

Measures of information are operationally useful, but they do not convey what information actually is, so they are not regarded as good definitions of information. From this point of view, referring to Shannon's information is not appropriate but referring to Shannon's measure of information is. The same logic applies to Kolmogorov's information, Fisher's information, and other similar measures of information. We call this class of information $information_{QT}$ under the proviso that this term pertains to measures, rather than definitions, of information.

Conceptualizations of quantified information have been discussed by researchers like Shannon [166], Chaitin [33, 34], Peirce [135], Shannon and Weaver [168], Kolmogorov [95], Klir and Folger [91], Avery [6], Solomonoff [174], Friden [64], Burgin [23], Stone [178] and Ly et al. [116].

We also cannot rely on measures of information to give us a deeper understanding of what information actually is. For example, Shannon's entropy of information has proved very useful in various applications [74, 166, 168], while other metrics–such as the Fisher metric (Friden [64]) and Kolmogorov's [95] and Chaitin's [34] algorithmic metrics, among others—are mathematical formulas that are called information measures, but they are designed for specific purposes under specific assumptions. Of course, these metrics fulfill their intended purposes exceedingly well, but the pragmatic (and domain-specific) or operational (technical) successes of an idea do not support its metaphysical status. (The question about the essence of information is indeed metaphysical.) Indeed, we could say that pragmatically efficient concepts are often metaphysically neutral. These quantified concepts of information are therefore not of general import, even if they have been applied successfully in many domains and "interpreted" as fundamentally defining information.

We mention also Fisher information that is a statistical measure of how much information one may obtain about an unknown parameter from a sample. Technically, Fisher information is the inverse of the variance of the Maximum Likelihood Estimator (MLE) for a parameter Θ from a sample X (for a normally distributed X). (The MLE is the maximum of a function of a specific parameter Θ given a random sample.) To simplify this, the concept of Fisher information allows us to find the value of the parameter(s) of a function fitted to the experimental data such that it minimizes prediction error. Fisher information has found many applications in experimental studies in fields like astronomy, biology, and social sciences (e.g., Friden [64], Ly, et al. [116]). For George Klir (Klir & Folger [91]), information is a reduction of uncertainty. Uncertainty may be considered as ambiguity or vagueness. Such uncertainty may be measured by Shannon's entropy of information (a measure of ambiguity), the Hartley measure (H), or measures of fuzziness. Both Fisher and Klir define information as a reduction in uncertainty based on information from perceived observations, so these concepts clearly belong to the class of epistemic information.

A quite extensive list of quantified models of information is also provided by Burgin [23, pp. 131–132], but the sheer number (32 formulas) of models for measuring information does not translate into clarity about the nature of what is being measured. In fact, the models listed by Burgin measure quite different properties of abstract constructs, usually probability spaces, so they do not necessarily convey the same concept of information. To clarify this point through an analogy, the numerous measures of mass led to multiple interpretations for the concept of mass, and these did not necessarily converge on a single concept of mass. Indeed, the concept of mass as we now know it has evolved significantly over the history of science. These measures pointed to varying conceptualizations of mass, but they did not address the question of what mass actually is. Likely, multiple measures for information do not translate into a better understanding of what information is–it only shows a range of possible interpretations [82, pp. 175–181].

Quantified theories of information also include topological information and information geometry. Information geometry was defined by its founder Shun'ichi Amari [3] as "...a method of exploring the world of information by means of modern geometry". Information geometry studies information science (an umbrella term for statistics, information theory, signal processing, machine learning, and AI [131] through geometry. Information geometry provides a pure, context–free method for studying relations like distances, such as between probability distributions. Information science is viewed as a science for deriving models from data, and it is often presented as the geometry of decision making (e.g., curve fitting, classification, etc.) [131, 132]. Topological information in turn views information as being topological in the sense that the relations between systems that manipulate and exchange information can be represented topologically. Such a topological representation of information and computing allows for Turing machines and computing to be generalized to the manipulation of information on tangle machines[7]). For more information on topology, see other works [28, 128]. The advantages of information geometry and topological information lie in their power to capture various forms of information processing (in terms of information science, decision science) in context–free, formal systems based on geometry or topology, thus allowing for results to be generalized from a specific domain.

The numerous conceptualizations for information convey how the concept of information appears to be fragmented, malleable, and elusive. Thus, is there a way out of this quandary?

3. Ontological and epistemic information

To simplify things somewhat, we propose that the concept of information can be viewed from two perspectives, namely epistemic and ontological. In the epistemic view, information is associated with meaning, semantics, knowledge, and communication between biological and/or artificial systems, while in the ontological view, information is understood as a property of physical objects that is expressed through the structure, organization, and form of these objects. Epistemic information depends on the cognitive system that creates or receives it, and as such, it is subjective. Objective information, meanwhile, exists independently of any observer, but it has no intrinsic meaning of any form, so it is, in this sense, objective. The concept of ontological and epistemic must be seen as defined by John Searle [158, 160–162].

Information has been most frequently understood as epistemic information throughout the 20th and 21st centuries. A keen reader will find many scholars referring to this type of information through various terms, such as cognitive information (highlighting information's dependency on cognitive systems), semantic information (stressing meaning as a defining feature of information), or most commonly just simply as information, thus adding further confusion to an already muddled concept.

Our proposed "bifocal" view is imperfect, however. There are likely some cases where it is difficult to cleanly assign information into one of these two categories. This difficulty stems from the fact that the critical concept when differentiating epistemic and ontological information is meaning, but this concept is not clearly defined. Nevertheless, with our proposed perspective and a tightly bound definition of meaning, we could generally classify most concepts of information into one of these two classes and thus gain revealing insights into the concept of information.

[7]"Tangle machines are topologically inspired diagrammatic models. The novel feature of tangle machines is their natural notion of equivalence. Equivalent tangle machines may differ locally, but globally they share the same information content. The goal of tangle machine equivalence is to provide a context–independent method to select, from among many ways to perform a task, the 'best' way to perform the task" (Moskovich and Avichy [128].

3.1. Information: the epistemic view

From this viewpoint, information as a concept is centered on humans or other conscious agents[8]. We call this epistemic information, because it emphasizes its relation to knowledge and meaning and denotes as $information_E$. The concept of epistemic information has seen many incarnations, so there is no single definition that is acceptable to everyone or even some nebulous majority. Take, for example, the works of Bar-Hiller and Carnap [12], Brooks [21], Rucker [151], Buckland [22], Devlin [45], Loosee [114], Sveiby [180], Dretske [53], Casagrande [30], Floridi [60–62], Lensky [108], Vernon [193], DasGupta [41], Millikan [124], or Carrol [29], among others, because this list is by no means exhaustive. Each of these authors has created a somewhat different version of epistemic information, but their various versions share several similarities. Indeed, they all associate information with meaning, knowledge, or semantics, thus providing a common thread that allows them to be collected under one heading.

Thus, epistemic information is associated with knowledge, belief, or a communication process in its more generally and broadly understood meaning[9]. We limit the application of meaning to cognitive systems with some form of linguistic capacity, whether artificial or biological. Epistemic information thus only exists if someone or something recognizes it as information (some suggest including artificial or non-human biological systems, but we need to be careful what we assign epistemic processing capacities to!).

Epistemic information is defined within the context of a communication system, so there is a sender, a receiver, and a communication process. This communication system may take many forms (e.g., Cherry [36]; Shannon [166]; Maynard and Smith [121]; Vernon [193]), but it will follow the general format described by Casti [32]. Epistemic information exists specifically in, and for, the minds, which are broadly understood as complexes of cognitive faculties, of the receiver and the originator. Epistemic information exists when communicated (i.e., created, sent, and received) as a message. This dependency on the sender and the receiver, as well as their cognitive functions, makes information epistemically and ontologically subjective. In other words, this information depends on something else to exist.

Thus, epistemic information exists relative to the cognitive faculties of the receiver or sender. (Cognitive faculties are understood very broadly here, with the human mind at one end of the spectrum and artificial systems with sensory functions at the other end.) It thus follows that a specific interpretation of a message's meaning and knowledge depends on the specific system. This cognitive system could be a person, a non–human organism, or a mechanical or electronic device, depending on

[8]The term "a conscious agent" may, in addition to human agents, include animals and artificial systems.

[9]Meaning has many interpretations. For this study, unless otherwise stated, we follow the definition from the philosophy of language, where the term "meaning" denotes how language relates to the world. A review of theories of meaning lays beyond the scope and purpose of this work, but an extensive list of references can be found in the work of Speaks [175] and other sources.

how broadly we want to understand cognitive functions. In most cases, a cognitive system is a receiver of information, but it may also be a sender. The received or sent information may be different for a human agent, a non-human biological system (e.g., a cell, a plant, a virus, a fragment of a DNA strand), or an artificial cognitive system. Yet within a specific system, the message, meaning, and knowledge fulfills the same role or function. This means that the definition of what a message represents, what its meaning is, and what constitutes an agent is context–dependent.

We can summarize main claims about epistemic information:

Claim 1. About interpretation of stimuli:

- **C1.1.** Epistemic information is interpreted as physical stimuli – which we may call data, a signal, the state of a physical system, or some other physical phenomenon–by a cognitive agent.
- **C1.2.** The interpretation of physical stimuli by an agent is a complex process of perceiving, and perception depending as well on the previous state of a cognitive faculties of an agent (in fact we do not know how exactly the interpretation of physical stimuli and its integration with other stimuli occurs (see e.g. [171]).

Claim 2. About cognitive agent:

- **C1.2.** Epistemic information (meaning) exists for a cognitive agent, so it is relative to that cognitive agent. In other words, epistemic information is subjective.
- **C2.2.** This cognitive agent may be a human agent, a biological system, or an artificial intelligence system, depending on how far we want to push the boundaries of what constitutes a cognitive system.

Claim 3. About abstractions:

- **C3.1.** Epistemic information includes also abstract and no–linguistic concepts created by a conscious agent without direct link to the outside stimuli such as e.g., music, pure mathematical concepts, or dreams.

3.2. Information: the ontological view

From this alternative viewpoint for information, we see it as a form or organization of nature. We do not ask, “What is information?” in the context of a specific domain, cognitive agent, or communication process. Instead, we conceive information as an objective, mind–independent phenomenon. We see it as something that is a part of the natural world, so people or other cognitive systems are not generally reference points for it. Information is less frequently conceptualized as an ontological phenomenon, yet as can be seen from the published studies, it is well justified. We denote this information as $information_O$.

The list of researchers conceptualizing information as something ontological includes Weizsäcker von [203], Turek [190, 191], Mynarski [129], Heller [78, 79], Collier [38], Stonier [179], Devlin [45], De Mull [44], Polikghorne [139], Seife [163], Dodig

Crnkovic [49], Hidalgo [80], Wilczek [205], Carrol [29], Rovelli [147], Davies [43], and Sole and Elena [173]. This list is certainly not exhaustive, but the above sources give a comprehensive overview of the current discussion for this topic.

The idea of information as an ontologically objective phenomenon has been seen in diverse contexts. Different authors have also attributed different, although somewhat similar, sets of properties to it. In these studies, ontological information is regarded as a phenomenon that exists independently of a human observer. In fact, it exists independently of any observer, even artificial or biological ones. Ontological information exists independently of any mind[10], whether natural or otherwise, or any kind of cognitive system or process. Ontological information is objective in the sense that it is not dependent on any observer. It is a natural phenomenon in the same way as all natural objects and phenomena, an element of nature itself[11]. Ontological information therefore has no inherent meaning, and it is "responsible" in some way for its own (perceived) structure, order, and organization. Researchers often interpret ontological information by recognizing its existence in the structure or order of nature, and it is often equated with the form or shape of a natural object or an artifact[12], although this is not entirely accurate.

Thus, from this viewpoint, information is a phenomenon that exists independently of the mind. Indeed, this is our fundamental assumption about ontological information. Being ontologically objective means it is mind-independent and thus has no intrinsic meaning. It also belongs to nature, but it relates to us through our conceptualization of what we perceive through the structures or forms of objects. In other words, these objects are what they are because they have organization.

The properties attributed to ontological information by Krzanowski [99, 100] reflect its physical nature. We claim that ontological information is characterized by three features:

1. epistemic neutrality (EN),
2. physical embodiment (PE),
3. formative nature (FN).

(1) The property of epistemic neutrality (EN)[13] means that ontological information has no meaning in itself. From some specific ontological information, however, an

[10]The word mind is understood here as a set of cognitive faculties including consciousness, perception, thought, judgment, and memory. It can also be understood as an artificial system that has a subset of cognitive–like functions.

[11]The word "nature" has many meanings (see, for example [83, 102]), and there are obvious differences between the common usage and the scientific and philosophical usage. In most cases, while the meaning should be clearly indicated by the context in which the word is used, some may still object to the lack of precision.

[12]Von Baeyer quotes eight synonyms for form: arrangement, configuration, order, organization, pattern, structure, and relationship. The term "relationships among the parts of the physical system" seemed to him the most general term capable of covering "applications in mathematics, physics, chemistry, biology and neuroscience" [7, p. 22].

[13]A concept is "epistemically neutral" when it does not have intrinsic epistemic import, or in other words, it does not mean anything by itself.

agent may derive something of value that has some significance for that agent's continued existence or effective functioning. What is more, the same ontological information may result in a different meaning for different agents, or it may have no meaning at all. An agent could, in principle, be any system, whether organic or artificial, if it can sense ontological information through the organization of natural phenomena. Indeed, natural agents (i.e., biological systems) have been shaped by nature to perceive nature's properties, including its organizational properties, to maximize their odds of survival. Artificial agents are of our own making of course, so in a sense, they also have biological origins. We are all therefore creations of nature and not separated from it. We are designed to interpret nature accurately, because evolution assumes this. Indeed, any organism that fails to correctly perceive its environment is unlikely to survive. This is also the general idea for building our artificial agents.

(2) The property of physical embodiment (PE) means that ontological information is a physical phenomenon. It may therefore be conceptualized as a matter–energy–information complex[14], one that indirectly implies Aristotelian hylemorphism), so it is fundamental to nature. In other words, anything that physically exists contains information. The claim that "ontological information is a physical phenomenon" can mean several things. For example, ontological information is not an abstract concept in the same way that mathematical objects, ideas, or thoughts are abstract. Ontological information does not belong to the Platonic realm of Forms in either the classical or neo-Platonic sense. Ontological information is real, observable, and measurable. Thus, we can claim that information exists much like other physical phenomena exist, because they exhibit the same class of properties (quantifiability, operational properties) as physical phenomena do. Furthermore, it seems that whatever exists in a physical sense contains information, so there can be no physical phenomenon without information.

(3) Finally, the property of a formative nature (FN) means that ontological information is responsible for the organization of the physical world, so information is expressed through the structures/forms and organizations of things[15], although information is not structure in itself. Organization is a fairly broad concept that may be, and is, interpreted as structure, order, form, shape, or rationality when perceived by a cognitive entity. We do not posit that information is structure, however, although this has been claimed several times. The problem with such a statement would be that we do not precisely know what structure is and what kinds of structures we could associate with information, nor do we know how this would be achieved. Information is certainly not the visible structure or shape of an object, but we can concede that the shape or structure of an object is how information expresses itself or how we sense its presence. Thus, the shape of a tea cup is not information, yet information is being expressed through the shape of a tea cup.

[14] The matter–energy–information complex has the status of conjecture but not of a theory.

[15] The synonymity of the terms "structure", "form", "organization", and "information" should not be accepted a priori despite the fact that these terms are often used synonymously.

We can summarize main claims about ontological information.

(C1) Claims about meaning:

- **(C1.1)** Information has no meaning.
- **(C1.2)** Information exists as a physical phenomenon regardless of the presence, or absence, of any cognitive faculties.

(C2) Claims about physical nature:

- **(C2.1)** Information is a physical phenomenon.
- **(C2.2)** Information exists in nature independently of the existence of any conscious agent.

(C3) Claims about organization, structure and quantification:

- **(C3.1)** Information is responsible for the organization of the physical world.
- **(C3.2)** Information is conceptualized as form or structure.
- **(C3.3)** Forms or structures are therefore what quantified models of information denote.

Information$_O$ and *information*$_E$ may be succinctly defined as:

Definition O. Ontological information or *informationO* is defined as is a physical phenomenon; it exists objectively, has no intrinsic meaning and is responsible for the organization of the physical world.

Definition E. Epistemic information or *information*$_E$ is a (artificial or biological) cognitive agent's interpretation of physical stimuli or the abstract and non- linguistic concepts created by a conscious agent without direct link to the outside stimuli. *Information*$_E$ is relative to a cognitive agent, i.e., it is ontologically subjective (ontologically subjective in Searle's sense).

The definitions to be correctly understood must be further interpreted in the context of referred sources. As well, we remind the reader that the term "ontological" in ontological information does not refer to the generally conceived notion that is the subject of pure ontological studies. As an adjective, "ontological" here denotes the existence of information as being independent of any observation, not having any inherent meaning, and being somewhat responsible for forms of reality [161,162].

At present, we do not have a physical interpretation of ontological information. We only claim that from the current studies, it seems that ontological information has several properties that we can attribute to a physical phenomenon.

From our ontological–epistemic perspective, natural information, pragmatic information, quantified information, relative information, semantic information, semiotic information, and syntactic information are all concepts that are derived from, or related to, the class of epistemic information, because they denote different views on communication, messages, knowledge gains, signs, coding properties (syntax), or practical gains (pragmatism). Quantum information, meanwhile, as long as it describes the quantum state of a system or the organization of a quantum system, could be seen as reflecting ontological information. Likewise, when biological information refers to the structure or organization of biological systems, it also has the properties of ontological information, because it can be seen as reflecting biological structures. In contrast, if biological information can be interpreted as having meaning for some system or intentionality, it belongs to the class of epistemic information.

As indicated earlier, the precise boundary between ontological and epistemic information depends to a certain degree, ceteris paribus, on our understanding of meaning.

A Note: we need to mention that these terms, ontological and epistemic information, have been used but to denote different concepts by Zhong [210]. We denote Zhong's objective information as $information_{ZO}$ and epistemic information as $information_{ZE}$. Zhong defines objective information as representing "the set of states at which the object may stay and the pattern with which the states vary"[16]. The equivalent name for ontological information is object information. Object information, $information_{ZO}$, indicates that information about the object comes only from the object itself, without any input from a subject. Epistemic information (or perceived information) is information that an epistemic subject has about an object[17]. Epistemic information, $information_{ZE}$, comprises semantic, syntactic and pragmatic information, all of these have a source in $information_{ZO}$. Epistemic information is also denoted as comprehensive information ($information_{ZC}$) by Zhong. Zhong's objective or ontological information represents the state of an object that can be perceived by an epistemic agent. It is not the internal structure of an object as denoted by ontological information in this study – $information_O$. In fact $information_O$ is never directly perceived by an epistemic subject as is. $Information_{ZO}$ is more akin to natural information as discussed later in the paper. $Information_{ZE}$ or equivalently $information_{ZC}$ comprises semantic, syntactic and pragmatic information (see Zhong's definitions). This composition would imply that $Information_{ZE}$ already in some linguistic form with associated symbolism and syntax. $Information_E$ has much more generalized form and does not imply symbolic representation. Thus, it accounts for animal cognition or other forms of no verbalized information—like intuitive knowledge or abstract ideas in human subjects.

3.3. Information and data

When we look at definitions of epistemic information, these definitions often, if not almost always, claim that information (i.e. epistemic information) is "data + meaning" [61]. There are similar claims that "information is derived from data" or "information is data endowed with relevance and purpose" [42,54], "information is organized

[16]Definition 1 (Object Information/Ontological Information). The object information concerning an object is defined as "the set of states at which the object may stay and the pattern with which the states vary" presented by the object itself [210].

[17]Definition 2 (Perceived Information/Epistemological Information). The perceived information a subject possesses about an object, which is also termed as epistemological information, is defined as the trinity of the form (named the syntactic information), the meaning (the semantic information), and the utility (the pragmatic information), all of which are perceived by the subject from the object information.

data" [152], or it is "interpreted data" [184]. It somehow seems that we need data to get information, that data is some kind of input to the process of creating information, that data differs from information, or that data is some "primitive stuff" from which information is formed. Data certainly seems to be not information – they are different. But are these claims warranted? Let us look at how data is defined and where this fits in our conceptual schema of the world in relation to epistemic and ontological information.

Even though the terms data and information are often used interchangeably, there is an important distinction between them. In information technology (IT) parlance, data consists of the raw numbers that computers process to produce information. Table 1 [117] shows the many possible interpretations of data and information, where information is interpreted here in its semantic meaning.

Table 1

Comparison between concepts of data and information [117]

	Data	**Information**
Definition (Oxford Dictionaries)	Facts and statistics collected together for reference or analysis	Facts provided or learned about something or someone; Data as processed, stored, or transmitted by a computer
Refers to	Raw data, stimuli, signal	Analyzed data
Description	Qualitative or quantitative variables that can be used to propose ideas or draw conclusions	A group of data that carries news and meaning
In the form of	Numbers, letters, symbols, or a set of characters.	Ideas and inferences
Collected via	Measurements, experiments, etc.	Linking data and making inferences
Represented through	A structured format, such as tabular data, a data tree, a graph, etc.	Language, ideas, and thoughts based on the data
Analysis	Not analyzed	Always analyzed
Meaning	Carries no specific meaning	Carries meaning that has been assigned while interpreting data
Interrelation	Information that is collected	Data that has been processed

Based on Table 1 above, it seems that the differentiation between data and information is somewhat arbitrary, a matter of interpretation as to what constitutes raw data versus analyzed data, no special meaning versus assigned meaning, collected versus processed, formal formats (tree, tables, graphs) versus linguistic interpretations, symbols versus ideas, and so on. These differences are not very well accentuated, so the boundary between data and information seems to be somewhat fluid, and the multitude of definitions of data only confirms this impression. Zins [211] documents no less than 130 definitions for data. The multitude of definitions supplied by experts is positioned as an important scientific feat but I would claim that for science and philosophy, it is more of an embarrassment.

Including data in some conceptualizations of information is a sign, in our view, of not being able to see the forest for the trees. Whatever is denoted as data already has some meaning imparted on it. Whatever information is, from this perspective, already has some additional meaning imparted onto already processed data. Knowledge it therefore processed information. The distinction between data, information, and knowledge can be therefore made, and this is certainly operationally useful in certain areas of research or technology, such as computing, artificial agents, Big Data, cognitive artificial systems, and artificial intelligence. Indeed, it is helpful whenever we want to denote or differentiate one narrow aspect or stage of information processing, especially with computers. However, these divisions overlook the strong similarities and stress the rather relative differences (see e.g., [41, 61]).

This division into data, information, and knowledge, which is often referred to as the DIKW (data, information, knowledge, wisdom) hierarchy, wisdom hierarchy, knowledge hierarchy, information hierarchy, or the data pyramid (e.g., [112, 150, 209, 211]).

On trying to find some firmer ground for the concept of data, we may say that data are a sort of epistemic information, symbols imposed on natural stimuli, elements in communication, numbers stored in digital form, or some kind of information (i.e. interpreted stimuli). The boundary between data and information is fluid and not very well defined. Thus, in some cases and for some purposes, data will be data, while in other cases, the same data will be information or information will be data. It seems that how we refer to data depends on where we are situated on the spectrum of information processing, from stimuli to knowledge.

From the perspective of computer information systems, however, this differentiation into data and information plays a useful role. Rajendra Arvind Akerkar and Priti Srivinas Sajja [2] provide definitions of data and information and point to the differences. For them, data and information are "factual, discrete and static things, and raw observations of the given area of interest. Information can be generated after systematic processing of such data". However, they do not realize that information for some may be data for others, making this distinction again relative.

There is no interpretation-free data, just as there are no assumption-free scientific theories. What they are actually telling us, without realizing it, is that information, however they mean it, is processed/interpreted data or that data is information minus some processing. This is true even if they later say that information is not data because information is data that has been processed and connected with some meaning. Such claims assume that data has no meaning, but we recall the previous definitions of information (or semantic information) as "data+meaning", but in this view, data has already had some meaning imparted on it, so we have the following dependency:

$$? \rightarrow data + meaning \rightarrow I_E$$

where the question mark "?" represents some undefined "original" source of an 'uninterpreted' physical process.

For the sake of completeness, we also need to mention the so–called metadata. Metadata, as a concept, represents what we may call "data about data"[18]. The term "meta–X", in philosophy, denotes study, enquiry about "X" , in our view x is data [15]. Metadata usually describe of the origins, the processing context, the originating systems, and other information about data. Metadata is therefore nothing more than data about data – it does not enjoy any special metaphysical or ontological status, let along grant such a status to data. The concept of metadata does not bring any new arguments to the discussion of data or information, at least from the perspective of this study.

4. Unifying theorems

Floridi's General Definition of Information (GDI) [60] and Burgin's General Theory of Information (GTI) [23] attempt to somewhat correct the profusion of various conceptualizations and establish some common ground that underlies these definitions. Both theories have a broad scope and are very rich in content, so in this short summary, we restrict ourselves to their main postulates.

4.1. General definition of information (GDI)

Floridi's [60] General Definition of Information (GDI) is a fairly comprehensive statement about the perception of information, so it is attached to the concept of information as something expressing meaning or knowledge. In other words, it reflects the epistemic perspective that prevails in current philosophy. Moreover, the GDI assumes the existence of a quasi–physical foundation for information through something called the infon (σ). Unfortunately, this foundational infon has a rather ambiguous explanation, and the purely epistemic perspective leaves the whole concept behind the GDI wanting. The GDI is defined as follows [60–62]:

GDI-σ (an infon) is an instance of semantic information if and only if:

GDI.1. σ consists of n data (d), for $n \geq 1$,
GDI.2, the data are well–formed (wfd),
GDI.3. the wfd are meaningful (mwfd = δ).

[18]Metadata is structured information that describes, explains, locates, or otherwise makes it easier to retrieve, use, or manage an information resource. Metadata is often called data about data or information about information [142]. See also Snowden [172].

GDI.1 states that semantic information consists of data, while GDI.2 states that semantic information consists of well-formed data according to some rules. GDI.3 then states that semantic information consists of well-formed data that has a meaning within the specific language system.

The elementary piece of information, a *datum*, is defined as:

$$datum = x \textit{ being distinct from } y$$

Where x and the y are two variables to be defined (i.e., content and domain). The definition pivots on the concept for the lack of uniformity as defined by Batenson [14][19].

The *datum* is a relative concept [61], and something may or may not be a datum. Floridi denotes it as a "taxonomic neutrality". A datum in GDI is further described through typological neutrality, ontological neutrality, genetic neutrality, and alethic neutrality, which are concepts explained by Floridi [61]. To avoid ambiguity, the GDI further constrains semantic information through the GDI.4 condition:

GDI*-σ (an infon) is an instance of semantic information if and only if:

GDI.1. σ consists of n data (d), for $n \geq 1$,

GDI.2. the data are well–formed (wfd),

GDI.3. the wfd are meaningful (mwfd $= \delta$),

GDI.4. the δ are truthful.

One may argue whether any data are not already semantic information of some sort, information with an imparted meaning. Such an interpretation would mean that the GDI definition translates as "semantic information is information composed of elements of semantic information". Nevertheless, more charitable interpretations are possible and preferred. Overall, the GDI is a well-defined concept that certainly helps organize our understanding of data, information, and information processing.

4.2. General Theory of Information (GTI)

The General Theory of Information (GTI) proposed by Burgin [23,25] and Burgin and Feistel [25] provides us with a fundamental grounding in the concept of information, and as such, it offers a foundation for epistemic and ontological information, as well as other derived concepts. Moreover, the GTI may also position the fundamental ontological properties of information as a physical phenomenon with fundamental structural and causal properties.

The General Theory of Information (GTI) offers a comprehensive framework for organizing and structuring all existing information theories. It provides a flexible and all-encompassing definition of information, applicable across various domains such as nature, society, and technology. GTI rigorously models static, dynamic, and functional aspects of information using algebraic, topological, and analytical structures.

[19] "In fact, what we mean by information – the elementary unit of information – is a difference which makes a difference" [14].

Serving as a metatheory, it synthesizes fields like physics, psychology, and information science. The theory also provides tools for measuring, representing, and analyzing information, and has supported the development of methods such as Shannon's entropy and algorithmic complexity theory. GTI accommodates multiple information models, including Shannon's communication theory and algorithmic information, and clarifies the relationships between information, knowledge, and data across various scientific and technological contexts. As Burgin claims [23, 25] the general theory of information (GTI) has three components:

- the axiomatic foundations,
- the mathematical core,
- the functional hull.

We focus on axiomatic foundations. The axiomatic foundation consists of principles, postulates and axioms of the general theory of information [23, 25].

- *Principles* describe and explain the essence and main regularities of the information terrain.
- *Postulates* are formalized representations of principles.
- *Axioms* describe mathematical and operational structures used in the general theory of information.

There are two classes of principles:

- *Ontological* principles explain the essence of information as a natural and artificial phenomenon.
- *Axiological* principles explain how to evaluate information and what measures of information are necessary.

There are three groups of ontological principles:

- *Substantial ontological principles* [O1, O2 and its modifications O2g, O2a, O2c] define information.
- *Existential ontological principles* [O3, O4, O7] describe how information exists in the physical world
- *Dynamical ontological principles* [O5, O6] show how information functions.

In a strict sense, information is stratified according to the global structure of the world, as represented by the Existential Triad of the world, which comprises the world's top–level components as a unified whole that reflects the unity of the world. This triadic structure is rooted in the long-standing traditions of Plato and Aristotle and comprises three components: the Physical (i.e., material) World, the Mental World, and the World of Structures [23, 25]. The Physical World represents the physical reality as studied by natural and technological sciences, while the Mental World encompasses different forms and levels of mentality. Finally, the World of Structures comprises various kinds of ideal structures. The Existential Triad involves differentiating information into two fundamental classes: ontological information and mental information.

Ontological information is the potentiality or cause of formations and transformations in the structures of the physical world (i.e., physical systems). As ontological information functions in the physical world, it is logical to treat it as a natural phenomenon [100]. Mental information, meanwhile, is the potentiality or cause for formations and transformations in the structures of the mental world (i.e., mental systems). Ontological information is unrelated, yet complementary, to mental information. Epistemic information, which has been studied by various researchers, is a type of mental information, so it is orthogonal to ontological information.

All in all while GDI provides the very detailed account of variants and versions and interpretations of semantic information, it is about semantic information only. Its physical foundations in infons depending on the concept of data or datum is rather (as explained above) wanting. But regarding semantic information GDI does a good job of bring all the divers strands of semantic information under one roof.

GTI on the other hand defines metaphysical foundations of information which seems to be more basic that semantic basis of GDI. GDI if correctly interpreted accounts for physical aspect of information, semantic aspect of information and for the existence of abstract information. So it is more complete and comprehensive than GTI.

5. Advanced topics

In this section we discuss three advanced topic in the study of information: the questions of information and its mass as proposed by Melvin Vopson, the concept of physical information with meaning proposed by Carlo Rovelli and the question of perdurace of information explored by Roman Krzanowski.

5.1. Does information have mass?

Several researchers attribute a physical nature to information. See, for example, the work of Weizsäcker von [203], Turek [190], Mynarski [129], Heller [78, 79], Collier [38], Stonier [179], Devlin [45], De Mull [44,139], Bayers von [7], Seife [163], Dodig Crnkovic [49], Hidalgo [80], Wilczek [205], Carrol [29], Rovelli [147], Davies [43], Sole and Elena [173], Krzanowski [100], and Landauer [103–106]. However, if information is physical, then Vopson (e.g., [194–197] claims it must have mass, as physical things generally have a mass, or at least most of them (e.g., Kane [90], Koks et al. [92, 93], Hecht [77]). Of course, things are not that straightforward with information.

Vopson's claim of information having mass is puzzling, so let us engage in a thought experiment. Say we have a piece of paper with some scribbles written on it in ink. We can precisely determine the mass of a paper plus the mass of the ink that was added to the paper. Now, if these scribbles convey information, and if information has mass, this piece of paper will have a greater mass than the same piece of paper with uninformative scribbles (e.g., gibberish) or even the same piece of paper with the same volume of ink but as an inkblot. Alternatively, take an old computer punched card, which was an early storage medium for computers. When the card has not yet been punched, it carries no information for anyone or anything. Once holes are punched in it, however, it may contain information, such as a computer program or accounting data. Yet this punched card with information has a lower mass than an information-free card without holes. Thus, adding information has subtracted mass from the card, which conflicts with Vopson's claim because it implies that information has a negative mass[20], at least if we insist that information has mass.

Obviously, Vopson's claim that information has mass must mean something different to what our examples would suggest. Indeed, it seems that Vopson argument is based on his conceptualization of information. In this section, we discuss the key points of Vopson's claim, because the question of information's relationship with mass, as posed by Vopson, has been studied and discussed in detail by Burgin and Mikkilineni in a paper upon which this discussion is based [26].

Vopson states, following Shannon, that "information (I) extracted from observing an event (X) is a function of the probability (p) of the event (X) to occur or not, I(p)" [194]. Furthermore, the average information per event, or the number of bits of information per event, that one can extract when observing a set of events X once is:

$$H(X) = -\Sigma_{j=1}^{n} p_j \cdot log_b p_j$$

Where $H(x)$ denotes the information entropy, p is the probability of an event X_j occurring, and b is the logarithm base, based on the work of Shannon [166] and follow-ups by Shannon and Weaver [168, 201].

There is a well-known formal similarity[21] between the $H(x)$ formula and that for Boltzman's thermodynamic entropy (i.e., the Boltzmann–Planck equation):

$$S = k_b \cdot ln(\Omega) = N \cdot k_b \cdot H(X) \cdot ln(2)$$

Where Ω is the number of microstates that are compatible with the macro–state, N is the number of sets of events, and $k_b = 1.38064 \cdot 10^{-23} J/K$ is the Boltzmann constant [5, 18, 87].

Furthermore, with $b = 2$, following Hartley and Shannon, we can talk about encoding (digital) bits as ones and zeros, and in turn, we can talk about the entropy of encoding digital bits of information (information entropy). The entropy of encoding one bit of information is then $S = k_b \cdot ln(\Omega) = k_b \cdot ln(2)$. To clarify, however, the bits used by Shannon in his information entropy ($H(x)$) formula are used to measure the amount of information, and no semantic interpretation is associated with this concept

[20] See, for example, "In our universe, there is no such thing as negative mass. Mass only comes in positive form" [8].

[21] By "formal similarity", we refer to similarity in the symbolic form. For example, the formula $x = ax - b$ is in form similar to the formula $f = kz + g$. However, the two formulas may express completely different sematic content. To make this clearer, we could say that the two phenomena are not necessarily similar or the same, even if they can be quantified by the same mathematical structure (e.g., a linear equation).

of information. This is the link between information and bits (0/1) that was forged by Shannon and adopted by others, including Vopson [74, 166, 168, 201].

Vopson observed that the total entropy S_{tot} of a physical system, by which he means digital memory, carrying information is the sum of the physical entropy S^i_{phys} related to the non–information–bearing states of the physical system and the information entropy S^i_{info} associated with the information–bearing states of the physical system (i.e., $S_{tot} = S_{phys} + S_{info}$).

Changes in S^i_{info} (bit erasure) must be compensated for by changes in the system entropy, similar to with the second law of thermodynamics. This dependency is presented as a rule and referred to as the Landauer principle [103, 138].

The Landauer Principle

For every bit of information irreversibly lost, the entropy of the system must increase with an absolute value of heat released per bit lost, such that $\Delta Q = k_b \cdot T \cdot ln(2)$.

With T being the temperature in (K^0) and ΔQ being the amount of heat released.

Vopson's claim about information and mass capitalizes on the Landauer principle. He states that holding (storing) information requires that a bit has mass m_{bit}, with him saying:

> In this paper a radical idea is proposed, in which the process of holding information indefinitely without energy dissipation can be explained by the fact that once a bit of information is created, it acquires a finite mass, m_{bit}. This is the equivalent mass of the excess energy created in the process of lowering the information entropy when a bit of information is erased. Using the mass–energy equivalence principle, the mass of a bit of information is:
>
> $$m_{bit} = k_b \cdot T \cdot ln(2)/c^2$$
>
> where c is the speed of light. Having the information content stored in a physical mass allows holding the information without energy dissipation indefinitely [195].

He then adds an explanation:

> The implications of this rationale are that the equivalence mass–energy principle inferred from the special relativity can be extrapolated to the mass–energy–information equivalence principle, which essentially represents an extension of the original Landauer's principle [195].

Vopson is aware that his claims are specific to the carrier media he chooses, so he writes:

> The mass–energy–information equivalence principle proposed here is strictly applicable only to classical digital memory states at equilibrium. Information carried by relativistic media, moving waves or photons require a quantum relativistic information theory approach and it is outside the applicability framework of this article [195].

Furthermore, he adds:

> Similarly, other forms of information including analogue information, or information embedded in biological living systems such as DNA, are not within the scope of this work [195].

Of course, the claim that "the information content stored in a physical mass allows holding information without energy dissipation indefinitely" is untrue, at least if taken literally, because information storage devices, particularly the magnetic media that Vopson refers to as standard storage devices, degrade over time [19, 118, 183]. Thus, Vopson's claim about indefinitely storing bits should be qualified by the phrase "for all practical purposes".

Nevertheless, barring this qualification, according to Vopson, a bit stored in storage media (classical digital memory, probably referring to magnetic media) has a mass equivalent to the energy required to erase it. This equivalence to energy is expressed as a mass–energy–information equivalence principle under the assumption that information is bits.

So, what is Vopson claiming? (1) Vopson defines information as a sequence of digital bits (0/1) encoded in computer memory, which is classical digital memory in the form of a magnetic carrier. By Vopson's own statement, his claim is not valid for other forms of information. (2) By encoding information as bits in a physical carrier, Vopson interprets it as adding (or subtracting) mass from the carrier. The creation or erasure of bits, or manipulating information on the physical carrier, requires energy. Storing, holding, or keeping a bit requires a mass that is equivalent to the energy required to erase or create this bit, and it does not involve any energy exchange. Thus, in a sense, the bit has a mass that is equivalent to some energy quanta (i.e., energy for erasing a bit).

We can reconstruct Vopson's argument (A) as follows:

(A1) Information is bits (0/1).

(A2) The erasure or encoding of bits in digital storage media requires work or energy.

(A3) Bits are stored indefinitely (for all practical purposes) in digital storage media without energy dissipation.

(A4) Bits are stored indefinitely (for all practical purposes) in digital storage media with physical mass.

Thus:

(C1) Information as bits has mass.

(C2) There is a mass–energy–information (as bits) equivalence.

Let us look closely at argument (A). If Vopson's claim is that information is stored in digital storage only, we can call it a narrow interpretation (1). However, if Vopson's claim is about information in general, it is a totally different ball game, so let us call this an extended interpretation (2). The second extended claim seems more in line with what Vopson had in mind, because the mass–energy–information equivalence that he proposed would be a physical law on par with, and indeed an extension of, the mass-energy equivalence of special relativity [194, 195, 197]. If Vospon's claim is limited to (1), he could not possibly generalize it to general physical law, because by his own admission, his claim applies only to standard digital storage.

Vopson's argument also presents other difficulties. Looking at the physics of encoding data on magnetic tape, Vopson's claim seems odd. Storing bits on magnetic tape involves manipulating the magnetic properties of the carrier medium [19, 118, 183]. In other words, encoding bits onto a tape changes the structure of carrier, but it does not add anything substantive to it[22].

Thus, the energy used to create a bit is not used to create mass but rather to rearrange the physical structure of the carrier medium. For example, recording bits on a magnetic tape rearranges "magnetic oxide particles in a plastic binder" rather than changing the mass of the tape. Indeed, most digital storage media works by changing the structure of the carrier medium (e.g., [69, 84, 119, 127, 146]).

Furthermore, in Vopson's paper, information is equated with the structure of the carrier medium, so information is added structure overlaying the structure of the medium with its own entropy. In other words, information structure has its own entropy S_{info} and the carrier has its own entropy S_{phys}. Nevertheless, information is rarely equated with the physical structure of a carrier, simpliciter. What Vipson claims to be information is a structure holding the information of the carrier or digital storage medium.

A simple explanation for Vopson's paper goes as follows: Information is always carried in some physical carrier, and we agree with Vopson here. It is encoded as, or in, a carrier's structure, but information is not the structure itself, and this is where we start to diverge from Vopson's claims. Indeed, bits are not information, not even for Shannon, but rather a measure of the amount of information, which may have other forms of disclosure. The work/energy attributed by Vopson to information (i.e., bit manipulation, encoding, erasing) is actually the work/energy required to change the carrier structure in order to encode information rather than changing the mass of the carrier by adding information. (Recall that with punched cards, we subtract mass when we add information).

This explanation agrees with most interpretations of information, including those of Landauer and Burgin and Mikkilineni. Information certainly has a physical manifestation, being always perceived in some physical form or being embedded in a physical object. As many researchers have pointed out, however, as already indicated, information is not a physical object [29, 38, 43–45, 49, 78–80, 100, 129, 139, 147, 163, 173, 179, 190, 203, 205].

[22]"The recording medium for the tape recording process is typically made by embedding tiny magnetic oxide particles in a plastic binder on a polyester film tape. Iron oxide has been the most widely used oxide, leading to the common statement that we record on a 'ribbon of rust' ... The oxide particles are on the order of 0.5 micrometers in size and the polyester tape backing may be as thin as 0.5 mil (.01 mm). The oxide particles themselves do not move during recording. Rather their magnetic domains are reoriented by the magnetic field from the tape head" [118].

As Burgin and Mikkilineni stated, quoting Landauer, " 'information is inevitably tied to a physical representation' [105] and not with his more far–reaching claims such as 'information is a physical entity' " [26].

The same principle is expressed in the concept of ontological information [100] and in the principles of the GTI theory. Burgin and Mikkilineni's paper [26] provides a detailed analysis of Vopson's proposal in light of the GTI.

In summary, what Vopson is observing and measuring is energy flow in encoding/erasing bits, and what he is observing as changes in mass (due to information) are energy flows and structural changes to information carriers like digital magnetic memory, as he explicitly restricts his claims to this type of memory storage, so bit encoding does not add mass through information.

Bit operations in computer systems are based on fundamentally physical processes, including thermodynamics (e.g., Feynman [59]). Whether the mass of digital memory changes with added or erased content is related to the carrier medium and the encoding processes, and it has no relation to the concept of information (see, for example, Burgin and Mikkilineni's paper). Last but not least, if information in Vopson's explanation has no mass, the mass–energy–information principle cannot be valid. What does hold, however, is that imparting information to physical media requires energy to change the structure of the carrier medium.

5.2. Rovelli and the meaning of physical information

Does purely physical information have meaning? We claim that it does not, if meaning is understood as in cognitive sciences (see e.g. [134]), which is a rather prevailing understanding of this term (see e.g. [175]). This understanding of meaning has been the key to the differentiation between epistemic and physical information. However, Carlo Rovelli's paper "Meaning=information + evolution" [147] discusses the concept of meaningful, physical information that seems to extend the cognitive science concept of meaning onto physical realm.

Information is mostly perceived (it is epistemic information in this paper) as an abstract idea that is closely associated with knowledge, cognition, or communication. It has meaning, intentionality, and purpose, and its presence depends upon the existence of a cognitive agent. Information may also be regarded as a concrete, physical phenomenon. Such information does not need an agent to exist, but it has no meaning, purpose, or intentionality.

So how can information be, at the same time, abstract and endowed with meaning while also being concrete and physical yet meaningless? Paul Davies [43] identifies this abstract–concrete dichotomy as a fundamental problem of information. Carlo Rovelli [147], meanwhile, also highlighted this gap between information as a physical phenomenon and information with meaning. Rovelli [147] outlines how to close this gap.

Rovelli [147] uses Shannon's theory of communication (TOC) concept for measuring information and derives from this the "relative information" between two physical systems. He denotes it as "a purely physical version of the notion of information" or a purely “physical correlation”. Pure correlation is defined as the correlation of two probability distributions (in compatible state spaces) or as the difference between (information) entropies of two probability distributions. As Rovelli states, “[these] correlations can exist because of physical laws or because of specific physical situations, or arrangements or mechanisms...” Therefore, a “purely physical correlation”, which is information for Rovelli, represents some (co–)dependence of the (two) states of physical systems. In other words, the two states are correlated, and the entropy difference or joint probability are formal expressions of this relation.

Further, Rovelli proposes, following the Wolpert and Kolchinsky paper [206], that Darwinian evolution provides the essential mechanisms to endow the natural/physical processes related to the evolution of organisms with some notion of meaning, purpose, and intentionality. From this viewpoint, environmental/physical stimulus has meaning for an organism if it increases its chances of its survival (or preservation). As a very rudimentary example, if bacteria are able to avoid a harmful environment by sensing it through some sort of physical stimuli, interpreting it correctly, and initiating evasive action, it creates meaning out of the physical sensory input. In other words, it creates meaningful information for itself. This is how environmental stimuli acquire meaning, intentionality, and purpose. (In the original text [206], the meaning of information is tied with an organism's ability to stay outside the “thermal equilibrium”, that is, to keep a low entropy state). By combining a Darwinian–based interpretation of meaning, purpose, and intentionality with information perceived as a correlation between physical states using relative information [166], Rovelli defines purely physical meaningful information. In his own words, he creates “the crucial first link of the chain” for connecting physical information with meaning, as expressed in the paper's title: “meaning = information + evolution”.

So, what is Rovelli's “purely physical definition of meaningful information”? Rovelli used Shannon“s information measure – Shannon never defined information but rather a measure of information and information entropy–to define the relative information (the information element of Rovelli's definition) and then applied this to the physical aspect of evolutionary processes, thus obtaining the Darwinian element responsible for meaning in Rovelli's definition. However, in his definition, Rovelli implicitly adopts the whole framework of Shannon's communication model (TOC) and the formula for the amount of information in messages between agents (i.e., information entropy). Why is this important? First, the model of relative information derived from Shannon's TOC information entropy implicitly includes at its basis the concept of the communication model. This implies that (physical) information is created by agents or exchanged between them, so the communication context is essential for the creation of meaning.

The author sensed he was on rather unstable grounds when blending the TOC, physical phenomenon, meaning, and intentionality, and he admits that his ideas are merely proposals. Rovelli also points out that this sort of meaning is a very primitive one. The distance between the theoretical models of the cosmos or Bach's fugues and a bacteria's reaction to its environment are light years apart, yet the reaction of the bacteria is, at its core, the seed for others. This is conceptual quicksand for sure. Granting meaning, intentionality, and so on to natural biological systems is, it seems an anthropomorphization of nature. Restricting these concepts to people runs the risk of incurring human exceptionalism. The proper approach is probably somewhere in the mythical middle, such as recognizing the exceptional human cognitive ability but viewing it as an emerging function in a higher level biological system. Another approach is to simply bite the bullet and stick to more widely recognized definitions.

Summing up Rovelli's view, information is correlation (pure correlation) between two physical systems (as defined above) and meaningful information is pure correlation in the above sense within the context of an evolutionary process being viewed as a communication process. This approach excludes, in principle, the concept of information where it is an intrinsic, not agent–relative, feature of physical phenomena.

Rovelli's meaningful information is certainly an interesting idea and worthy of study. However, its novelty and import must be placed in perspective. Shannon's TOC naturally lends itself to the concept of physical information in evolutionary processes, because communication is a physical process at its foundations and the very essence of evolution is based on communication between the environment and living agents. It must be said, however, that Shannon probably did not intend to make an association between purely physical processes, evolution and information [167]. As we said, Darwinian evolution is in some sense just a specific instance of a communication model being adopted for an evolutionary process. It is rather obvious that we are the creations of evolution (and therefore created through communication), and our cognitive faculties are the product of this process (see e.g., [130, 159]).

5.3. How does information perdure?

Information is a physical phenomenon that is perceived as a form or organization of nature. (For the different explanations of this concept, see the works of physicists and philosophers like Turek [190], Collier [38], Wilczek [205], Carroll [29], and Rovelli [148]; cosmologists such as Reeves [140], Stonier [179], or Heller [78, 79]; and philosophers such as Seife [163], Burgin [25], and Krzanowski [100].) As every physical phenomenon exists in time and space, at least for a certain time, so does physical information[23]. All physical things (including the Universe itself) persist in that they come into existence, exist for a certain time (maybe in changing forms), and disappear (as with Heraclitian flux), but what happens to information?

[23]The term "physical" in "physical information" denotes information in nature. Modern use of the term "physical" seems to be limited to specific domain of research (e.g. "Of or relating to matter and energy or the sciences dealing with them, especially physics" (physical n.d.). The proper understanding of the terms "physical" and "nature" can be gained from the Greek meaning pertaining to what exists as in "Greek *physikē* (*epistēmē*) (knowledge) of nature", from fem. of physikos "pertaining to nature", from physis "nature", from phyein "to bring forth, produce, make to grow" (related to phyton "growth, plant", *phylē* "tribe, race", phyma "a growth, tumor") from PIE root *bheue- "to be, exist, grow" [58]. See also Rovelli [149].

Persistence is the propensity of an object to exist through time [109]. Persistence theories are concerned with the identity and constitution of things over time, whatever they may be. Lewis's definition – with its use of vague terms like something, somehow, and various times–is quite generic and denotes nothing specific.

Two leading proposals are the theories of endurance and perdurance [4,10,39,75, 76,109,115,122,170,199].

Theories of persistence apply to objects with proper parts (i.e., things, hunks of matter), persons, events, and processes (e.g., [31,115]). However, physical information is not any of these, so the current theories of persistence do not seem to apply. Furthermore, as all the current persistence theories have been criticized, selecting one or another to account for the persistence of information would not resolve the problem but rather initiate a debate, because each option would be contested.

We posit that our understanding of the persistence of information may be enhanced by studying the persistence of snowflakes as epitomes of natural objects caught up in Hericalitian flux.

We regard snowflakes as low-entropy complexes that epitomize the persistence of natural objects [140]. Forming complexes (i.e., ice crystals) that later disintegrate exemplifies nature's flux: transition from low to high and to low organization states. Snowflakes come into being in specific conditions, under the spontaneous (natural) process of crystallization, such that water vapor crystallizes to form a solid: an ice crystal. They exist for a certain period before disappearing when the surrounding conditions change (e.g., [5,40,65,192]).

Information in snowflake crystals is disclosed through their complex morphologies, but it is not morphology as such. Information is rather latent order in nature that is seen in nature's organization. But information (as latent order) is not directly observable, so what is observed as natural structures are its effects, i.e., information discloses itself through the morphology (i.e., structure, form) of a physical object.

Generalizing this observation from snowflakes to nature, we could say that establishes information as a fundamental element of nature that is responsible for nature's structural properties, one that is always present and not vanishing or emerging as a "force" or "tendency" that counteracts the Second Law of Thermodynamics (e.g., [40,57,207]).

Nevertheless, can we really generalize, as we just did, this observation from snowflakes to nature? It seems that we can. A snowflake's emergence and disappearance are results of the interplay between two tendencies of nature, namely (a) the creation of local low–entropy complexes and (b) nature's drive toward the increased global entropy [40,96,110,111,155,207]. It may be suggested that (a) is an expression of nature's power for latent order (the term used in this study) or an inherent feature of nature much like entropy is, although it may counteract it in a local context. Thus, the interplay between (a) and (b) resulting in the emergence of natural complexes that is observed for snowflakes discloses persistent properties that are intrinsic in nature in general, not just in snowflakes.

On the persistence of information, we may say:

- Physical information as latent order (i.e., the potential of nature to create complex morphologies or low–entropy complexes) is intrinsic to nature. It does not disappear when an object disappears, nor does it emerge out of nothing when a complex object emerges. It persists alongside nature.
- Consequently, persistence theories (i.e., endurance, perdurance, and their derivations) do not apply, because these theories have been mostly constructed to account for the persistence of ordinary objects.

We may also claim that:

- If physical information plays a fundamental role in nature, information cannot be identical to, or identified with, the external form or shape of an object, because this is temporal and ephemeral. These forms would be better regarded as the medium through which information discloses itself to us at any given moment in time as unstable states of matter, rather than information itself.
- Thus, information conceptualized as latent order in nature, or nature's potential to spontaneously form local low–entropy complexes, satisfies the properties attributed to information in the works of Burgin [25] and Krzanowski [99, 100].
- Further, the definition of information formulated by Burgin [24, 25], stating that information is a capacity (ability or potency) of things, both material and abstract, to change other things (Ontological Principle O2) [24, 25] reflects best information as latent order in nature.

6. Conclusions

Now, what can we say in conclusion to this review? The concept of information under different meanings is used in almost every possible area of research, whether it be the popular press, technology and engineering, philosophy, the humanities, communication, the social sciences, and so on and so forth. Unfortunately, this leads to a multitude of definitions and gives the impression that we are facing numerous phenomena, but we have disputed this impression, both methodologically and philosophically.

The several proposals discussed in this paper may help develop a more comprehensive perspective for the nature of information. Adopting ontological and epistemic perspectives for information represents an attempt to better organize what we know. Indeed, reducing the hundreds of definitions to just two can be regarded as progress, even if it is not a perfect solution. The GTI is certainly so fundamental that it creates a metaphysical basis for any type of information. If you want to regard information as a kind of Platonic essence, the GTI is the way to go. Nevertheless, the GDI, complete as it is, is in large measure limited to semantic information. As comprehensive as such theories are, none of these theories have received the level of recognition attributed to Shannon's TOC and its measure of information entropy. Shannon's TOC is operational and computable and has immense practical import, and it has inspired several extensions. It correlates with the Kolmogorov–Chaitin complexity theory and points to possible connections between information and fundamental physical laws, so it is a hard act to follow. In contrast, the GTI is a deep, philosophical, conceptual, foundational theory that tells us about foundational concepts and organizes dispersed conjectures into a whole, which is no easy task. Nevertheless, being highly theoretical, the GTI may not play as large a role as the TOC, except perhaps in the philosophy of information and in guiding our general comprehension of information. In reality, though, Shannon's TOC and Burgin's GTI are not competing theories. Using the metaphor of a car engine, we could say that Shannon's TOC tells us how the car engine is working, while Burgin's GTI tells us why it is working.

For now, it seems that we all agree that information is in some form certainly embedded in nature, which we are part of, although we may disagree about what this form is. Thus, one may argue that talking about information in a variety of contexts, versions, and domains is not in any way a mistake. Instead, it expresses its ubiquitous, multifaceted presence in our world and in ourselves. (Recall the old story of the wise men and an elephant in a dark room).

However, we should strive to prefer synthetic views that promote a deeper, more wholesome understanding rather than novel, exciting proposals that serve to further fragment our already shattered concept of information. Indeed, we should strive for unity rather than for multiplicity, because the latter will always partial and incomplete.

In closing, we should point out that while we tried to be comprehensive, this review is in no way complete. The sheer volume of ideas that has been produced, and continues to be produced, for information means that any effort will always be non–exhaustive. Nevertheless, a more coherent picture of the various conceptualizations can be seen to emerge. We therefore have reasons to be both satisfied and disappointed. We know much more, and understand much more, about information than we did in Shannon's time and before it, which is a good thing. We also have deep metaphysical theories about information, such as the GTI, which seems to cover the phenomenon of information quite comprehensively. Nevertheless, we still have a profusion of information theories, definitions, and variants thereof. The desire for unity in information has not permeated through the philosophical commons (see Wikipedia), however. The profusion of information theories has resulted from attempts to distinguish one's own research from that of others by claiming to have discovered something new or corrected some misunderstanding about what information is. In other words, the trees have been mistaken for the forest. Moreover, despite his explicit warning, Shannon is often the unwitting source of such works [167]. In the meantime, information is all around us, whether we define it or not.

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Affiliations

Roman Krzanowski
The Pontifical University of John Paul II in Krakow, ul. Kanonicza 25, 31-002 Krakow, Poland, rmkrzan@gmail.com

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