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What Is Physical Information?

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Abstract: This paper presents the concept of physical information, and it discusses what physical information is, and how it can be defined. The existence of physical information has been discussed in several studies which recognize that properties of information are characteristic of physical phenomena. That is, information has an objective existence, a lack of meaning, and can be quantified. In addition, these studies recognize how a phenomenon that is denoted as physical information can be expressed as an organization of natural or artificial entities. This paper argues that concepts of (abstract) information that are associated with meaning also depend (to a substantial degree) on physical information.

Keywords: physical information; abstract information; physical phenomena; abstract entities

1. Introduction

In this paper, we study information that is defined as physical concrete phenomena. We also discuss its properties, and its relation to abstract concepts of information. This section presents the background to this study, the justification for undertaking it, and its potential benefits. This section also introduces some basic terms used within the paper.

The various definitions of information range from abstract notions of knowledge, messages, symbols, and signals [1–7], through to more physical notions as objective phenomena [8–11], and on to more quantified concepts—often expressing information as a series of bits [5,11–16].[1] It seems, however, that most concepts of information can be subsumed under two broad categories.[2]

In the first category, we bring together concepts that present information as something abstract, while in the second category, we can gather concepts that define information as a concrete physical phenomenon.

Information in the first category is presented as an abstract concept, therefore, we denote it as information$_A$, where the "A" represents "abstract".[3] In some definitions, information$_A$ results from a human agent's interaction with nature [17]. In some other definitions, information$_A$ may result from the cognitive activity of some non-human organism [18–20] or even some artificially intelligent agent [21,22]. However, in other cases, information$_A$ is claimed to exist independently in some world of ideas [23], or in other cases, information$_A$ may be seen through semiotic concepts [24]. Yet others claim that this information is data, or at least derived from data; from this perspective, the boundary between data and information$_A$ is quite fluid [4,5,25–30]. To many authors, information$_A$ is the prevalent conceptualization of information, and when they write about information, they claim that this is what

[1] Mark Burgin [14,16] lists 32 mathematical formulas for information.
[2] We acknowledge that a generalization like this will never be 100% accurate, therefore some concepts of information may not fit into either of these two categories, or they may, in some sense, belong to both.
[3] By "abstract," we refer to something not existing in space-time as a physical object.

information is really like [5,14,22,31–39] (note that this list is by necessity selective, and therefore incomplete).

In the second category, information is regarded as a physical phenomenon, so we denote it as information$_C$, where the "C" represents "concrete".[4] As information$_C$ is a physical object or phenomenon, it can be measured and quantified, transformed, observed, and used. In this sense, such information is a property of matter and the physical world, and some claim it is the third constituent element of reality (e.g., [9]). Information$_C$ relates to the organization of nature, from the sub-atomic level to large-scale objects, from particles to cosmic bodies [40]. Authors who recognize the existence of physical information and its function in nature include the likes of von Weizsäcker [41], Turek [8], Hidalgo [10], Rovelli [11], Nagel [17], Devlin [34], Heller [42,43], Collier [44], Stonier [45], Polkinghorne [46], Seife [47], Schroeder [48,49], Dodig Crnkovic [50], Wilczek [51], Carroll [52], Davies [53], and Sole and Elena [54]. (As before, the list is by necessity selective and incomplete.) Table 1 below summarizes the main properties of information$_A$ and information$_C$.

Table 1. Main properties of information$_A$ and information$_C$.

	Information$_C$	Information$_A$
1	Information$_C$ is a physical phenomenon, so it exists objectively and is not relative to anything.	Information$_A$ is a cognitive agent's (artificial or biological) interpretation of physical stimuli, which may be a signal, the state of a physical system, or some other physical phenomenon.
2	Information$_C$ has no intrinsic meaning.	Information$_A$ exists for a cognitive agent, or it is relative to a cognitive agent. In other words, information$_A$ is agent-relative or ontologically subjective. Information$_A$ has meaning for a cognitive agent.
3	Information$_C$ is, in a sense, responsible for the organization of the physical world.	The cognitive agent may be a human, a biological system, or some artificially intelligent system.
4	For information$_C$, existence implies existence in the physical world, somewhere in the space–time continuum.	For information$_A$, existence denotes the presence of an abstract notion somewhere outside of space and time.

This study focuses on the second category of information, namely, information$_C$, and discusses how the existence[5] of this information is recognized, the properties that can be attributed to it, and its relationship to information$_A$ (see also Krzanowski [55]).[6] But why is the concept of information$_C$ so important, at least to the author? With the multiple definitions and classifications for information, our understanding of it resembles the parable of the blind men studying an elephant (Shah [56]): We each know a part of the investigated object, but not the whole. The hope is that the concept of information$_C$ may unify our view of information or put it in some order. Unifying the different concepts will further our understanding of reality and increase our recognition of its complexity and coherence, and such things are worth pursuing in their own right. That is why we search for a Grand Unified Theory (GUT) or a Theory of Everything (ToE).

Is information$_C$ a completely novel idea, though? Well, yes and no. On the one hand, the concept of information as a physical phenomenon is certainly not new. Information as a physical entity in various forms has been proposed by many authors (as mentioned above). On the other hand, no comprehensive study has investigated what the concept of information$_C$ entails or how it should be interpreted. This study, therefore, attempts to fill this gap.

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4 By "concrete", we mean existing in space and time as a physical object.

5 In all cases of information, though, how can we say that both kinds of information exist? After all, the statement about how information$_A$ "exists" is not compatible with the statement about how information$_C$ "exists". The concept of existence in the case of information is discussed later in the study.

6 Information$_A$ and information$_C$ have many interpretations that vary depending on what a specific author regards as concrete or abstract, so this division into two basic classes of information is certainly a generalization. There are also proposals for combining abstract and physical aspects into some sort of unified form of information. One example of this is Rovelli's purely physical meaningful information (i.e., physical information with meaning). We could denote such information as information$_{AC}$. The concept of information$_{AC}$ is not discussed here any further, however, but more details can be found in Rovelli's paper (Rovelli [11], Krzanowski [55]). Something worth noting, however, is that a concrete-abstract combination is only plausible after significantly changing the meaning of its component terms. In Rovelli's case, the concept of meaning (i.e., abstract knowledge) is reworked. In addition, the suggested resolution by Rovelli for the concrete–abstract concept of information has little to do with the general abstract–concrete problem of metaphysics [57,58]; Rovelli's proposal specifically addresses the concept of information, but it does not resolve the metaphysical abstract–concrete division.

In the following discussion, we first present how information as a physical phenomenon may be recognized and comprehended. The cited authors have supplied a short list of features that ground the claims of this phenomenon's existence in physical facts. We then focus on three characteristics of information as a physical entity, although these characteristics are not necessarily novel, however, because every physical phenomenon must, by definition, possess some of these properties (see also [57–59]).[7] The question then is, therefore, one of whether we can attribute these features to information, not one of whether these features have been correctly chosen. Next, we look at the dependency between information$_C$ and information$_A$. We then propose that information$_A$ can be derived from information$_C$, but information$_A$ cannot be simply reduced to information$_C$. In the final section, we summarize the main points of this paper and present some problems that have been indicated for information$_C$, but left unresolved in the reviewed studies.

When we talk about concrete information (information$_C$) in this paper, we may use the term interchangeably with other terms like objective information (i.e., information that exists objectively) or physical information (i.e., information as a part of physical reality), or we may follow Rovelli's example of purely physical information (i.e., equivalent to physical information). Likewise, when we talk about abstract information (information$_A$), we may use the term interchangeably with similar terms like subjective information (i.e., information that depends upon a cognitive agent), epistemic information (i.e., information related to knowledge), and meaningful information (i.e., information conveying meaning). Finally, the generic term "information" is used to denote any specific concept that must be qualified according to a context or a descriptive term, otherwise it is devoid of meaning. In addition, when we talk about an object, we are referring to something that exists in physical reality.

2. Is Information$_C$ a Physical Phenomenon?

This section seeks to answer the following questions: Why do we claim that information is a physical phenomenon? Are there natural phenomena that we can class as information?

The concept of information is always associated with form, structure, or organization in some way. For example, information$_A$ represents meaning that a cognitive agent has associated with the form, structure, or organization of some entity. Information$_C$, in contrast, recognizes the form, structure, or organization of some entity as a purely physical phenomenon in itself. But what are the consequences of saying that information$_C$ is a physical phenomenon? It essentially means that information$_C$ is an irreducible aspect of physical reality. Information$_C$ is therefore not like a rainbow or a temperature of a volume of gas[8]. Instead, information$_C$ exhibits properties that we attribute to physical entities, namely, that (a) it is observable, (b) it is ontologically objective, (c) it can be manipulated, (d) it has no meaning, and I it can be quantified or measured.[9] Information$_C$ exists wherever physical reality exists, just like other physical phenomena. Information as a physical phenomenon that exists objectively has been recognized in the studies of, for example, Mynarski [9], Rovelli [11], Devlin [34], Heller [42,43], Collier [44], Stonier [45], Polkinghorne [46], Seife [47], Caroll [52], Dodig Crnkovic [50,60], and Dodig Crnkovic, Muller and Burgin [61]. Furthermore, Hidalgo [10], Stonier [45], and Seife [47], among others, posited that this information can be manipulated. VonWeizsäcker [41], Seife [47], Carroll [52], Stonier [45], Hidalgo [10], and Collier [44], meanwhile, recognized that this information is not associated with any meaning, and this observation has been confirmed in many other studies. In addition, the studies of von Weizsäcker [41], Barrow [62], Davies [53], Sole and Elena [54], and Heller [42,43] demonstrated that this information can be quantified. Thus, information$_C$ is not

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[7] The general features that characterize a physical phenomenon are often disputed, so we follow the most prevalent views on scientific realism [59].

[8] A rainbow and a temperature of a volume of gas are physically reducible to (can be explained by) more fundamental phenomena: white light refraction and the average kinetic energy of gas molecules, respectively.

[9] For more about the conditions for attributing ontology to a physical phenomenon, see the works of Worrall [59], Klee [63], Chakravartty [64], and Liston [65]. We bypass the discussion between the scientific realists and the anti-realists and assume the first position.

conceptualized as an abstract concept in the way that mathematical objects, ideas, or thoughts are abstract (i.e., they exist outside of space and time). Therefore, information$_C$ also does not belong to the Platonic realm of Forms in either the old- or neo-Platonic sense (there will be more about information$_C$ and Plato's Forms later in the study). Information$_C$ is a natural phenomenon, and therefore, contained within nature, just as every physical object is (see also [63–65]).

To avoid making any unfounded claims, we state that information$_C$ must always exist within a physical medium (i.e., it cannot exist on its own). In other words, it is not something existing outside of physical objects, like Forms in Plato's Theory of Forms, but rather a part of physical reality.[10] From this perspective, information$_C$ is the third constituent element of nature [9,34,47], with the first two being energy and matter. This perspective, therefore, excludes any conceptualization of information$_C$ as something mysterious or esoteric or any other form of magical phenomenon hitching a ride on a physical medium.[11] What is more, we also prevent anyone from associating this information with some structure that overlays physical objects, as was suggested by Bates [66], Dinneen and Brauner [67], and in some sense Von Weizsäcker [41].

We now ask another question: What properties should we assign to information$_C$, and how should we interpret these properties?

3. Three Features of Information$_C$

When information is defined as a physical phenomenon, it has to have properties in common with other physical entities, namely, the ones that make them physical phenomena (e.g., Worrall [59], Klee [63], Chakravartty [64], Liston [65]). In addition, information$_C$ has a property that makes it a phenomenon in its own right. These properties are discussed below.

We posit that information$_C$ (1) exists objectively, (2) lacks meaning, and (3) expresses the organization or form of physical objects (we will further explain this last claim later on). We posit that we need all three of these features to describe information$_C$. First, objective existence alone is insufficient to uniquely characterize physical information, because everything in the real world exists objectively. The same applies to the lack of meaning and the presence of some organization when considered separately.[12] Any combination of two of the three features (e.g., lack of meaning with objectivity, organization with objectivity, etc.) is also not specific enough. Only the combination of these three features is sufficient to make information$_C$ a distinguishable physical phenomenon, so all three features are needed to adequately describe information$_C$. We do not claim that information$_C$ has only these features. But we only claim, based on our current understanding of information$_C$ these three features are sufficient to characterize it. It is possible that, in the future, this set of properties may change.

3.1. Information$_C$ Exists Objectively

If information is a physical phenomenon, it exists objectively. In other words, it has ontological objectivity [68]. Objectivity, in this context, refers to how the phenomenon in question exists independently of an observing agent, much like how rocks exist on the dark side of the Moon even though we cannot see them from Earth, or how the Earth existed for eons before sentient beings appeared.

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[10] Several authors explain the place of physical information in nature and propose a sort of matter–energy- information complex. As a conjecture, this proposal can remain, but as a scientific or even philosophical claim, it lacks enough specificity.

[11] The analogy of thermodynamic entropy may help here: Entropy itself is an abstract concept, but it refers to a real, physical phenomenon that can be measured, observed, and so on. The same is true of information$_C$: The concept is abstract, but it denotes a real physical phenomenon with specific properties.

[12] The common meaning of chaos should not be confused, as is often the case, with the meaning of chaos in nature. Chaos in nature (or what we call chaotic phenomena) is actually highly organized dynamic phenomena; entropy (incorrectly) that is often associated with chaos. It is incorrect to claim that these two phenomena are unstructured or disorganized. Nature is never disorganized—it is just the way it is. It only appears disorganized to us.

Claiming that information$_C$ is a physical phenomenon is both necessary and obvious if we are to perceive information as part of the physical world. If this is the case, as we presume it is, this information must be subject to the laws that govern the physical realm, although we are not exactly sure which laws apply to information$_C$ (e.g., the law of gravity, the law of conservation of energy, the three laws of thermodynamics, the theory of general relativity, or other yet unknown laws for information)[13].

The claim that information has a physical nature has been voiced in several studies. Von Weizsäcker claims that information has an "objective character," adding that information is related to the combination and composition of elementary particles. Heller, meanwhile, claims that information may be regarded as a material of the world, with the word "material" being used here in the sense of some physical substance from which things can be made, although Heller does not clarify synonyms like substance, stuff, or medium. Dodig Crnkovic, meanwhile, claims that information is an ontologically fundamental entity of physical reality, while Hidalgo proposes that what remains after separating meaning from meaningful information is just a physical phenomenon. Devlin claims that information is a part of reality that is on par with energy and matter, and Mynarski makes a similar claim. In a similar vein, Stonier claims that information has a physical reality, so it is an intrinsic feature of the universe. Finally, Seife claims that the world is composed of matter, energy, and information. In many other studies [9], the complex of matter, energy, and information is considered to be foundational in nature.[14]

3.2. *Information$_C$ Has No Meaning*

This claim states that information$_C$, as a natural/physical phenomenon, is meaning-less,[15] so the meaning is overlaid on, or added to, information$_C$ rather than it being an intrinsic part of it. How this meaning is created from, or associated with, information$_C$ is an open issue, however. Information$_C$ is just present out there, much like the rocks and the trees, regardless of whether or not some cognitive agent is there to observe them (see also [69–72].)[16] When a tree falls in the forest, it creates a wave of air pressure (i.e., an organized physical phenomenon), which in itself is meaningless. If we are close enough to hear, we add meaning to the sound. (Such a claim is easily verified through a first-hand experience)

Meaning is defined as something that has value or import for a cognitive agent, but this is just one possible definition. An agent may obtain something of value from information$_C$, something that has some significance for the agent's existence. The meaning may also be an interpretation of information$_C$—which otherwise, as we have said, is just an inert physical phenomenon—with us attributing to its various properties, such as structure, shape, or importance. Reading tea leaves and astrology are just two examples of such interpretations. The same information$_C$ may have different meanings for different agents, however, or it may not have any meaning at all for some agents. An agent is primarily an artificial or natural system that creates meaning for itself.

In principle, when perceiving environmental stimuli, some claim that there is no clear distinction between an artificial cognitive system, a simple biological system (e.g., a cell or a simple organism), and a conscious cognitive agent in terms of creating meaning [73–77]. From this perspective, and with

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[13] Every element of the physical realm is a subject to some physical laws, otherwise, by definition, it would not be physical.

[14] The term "complex" denotes a combination of elements as "a whole made up of complicated or interrelated parts". We use this term to avoid referring to hylemorphism.

[15] Meaning-less denotes an entity that lacks meaning in its essence, while meaningless denotes an entity that has no meaning in a specific context.

[16] Meaning has many interpretations. For this study, if not otherwise stated, we follow the definition from the philosophy of language, where the term "meaning" denotes how language (linguistic constructs) relates to the world. A review of the various theories of meaning is beyond the scope and purpose of this work, however. An extensive list of references can be found in [69], among others. The theories claiming that meaning is the *correlata* to the world are contested by some good arguments by Chomsky [70–72].

a sufficient degree of abstraction, an agent could, in principle, be any organic or artificial system that senses and reacts to information$_C$ in some way.[17] The lack of any sharp boundaries between meanings in different agents creates a problem for identifying the locus of information$_A$, which is discussed later in this study.

3.3. Is Information$_C$ the Organization of Matter, or Is Responsible For It?

This claim asserts that information$_C$ is responsible for the organization of the physical world.[18] On the one hand, this seems to be the most critical aspect of information, because information, in general, is fundamentally associated with the concept of some form, organization, or structure. On the other hand, it is very difficult to define what it precisely means when we say that "information is associated with the concept of some form".[19] The difficulty arises from ambiguity in the concept of form and organization, as well as in the concept of "association".

Organization may be, as is commonly the case, interpreted as structure, order, form, shape, or rationality when it is perceived by a cognitive entity. We do not posit that information$_C$ is a structure in itself, because we do not know exactly what structure is, nor do we know what kind of structure would be associated with information or how this association would take place. Information$_C$ is certainly not the visible structure or shape of objects, although we admit that information$_C$ does reveal itself through the shape or structure of objects. Objects may be seen in a certain way, as being something, yet this may not be their essence, i.e., information$_C$ is responsible for the shape of things, but it is not their visible shape that is information$_C$. By way of an analogy, energy presents itself as the capacity of a system to do work, yet it is not work in itself; see the discussions in [78–83].

The word "association" denotes the relationship between the organization or form of information$_C$ and physical reality. This concept is critical to information$_C$, but we simply do not know what this relationship is. We only guess at its importance. More specific solutions always come down to, in some way, the matter–energy–information complex, but this relationship is as enigmatic as hylemorphism, both in its old and new renditions. The cited authors, despite referring to it, are also not clear about the meaning of this association. It seems that, for now at least, we need to remain at this rather imprecise descriptive level.

Why do we not associate information$_C$ with a specific structure, though? If we did try to equate information$_C$ with some domain-specific structure, such as a mathematical structure or the structure of the physical laws, information$_C$ would simply acquire the characteristics of that domain. In other words, such information would take on a mathematical or scientific flavor, respectively. It also seems that quantifications of information tend to quantify "sensible shapes" rather than the information itself. As an analogy, when we measure mass, we usually measure the gravitational force between it and the Earth rather than the actual mass.[20] In addition, stating that information$_C$ is a mathematical

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[17] Natural agents (i.e., biological systems) have been shaped by nature to sense its properties, including its structure (i.e., information$_C$). Nagel [17] discusses the dependency between an environment and an agent in detail. Indeed, we are built to interpret nature, so we could say that interpretation comes to us naturally (we are interpreters per se). Indeed, we seek interpretations, because they are essential for survival and because evolution deems that agents who fail to adequately perceive their environment will not survive.

[18] We are not sure how to interpret the function of information$_C$ in nature. One thing that is certain, however, is that the existence of information$_C$ is recognized in the form of objects. However, whether its role is that of Plato's Forms or Aristotelian *eidos*, or whether the role of information$_C$ is causal or not, is not well understood at present. Some studies claim [9] that information is a primary element of nature, or that information is a third element of nature in an energy–matter–information complex, but these are just intuitions. Due to this ambiguity about the role of information, the statements about information$_C$ and the organization of matter are imprecise.

[19] The structure/organization of physical reality is such a fundamental concept that it cannot be described through other concepts, because structure lies at the foundation of everything that exists. We cannot talk about reality without talking about structure. However, this is, of course, just conjecture.

[20] We stay away from unresolved disputes about the nature and ontology of mathematical constructs, because bringing unresolved disputes into the discussion will not further the resolution of other unresolved disputes, such as the nature of information$_C$ in this case.

structure of reality would entail adopting some form of Neo-Platonism, which is not a generally accepted interpretation of mathematical objects (see e.g., [84]. We should, therefore, avoid these domain-specific claims and accept that information$_C$ is domain-neutral. What is more, if we were to just claim that information$_C$ is structure, it would not mean much, due to the ambiguous concept behind this unspecified structure. We would then ultimately end up treading the path of structural realism or informational structural realism with its epistemic or ontological versions. In addition, the structures in structural realism are passive, and they do not carry the meaning of "informare" (to shape), or at least nobody has attributed such causal powers to structures in the structural realism literature.

We must add here that different formal representations for information$_C$ are not incorrect (e.g., Shannon, Fisher, Chaitin), but they simply do not address the essence of what they measure[21]. This is how mathematical formula typically relate to nature [84].

Thus, we merely posit that information$_C$ is just one factor responsible for the organization of the physical world.

3.4. Information$_A$ and/or Information$_C$

We have differentiated two classes of information: abstract and concrete. In this section, we discuss how these two concepts relate to each other.

Information cannot be both abstract and concrete at the same time and in the same sense. What is abstract cannot be concrete, and what is concrete cannot be abstract, not when these terms are interpreted through their most common meanings.[22] Information$_C$ is a purely natural phenomenon—it is in nature, and it is a part of the physical world. Existence for this information implies the existence of a physical entity. Information$_A$, in contrast, is abstract, so it relies upon the existence of some cognitive system. (We exclude here Popper's concept of World 3 and similar ideas.) Now, let us explore these differences through an example.

Different physical structures may represent the same piece of music. It may be a series of air pressure waves with physical structure S_A, or it may be the grooves on a vinyl record with physical structure S_B. These and many other structures, can, under certain conditions, all be interpreted as the same piece of music (i.e., the same information$_A$). Thus, we have several physical objects, each with its unique organization, or information$_C$ (i.e., S_A, S_B, etc.), yet there is only one information$_A$, namely, the piece of music.[23] This piece of music is, therefore, clearly a common element of the objects with structures S_A, S_B, and so on. Obviously, this common element cannot be physical, however, because there is nothing physically common among these very different physical structures. Indeed, the only thing these physical objects share is how they all can be interpreted in the same way by someone or something (i.e., as the piece of music). As the music is not embedded in the physical structures, it must therefore exist outside (transcend) those physical structures in some sense. Thus, it would appear that information$_A$ clearly "exists" in some way. After all, how else could completely different physical structures convey the same meaning? It would seem clear to conclude that abstract information exists, so information is really information$_A$, not information$_C$. Such a conclusion has been reached in many studies [66,67,85,86]. However, we claim that this conclusion is incorrect or at least inaccurate.

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[21] The case of the different mathematical representations of physical information is to some extend but not exactly, similar to the case of two different mathematical models of quantum mechanics (Schrodinger and Heisenberg). Herman Weyl stated that these models are "alternative representations of the same mathematical structure" (as quoted by Heller [86]). We do not claim that physical information is a mathematical structure but we suggest that the different mathematical models of information represent the same physical information as organization, as Schrodinger and Heisenberg's models are different representation of the QM structure.

[22] Abstract things are objects outside space–time. Concrete objects exist in the physical world and are subject to the laws of physics [57,58].

[23] These physical structures can also generally be converted from one to another (e.g., recording a radio performance onto a cassette tape) while preserving the capacity to be interpreted as the same piece of music (i.e., the same information$_A$).

As controversial as it may seem to some, it seems that the proposed explanation for the piece of music is equally applicable to books, symbols, computer programs, game rules, works of art, and so on.

The correct explanation, we believe, goes as follows: The physical structures (S_A, S_B, etc.) seem to carry the same information$_A$ because we, as cognitive agents, shape these structures in a certain way and later read/interpret them in a corresponding way, thus attributing an interpretation to them. These music-carrying physical structures are radically different, as are their physical carriers (e.g., airwaves, the impression of a vinyl record, etc.). What makes these carriers seem like they "carry" the same music is the interpretation of the agent rather than some factor (information$_A$) that exists outside (or transcends) the physical realm. The agent merely imposes (encodes) appropriate structures over a physical entity following some agreed-upon standard and later decodes it through an appropriate physical process, again following the agreed-upon standard. Music exists purely in the mind of the listener, composer, or interpreter, however, and "abstract information" does not float around in some metaphysical space, a sort of world of ideas that stands ready for us to access it.[24] As we said, information$_C$ is a multilevel organization of physical entities. In the case of music, we are interpreting the macro-level structures of physical objects, not their micro-level organization.

We need to be careful when using terms like "is in," "carries," "is embedded," "locked in," and "contains" when describing how information$_A$ relates to information$_C$. For example, information$_A$ is not "embedded" in a physical object in the usual sense of the word. Information$_A$ does not exist as some component, substratum, or ingredient of a physical object. Information$_A$ is created by a cognitive agent when it encounters some otherwise meaning-less physical phenomenon and decodes its form or organization (usually only a very selective subset of information$_C$) for its own use or benefit. This explanation should, we hope, counter any assertions that a physical object cannot be information because it cannot carry information$_A$ [67,85].

It is entirely possible that a different mind from some other world would interpret the same physical structure differently, so these structures actually only carry music for us. There is no music as we know it in viruses [87], biological cells [88], or heavenly bodies [89], yet these physical objects all have specific structures or organizations. We more or less understand the neural perceptual processes for perceiving the organization of physical objects through our cognitive systems, but we do not know how we perceive music. In short, we do not understand the phenomenology of music, nor do we understand the phenomenology of information$_A$ in general.

We assume here that the mind is a non-reducible biological phenomenon rather than a reducible emergent phenomenon, even if we cannot accurately explain what it is at our current level of knowledge (apparently, some animals also enjoy Mozart or Bach [90]). We obviously try to avoid Descartes' duality, so we do not postulate the existence of abstract information as some esoteric entity. We also do not advocate the strict reductionism of mental features to neuronal levels. Of course, this argument can apply only if the concept of the mind is positioned as the locus of information$_A$, which is created (in part) based on different physical signals/stimuli [91]).[25] While this explanation takes away the "abstractness" of information$_A$ (because it grounds such information in a biological system), it does not explain how the information in our minds is created, transformed, stored, accumulated, and "transferred" back into our artifacts when we shape physical things. For example, there is no natural law that shapes a car, a table, or a watch (see the modern version of Paley's argument in [92]).[26] We must admit that we simply do not yet understand how the mind works, so our theories of the mind cannot provide a conclusive explanation for it at present.[27] The only thing we can assume is that the natural world,

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[24] Apparently, Mozart claimed that he did not compose the music but merely noted it down, however this may be a psychological phenomenon rather than a scientific argument for the independent existence of information$_A$.

[25] See, for example, "human behavior is determined by physical processes in the brain" [91]. Similar views are widespread in the literature of the field.

[26] I am referring to the 747 junkyard argument, the details of which may be found in [92].

[27] We assume that the current explanations of the mind as a kind of software and the brain as a kind of hardware are wrong and misguided. See, for example, the arguments of Searle [94].

including the mind and its created artifacts, is causally closed, and there is no "bifurcation" of nature into the world of nature and the world beyond, as implied by Descartes but denied by Whitehead and other modern philosophers of science. What is more, we may safely claim that thoughts and the mind are part of this world, much like the other phenomena we experience and observe. This claim, however, is not meant to endorse material monism and certainly not physical reductionism [93,94]. There are philosophies of the mind (e.g., biological naturalism) that classify the mind, consciousness, thoughts, ideas, and so on as not being reducible to matter, yet they have a material base [68,95–99] (note that many philosophers of the mind contest this antireductionist view, such as [100]).

In summary, we claim that information$_C$ exists objectively in the physical realm. It is unique in the sense that every physical object has its own organization or structure. Two physical objects may have a similar organization, or their organization may mean the same thing to us (as in the example of music), but their sameness (to us) does not come from these objects. Information$_A$ also exists (as an abstract entity), but its existence is contingent upon the presence of a mind or other cognitive system. Information$_A$ can also be transferred, stored, communicated, preserved, and transformed, but it needs a physical media to carry it and a mind to recreate it.

4. Information$_C$: To Be or Not to Be?

Thus far, we have presented research that recognizes the existence of information$_C$, but some authors deny that such information exists. We look at some of these studies and weigh their arguments.

Dinneen and Brauner [67] claim that "information-as-a-thing," which for them is information as a physical phenomenon, cannot account for "typical views of information".[28] These problems are avoided, they say, if information is seen as an abstract entity. The only example of "information-as-a-thing" (i.e., physical information) they provide in their 2018 study is a book (as a physical object). We could delve deeper into Dinneen and Brauner's argument, but this is not necessary. It seems that they set up their definition of physical information to fail, because according to their definition, physical information (a book) cannot be information because it cannot have meaning, so information is not physical. This is rather obvious, though. Physical information, or a book in their example, is meaningless by definition (a book is a physical object). Dinneen and Brauner's claim is in some way correct, because the physical object (the book) is meaningless in itself, as all physical objects are. However, their argument against the existence of physical information as a physical phenomenon, based on the example of the book, is incorrect because they are looking for meaning where there is none to be found. Dinneen and Brauner's attempt was, therefore, certain to fail, because they were looking for meaningful information or meaningful physical information rather than just physical information. For Dinneen and Brauner, "typical views of information" reflects what we refer to in this study as information$_A$. There is nothing typical about this, even though it may be the most prevalent view of information. In science, however, the truth of a theory is not determined according to a majority vote, and the minority opinion is often the correct one. Dinneen and Brauner, it seems, missed the nature of information$_C$; information$_C$ is not a physical object itself, but its organization (in a sense) discussed here.

In their earlier paper, Dinneen and Brauner [85] formulate three arguments for why a physical thing cannot be information or, more precisely, why what they call "information-as-a-thing" cannot exist. First, "the value of the physical representation is first and foremost its content, and not the physical embodiment of it". Thus, putting forward information-as-a-thing as information is clearly ignoring the content of a physical thing, and we are concerned with this content. Second, talking about physical objects as information is not accurate, because when talking about information, we are more interested in what these physical objects (e.g., DVDs, CDs, USB sticks) contain rather than the things themselves. Thus, the definition of information as a physical object is misleading, as well as the conclusion of the first argument. Third, the same physical object may contain different information

[28] " . . . that physical things cannot be information, and information therefore cannot be a physical thing" [67].

depending on time and place: For example, a book's content may be interpreted differently. This creates, according to Dinneen and Brauner, a metaphysical problem of identity. If information is a physical thing, it must be the same in all circumstances, otherwise we would have two or more things being the same physical object. We have partially addressed these three arguments in Section 4. As in the above discussion, Dinneen and Brauner do not distinguish between information$_C$ and information$_A$. When they talk about information, they are actually talking about information$_A$. They are, in a sense, attributing information$_A$ with a physical presence, and as we have pointed out many times in this study, information$_A$ is not physical, and a physical object is not information$_A$. It may "contain" information$_A$ for one or more agents, at least in the sense of "contain' as explained above, but a physical object is never information$_A$. In a rather stretched analogy, we could say that energy does not work, nor does it contain work, but it is certainly related to work. The analogy stops here, though. In defining information (information$_A$) as a physical object or information-as-a-thing, we are obviously making a mistake by conflating the abstract with the concrete, which will clearly never work. As we said before, physical information is not a physical object in the sense of specific object like a book, a DVD, etc. Physical information, or information$_C$, is the organization of these objects, as explained in the previous sections. What Dinneen and Brauner face is the concrete-abstract split indicated by Davies [53] and Rovelli [11],[29] but while Rovelli and Davies managed to comprehend and overcome it, Dinneen and Brauner did not.

Bates [66], following Edwin Parker (quoted by Bates), identifies information in nature as a pattern of, or within, physical things. However, Bates' information is not physical, because it is a pattern, an abstract concept realized through a physical medium and recognized by a cognitive agent. This interpretation is seen in Bates' claims that while information as a pattern is everywhere in the universe, total entropy is pattern-free,[30] so it has no information. Therefore, according to Bates, total entropy cannot be interpreted as a pattern, so Bates' notion of "information as a pattern of physical things" is added to some physical phenomena, but not to others.[31] In short, we may say that in Bates' view, information is not a physical entity, even when it is associated with physical objects, but rather a perceived pattern of physical objects. In her own example, some physical phenomena are information-free. It therefore seems that Bates' information has nothing to do with information$_C$ and is more akin to the concept of natural information seen in Millikan's work [101], which is also not information$_C$. By Millikan's very definition, natural information comprises infosigns carried by natural phenomena that "initiate perception" [101]. In this definition, natural information appears to be simply information$_C$ plus the meaning or interpretation for a physical carrier. Recall that information$_C$ does not need to initiate perception to exist. A similar definition of natural information is given by Piccinini and Scarantino [102].

The conviction that information must have meaning has prevented many researchers from recognizing the existence of physical information. This "epistemic turn" (see James [103]).[32] is characteristic of modern philosophy, and it began with Descartes. For example, von Weizsäcker [41] and others later on, claimed that information must be also physical in some way, yet he could not recognize information without meaning.

Some of the arguments against the concept of information$_C$ have been generated by identifying information$_C$ with Plato's Forms. One such argument, namely, a modified version of the Third Man

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[29] The problem is stated as follows: "How can information be physical and abstract at the same time?"

[30] We do not go into details about what is "total entropy" or whether information as a pattern would appear if entropy was less than total (whatever that means for Bates) (i.e., would information as a pattern disappear at one point, or would it appear or disappear gradually?).

[31] The claim that "total entropy is pattern-free" is incorrect, because every physical phenomenon has some organization or pattern, although it may be beyond our understanding in some cases. Bates repeats the common misconception of equating entropy (assumedly thermodynamic entropy) with the popular notion of chaos (of sorts).

[32] The "epistemic turn" denotes the reorientation of modern philosophy from ontology to epistemology as the main philosophical perspective on nature.

argument, asks: If information$_C$ is in every physical object, is information$_C$ in information$_C$? Another argument questions how the same information$_C$ may exist in different physical objects at the same time (i.e., how does the same physical thing (information$_C$) exist in many different places at the same time?) These problems apply to Plato's Forms in his metaphysical view, but as we said from the start, information$_C$ is not one of Plato's Forms, because such objects exist outside space and time, so in this sense, they are abstract objects. While Plato's Forms are in some way physical things (in Plato's view), the nature of their existence (outside the space-time) and relation to reality is exactly what makes them controversial. Information$_C$ as a physical phenomenon does not suffer from these shortcomings, just as physical objects do not suffer from the same shortcomings. For example, we do not question whether energy is within energy or whether matter is within matter, even though these phenomena are everywhere. Information$_C$ is more akin to the Aristotelian concept of eidos, but as we pointed out earlier, such analogies to ancient ideas are very precarious and should be drawn with great restraint. This is why we do not discuss them further in this study, or we do not propose them to be renditions of information$_C$.

Taking a larger view, any researcher who claims that the concept of information is inherently and exclusively associated with meaning and knowledge is implicitly denying the existence of information as a physical phenomenon for the obvious reasons explained above (i.e., information cannot be both abstract and concrete in the same way and at the same time). Surprisingly, such claims are made with full knowledge that human agents are physical-information-processing systems (see, for example, [18,19,104–106]), and as a computer, our main data-processing system is a purely physical, mindless, and meaningless device. We need to take us (or the mind) out of this picture in a kind of Copernican move to see information$_C$.[33]

As a reminder, the existence of information as a physical entity is supported by the studies in which information (the concept of information) has been found to have properties that are attributable to physical objects, the studies that have found information useful for explaining certain physical processes, and the studies that have found information as a unifying factor in explaining a range of natural phenomena. (See the authors quoted in the earlier sections of this study.)

5. Physical Information Revisited: Conclusions and Questions

The time has come to summarize the main findings of this study. We conceptualized physical information, or information$_C$, as a natural phenomenon that has three properties: (i) a physical, objective existence, (ii) the absence of intrinsic meaning, and (iii) an organization of, or within, nature. These properties are, of course, subject to many interpretations, so they need to be understood within the context of the cited studies.

Information$_C$, (as a physical phenomenon) exists objectively in the same sense as the physical world around us. Information$_C$ is not abstract in the way that mathematical concepts and ideas are abstract. However, whatever exists contains information$_C$ in some form, and there is no physical phenomenon without information$_C$, because every physical phenomenon has some level of organization (even if we do not recognize it). Information$_C$ is meaning-less, however, just like all other physical phenomena. Meaning is associated with, or attributed to, information$_C$ by some sort of cognitive system. How meaning is created, though, lies beyond the scope of this study. Information$_C$ is a constituent element of nature, and it discloses itself through the organization of the physical world. 'Organization' is a fairly broad concept, but in this study, organization can be regarded as structure, order, form, or shape, although it cannot be simply identified with it.

Information$_C$ is a carrier (in the sense that was explained earlier) of information$_A$, which is information with meaning or value. Meaning is what we, or generally any cognitive agent,

[33] By "a Copernican move' we understand the position in which a human person is not the vantage point from which to look at nature.

associate with information$_A$. The process of creating information$_A$ depends upon the cognitive agent, and in some sense, information$_A$ exists in the agent in the same way that thoughts and ideas exist. We always need to be careful when using the term "exist," however, because it means different things for abstract and concrete information. Meaning is defined as something of value for the cognitive agent. From information$_C$, an agent may derive something that has some significance for the agent's existence or functions, so the agent essentially creates meaning for itself. The same information$_C$ may have a different meaning for a different agent, or more significantly, the same information$_C$ may have no meaning at all for an agent. What constitutes an agent, as well as which agents can create and possess abstract information, is disputable. We could represent the meaning of information on a linear spectrum from purely physical information at one extreme to fully meaningful information for a human agent at the other extreme. The precise boundary between concrete and abstract information may seem fluid, because the concept of meaning is often extended to minimally cognitive organisms, whatever that means, and artificial systems [107,108]. (Indeed, the fluidity of this boundary was exploited by Rovelli in his concept of information$_{AC}$.) However, one pole of this meaning spectrum is meaning-less, and this is where information$_C$ lies. The problems with information$_A$ vs. information$_C$ begin when we start trying to attribute meaning to information$_C$.

The fact that we do not propose any mathematical or formal formula for information$_C$ derives from the fact that this information is represented as an organization or structure of nature, so it may be quantified at different levels in many different ways through many different mathematical models, yet there is no single preferred way to do this. Some models may seem more useful than others, so they may acquire an aura of being "the right model".

Last but not least, we may ask how relevant Floridi's General Theory of Information (GTI) is to the concept of information$_C$ [4]. We ask this because the GTI is seen as an exemplary, comprehensive attempt to define what information is and subsume most, if not all, of the other definitions [85]. Very briefly, the GTI is defined as "data + meaning". In other words, GTI information is data endowed with meaning. We have already discussed what meaning is, but what is data here? Floridi is not clear, however. He writes: "nothing seems to be a datum per se. Rather, being a datum is an external property". This definition somewhat expresses the idea that a datum does not exist in its own right but rather that it is some "X" with added meaning (i.e., it is an external property). Thus, the concept of a datum in the GTI is relative, and its existence depends on some agent elevating it to the status of a datum. Thus, the GTI may be alternatively expressed as "(X + meaning) + meaning". This X is defined as a "fracture in the fabric of being," a "lack of uniformity," or an "external anchor of information". In fact, we do not know what it is, and we cannot by definition know what it is (Floridi compares it to Kant's noumena). So, the GTI is essentially grounded in something we do not know. A somewhat charitable interpretation of the GTI (by disregarding the status of X) would be that because GTI information is tightly coupled with meaning, it actually has nothing to do with information$_C$. The GTI information is, therefore, a comprehensive, very detailed formulation of information$_A$, but as we said, this would be a charitable interpretation. Notwithstanding the grounding problem (the status of X), the GDI is still a very useful and thorough attempt to organize and rationalize information$_A$ and may serve as a reference point in the discussions about the nature of information.

Maybe we should again emphasize what is proposed in this study. Every physical phenomenon has some organization or form (in the sense explained), and we denote this as information$_C$. Information$_C$ is a concrete, physical phenomenon, thus it has no meaning. Cognitive agents that interact with nature—or as we could instead say, the physical environment—sense and react to information$_C$. The interaction between an agent and the environment is physical. In some cases, an agent absorbs some subset of information$_C$ via its sensory apparatus, and on combining this with its internal resources in some way, it creates information$_A$. At present, the process in which information$_A$ is created is only vaguely understood. (We do not accept any views that would reduce the mind to neuronal levels or explain the mind as an illusion, a kind of software, or other emergent phenomenon in a reductive sense.) A physical object (a book, a DVD, a CD disk as in the examples cited) is not information$_C$, although

information$_C$ is part of it, and in principle, it does not carry any information$_A$. Unless we were to postulate some transcendent ontology for meaningful entities (see Popper or Peirce), information$_A$ does not exist in a physical sense. Information$_A$ and information$_C$ may coexist, but existence in both cases means a different thing. The conflict arises when we try to conflate information$_A$ and information$_C$ or attribute the same mode of existence to them.

Several questions about the concept of information$_C$ remain unresolved, and the proposed list below presents some of them. These questions are speculative, but they appear in the research on information$_C$, so they are related to this work. Of course, the real list of unresolved questions about the nature of physical information is likely to be much longer than the one below.

In all the questions below, the term "information" refers to information$_C$.

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 Carroll [52], for example.)

Question 2: Can we claim that whatever exists must contain information$_C$? 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 Stonier [45], Turek [8], and Carroll [52], for example.)

Question 3: Can we interpret information$_C$ 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 Carroll [52], and von Weizsäcker [41], for example.)

Question 4: Information$_C$ 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 Heller [42,43], Dodig Crnkovic [60], Stonier [45], 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 [2].)

Question 6: Does information$_C$ imply some form of modern hylemorphism?[34] *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* (see Jaworki [109]) (Suggested by the writings of Polkinghorne [46], Turek [8], Krzanowski [110], and Carroll [52], for example.)

[34] William Jaworski argues why the hylemorphic structure is the best, and perhaps only, means for explaining the persistence of individuals who change their matter over time. Hylemorphism claims that some individuals, paradigmatically living things, are composed of physical materials with a form or structure that is responsible for them existing and persisting as the kind of things they are. One objection to hylemorphism is that an account of the physical materials that comprise an individual is insufficient to account for everything it is and everything it does. William Jaworski, however, argues that this objection fails insofar as hylemorphic structure is the best, and perhaps only, means for explaining the persistence of individuals who change their matter over time [109]. A similar claim was made almost 40 years earlier by Turek in a 1978 article on the concept of information and its relation to a restricted form of hylemorphism [8].

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 Seife [47], Dodig Crnkovic [50,60], and Dodig Crnkovic and Mueller [61], 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$_C$ through the concepts of structure and structural realism.* (Suggested by the writings of Heller [42,43], and Schroeder [48,49].)

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