information

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Review

Theory and Metatheory in the Nature of Information: Review and Thematic Analysis

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Abstract

This paper addresses the nature of information through a thematic review of the literature. The nature of information describes its fundamental qualities, including structure, meaning, content and use. This paper reviews the critical and theoretical literature with the aim of defining the boundaries of a foundational theory of information. The paper is divided into three parts. The first part addresses metatheoretical aspects of the discourse, including the historicity of information, its conceptual ambiguity, the problem of definition, and the possibility of a foundational theory. The second part addresses key dimension of the critical discourse, including the subjective, objective and intersubjective nature of information, its relationship to meaning, and its relationship to the material world. The final part summarises the main conclusion and outlines the scope of a foundational theory. This paper highlights important gaps in the critical tradition, including the historicity of information, and in its relationship to material reality, complexity and computation. This paper differs from prior reviews in its thematic focus and consideration of metatheoretical aspects of the critical and theoretical tradition.

Keywords: information theory; nature of information; information philosophy; information science; meaning the representation; thematic review

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1. Introduction

This paper addresses the nature of information as a foundational theoretical concept. The nature of information encompasses both epistemological and ontological questions, and describes its fundamental characteristics, including its structure, meaning, context and use. It has been called both the fundamental problem of information science [1] and "the hardest and most central problem" in the Philosophy of Information [2] (p. 30). Yet, despite its conceptual importance across a number of disciplines, there remains little general agreement on what information signifies. Krzanowski, for example, observes that "we still have a rather vague understanding of what information is" [3] (p. 1), and Beavers suggests that "we can scarcely say precisely what the term means" [4] (p. 16). Information is the absent signifier, a concept that defines contemporary experience but whose underlying nature remains hidden.

The nature of information matters because of its role in defining aspects of contemporary experiences. We live in an information age, dependent on information technologies and embedded in an information ecosystem. Information has become a critical component in our understanding of both the social world and our material lives. Floridi, for example, observes that "much theoretical work relies on a clear analysis and explanation of information and its cognate concepts" [2] (p. 30). Indeed, information has been described as both

"a privileged term in our culture" [5] (p. 7) and "a pivotal concept in the sciences and humanities and in our everyday life" [6]. Yet, despite its centrality, we still lack a foundational theory of information.

This paper does not seek to develop such a theory but to trace its boundaries, mapping the conceptual issues that information poses in a thematic review. The literature on the nature of information is very broad, spanning multiple disciplines and many decades. This breadth makes systematic sampling intrinsically problematic owing to the risk of unintentional bias. Accordingly, the paper adopts a pragmatic and iterative approach to sampling, identifying from the literature itself those theories, papers and traditions that have been most influential. The discussion is presented thematically. This paper first addresses metatheoretical aspects of the nature of information, including the difficulty posed by information as a theoretical object, and the possibility of a foundational theory. It then discusses the key ontological and epistemological aspects of information in an attempt to map-out and define the boundaries of theoretical and critical concepts. Finally, the paper sets-out the scope of a foundational theory of information.

Prior general reviews of the nature of information include Wellisch [7], Wersig & Neveling [8], Shera & Cleveland [9], Belkin [10], Cornelius [11], Capurro & Hjørland [12], Logan [13], Adriaans [6], Robinson & Bawden [14], Bawden & Robinson [15] and Krzanowski [3]. Burgin has also provided a useful discussion on approaches to understand the nature of information [16]. This paper differs both in its thematic approach and its critical focus on central issues of disagreement and metatheoretical aspects of the discourse.

2. Metatheoretical Aspects of the Nature of Information

2.1. Historicity of Information

Information is a word with considerable reach and social significance. It is amongst the "main semantic words which form the substance of ordinary, everyday speech and writing", alongside basic words describing common aspects of the immediate world and for describing the world in abstract terms [17]. It is therefore clearly an important concept for describing common aspects of everyday contemporary experiences. However, this has not always been the case. Although attested in English since the Middle Ages in the sense of 'knowledge communicated', the term 'information' came into more common use in the nineteenth and twentieth centuries [17]. This shift is significant, testifying to the profound social and technological changes accompanying the industrial and communications revolutions, and to the emergence of information as a defining concept of late modernity.

Language use tracks historical change of a more subtle kind than implied by the mere etymology of individual concepts. Weller, for example, has argued that "language is the most subtle reflection of social change", noting that changing language use during the nineteenth century in particular can be obscured by our over-familiarity with the resulting vocabulary [18] (p. 138). Baugh and Cable make a similar point, suggesting that language captures the moment that "the object, experience, observation or whatever it is that calls it forth has entered public consciousness" [19] (p. 295). From the nineteenth century, information lent itself to innumerable neologisms that trace changing perceptions. These include informational (1821); information-giving (1829); non-information (1852); information-seeking (1869); information work (1890); information gap (1891); information-carrying (1920); information explosion (1941); information flow (1942); disinformation (1955); meta-information (1956); informatics (1967); information poor (1970); information bubble (1975); infomercial (1980); information warfare (1982); informatisation (1984); and information fatigue (1991) among many others [15].

These emerging uses map the scope of information's changing significance, reflecting the complex interaction of technological and social changes. They testify to profound

shifts in the organisation and structure of human culture. Information is also a social product [20] (p. 386). Poster, for example, observed that "each method of preserving and transmitting information profoundly intervenes in the network of relationships that constitute a society" [5] (p. 7). The historicity of information is therefore also a history of its changing uses. This has important consequences for understanding its fundamental nature, emphasising what Roberts described as its social significance [21]. Both Weller [18,22] and Adriaans [6] have argued for the nature of information to be understood in relation to this richer historical context. Weller in particular notes that "there is too often an emphasis upon how the tools and technologies for organising and disseminating information have evolved and changed, while assuming that information itself has remained fixed and constant" [18] (p. 139). This history should be a part of the theoretical discourse. But the conceptual history of information also includes the ways that critical and theoretical discourse remediates its social and technological contexts. Shannon's theoretical work, for example, arguably reflects the immediately prior context of wartime cryptography. His theoretical work in this area included an analysis of redundancy and the use of probabilistic approaches that were subsequently generalised in information theory [23,24]. Information Science arguably "emerged in the post-war proliferation of scientific activity" [25] (p. 589) and traced new methods of documentary reproduction [9]; Buckland in particular has highlighted "the presence of technologically-minded individuals from outside librarianship who were seeking to marshal new technology to solve old problems" [26] (p. 16). The story of our theoretical understanding of information is rich and complex. Yet, as Adriaans notes, "the detailed history of both the term 'information' and the various concepts that come with it is complex and for the larger part still has to be written" [6].

In general, the critical discourse addressing its fundamental nature has avoided historicising the problem of information, and this remains as a significant gap in the literature. While the historicity of information has been frequently traced through its etymology (e.g., [12,16,27–31]), these accounts lack the richer engagement with historical context that typifies information history. This arguably reflects an implicit assumption that both the nature of information and its accompanying theoretical discourse are largely independent of the social, cultural and historical contexts within which information is created, disseminated, used and stored. That assumption reveals itself in a present-centred bias that emphasises developments in technological and documentary culture over the relatively recent past, and overlooks their broader social context. There is much to be gleaned about the nature of information from a thorough analysis of these changes.

The historicity of information has been more fully addressed by mass-market and popular accounts, including those by von Baeyer [32], Gleick [33] and Harari [34]. It has also been addressed in information history in, for example, the work of Alistair Black [35–37], Toni Weller [18,22] and others [38,39]. Studies of this kind have the potential to contribute to a richer understanding of the nature of information.

2.2. Ambiguity of Information as a Concept

The complex history of information has left what is widely regarded as an ambiguous concept with a wide range of reference (e.g., [40–43]). This is among the most common and consistent observations about the nature of information in the critical literature. Raber, for example, describes information as "a complex sign characterised by considerable ambiguity" [42] (p. 2). Fairthorne suggests that information is a convenient label "for an amorphous mass of ill-defined activities and phenomena" [41] (p. 710). Hayes describes information as "a slippery concept, amorphous, loaded with connotations and implications" [44] (p. 218). Yovits notes that the definition of information within information science is often "nebulous, varied, and non-rigorous" [45] (p. 6). More recently, Krzanowski suggests that "the concept

of information appears to be fragmented, malleable and elusive" [3] (p. 14) and Hjørland that "information is a polysemic and vague word" [31].

This perceived ambiguity has frequently been taken as evidence that information denotes a complexity of largely independent phenomena, each requiring its own theoretical justification. Shannon famously argued that "It is hardly to be expected that a single concept of information would satisfactorily account for the numerous possible applications of this general field" [46] (p. 105). Goffman suggested that information "can neither be formally defined nor precisely measured" [25] (p. 591) and concluded that its use in many different contexts precluded a single definition encompassing them all. Otten stated that "when we try to define information we recognise that there is a variety of apparently fitting statements, but that none is universally valid" [47] (p. 93). More recently, Bawden and Robinson questioned whether information denotes a range of "things and processes which have only a superficial, or a very general, similarity" [15] (p. 1). It is not obvious or apparent that information denotes a unified phenomenon susceptible to a single theoretical description.

Alternatively, information may lack stable referents. Krzanowski notes that it may well be "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 to information than what we already know" [3] (p. 2). Fairthorne suggests information is a convenient label "for an amorphous mass of ill-defined activities and phenomena" [48] (p. 710. Wellisch reluctantly agrees with this position, suggesting that "one must [. . .] abandon any attempt at a scientifically sound statement on the nature of information" [7] (p. 175). Burgin claims that "information is related to everything, in other words, there is nothing that does not involve the use of information" [16] (p. 51), and Buckland has noted that "If anything is, or might be, informative, then everything is, or might well be, information. In which case calling something information does little or nothing to define it" [49] (p. 346). Roszak warned that "words that come to mean everything may finally mean nothing; yet their very emptiness may allow them to be filled with a mesmerising glamour" [50] (p. 10); a theory of information may well be a theory without consistent foundation.

Nevertheless, as Kaplan notes, the lack of agreement on the specification of meanings of particular terms does not imply that these terms are used without commonly understood meanings [51]. While information is often described as ambiguous, there is little evidence of significant misunderstandings or confusion about its meanings. Indeed, the importance of information in contemporary theory across a wide range of disciplines implies that even without a precise definition, information remains a useful and comprehensible concept. Raber has noted that "while there may be disagreements over its exact nature [. . .] information remains like other natural phenomena, is a rationally intelligible object" [42] (p. 8) and argues that information is indeterminate only because it "can plausibly and usefully be determined in so many contradictory ways" [42] (p. 19). This suggests that the problem of conceptual ambiguity may have been overstated; information may not be ambiguous but overdetermined, lending itself to multiple interdependent meanings.

Overdetermination may highlight an underlying ontological principle rather than confusion about its nature. Krzanowksi has noted that "the root of the divergent views may lie in the nature of information itself" [3] (p. 3). It may imply, for example, that information is a complex phenomenon revealed indirectly through its emergent properties. Alternatively, overdetermination may arise from different socially and epistemologically situated assumptions about the uses, reach and significance of information. Raber, for example, has noted that "different ways of thinking about information as a phenomenon are closely related to different ways of thinking about what needs to be studied and why" [42]

(p. 9). Qvortrup suggested that while information "seems to be innocent [. . .] its definition implies a whole theory of knowledge" [52] (p. 3). Tredinnick has also noted the following:

> "While it may appear that different theoretical viewpoints share a basic understanding of key problems because they share a basic vocabulary in which those problems can be articulated, the reality is more complicated. In the spaces of seemingly trivial terminological disagreements violent ideological battles are waged". [53] (p. 19)

Information is a contested concept, and its theoretical framing has developed within independent disciplinary traditions with different basic assumptions. While there have been some attempts to bridge these divides [12,14–16], more work remains to be conducted, both to map different disciplinary perspectives and to understand their influence on different conceptions of information. Yet, by exposing the tensions that underpin our conflicting notions of the nature of information, its contested nature also presents opportunities for analysing and understanding the driving forces informing different theoretical traditions. While the observation of conceptual ambiguity is commonplace, far less common is the analysis of the underlying theoretical and metatheoretical causes of this apparent ambiguity.

2.3. Theoretical Enquiry Through Conceptual Definition

The apparent ambiguity of information as a critical and theoretical object perhaps explains why theoretical discussion has too often proceeded through simple conceptual definition, or what Kaplan described as the specification of meaning [51]. Belkin notes that "the literature of information science is littered with 'one-line' information definitions" [10] (p. 55). Van Rijsbergen and Lalmas argue that "many attempts have been made to come up with some sensible and intuitively acceptable definition of information; up to now, none of these succeeded" [54] (p. 385). Burgin suggests that "being mostly vague and limited, these definitions have brought confusion" [55] (p. 148) and have "yielded little and have certainly not led to a generally accepted definition." [16] (p. 5). The general consensus is that attempts to define information have ultimately contributed little to our understanding of its fundamental nature.

After Shannon, the single most widely cited definition of information is Bateson's aphorism that information is "a difference that makes a difference" [56] (p. 460). Schroeder argues its imprecision may increase its attractiveness [57]; this may also explain its wider interdisciplinary adoption. Other widely cited definitions of information include information as negative entropy [58–60], the reduction in uncertainty [61,62], the organisation of matter and energy [5,63,64] and eliminated complexity [65–67]. Nauta argues that "something is information to the extent that it is unknown, unexpected, surprising, or improbable" [68] (p. 19). Information has frequently been defined in relation to knowledge. For example, Farradane defines information as "any physical form of representation or surrogate of knowledge or of a particular thought used for communication" [69] (p. 13) and later as "any form of these representation or surrogates for knowledge" [70] (p. 99); more recently, Floridi defined information as "well-formed, meaningful veridical data" [2] (p. 80). Other influential definitions include "a capacity (ability or potency) of things, both material and abstract, to change other things" [16] (p. 99), "a human artefact, constructed and reconstructed within social situations" [71] (p. 19), and the propositional content of a sign [57,72–75]. A very great number of additional definitions have been proposed, and there have been several attempts to organise these different perspectives into a coherent schema [10,76,77].

MacKay has been widely cited as defining information as "a distinction that makes a difference" (e.g., Floridi [2,43,78–80]; Logan [13]; Burgin [16]; Brier [81]). This is normally attributed to his major work *Information, Mechanism and Meaning* [60]. Floridi contrasted it

with Bateson's "better known although less accurate" definition [43] (p. 23), and Logan suggested that it may have directly influenced Bateson [13]. Hofkirchner attributes the phrase to MacKay but notes that it is unsourced [82]. Indeed, it is not found in MacKay's work [83], and was not attributed to him until 2003. It is notable that the apparently mistaken attribution has been very widely repeated, including by many of the major recent theorists in this area. However, this also illustrates both the persuasive power and problem of definitions in the discourse of information, which are frequently discussed independently of the critical and theoretical contexts which inform them.

While definitions play an important role in theoretical discourse, Taylor suggests that "the very notion of a "definition" is a complex and contested one" [30] (p. 8). Quine notes that "The word 'definition' has come to have a dangerously reassuring sound" [84] (p. 26). Definition is not merely a matter of specifying meaning, but also of asserting particular epistemic, epistemological and ontological assumptions. It may also serve a disciplinary gatekeeping function. Schroeder, for example, has written the following:

> "more attention is paid to the normative question what "should" be called information than to the issue of the explanatory power of the concept in the contexts of its use". [57] (p. 1)

Krzanowski notes that the proliferation of definitions has "served to further obfuscate an already muddled concept" [3] (p. 4), and Capurro and Hjørland have warned against "persuasive definitions" which serve only to impress [12] (p. 349). Although their ostensible purpose has been to clarify an apparently ambiguous concept, the outcome has often been to add further confusion to an already contested domain. Conflicting definitions of information may, in addition, inhibit understanding by creating a misleading impression that information is a more complex, manifold, and more poorly understood concept than it truly is, or that information is fundamentally ambiguous, as already discussed. Krzanowski notes, for example, that the proliferation of definitions is responsible for creating the impression that information is diverse in nature and argues that "multiple measure for information do not translate into a better understanding of what information is—it only shows a range of possible interpretations" [3] (p. 14). In addition, many of the definitions that have been proposed for information are unfalsifiable.

While definition has an important role in theories of information, the two are not synonymous and do not have the same function. Kaplan notes that "specification of meaning is processive; it is hypothetical and provisional, and undergoes modification as inquiry proceeds" [51] (p. 281). The use of definition in the discourse on the nature of information has often preceded critical enquiry rather than emerging from it and has tended to confuse rather than clarify the nature of information. This is in part because many of the proposed definitions are stipulative rather than descriptive or explicative [85], delimiting the ways in which information should be understood for a specific context or practice, rather than forming the basis for an open enquiry. Defining concepts in stipulative terms is necessary to introduce presuppositions about the scope of that concept within a specific context. While some work has been conducted in this area [12,14–16,86], more work is required to map the underlying ontological, epistemological assumptions and to understand the disciplinary influences on approaches to defining information. There also needs to be much greater acknowledgement of the contested nature of information as a theoretical and critical object, particularly in relation to the different disciplinary traditions in which information plays a key role, and the consequences of this contested nature for defining the scope of critical and theoretical enquiry. Too often, the contested nature of information has itself been taken as evidence of its diverse or ambiguous nature rather than of the underlying tension in the critical discourse.

2.4. Theories of Information

Notwithstanding the breadth of work in this area, a number of theoretical frameworks are worth highlighting. Shannon's *A Mathematical Theory of Communication* is foremost amongst these [87]. Despite its complex legacy, Hjørland emphasises its "enormous influence on the discourses about information" [31]. Shannon's account was built on a number of prior technical papers, particularly those of Nyquist [88] and Hartley [40]. Therefore, it can be understood as a development and synthesis of prior ideas, in part reflecting the contingencies of wartime communications and cryptology. Shannon also credited Norbert Wiener for "much of its basic philosophy and theory" [87] (p. 55, n. 4). Nevertheless, Shannon approached communication as a technical problem and largely eschewed information's theoretical implications. As a consequence, it has been argued that it does not present a theory of information as commonly understood [43,73,89]. Weaver added theoretical context and commentary [90] and "arguably had greater influence in promoting information theory than any of its originators' writings" [14] (p. 126). Early advocates such as Brillouin [59] helped establish the wider significance of the work outside of communications engineering. Kolmogorov's work on algorithmic information theory and Chaitin's development of this also significantly expand the application of Shannon's work [65–67], creating a bridge to theories of computability.

Semantic information theory represents a very broad perspective that in recent years has become strongly associated with the work of Floridi [2,43,78,79,91]. Significant earlier contributions were made by Bar-Hillel & Carnup [92], MacKay [60], Mingers [93,94] and Dretske [72], among others. There is a wide variety of perspectives within this broad tradition and significant areas of disagreement, particularly in relation to the subjective nature of meaning and the relationship between information and truth. However, semantic information theory generally focuses on semantically meaningful anthropic information, and therefore does not necessarily aspire to universality, emphasising questions of meaning, value and significance. It draws from information theory in associating semantic content with the unpredictability of a message, but generally rejects Shannon's ontological focus.

Burgin's general theory of information is perhaps the most comprehensive and detailed recent attempt to create a foundational theory of information [16]. Burgin's theoretical work ranges across related issues, including the theory of knowledge [95,96] and data [95,97], and develops a unified axiomatic description of information. His approach is broadly synthetic, seeking to integrate statistical and semantic approaches to information [16] and encompassing a very wide range of reference. Burgin's general theory of information addresses diverse theoretical and critical perspectives, including information theory, semantic information theory and semiotics. Consequently, the general theory of information is a complex body of work, and questions arise concerning the incommensurability of the different perspectives on which it draws. Too often, important details are lost in its light touch over a very wide range of reference, and its arguments and interpretations are sometimes idiosyncratic.

> Other significant theories include Bates' theory of information 1 and 2, which has been influential within Library and Information Science [63,64]. Emergent information theory situates information as an emergent quality of complex systems [82,98–100]. Stonier's provocative account of the objective physical reality of information has many valuable insights but strays into speculation, particularly in relation to the hypothetical massless particle, the infon [101,102]. Stonier emphasised that the physical reality of information is "axiomatic to creating a general theory of information" and suggested that intelligence is an emergent property of an organised information system [103] (p. 9). Finally, Søren Brier's Cybersemiotics draws on the work of Chales Sanders Peirce to situate the nature

> of information and its social significance [81,89,104]. The synthesis of semiotics and information theory has some significant prior history. Nauta also drew on Peircean semiotic descriptions [68], and Warner advocated for the role of semiotics in clarifying the nature of information [105]. Stamper notes the following:"Information is a vague and elusive concept, whereas the technological concepts are relatively easy to grasp. Semiotics solves this problem by using the concept of a sign as a starting point for a rigorous treatment for some rather woolly notions surrounding the concept of information". [106] (p. 1)

Raber and Budd also draw on Saussure to advocate for "the affinity between the informative object and the sign, and between information and language as theoretical objects" [107] (p. 515). Brier's approach then can be seen as an iterative development of this important role of semiotics in the discourse on the nature of information. There is still much that may be developed from this semiotic perspective, particularly in relation to its intersection with complexity theory and emergence; this remains an underdeveloped aspect of the critical discourse.

Giulio Tononi's Integrated Information Theory (IIT) is worth mentioning briefly [108,109]. Although not a theory of information as such, the model posits a mathematical framework that posits that consciousness is equivalent to the amount of information generated by a system as a whole, independent of its component parts. IIT has been criticised as a pseudoscience [110] and unscientific [111]. As the work is primarily focused on understanding the nature of consciousness rather than the nature of information itself, it is not directly relevant to this paper, but nevertheless, both emphasise the important role of information in contemporary theory and imply significant elements of emergentism that have become important to understanding the nature of information itself.

In addition to these, there are various implicit theories and quasi-theoretical discussions that have contributed to a general understanding of the nature of information, but have had less general or widespread influence, or are less fully developed. We can include, for example, Brookes' fundamental equation [1], Belkin's work on adapting information theory to library and information science [112], and work in biosemiotics, including Hofmeyer [113] and Wheeler [114–116], among others. Information is playing a growing role in the description and understanding of biological systems, as exemplified by Adami's work on the topic [117,118], which draws on the classical information theory. While they are not fully developed theoretical accounts, these works often raise relevant theoretical issues and positions. There have been many other proposed theories in addition to those listed here; Burgin provides a recent thorough account of these [16]. Table 1 (below) summarises some of the distinctions and complementarities between different theoretical perspectives discussed above and throughout this paper, organised chronologically.

Table 1. Summary of major theories of information.

Theorist	Core Concept	Type of Information	Scope/Domain	Epistemological/Ontological Orientation	Complementarities
Claude Shannon [87]	Quantitative measure of information as reduction in uncertainty	Syntactic/Statistical Information (bits)	Communication systems, engineering, signal processing	Mathematical, engineering-focused; avoids semantics	Provides quantitative foundation for much subsequent theoretical work
Louis Brillouin [59]	Information as negentropy; links information with physical order and thermodynamics	Physical/Entropic Information	Physics, thermodynamics, early cybernetic	Physicalist; formal; emphasises energy–information relationship	Bridges Shannon's formalism and biological/organisational perspectives; anticipates Stonier and Brier

Table 1. *Cont.*

Theorist	Core Concept	Type of Information	Scope/Domain	Epistemological/Ontological Orientation	Complementarities
Donald MacKay [60]	Information as interpretive and semantic; emphasises receiver's role in generating meaning	Semantic/Interpretive Information	Philosophy of mind, communication	Contextual and epistemic; receiver-centric	Complements Shannon and Bateson; bridges syntactic and semantic approaches; overlaps with Dretske and Floridi
Gregory Bateson [56]	Information as meaningful differences that make a difference in context	Semantic/Relational Information	Biological, cognitive, social systems	Context-dependent, semiotic	Bridges Shannon and Floridi, Stonier, and Brier; emphasises meaning and relational effects
Fred Dretske [72,73]	Information as semantic content: information represents states of the world and carries meaning	Semantic/Representational Information	Philosophy of mind, epistemology, cognitive science	Realist, epistemic; emphasises representation and signalin	Bridges Shannon/Bateson (signal) and Floridi/Brier (meaning); complements cybersemiotic and semantic perspectives
Tom Stonier [101–103,119]	Information as a measure of organisation and evolution; "natural history of intelligence"	Biological/Organisational Information	Biology, evolution, cybernetics	Systems-oriented; bridges physical, biological and cognitive domains	Connects Shannon and Bateson with Brier's semiotics; emphasises evolution of information
Søren Brier [81,89,104]	Cybersemiotics: Integrates Peircean semiotics with cybernetics and information theory	Semiotic/Cognitive/Experiential Information	Cognition, communication, consciousness, philosophy of mind	Pragmatic, phenomeno-logical, semiotic; includes subjective experience	Integrates Bateson, Stonier's biological info, and Floridi's semantic info; emphasises meaning in living and conscious systems
Luciano Floridi [2,43,78–80,91]	Information as data + meaning; Informational Structural Realism	Semantic Information (well-organised meaningful veridical data)	Philosophy of information, ethics, knowledge representation	Ontologically realist; emphasises meaningful content	Extends Shannon and Bateson; formalises meaning; complements Burgin and Brier
Mark Burgin [16,55,95–97,120–122]	General Theory of Information (GTI): Information depends on the system receiving it	Relational/Contextual Information	Mathematics, computing, general systems theory	Relational; systemic; formal but adaptable	Formalises context-dependence; unifies Shannon, Bateson, and Floridi

2.5. The Possibility of a Foundational Theory of Information

A foundational theory of information describes a single theory that fully accounts for information in all or most contexts within which it plays a significant role. Although there have been notable attempts to construct such a theory, scepticism about its possibility remains commonplace. Floridi, for example, has expressed scepticism towards what he termed a "grand unified theory" [2] (p. 30) rooted in information's conceptual ambiguity, semantic and subjective richness, and its variant framing in different disciplinary traditions. Nevertheless, there are strong arguments for the possibility of a foundational theory in which information's apparent ambiguity and widespread reach are shown to be variant expressions of an invariant phenomena. These arguments derive in part from the complex influence of Shannon's *A Mathematical Theory of Communication* [87].

Shannon's account implies the possibility of a foundation theory in three ways. In the first place, its definition of information can be said to have had unreasonable reach: it is far more widely applied than could be reasonably inferred from its disciplinary origins in communications engineering. Indeed, it is among the most successful theories of the mid-twentieth century, finding application in an extraordinarily wide range of contexts, from theoretical physics to biosemiotics, and has become fundamental to the ways in which we organise and understand the contemporary social and technological world.

The fact that the bit can be used, for example, to quantify the information encoded on the event horizon of a supermassive black hole (estimated 1091 bits for Sagittarius A), coiled in the DNA of a single human cell (approximately 1.5 GB) and comprising the *Complete Works of Shakespeare* (about 5 MB in 8 bit ASCII encoding) implies a fundamental relationship between the concept of information that is employed in these very different contexts. Arguably, anything that we generally describe as informational can be measured in Shannon bits to any arbitrary degree of precision. This strongly implies that everything we describe as information is similar in at least one respect. While information possesses various significances, affordances and effects that remain unaccounted for in Shannon's theory, its unreasonable reach makes it harder to argue that different forms of information are wholly independent phenomena that require individual theoretical explanation.

In the second place, Shannon's definition of information possesses surprising consonance with other foundational theories, particularly thermodynamics and quantum mechanics. There is a surprising similarity between the equation for information entropy and the equations of Gibbs', Boltzmann's and von Neumann's, which is not explained by the communications contexts of their work. As Weaver notes,

> "When one meets the concept of entropy in communication theory, he has a right to be rather excided—a right to suspect that one has hold of something that may turn out to be basic and important". [89] (p. 103)

This relationship between information and entropy remains the subject of debate. In the subsequent discourse, for example, a distinction between information entropy and negative entropy emerged [58] (p. 11); [59] (p. xii); [60] (p. 16). However, while there are other explanations, the surprising consonance of Shannon's account implies information may be knitted-in to our theoretical understanding of material reality in a fundamental way, perhaps even to the extent suggested by Wheeler's it-from-bit hypothesis that "every physical quantity, every it, derives its ultimate significance from bits" [123] (p. 309), or to the extent suggested by Tegmark's mathematical universe hypothesis [124,125], or the holographic principle [126,127]. It therefore implies that Shannon's work may approach a description of the fundamental nature of information.

In the third case, Shannon's account can be said to possess a convergent influence on the discourse on the nature of information. Shannon's work was preceded by related measures, including those proposed by Fisher [128], Nyquist [88] and Hartley [40]. Nyquist had equated the speed of transmission of "intelligence" to "the number of characters, representing different letters, figures, etc., which can be transmitted in a given length of time" [88] (p. 333), providing a logarithmic definition. Hartley's account was closer to Shannon's, proposing "a quantitative measure of 'information' [...] based on physical as contrasted psychological considerations" [40] (p. 535). Shannon's work also shares conceptual similarities with Turing's [129] and Post's [130] definitions of computability. This may reflect a convergence around underlying physical principles. In addition, Shannon's account has provided a foundation for much of the subsequent discourse of information, framing significant issues in that debate, such as the relationship between information and meaning. That information exists as a theoretical and critical object is largely a consequence of Shannon's work, and much of the subsequent theoretical discourse has been in response to it. This convergent influence implies that different theoretical traditions in different fields may be addressing the same fundamental phenomenon.

The unreasonable reach, surprising consonance and convergent influence of Shannon's work imply not only that a foundational theory of information is possible in principle, but also that, as Floridi argues, information theory itself "provides a rigorous constraint to any further theorizing" [43] (p. 52). Any foundational theory of information should reasonably be expected to be consistent with or encompass Shannon's account. Nevertheless, this does

not mean that Shannon's account of information is itself a sufficient or complete one (see below). While Shannon's definition approaches a description of the fundamental nature of information, its precise relevance to a foundation theory remains to be demonstrated.

2.6. Incompleteness of Theories of Information

Shannon's account of information remains the most plausible basis for a foundational theory of information, but it is nevertheless incomplete in at least three respects. Firstly, its focus on the technical aspects of communication means that its conception of information is reductive and formal, failing to account for its underlying nature and only addressing information in a single aspect. Brookes, for example, notes that it "measures a rather arid statistical aspect of information" [1]. Hayes goes further, suggesting that Shannon's theory only defines information as a function of probability with no connection to its materiality or meaning [44]. Secondly, as an abstract model that idealises and simplifies the context of communication, the model has little to say about information that is commonly understood in everyday contexts, nor does it explain how complex informational objects arise from its basic description. Dretske, for example, suggested that it "is not dealing with information as it is ordinarily understood" [73] (p. 56). Brier states that "what people and animals conceive as information is quite different from what Shannon and Weaver's theory of information is about" [89] (p. 186). Finally, Shannon's account discounts aspects of information that are widely regarded as either fundamental or requiring explanation, such as meaning, context and the emotive aspects of human communication [87] (p. 3). Brookes notes, for example, that "the theory is not directly applicable to human communication of the cognitive kind" [1], and Capurro has commented that it lacks universality because "the semantic and pragmatic dimensions are excluded" [131]. Mingers suggests that "it is like measuring the volume of a container without knowing what it contains" [94] (p. 192). In combination, these problems suggest that Shannon's definition cannot explain everything we might want to know about the nature of information. In Fairthorne's terms, it is "necessary, but not sufficient" [41] (p. 712).

Incompleteness may be a general characteristic of theories of information. This possibility arises in part from Capurro's Trilemma, which outlines three ways in which the concept of information can be understood [132] (p. 2):

- It has the same meaning in all contexts (univocity);
- It has an original meaning in a specific context, and is applied as an analogy in other domains (analogy);
- It has different, but equally valid, meanings in different contexts (equivocity).

Bawden has noted that the trilemma implies "that a truly unified theory of information is impossible, since, whichever of these options is adopted, no satisfactory theory can result" [133]. Capurro himself argued that while equivocity ruled out any foundational theory by definition, and univocity is ruled out by the diverse ways in which information presents itself across disciplines, the possibility of a unified theory in the case of analogy remains by "taking a certain definition and its context as the first and original one" [131]. Nevertheless, there are problems with this general argument. In the first place, the three options presented may not exhaust the possible explanations. For example, Hofkirchner has suggested a fourth option of integrative thinking, which might resolve the question [98] (p. 365). Secondly, Capurro's objection to a univocal concept of information is based on the observation of divergent descriptions of information in different disciplinary domains and an assumption that these reflect a divergent underlying nature. The conclusion that a univocal definition is impossible is therefore already contained within this assumption. Furthermore, because the trilemma frames the issue as a definitional problem of semantics and

usage, it does not directly address the ontological or epistemological question of whether information, as a phenomenon or entity, might have an underlying unity.

While Capurro's trilemma has been widely discussed, the possibility that incompleteness is an inevitable quality of theories of information is perhaps better shown by what Ellis described as a "irreducible duality" at the heart of our conceptions about the nature of information [134] (p. 60). Ellis framed that duality is the difference between theoretical paradigms, in which "the physical paradigm takes as its primary focus the artefacts, whereas the primary focus of the cognitive paradigm is the people" [134] (p. 60). Raber renamed these cognitive and physical metaphors to escape the Khunian framing [42]. In effect, Ellis describes a category error that emerges in comparing different common understandings of information. While there is some variation in how this issue is presented, the existence of dualities in our understanding of information is widely noted. Furth, for example, distinguished between "information as a coded fact and information as a process of knowing" [135] (p. 21). Thellefsen et al. highlight "a mismatch between subjective and objective perspectives." [136] (p. 381). Most recently, Krzanowski has made a similar distinction between epistemic and ontological theories of information:

> "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". [3] (pp. 14–15)

Dualities of this kind frequently highlight missing aspects of our understanding. They may imply, for example, an underlying complexity to the nature of information, and reflect our inability to derive its emergent properties from their component parts. This understanding is evident in, for example, the work of Deleuze and Guattari [137] and DeLanda [138–140] among others, and informs the field of emergent information theory [82,98–100]. Categorical dichotomies may also imply incommensurability arising from fundamental differences in perspective, emphasis or approach [141,142]. It is therefore important to understand where and why this perception of information's dichotomous nature arises, and what this implies about underlying theoretical assumptions. Too often, theoretical enquiry has stopped with the observation of a dichotomy rather than exploring its underlying causes. There is important work to be conducted in unpacking this issue, which is likely to include a better understanding of the historicity of information as a critical and theoretical concept and the influence of disciplinary perspectives, traditions and cultures on that development as discussed above.

3. Dimension of a Foundational Theory of Information

3.1. Differences and Similarities

There is general agreement in the theoretical debate that information is a manifestation of either individual differences or their aggregation into patterns, structure, organisation or form. The use of "difference" in this context originates in Bateson's widely cited definition of information, and was plausibly influenced by the similar concept in semiotics [57]. However, Bateson's concept also echoes Shannon's definition of information as a choice between messages from a set [87] (p. 3). Bateson's notion of difference has influenced a range of theorists in very different frameworks, including Brier [81,89,104], Mingers [93,94], Mingers and Standing [75], Hofkirchner [82,100] and Floridi [2,43], who reinterpret the idea

within a formal definition of data. The importance of difference suggests that information is generally understood as a simple phenomenon that gives rise to complex and divergent effects rather than as intrinsically complex.

That information is widely understood as a manifestation of difference does not mean that there is a common understanding about what this means. Difference is a concept with a range of theoretical connotations and implications. Bateson described it as "a very peculiar and obscure concept. It is certainly not a thing or an event [. . .] A difference, then, is an abstract matter" [56] (p. 458). Formally, difference arises from the principle of identity, understood as "the relation everything has to itself and to nothing else" [143]. Difference also plays an important role in Saussure's semiotics as the syntagmatic and paradigmatic differentiation of signs, implying its relational nature [144]. Difference can also simply imply an effect. Bateson's definition of information playfully exploits all three of these senses: information is a formal difference that implies a semiotic difference that has an effect [56]. In other words, it is a situation, relational and causal. As a consequence of this ambiguity, difference has been incorporated to varying degrees and through different philosophical lenses, from cybersemiotics [81,89,104] to the philosophy of information [2] and critical realism [145,146]. Therefore, while there is broad agreement on its centrality, there is less agreement on what difference means or whether it exhausts the definition of information.

It is also disputed whether information is constituted in a single difference or in their aggregation into structure, form, organisation or pattern, each of which encounter subsequent problems of definition. Theories of information that address pattern [5,63,64], structure [8,16,147] or form [56,148] emphasise how individual differences combine into larger ontological units often treated as fundamental, especially in relation to semantic meaning or interpretation. However, this distinction between individual differences and their aggregation is not always explicit. This tension reflects a broader philosophical divergence between reductionist accounts of information and holistic accounts that see meaning as emerging only at higher levels of structural complexity.

Shannon, for example, posited a single binary selection as the basis of a single bit of information, but what that signifies depends on the code employed [87]. Weaver emphasised the arbitrary nature of this relationship, noting that a single bit might in principle encode the entire text of the King James Bible, or simply the word "yes" [89] (p. 100). In general, this interdependency between information and its codes has not drawn a lot of comment, although MacKay suggested the following:

> "Implicit in the estimation of information content in terms of selective power there lies a further assumption of communication theory, namely that knowledge of the code is free information for the receiver". [60] (p. 134)

This is not quite correct as any act of communication assumes the prior transmission of or shared agreement on the code employed, and therefore, knowledge of the code cannot be considered to be freely available to the receiver. Nevertheless, MacKay correctly identifies that the code is part of the information that comprises a message. Because of this, a bit is not necessarily an elementary unit in itself, but is relative to the context within which it is defined. However, any choice from any finite set can be analysed into further choices to any arbitrary degree of specificity; thus, a bit is also a generalisation to any arbitrary degree of specificity. This point can be generalised; any conceptual understanding of information rooted in the idea of pattern, structure or forms can be analysed or understood as an emergent effect of more fundamental elements, with the qualification that some qualities may not be analytically reducible to their underlying components. While the analytical units may be complex, the underlying concept of information they embody is often implicitly simple.

There are some other areas of notable, if not quite universal, agreement on the nature of information. Information is widely understood to be independent of its material and conceptual vehicles. Wiener is widely quoted in stating that "Information is information, not matter or energy" [58] (p. 132). In a comparatively early work, Burgin noted that "what people call information is, as a rule, only a container of information but not information itself" [120] (p. 156). Mingers has noted that "information is 'the propositional content of a sign', it is not the sign itself" [74] (p. 398), and Raber notes that "a text cannot be regarded as equivalent to the information that it communicates" [42] (p. 7). There are many such similar statements. In general, information has been assumed to be ontologically distinct from its material vehicles, although Buckland, for example, argues that the distinction is often irrelevant [49].

There is also some general agreement that information involves signifying, semiotic or representative processes, although this is much less universal, and while semiotics is frequently invoked as a means of bridging the gap between information and its meanings or signification (e.g., [16,43]), the theoretical implications of this are only occasionally embodied. Outside of fully semiotic accounts of information, there has been little engagement with more recent developments in semiotic theory and only occasional engagement with developments in biosemiotics [15]. This is despite the fact that, as Raber notes, "information science may very well be an important branch of what Saussure identifies as semiology, a science of signs" [42] (p. 4) and biosemiotics in particular generalises questions of meaning and signification that have been central to the theoretical discourse on the nature of information. Much that is relevant may be derived from the convergence of semiotics and complexity theory, particularly in relation to Deleuze and Guattari [137] and their influence on, for example, Delanda [138–140]. It is perhaps surprising not to see more work addressing this.

There is some general agreement on the broad distinction between environmental information and anthropic information, although they do not generally use these terms. Environmental information is widely understood as that produced through natural processes, such as light spectrums, growth rings or the information associated with natural systems such as quantum or complex systems. Anthropic information is used in this paper to describe information produced through deliberate human action or as the result of human technologies, including most of the information that defines our digital culture. In principle, there exists a great deal more environmental information than anthropic; however, in practice, anthropic information has played a more significant role in the debate concerning the nature of information and arguably has a greater and more immediate impact on our everyday lives.

3.2. Objective, Subjective and Relational Theories of Information

The apparent categorical dualities that appear in the theoretical analysis of information most frequently arise from the distinction between the description of information as a wholly objective phenomenon and as a phenomenon that always implies aspects of subjective experience. For example, Capurro & Hjørland note that different concepts of information generally "reflect tensions between a subjective and an objective approach" [12] (p. 345), and Mingers and Standing describe it as a significant divergence in approaches to theorising information [75]. This issue encompasses questions of meaning and significance that are dealt with separately below.

It is widely acknowledged that information exists as an objective property of the material world and is not a wholly subjective in nature. Brillouin describes these objective aspects as "absolute information", or information without consideration of its human value [59] (p. 10). While information can be defined straightforwardly in these objective

terms, Brookes has noted that "when that objective information reaches us it becomes subjective information" [149] (p. 133). Information gives rise to subjective experiences in its integration with social or cognitive processes, implied by concepts such as meaning, interpretation, significance and relevance. Brillouin expresses this distinction in the following terms:

> "Information is an absolute quantity which has the same numerical value for any observer. The human value of the information on the other hand, would necessarily be a relative quantity, and would have different values for different observers according to the possibility of their understanding it and using it later". [59] (p. 19)

This infiltration of the subjective into the objective sphere is particularly problematic because information is the basis on which we form understandings about the world [6] and therefore "the separation of objective from subjective effects is not easy to maintain" [149] (p. 126). The difference between objective and subjective accounts of information has therefore often been considered fundamental and is of significant consequence. Hjørland has noted, for example, that it "is a built-in conflict in theories of information at least back to Shannon" [146] (p. 1451).

Accounts of information as a wholly objective phenomenon either treat information as the "invariant characteristics of informative objects" [42] (p. 53), which can be "described abstractly and independently of the particular form in which it appears" [42] (p. 51), or as a fundamental phenomenon of the material world like matter or energy [150]. Advocates for this view generally accept that information has subjective effects but understand these as secondary or supplementary to its fundamental nature. Stonier offers a particularly emphatic expression of this position, arguing the following:

> "Information exists. It does not need to be perceived to exist. It does not need to be understood to exist. It requires no intelligence to interpret it. It does not have to have meaning to exist. It exists". [102] (p. 21)

Shannon's account has also generally been understood as exemplifying an objective perspective, although Qvortrup has suggested that it also implies aspects of subjective selection [52].

Subjective accounts emphasise information's role in human communications and their broader socio-cultural contexts. Mingers, for example, has objected to information being defined as an invariant mind-independent phenomenon because "it assumes both that objective information exists and that it produces a similar effect on all those who receive it" [93] (p. 287). This arguably mischaracterises the issues by conflating information with its effects. Nevertheless, the perception that information is inseparable from its subjective qualities, particularly meaning, value and use, has led many to conclude that information cannot be defined in wholly objective terms. Fairthorne, for example, questioned whether information was a universal essence [48]. Ashby highlighted that information "is not an intrinsic property of the message" [151] (p. 124). Raber has asked whether "information is unambiguously apart and separate from our perception and experience of it?" [42] (p. 16). This scepticism about the value of objective accounts can be attributed to the observation that what is most interesting and arguably most important about information as a critical and theoretical object is its capacity to generate and convey subjective experiences, such as meaning, understanding and knowledge.

Mingers defined the subjective understanding of information as "the idea that different observers will generate different information from the same data since they have differing values, beliefs, and expectations" [93] (p. 286). Bosancic & Matijevic characterise it as a description of information and a "subjective, socially constructed entity which informs

users' behavior" [152] (p. 630). Information has sometimes been defined as a wholly or largely subjective phenomenon that is produced in the human mind. Mikhailov and Giljarevskij, for example, differentiate between elementary, biological and logical information and state that the latter consists of ideas and images and is "obtained in the process of cognition" [153] (p. 15). Hoshovsky and Massey similarly described information as a process occurring in the mind when problems and data are brought together [154]. However, more commonly, information has been highlighted as relational and located in the relation between objective aspects of the world and subjective experiences.

One approach to dissolving the dichotomy in relational terms has been to emphasise and isolate the distinction between subjective and objective aspects of information. Dretske's account of information as the propositional content of a sign, for example, rigorously differentiates between the objective aspects of signification and the subjective aspect of interpretation [72,73]. Dretske rejected Shannon's reductionism, writing the following:

> "It is only the particular signal (utterance, track, print, gesture, sequence of neural discharge) that has a content that can be given propositional expression (the content, message, or information carried by the signal). This is the relevant commodity in semantic and cognitive studies, and content—what information a signal carries—cannot be averaged. All one can do is average how much information is carried. There is no meaningful average for the information that my grandmother had a stroke and that my daughter is getting married. If we can say how much information these messages represent, then we can speak about their average. But this tells us nothing about what information is being communicated". [73] (p. 56)

Dretske argues that while information is objective, its meanings remain subjective [72]. Mingers likewise argues that information is "objective and independent and exists whether or not anyone actually interacts with it" and that "receivers then process this information [. . .] in such a way as to produce meaning (import) for them", and therefore "information is objective and meaning is subjective" [74] (p. 399). Mingers, later with Standing, framed information as both "objective and veridical" and sought to "recognize the subjective effects of information on receivers" [75] (p. 5). Thellesfsen et al. have argued something similar from a semiotic perspective, stating that information "should be defined ontologically having certain epistemological consequences" [136] (p. 381).

Accounts that differentiate between its objective and subjective qualities generally assert a fundamental relationship between objective information and its subjective effects, but arguably encounter difficulties uniting these under a single concept. Bates' differentiation between Information 1, defined as "the pattern of organization of matter and energy", and Information 2, defined as "some pattern of organization of matter and energy given meaning by a living being" [63] (p. 14), illustrates this issue. The distinction rests on the subjective meanings that information generates. It is therefore unclear that Information 1 and Information 2 are ontologically related, and if not, whether either is an adequate and sufficient description of information in itself. Bawden and Robinson, for example, questioned "how the gap between information in the physical realm and in the realm of meaning is bridged" [15] (p. 7). Closing this gap has continued to be problematic in such accounts. Rigorously differentiating objective and subjective aspects arguably defines independent phenomena.

Another approach to addressing the dichotomy in relational terms has been to appeal to the relativistic, situational or context-dependent nature of information defined in objective terms. Hjørland, for example, has developed a pragmatist and critical realist account of information, arguing that while it "is possible to define information as a universal phenomenon"; nevertheless, this "implies that what is information always depends on a

specific organism or system and is therefore context specific" [31]. In a critique of Bates' model, Hjørland highlighted that a stone found in a field conveys different information for a geologist than for an archaeologist [146]. This appears to account for the subjective aspects of information as objective differences in the contexts of their discovery and use. However, it is perhaps equally plausible that the information conveyed by the stone is identical in each case, and that it is only the inferences drawn on the basis of that information that differ.

Burgin also views information as highly situational, arguing that "It is necessary to separate information in general from information (or a portion of information) for a system R. In other words, empirically, it is possible to speak only about information (or a portion of information) for a system" [16] (p. 93). This means that information can only be considered as an empirical object in relation to the specific system or context within which that information is employed. As with Hjørland, this approach attempts to define more clearly the contexts within which information becomes meaningful so as to demarcate something like an objective account of relative meanings. Thus, Burgin argues that "the same message can contain a lot of information for one person and no information for another person" [16] (p. 5). This claim is relatively common and frequently justifies subjective approaches. To illustrate this, Burgin presents the following thought-experiment:

> "Let us consider a textbook, for example, in mathematics. If it is a good textbook, then it contains a lot of information for a mathematics student. However, if we show this book to a professional mathematician, she or he might say, "Oh, I know everything in this book, so it contains no information for me." We will have the same result but for a different reason if we give this book to an art student who is bored with mathematics. Weinberger (2002) [155] writes that the meaning of a message can only be understood relative to its receiver. Thus, the latter student will not read the book and the book will not contain information for her". [16] (p. 93)

It is notable that this example equivocates between quantitative ("a lot of information"; "no information") and qualitative ("the meaning of a message") measures of the value of information. These are very different propositions, and it is unclear whether Burgin is referring to the content of the book, the meanings extracted from it, or both. This reflects a common conflation of information as a tangible object and information as a process of becoming informed. The imagined exclamation of the professional mathematician feels contrived; it might seem more natural and less ambiguous, or at least equally plausible, to state that "it contains no new or useful information for me." A maths educator in particular might be expected to recognise the information content of the work regardless of their own state of knowledge. The claim that the book contains no information for an arts student also seems like an overstatement, better expressed as containing no relevant information. Equating a failure to read a book with an objective absence of informational content appears to be a category mistake. These appear to be subjective rather than objective judgements. It might plausibly be argued that the same information in the textbook has varying degrees of novelty, interest or relevance for different readers, and that this fully accounts for the perception of its varying value to different readers. Stonier, for example, argues that "the information contained in a book is there irrespective of whether anyone reads the book" [103] (p. 8). Burgin's claim that his account avoids subjectivity because "subjectivity is what depends only on the opinion of an individual" [16] (p. 95), which is idiosyncratic and unpersuasive in this case because the opinions and experiences of individuals are precisely what is in question.

While the dichotomy between subjective and objective perspectives has been frequently highlighted as discussed above, comparatively little work has been conducted to understand why the perception of a dichotomy exists in the first place. As noted, du-

alities of this kind frequently highlight missing aspects of our understanding or hidden assumptions. There are likely many factors that have contributed to this perception. In the first place, Qvortrup highlights that while presenting an ostensibly objective account of information, Shannon introduced subjectivity both in the choice or selection of messages through the code which determines interpretation [52]. The significant influence of Shannon's work may have embedded an implicit dichotomy, framing the subsequent discourse even when this dichotomy was not explicitly acknowledged. Secondly, the discussion of the dichotomous nature of information has often failed to acknowledge and differentiate between the different levels or scales at which information is conceptualised in different theories. Semantic information theory, for example, generally conceptualises information at the level of the document, statement or sign, and information theory at the level of the bit. While the former implies subjective interpretations, an individual bit is generally not considered to be subjectively meaningful or to convey meaning independently of the code in which it is employed. Burgin, for example, notes the following:

> "While the concept of a bit may allow one to measure the capacity of a floppy disc or a hard-disk, it is useless in relation to tasks such as indexing, collection management, document retrieval, bibliometrics and so on. For such purposes, the meaning of the signs must be involved, making a kind of semantic information theory a much better theoretical frame of reference compared to statistical information theory". [16] (pp. 20–21)

This statement conceals the assumption that meaning emerges in the transition between scales, but that emergence is not accounted for; it is merely implied. Meaning and significance therefore seem to emerge for free driving the perception of a dichotomy between subjective and objective descriptions.

Thirdly, the subjective/objective dichotomy may arise in a disciplinary bias towards richly meaningful forms of anthropic information, which is information created by or for humans in highly contextualised, semantically dense forms. While richly meaningful anthropic information has understandably attracted attention, most information is not richly meaningful or anthropic in nature and does not raise the same questions. For example, the growth rings of a tree are not intrinsically meaningful but become so only in light of a conceptual or scientific framework that explains their significance. Finally, there has been a general conflation of information and its effects or affordances. That information may give rise to subjective experiences does not mean that those experiences are aspects of information itself. What Brillouin [59] called absolute information—understood in terms of physical order or negentropy—and the human value attributed to it, may be as they appear ontologically distinct. In general, the dichotomy between objective and subjective accounts of information arguably describes differences in the position, focus and emphasis amongst theorists rather than the intrinsic nature of information itself.

In many ways, it is surprising that the subjective nature of information has caused such difficulty. While information can be described as both objective and subjective, these operate on different levels of description. Information gives rise to subjective experiences that cannot be fully described in objective terms, but these experiences do not necessarily require a subjective account of information. Nor does an objective account of information preclude or invalidate its subjective and intersubjective effects. This implies that the information and its meanings may be distinct issues. There is good evidence that information functions as an objective feature of material systems, as implied by the applicability and success of Shannon's definition across multiple scientific fields. However, treating the subjective experience of information as ontologically equivalent to its objective properties risks conflating distinct categories, potentially undermining the theoretical clarity and critical utility of the concept. Nevertheless, the subjective experiences of information are

not illusory and give rise to shared meanings, cultural continuity and stable interpretations. A foundational theory of information must therefore account for how meaning emerges, particularly in the transition from syntactic structures to semantically rich cultural artefacts. This again may point to complexity and emergence as possible means to bridging the gap between subjective and objective accounts.

3.3. Information, Signification and Meaning

A particular aspect of the distinction between subjective and objective accounts has been the relationship between information and its meanings. Meaning is itself a complex and contested concept. In their classic account, Ogden and Richards discussed over twenty ways of understanding meaning and sought to show how confusion and misunderstanding arose from their conflation [156]. Leech has differentiated between seven kinds of semantic meaning: conceptual or denotative; connotative; social; affective or emotional; reflected; collective; and thematic meanings [157]. Beyond semantics, meaning can also imply value, significance and effect. Other intellectual traditions offer alternative perspectives that engage with meaning as situated, embodied or biologically embedded, including pragmatics, phenomenology and biosemiotics. For example, Jesper Hofmeyer's account of biosemiotics presents meaning as an intrinsic feature of living systems, where biological codes and sign processes underpin the emergence of meaning beyond human language [113]. Wendy Wheeler similarly argued that meaning and information in biological and environmental systems cannot be fully understood separately from their semiotic and ecological contexts [114,115]. Together, these perspectives challenge the dominant focus in information theory on anthropic information and denotative meaning, suggesting a richer and more nuanced understanding.

Awareness of the problem of meaning is co-incident with the emergence of information as a theoretical and critical object. Hartley noted that communications systems "by general agreement convey certain meanings to the parties communicating" [40] (p. 536). Despite this, his model sought to "eliminate the psychological factors involved and to establish a measure of information in terms of purely physical quantities" [40] (p. 538). Shannon broadly followed this lead. It is widely asserted that he discounted the problem of meaning. Brier, for example, argues that Shannon's model "never had anything to do with the semantic content of messages" [89] (p. 186); Duguid has gone further, arguing that "Shannon's theory held meaning as irrelevant to information" [158] (p. x). However, Shannon's position is more nuanced. In his most well-known statement on the problem, he argued the following:

> "The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently these messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities. This semantic aspect of communication is irrelevant to the engineering problem". [87] (p. 3)

This extract emphasises the importance of meaning and frames it as either a system of reference ("they refer to") or a system of what Saussure had called difference ("or are correlated according to") [144]. Meaning implicitly arises from this correlation with or reference to a system of conceptual or physical entities, and is therefore a product of the entire communication context rather than an intrinsic property of the message itself. While hesitant, Shannon's succinct statement has been of incalculable influence in framing the problem of meaning within the subsequent discourse.

Weaver developed a fuller account of the semantic aspect of communication. Noting first that "information must not be confused with meaning", Weaver stated the following:

> "The semantic problems are concerned with the identity, or satisfactorily close approximation, in the interpretation of meaning by the receiver, as compared with the intended meaning of the sender". [89] (p. 96)

This in fact merely restates the technical problem in semantic terms ("that of reproducing at one point either exactly or approximately a message selected at another point" [87] (p. 3)). However, it also asserts an intention/interpretation model of meaning combined with an instrumentalist view of the socio-communicative context ("the procedures by which one mind may affect another" [89] (p. 3)); the success of communication is equated with the degree to which "the meaning conveyed to the receiver leads to the desired conduct on his part" [89] (p. 97). Meaning, for Weaver, is a concept that applies to individual messages rather than the entire communicative context [89] (p. 100); it is implicitly an intrinsic property of those messages and framed in reductive terms as predominantly denotative. This is almost certainly an over-simplification of the issues and has been described by Chandler as a transport metaphor of communication in which meanings are shuttled from place to place via their carriers [159].

The differences between Shannon and Weaver's approach highlight a distinction between conceptions of information as a site for the production of meanings and as a carrier or conveyor of meaning. The former has generally emerged in both semiotic and emergent information contexts and implies that meaning is a product of the whole communicative process. Brier, for example, argues that meaning is not objective but is "determined by social practice in a historical context" [89] (p. 120). He draws on Bateson's work to describe meaning as an emergent property of self-organising systems, writing the following:

> "From a cybersemiotic perspective, one can view autopoiesis as a precondition for differences in the environment to become meaningful signs through the process of semiosis". [89] (p. 390)

Mingers has also addressed autopoiesis in respect of information [160]. This recalls the concept of unlimited semiosis in which meaning is endlessly deferred across a complex web of signification [161]; it is the signifying semiotic system itself that produces meaning at the level of the system rather than at the level of the individual sign, sign-string or statement, and meanings are not intrinsic properties of particular messages as such. Meaning is, in this sense, an emergent property of the system. While complexity theory and semiotics superficially appear to derive from very different assumptions and make very different kinds of statements about the world, Cilliers [162] has noted a close relationship between the two, and Fleissner & Hofkirchner [100] and Hofkirchner [82] draw on semiotics in their emergent model. Therefore, there are strong similarities in their approach to the problem of meaning. However, both encounter what has become known as the symbol grounding problem [43,163] as they lack direct reference to external reality, which has been assumed to be necessary for meaning.

Another approach has therefore been to interpret meaning as the reference made by information. McKay defined information as "that which adds to a representation" [60] (p. 162) and argued that "the concept of information is inseparable from that of meaning" [60] (p. 108). He describes representation as "any structure (pattern, picture, model) whether abstract or concrete, of which the features purport to symbolize or correspond in some sense with those of some other structure" [60] (p. 161). Meaning emerges as a consequence of this correspondence, and this informs how MacKey understands the nature of information:

> "information is defined, in general, as that which causes or logically validates representational activity—activity in which a structure, purporting to represent something else, is produced or augmented". [60] (p. 133)

It also informs MacKay's understanding of the nature of knowledge and its relationship to information, which causes "a change in the symbolic picture, or representation, that we could use to depict what we know" [60] (p. 42). Burgin pursued a similar account, ultimately concluding that meaning is an effect of information's transformation of knowledge structures, which he pictures as a hierarchical thesaurus showing relationships between concepts [16].

However, the dominant approach to the problem of meaning has been through semantic information theory and the "inverse relationship principle" [2] (p. 239) which originates in the work of Bar-Hillel & Carnap [92] and which states that the semantic content of a message is inversely proportionate to its logical probability. This is often interpreted as the reduction in uncertainty that information brings about. Mingers, for example, notes that "a single event carries information [. . .] because it reveals a reduction in the possibility of what might have happened" [93] (p. 289). Yovits also argues that information reduces uncertainty [61]. While the inverse relationship principle implies the objective nature of meaning, Dretske [72] and Mingers [93,94] in particular maintain meaning as intrinsically subjective.

Burgin notes that the inverse relationship principle "is rooted in the approach of Hartley and Shannon where information is assigned to messages about events and the chosen information measure depends on the probability of events the message informs about" [16] (p. 321). There is certainly a superficial relationship based on an analogy between the measurement of information and of semantic content. However, uncertainty in Shannon's theory is aleatoric—an objective property of the system itself from which information entropy is derived [87]. In contrast, uncertainty in semantic accounts of information is epistemic, involving the knowledge, context and pragmatic factors related to an observer. These two forms of uncertainty are conceptually distinct and not directly comparable; one cannot be justified on the basis of the other. In addition, it is unclear that information always reduces epistemic uncertainty in any meaningful sense. Warner, for example, notes that "acquiring information can also aggravate uncertainty" [105] (p. 18). New information may allow us to recognise a prior lack of understanding of the complexity of an issue and increase our epistemic uncertainty. The assumption that information reduces uncertainty by ruling out all contradictory propositions also implies that all contradictory propositions are already known or implied. In a different context, Turing described the fallacy involved as one "to which philosophers and mathematicians are particularly subject":

> "This is the assumption that as soon as a fact is presented to a mind all consequences of that fact spring into the mind simultaneously with it. It is a very useful assumption under many circumstances, but one too easily forgets that it is false". [164] (p. 451)

The subjective experience of receiving new information is often that it adds to our understanding, rather than subtracting from our doubt. Therefore, the inverse relationship principle arguably fails to save the phenomena that it purports to explain.

More recently, Floridi has become the leading proponent of semantic information theory. Floridi defines information as well-formed, meaningful veridical data [2] (p. 80). Mingers and Standing note that while Floridi recognises environmental information, it is not encompassed within this definition [75]. Floridi argues that "semantic content may be Instructional [. . .] or factual" [43] (p. 49), although his account largely addresses the latter [75]. Indeed, the major part of his argument applies only to declarative, semantic and factual information [2] (p. 83), which already implies several of the significant arguments; this narrow scope is not reflected in all subsequent accounts (e.g., [43]). Thus, Floridi's veridical principle addresses a narrow range of meaning applied to a narrow range of information. This is not intrinsically problematic, but it does limit its applicability beyond

that scope. Mingers has, in addition, identified some equivocation over whether Floridi understands meaning to be an objective quality of information or a subjective aspect of interpretation [74], arguing that "Floridi is not wholly clear as to whether it is meaningful in itself or meaningful for somebody, which is the essential question" [75] (p. 8).

Floridi is not alone in understanding information to be characterised by a propositional, truthful or factual nature. Shera, for example, argued the following:

> "Information, both in the sense in which it is used by the biologist and in the sense in which we librarians use it, is 'fact'. It is the stimulus which we perceive through our senses. This information may be a single isolated fact or it may be a whole cluster of facts; but it is still a unit; it is a unit of thought. It can have any dimension. It is that intellectual entity which we receive, the building block of knowledge". [165] (p. 96)

Roszak has expressed this in pithier form, describing information as "discrete little bundles of fact" [50] (p. 106). MacKay similarly states that "we have received information when we know something that we did not know before", implying information's factive nature [60] (p. 136). There is a longstanding view that information can only be understood to inform its recipient if its semantic content is truthful. This implies that information that is not truthful is not information at all. Mingers & Standing argue, for example, that "false information is not information any more than a false friend is a friend" [75] (p. 19). Floridi makes a very similar argument, writing that "false information is not a genuine type of information" and suggesting the following:

> "One speaks of false information not as one speaks of a false sentence, which is a sentence that happens to be false, but in the same way that one qualifies someone as a false friend, i.e., not a friend at all". [43] (p. 50)

While the point stands, this is a curious analogy. At face value, semantic information is more alike to represent a sentence than a friend. In fact, Floridi's criteria for information closely align with the notion of a declarative or propositional sentence. Furthermore, the term "false friend" more commonly refers to words that appear similar in two languages but have different meanings, such as "library" in English and "Librairie" in French. This linguistic sense may in fact better support the point, insofar as it describes something that misleadingly appears to convey accurate meaning. Nevertheless, Floridi and Mingers agree that as a consequence of their lack of factual content, misinformation and disinformation are not types of information.

Defining information as implicitly truthful, factual or veridical is problematic. In the first place, only a small proportion of information exists in a propositional form to which such judgements can be applied. A weather forecast, for example, is not veridical, but it is arguably informative. Any semantic expression or meaningful sign can be analysed into propositional statements; Russell, for example, argued that the meaning of any statement arose from the implied propositions of that statement [166]. However, Harland's observation that in doing so Russel increased the degree of assertion at the expense of the degree of assumption also applies to information [167]. We can assert, for example, that the weather forecast is true in respect of being an honest forecast of the weather, but this is a statement about the context of communication rather than about the content of the forecast.

In the second place, truth judgements are both highly subjective and widely contested, rendering agreement on what constitutes information essentially impossible. Indeed, the distinction between information and misinformation often has no material impact; people may act on misinformation and disinformation as if they were truthful and ignore truthful statements they dispute. The truth or otherwise of a statement may never be established, and in many cases, does not matter to a description of information's effects.

Crnkovic & Hofkirchner observe that "from the everyday experience we know that we act based on knowledge we judge plausible and which may be true or not" [168] (p. 340). We do not, in most contexts, verify information that we receive. Truth is not absolute, and judgements about what constitutes truth change over time, which makes the definition of whether something is or is not information historically and situationally contingent. Untruthful statements may also be the foundation of accurate inferences; an exposed lie may testify to the utterer's state of mind, but this is not the propositional content of the lie. Finally, many propositions—such as conjectures, for example—can neither be said to be definitively true nor false and therefore occupy an indeterminate position in which they are neither information nor misinformation. It therefore seems anti-intuitive and unhelpful to apply a rigid truth criterion to information, not least because it is in effect inoperable. Mingers & Standing have briefly addressed some of these objections [75].

Most importantly, the truth criterion implies a rather narrow understanding of human communication, as if it consisted of the transmission of well-established facts between otherwise entirely rational actors. In practice, much communication is messy, uncertain, full of contradiction and hesitancy, requires nuanced interpretation and contextual understanding, and is more often a matter of emotions and states of minds than it is a matter of fact. These emotive and affective aspects of communication complicate our understanding of truth in communication. The definition of information as a neutral vehicle of objective truth risks idealising and simplifying a complex aspect of human behaviour. While there is often an expectation that information should be truthful or factual in nature, especially in science of journalism, truth is often not the central concern in the socio-cultural and political contexts within which information is produced and consumed. In many cases, what counts as "information" is shaped by power relations, rhetorical strategies or shared assumptions, regardless of factual accuracy. Therefore, Floridi's veridical account restricts the applicability of his theory to a relatively small domain of human communication. Crnkovic & Hofkirchner suggest that Floridi's work aims "to provide the basis for understanding of knowledge, truth and justification in terms of information" rather than provide the basis for understanding information itself [168] (p. 339). It may say more about truth than it does about information as it functions in everyday communication.

The relationship between information and meaning remains uncertain; however, this uncertainty may reflect the assumptions we bring to information as a theoretical object. In the mid-1950s, Brillouin confidently asserted that "most of the information we use is communicated by means of language" [59] (p. 4). If this was ever true, it is less so today. The vast majority of anthropic information now produced is digital traffic over networks, often not intrinsically meaningful in the ways that semantic information theory presupposes. More importantly, the vast majority of information that exists is environmental information arising from natural processes and implying no intrinsic meanings. Yet, the question of meaning has predominantly been posed in relation to writing and speech, with only limited generalisations beyond that to other meaningful aspects of human culture. It has also tended to focus on a very narrow conception of meaning as the semantic content of a meaningful statement, sidelining paralinguistic and contextual factors. While such definitions may be useful within the bounds of propositional truth and human communication, they risk excluding a vast array of non-linguistic, embodied and environmental information phenomena. Furner has noted that "philosophers of language have modelled the phenomena fundamental to human communication in ways that do not require us to commit to a separate concept of 'information,'" [169] (p. 428), suggesting that the term may be redundant. While semantic information theory has presented itself as a theory of information, it is perhaps better understood as a specialised theory of semantics.

It is undeniable that information frequently conveys or produces meaning. However, questions concerning the meaning of information are not, in principle, different from those addressing meaning in other contexts—such as art, literature, language, signs, music or text. The methods and contextual applications for exploring meaning may vary across these domains, but the nature of meaning arguably does not. Moreover, the range of meanings that information conveys does not fundamentally differ from those arising in other social practices or cultural products. Therefore, it is unclear that information poses any specific issues that require an informational approach to semantics. While it is plausible that all meaningful things are informational in nature, not all informational things are intrinsically meaningful in nature. A light spectrum from a distant astronomical object is only meaningful in the context of an explanatory framework. Information very often does convey or produce meanings, and therefore meaning can be understood as a potential effect or affordance of information, but because meaning is often not absent, it cannot be an intrinsic aspect of information. Questions concerning the meaning of information appear primarily to be questions about the nature of meaning. Information is arguably an objective aspect of material reality to which humans give meaning.

3.4. Data, Information and Knowledge

The problem of meaning draws attention to an apparent distinction between data, information and knowledge, which have often been understood as closely related concepts. Zins, for example, explored the understanding of data, information and knowledge in the library and information fields and noted that, while there was surprisingly little agreement about their definition, there was a broad consensus that the concepts were closely related [170]. Traditionally, data has been conceptualised as raw, unorganised facts; information as data that has been processed and organised; and knowledge is information that has been internalised and formed into meaningful understandings. This description, often known as the Data–Information–Knowledge–Wisdom (DIKW) model, was popularised in its current form by Ackoff [171] but probably dates back to at least the 1960s [84]. The relationship is often implicitly or explicitly hierarchical, with knowledge understood as the most complex and of the highest value. However, while data, information and knowledge appear distinct, they are often used in interchangeable or overlapping ways.

The apparent dependency of information on data is embedded within the discourse on the nature of information. Brillouin, for example, stated that "information is the raw material and consists of the mere collection of data" [59] (p. ix). Yovits defines information as "data of value in decision making" [45] (p. 9). Curtis and Cobham argue that data becomes information when "it undergoes some sort of processing and the results of the processing are communicated for a particular purpose" [172] (p. 3). There has been a broad consensus that data is the constituent parts from which information is constructed, and data is transformed into information when given meaning or significance.

This relationship informs, for example, Floridi's account of information, in which information is defined as well-formed meaningful data [2] (p. 84), and semantic information as well-formed, meaningful and veridical data [2] (p. 80). The distinction enables Floridi to derive a "robust and intuitive link between factual semantic information and knowledge" [43] (p. 51), completing the traditional hierarchy. Floridi acknowledges that "the nature of data is not well understood" [2] (p. 82) and defines data negatively in respect of information, drawing on Bateson's definition of information as "a difference that makes a difference" [56] (p. 460). This arguably introduces circularity into the definition. However, the distinction Floridi makes between information and data is not always clear. For example, a text written in an unknown language is data before it has been decoded but information afterwards when its semantic content becomes available [43] (p. 23). A

binary encoded ASCII text is data [43] (p. 28); however, if we taught ourselves to read binary encoded ascii texts then it would become well-formed meaningful data and therefore information. As a consequence, the distinction between information and data often appears to be subjective, and individual examples can migrate between the categories depending on context. Mingers also notes that because "semantic information is identified with data, albeit only a special type of data (well-formed, meaningful, true)", it can be understood as "nothing but the data" [74] (p. 398) and therefore is not an ontologically distinct category of its own.

The converse position that information is closely related to knowledge, knowing or cognition is also widely asserted. Mikhailov and Giljarevskij, for example, state that information is "obtained in the process of cognition" [153] (p. 15). Hoshovsky and Massey's contention that information derives from a cognitive process arising from a problem combined with the data useful for its solution [154] prompted Wellisch to comment sardonically that it "seems to suppose the minds of human beings are constantly occupied with solving problems" [7] (p. 172). Farradane suggested that information can be considered as a representation or surrogate of knowledge or thought [69,70]. Burgin writes that "all knowledge is possible only because we receive, collect and produce information" [16] (p. 1). Brookes regarded the problem of relating information to knowledge as fundamental and argued that "knowledge is a summation of many bits of information" [1] (p. 48). He later argued that "information is a small bit of knowledge" [149] (p. 131). Relatively few of these assertions of an intrinsic relationship between information and knowledge draw on rigorous definitions or theories of knowledge.

Floridi also addresses the relationship between information and knowledge, arguing that they belong to the same conceptual family and describing knowledge as a network of semantic associations [43]. This is similar to Brookes' position that treats "knowledge as a structure of concepts linked by their relations and information as a small part of such a structure" [149] (p. 131) and not entirely dissimilar to Burgin's analogy of an informational thesaurus [16]. Floridi's veridical principle is carried through to this account of knowledge, which "encapsulates truth because it encapsulates semantic information" [43] (p. 51). This appears to rely on a tradition but reductive notion of knowledge as justified true beliefs [2] (p. 209) and fails to account for other ways of knowing, such as tacit, procedural, embedded or attitudinal knowledge, although Floridi also developed an account based on modal logic [2] (pp. 224–243). The distinction between knowledge and information therefore remains unclear, particularly as Floridi asserts that "knowledge can be built in terms of explanations or accounts that make sense of the available semantic information" [43] (p. 51) but acknowledges that "it is still unclear how semantic information may be upgraded to knowledge" [2] (p. 209), implying once again an assumed implicit hierarchy in the account.

Distinguishing between data, information and knowledge is often convenient for practical and professional purposes; however, that differentiation can lack rigour when applied to the question of the nature of information. Raber has written the following:

> "This approach to these concepts, however, assumes that the criteria by which data, information, knowledge and wisdom are defined are fixed, exhaustive, and unambiguous. But at what moment and how does information become knowledge? Can wisdom be derived from false knowledge, or is all that we call knowledge true by definition? The relationship between knowledge and truth is especially problematic". [42] (p. 8)

Stenmark has written that "It has often been pointed out that data, information, and knowledge are not the same, but despite efforts to define them, many researchers use the terms very casually" and adds that "the terms knowledge and information are often used interchangeably" [173] (p. 3). Buckland suggests that information and knowledge

are often essentially synonymous [49]. Krzanowski notes that while the differentiation can occasionally be useful, the distinction between data, information and knowledge can "overlook the strong similarities and stress the rather relative differences" [3] (p. 22). Mingers has argued that the distinctions between data, information and knowledge suffer "from inadequate and unclear conceptualizations of the nature of information and its possible relationships to knowledge" [145] (p. 5).

Despite the fact that information, data and knowledge are often stated to be ontologically and epistemologically distinct, we do not have a clear or consistent account of that distinction, nor a very compelling reason for accepting it. It is possible to rigorously demarcate data, information and knowledge as part of a theoretical analysis of the nature of information. But had we not started with three closely related and overlapping terms, there is no obvious reason for choosing to do so. Several dangers emerge from this for the discourse on the nature of information. The first is that motivated definitions of this kind add to the confusion around the nature of information by applying arbitrary criteria. The second is that the differentiation invariably implies a hierarchy. It is unclear that such a hierarchy exists, and indeed, there are good reasons to suppose that information is the more fundamental concept. The third is that the differentiation is assumed rather than demonstrated.

A comprehensive theory of information that depends on prior assumptions concerning the distinction between either information and data or information and knowledge or between information, data and knowledge is also dependent on robust and widely accepted theories of data and knowledge. Without this, the domains of data and knowledge can become places where difficult questions are hidden, robbing the theory of both predictive and explanatory power. These robust and widely accepted theories do not exist. While theories of data and knowledge can be proposed in tandem with theories of information, there is no strong reason for doing so without the prior assumption of a difference. Therefore, a comprehensive theory of information should avoid begging the question of the nature of data and knowledge. A better understanding of the relationship between data, information and knowledge may well be an outcome of a foundational theory of information; however, it may also show that data, information and knowledge are essentially or effectively either synonymous concepts, or concepts that reduce to information in fundamental terms.

3.5. Material and Form

In comparison with the problem of meaning and dichotomy of subjective and objective perspectives, the physical nature of information and its ontological properties is less problematic. It is widely recognised that information has a physical dimension. Nauta, for example, argues that "there is no information without information vehicles" which represent the physical material in which information is encoded [68] (p. 28). Floridi notes that "Information is also a physical phenomenon" [43] (p. 60). Hjørland argues that while "Information is not a thing", nevertheless "all things can be informative" [174] (p. 25). Raber has noted that the physical description of information "begins with observations of the general and invariant characteristics of informative objects" [42] (p. 53). Landauer notes the following:

> "Information is inevitably inscribed in a physical medium. It is not an abstract entity. It can be denoted by a hole in a punched card, by the orientation of a nuclear spin, or by the pulses transmitted by a neuron". [175] (p. 1)

Hofkirchner has gone further, arguing that "There is no sharp difference between matter and information. The latter arises from the former. That is, if matter transcends the limits of determination, if it begins to organize itself, then information is generated" [132] (p. 11).

While there is general agreement that information is always associated with material vehicles, there is less agreement on the significance of that observation. Farradane, for example, objected to defining information as "a characteristic of physical objects or of the relations between them" on the basis that "human beings and actual or potential communication are always involved" [70] (p. 95). While it is certainly the case that information is the basis on which we understand and make sense of the world, it is not necessarily true that information always implies subjective meanings, as discussed above. Conversely, Buckland argues that the material embodiment of information is the only form in which information can effectively be exploited, and that, therefore, information can be treated as a physical entity in most circumstances [49]. Disagreements on the physical nature of information are often a matter of whether the physical vehicles or carriers of information, or its epistemic, cognitive and social effects or significance are emphasised.

Information has frequently been defined in wholly ontological terms or as patterns or structures in material reality. Shannon, for example, defined information as the choice between messages in a set [87] (p. 3). Bateson transforms this idea into an ontological principle in the aphorism that information is "a difference that makes a difference" [56] (p. 460), stressing the relational nature of information. Bates has argued that "information is the pattern of organization of the material, not the material itself" [63] (p. 17). Bates later suggested the following:

> "Information is the pattern of organization of the matter of rocks, of the earth, of plants, of animal bodies, or of brain matter. Information is also the pattern of organization of the energy of my speech as it moves the air, or of the earth as it moves in an earthquake. Indeed, the only thing in the universe that does not contain information is total entropy; that alone is pattern-free". [64] (p. 1033)

Burgin's conception of information as structure [16,121] draws on an idiosyncratic reinterpretation of platonic forms [122]. The emphasis of pattern, form or structure is also central to emergent theories of information [82,98–100]. This emphasis highlights information's independence from its material vehicles. Wiener's statement that "Information is information, not matter or energy" [58] (p. 132), for example, emphasises that information is not merely a proxy for some other material quality. This implies that information can exist in a variety of physical forms without any fundamental differences in the nature of that information. Dretske's xerox principle, for example, argues for the transitivity of information flow [72] and highlights that information is not lost as it moves from one thing to another. It follows that information is not identical with its material basis. That is to say that whatever we define as the information aspects of a physical system is in some way different from merely a description of that physical system in material terms. Information is always carried by and cannot exist independently of its material vehicles, but information is not simply the material things by which it is transmitted or in which it is recorded. It therefore seems reasonable to understand information as a physically instantiated ontological principle, rather than as a physical thing as such.

The physical basis of information nevertheless has important consequences. Stonier argued that "information is the raw material which, when information-processed, may yield a message." [119] (p. 14). Elstob differentiated between physical (p-information) and semantic (s-information) and observes that the relationship between them is not reciprocal, writing the following: "we can consider p-information without any concern for s-information. But the reverse is not true; all questions of meaning and significance necessarily involve, at some stage, questions about physical embodiment" [176] (p. 298). Buckland has made a similar argument, writing that physical information "is the only form of information with which information systems can deal directly" [49] (p. 359). Landauer

has argued for a strong two-way relationship between fundamental physical laws and information, noting the following:

> "information handling is limited by the laws of physic and the number of parts available in the universe; the laws of physics are, in turn, limited by the range of information processing available". [177] (p. 29)

While weaker than Wheeler's it-from-bit hypothesis [123], Landauer sees physical reality as constrained by the limits on information processing imposed by physical laws.

From the fact that information is always manifested by material vehicles, delimitations on its fundamental properties can be inferred, defining, for example, material limits on the density of information storage, such as the Berkenstein bound [178], or the maximum speed of its transmission. This means that information flow and information transfer can be conceptualised as physical processes related to the physical world and its causal interactions. This is because information transfer requires a causal interaction. Information can therefore be conceptualised as a consequence of physical laws and not purely an abstract concept. This physical basis of information strengthens Dretske's contention that information is related to its causal antecedents [72]. Mingers, for example, has observed the following:

> "Dretske argues that the content of the information carried by a sign is that which is causally implied by the occurrence of the sign. That is, what must be the cause given that the sign or event has occurred". [93] (p. 290)

As Mingers notes, this is consistent with Shannon's model because "we must assume some causal link exists between the source and the receiver otherwise no information can be transmitted" [93] (p. 289). However, Dretske's conclusion that information is the propositional content of the sign does not directly follow from this assumption.

Two aspects of the material nature of information have received relatively little discussion in the general discourse addressing its fundamental nature, despite their centrality in their respective fields. In some physical theories, the conservation of information is treated as a fundamental principle, particularly in quantum mechanics and black hole thermodynamics. This states that information is not lost in closed systems. If information is regarded as a universal invariant—independent of frames of reference and objectively defined—then its conservation necessarily follows. This feels intuitively plausible because information is often more persistent than expected; overwriting the data on a magnetic medium, for example, may not destroy the information previously recorded. Yet despite its implications, conservation of information has rarely been integrated into broader theoretical accounts of information. Similarly, quantum information is intrinsic to quantum mechanics and to quantum computing, and while this has been acknowledged (e.g., [16,82,89]), its specific relevance to general theories of information has not been sufficiently addressed in detail. Burgin for example discusses the issue in the introduction of his major work [14] and the topic is occasionally addressed in other contexts [121] but in nothing like the depth of his account of classical information. Indeed, while there are notable exceptions, the physical grounding of information has generally received less attention than its ontological, semantic or epistemic aspects. However, a comprehensive theory of information cannot treat this as peripheral and must account for the relationship between information and material reality in explicitly objective terms.

3.6. Time, Sequence and Causation

An important aspect of the physical and ontological nature of information is its existence in and relationship to time. Time, sequence and causation are amongst the least discussed aspects of information despite being implicit parts of many, if not most, defini-

tions. It is widely acknowledged that information to some degree reflects change and is a temporal phenomenon. Whittemore and Yovits, for example, argue that information is both situational and time dependent [61]. Time and sequence are both central to Shannon [87] and Wiener's [58] discussion of information. Bateson's definition of information implies that information is a cause of subsequent changes, although he notes that "the coding and transmission of differences outside the body is very different from the coding and transmission inside" [56] (p. 461). Semiotic approaches to information generally exploit Saussure's differentiation between syntagmatic and paradigmatic difference. Yet the significance of time has generally not been directly addressed in much of the discourse on the nature of information.

Sequence is frequently important to the ways in which we understand information; that is to say that information not only has a paradigmatic dimension but also a syntagmatic dimension (selection over time). Derrida's concept of différance usefully highlights this distinction in framing the ways that meaning in language is endlessly deferred in part because adding to the sequence of signs always threatens to disrupt or overturn the existing interpretation [179]. How we understand sequences in communications and in information is therefore often determined retrospectively. That is to say that information can be understood to relate to or reveal the prior states of a system, and this relationship between information and system states has been an important aspect of the definition of information. Sequence is fundamental to information in many contexts, such as in biological codes. Sequence is also fundamental to Shannon's description [87]; a bit of information has significance only as part of a sequence. It is surprising then that sequentially has not been more of a focus of the discourse on the nature of information, which has arguably tended to conceptualise information in terms of static structures and patterns.

The perspective on information in which time has placed the most significant role is what Buckland describes as information-as-process approaches to defining information [49], and what Floridi describes as the dynamics of information [2,91]. Floridi, for example, asks "how is it possible for something to carry information about something else?" [2] (p. 32). Information can be understood to exist only in change, in its transformation from one state to another, or more precisely, in the transformation of those systems in which information is embedded and produced as a consequence of their change. This is anti-intuitive because much of the information appears to be stably encoded in material vehicles, from the texts in books to the growth rings in trees; however, in the process of their use, there is always a transformation and transfer of information. Crnkovic & Hofkirchner, for example, have highlighted the difficulty in translating between our static and dynamic conceptions of information [168]. Nevertheless, dynamic information can be conceptualised in the process of encoding and decoding these static forms; static forms of information are, in this sense, pure potentiality that becomes information proper only in their use.

To some extent, then, while we are more familiar with considering information as a static or stable pattern or structure, information can be understood as a wholly temporal phenomenon for which time is a critical element. MacKay has gone further, suggesting that "a strong case can be made for the suggestion that our concept of time, in at least one of its aspects, is directly linked with the objective notion of the flux of information" [60] (p. 16). This echoes the idea that the arrow of time emerges out of the laws of thermodynamics, sometimes attributed to Eddington; the close relationship between information and entropy makes this a natural inference. However, MacKay has perhaps overstated the case. Nevertheless, it does highlight the potentially close relationship between information and time, one that is worthy of further discussion.

An important element of time and change in the nature of information is causation. Information is frequently situated as a cause of subsequent changes either in general or

systemically. Bateson's definition of information as "a difference that makes a difference" implicitly situates information as a cause of subsequent changes [56] (p. 460). Sometimes information is understood to act on cognitive states, and sometimes it is seen to cause material changes. Burgin's second ontological principle, for example, states that "information for a system R is a capacity to cause changes in the system R." [16] (p. 99). Information is "a capacity of things. . . to change other things" [16] (p. 99). While admitting this is a very broad definition, Burgin also states that "a piece of information is the information that comes to a system in one interaction of that system" [16] (p. 100). This seems to imply that information is both a capacity to cause change and the change that is caused. Burgin draws out the consequences of this capacity of information to cause change, arguing that it explains "why information influences society and individuals as well as why this influence grows with the development of society" [16] (p. 100); this does not follow as such. Importantly, Burgin's second ontological principle gives information a future orientation: it is its capacity to cause future change that defines information in the present.

However, information's past orientation seems more plausible, that information is a consequence of causation rather than a cause in its own right. Dretske has argued that information is the basis on which we make inferences about prior causes and posits this in propositional terms [72,73]. Mingers and Standing follow this account, writing that "Signs carry information about their causal origin—what, given the occurrence of the sign, must be the case—whether or not it is observed or correctly interpreted" [75] (p. 19). As noted above, this reflects the order of priority in causal relationships and therefore has an objective physical basis: in order for information transference to take place, there needs to be a causally related interaction. This is consonant with physical laws. Mingers also addresses this point, writing the following:

> "Independent events can transmit no information, but a causally linked even carries information about its cause. Instruments (e.g., thermometers) are good examples. They are designed specifically to have some causal relationship to a particular state of affairs. Assuming it is working properly, a particular thermometer carries information about the surrounding temperature". [93] (p. 289)

This posits a mechanism for information dynamics that addresses Floridi's question about the possibility of something carrying information about something else [2] (p. 32). The informational content is not a property of the material vehicles as such, but what can be deduced from those material vehicles by virtue of the properties that they possess. From the thermometer, the temperature that caused the mercury level can be deduced; from the book or work of art, the intentions that perhaps caused the patterns etched in their surfaces can be deduced. The propositional framework that Dretske [73] and Mingers [93,94] construct around this principle perhaps reflects a desire to account for meaning over a desire to account for information itself. Nevertheless, the notion that information is, at its most fundamental, the trace of prior causes is persuasive.

3.7. Information and Computation

These questions about the relationship between information, time, sequence and causation become most important when considering the role of information in computation. Computability arguably ties together disparate aspects of information's fundamental nature. While defined by Turing in abstract terms as symbol manipulation according to well-defined rules by conceptual machines [129], computability can also be considered a material fact and consequence of the fundamental laws of nature, and this has important implications both for computational models of nature but also for understanding the relationship between computation and information. As Landauer notes, "computation is inevitably done with real physical degrees of freedom, obeying the laws of physics, and using parts

available in our actual physical universe" [177] (p. 23). However, the relationship between computability and information is complex and foundational to theoretical computer science. This section is only able to touch on that.

The notion of computability was formally defined in Turing's On Computable Numbers [129], which set out the model of what became known as the Universal Turing machine. The same year, Emil L Post published a similar paper, describing a symbol space consisting of "a two way infinite sequence of spaces or boxes" [130] (p. 103) employing a unary rather than binary notation system. While neither Post nor Turing addressed the concept of information directly, their papers imply a formal notion of information processing based on symbol manipulation, particularly in Turing's proof of the universality of computation models. The following year, Shannon demonstrated that electrical circuits could be designed to carry out Boolean functions, concluding the following:

> "It is possible to perform complex mathematical operations by means of relay circuits. Numbers may be represented by the positions of relays or stepping switches, and interconnections between sets of relays can be made to represent various mathematical operations. IN fact, any operation that can be completely described in a finite number of steps using the works "if", "or", "and" etc. [...] can be done automatically with relays". [180] (p. 22)

Shannon later demonstrated (1956) that the Turing model could be further simplified, suggesting "it is possible to exchange symbols for states and vice versa (within certain limits" [181] (p. 165). This represented a significant conceptual leap, clarifying how abstract logic could be mapped onto physical mechanisms and, conversely, how physical systems could embody universal computation.

The connection between computability and Shannon's model of information is merely implied by their convergence of binary expressions, but this connection is not coincidental. It reflects an important relationship between information processing and Boolean logic. Boolean logic is functionally complete, meaning that any logical operation of any complexity can be expressed using a minimal set of logical operators. This indicates that complex logical operations can arise from simple rules, and may imply that information is inherently discrete in nature. However, while Boolean Logic implies a fundamental relationship between computability and Shannon's model of communication [87], Kolmogarov's algorithmic information theory provides a bridge between these ideas [65], synthesising key insights from Shannon's information theory and Turing's computability theory.

This relationship is illustrated by the connection between computability and cellular automata. First developed in the 1950s by John von Neumann [182], it was later recognised that cellular automata provide a discrete model of computation. Well-known examples include John Conway's Game of Life [183] and Wolfram's Rule 110 [184,185], which have both been shown to be Turing complete [186,187]. This means that, in principle, they can perform any computable function, such as running contemporary generative AI systems within their dynamics of evolving patterns, providing that they are unbounded in time and space. They are therefore powerful minimalist models connecting computability, information and discrete causality. Cellular Automata do not merely illustrate the relationship between information and computability; they embody that relationship, implying a deep connection between physical laws and our understanding of information. But cellular automata also provide a bridge to complexity as a model of the nature of information. Wolfram defined four classes of behaviour of cellular automata [185]:

- Class 1: patterns stabilise quickly to a homogeneous state.
- Class 2: patterns evolve into stable or periodic structures.
- Class 3: patterns exhibit chaotic, seemingly random behaviour.

- Class 4: patterns show complex, long-lived localised structure capable of universal computation.

Class 4 broadly aligns with Langton's evocative description of the edge of chaos as a description of adaptive complexity [188], a thin boundary between systems that tend towards stasis and systems that tend towards chaotic behaviours. Adaptive complexity sits in this boundary, describing the behaviour of large-scale, highly dynamic systems which, although driven by the aggregated behaviour of simple elements and limited rules, appear to function in coherent and motivated ways. Cilliers has noted that "the distinction between complex and simple often become a function of our 'distance' from the system" [162] (p. 3); complexity only becomes "manifest at the level of the system itself" [162] (p. 2). This characteristic is highly relevant for understanding information, where complex patterns and meanings apparently arise from information often regarded in fundamental terms. Thrift has argued that "the chief impulse behind complexity theory is an anti-reductionist one" [189] (p. 32). Urry has argued that "it is not that the sum is greater than the size of its parts—but that there are system effects that are different from the parts" [190] (p. 5), or in Anderson's pithier terms, "more is different" [191]. Again, this is relevant to information, suggesting the means to overcome the apparent categorical dualities that have plagued the theoretical discourse. Fundamental to this spatial re-envisioning is the network or "meshwork" [140] of interlocked agents, motivations and forces that make up the complex system.

One important aspect of complex systems is that they can be defined in informational terms. Wolfram's rule of computational equivalence states that most systems, even simple ones, can perform computations up to a maximal level of computational power, making them effectively equivalent in their computational sophistication [185]. This means not only that complex behaviour can emerge from simple rules, but also that many natural systems can be considered as equivalent computational power to any designed computer. The rules that define cellular automata can also be considered as abstract representations of causal relationships; this is implied, for example, in Conway's description of cells springing to life through underpopulation, dying of loneliness or overpopulation. This creates a powerful link to Dretske's contention that information is associated with the inferences that arise from prior causes [72]. These ideas have been explored in emergentist conceptions of information, but these have tended to imply that information is itself an emergent property. However, it is plausible perhaps to regard information as discrete differences that, through their causal interaction, lead to emergent phenomena. The fact that we sometimes also describe these higher-level patterns or structures as information and analyse their characteristics as discrete ontological units is immaterial to their characteristics as emergent patterns.

This approach has the advantage of closely aligning with and demonstrating the relationship between both Shannon's model of information and Turing's model of computation [129], showing how semantics arises from syntax and complex effects arise from simple causes. That is not to say that information is merely a product of computation or complexity. Information is only the difference that makes a difference, or a selection between messages. Rather, it is to suggest a consistent mechanism to explain the transition between levels of description discussed above, to relate information as a physically instantiated ontological principle to its dynamics, and to show how subjective effects might arise from objectively defined information. While the discourse on the nature of information is broad, there are deep connections and similarities between the various approaches to information as a theoretical and critical concept that imply a single theoretical model that might explain them all, not through the synthesis of incommensurable ideas, but by showing how they arise as higher-level descriptions of a more fundamental theory. Contrary to Brier [89], information is enough.

4. Summary of Conclusions Concerning a Foundational Theory

4.1. Introduction to Summary and Conclusions

This paper has sought to trace the boundaries of the theoretical literature addressing the nature of information in order to map the conceptual issues that information poses as a theoretical concept. The intention has not been to propose a new foundational theory of information, but to highlight from the existing literature what the underlying principles of such a theory may be, highlight gaps in the existing body of knowledge, and propose a roadmap for future theoretical research. This section outlines some of the key findings of this review and how they relate to potential future theoretical developments.

4.2. The Simplicity of Information

At its most fundamental, information has been predominantly understood in simple terms, as a choice between messages, a difference that makes a difference, or the inferences implied by a causal event. However, information is a phenomenon that also gives rise to diverse and complex structures and effects that are situated and understood in divergent ways. These are often of more immediate and obvious interest to human experience. Critical enquiry into the nature of information has therefore tended to address these diverse and complex structures and effects, treating them as the starting point of analysis, rather than as products of information's fundamental nature. As a consequence, information has attracted varied meanings and definitions that have complicated the understanding of its fundamental nature. The transition between these scales of description is poorly understood. A foundational theory of information should posit information as a simple phenomenon that gives rise to complex phenomena, maintaining that distinction between the nature of information and the nature of its effects and affordances.

It is most widely accepted that information is a physical instantiation of an ontological principle; it is not physical in nature, but it is inseparable from the materials in which it is instantiated, and the properties of those materials constrain the nature and behaviour of information. The behaviour of information is therefore governed by physical principles; while these may not be identical to those that define computation, the fact that computation can be reduced to simple combinatory rules demonstrates this principle. A foundational theory of information, by virtue of being foundational, should address the fundamental nature of information and the rules governing its behaviour, rather than the diverse complex phenomena to which it gives rise, although it should also seek to explain how such diverse complex phenomena arise as a result of those rules and behaviours. This is not to exclude the value of those higher-level descriptions that have tended to predominate in the critical discourse.

Information is the means by which the human cultural and intellectual tradition is recorded and transmitted. It is also the means by which we obtain an understanding of the world and our place in it. However, it is not identical to that tradition, nor is it identical with the various cultural and intellectual forms that comprise that tradition. That which is most subjectively important about information—its capacity to convey meanings that build empires and slay gods—is not necessarily that which is most fundamental to information as an objectively defined phenomenon. Nevertheless, the very fact that information is the means by which we come to know and experience the world and transmit that knowledge over time means that the analysis of the nature of information needs to account for the historical context of its meanings and uses. Understanding the nature of information requires a more thorough analysis of the development of the concept and its relationship to historical contexts. This includes a more thorough account of the ways in which the changing contexts of information creation, dissemination and use have influenced the

development of theories of information, particularly in the second half of the twentieth century and beyond.

4.3. What Information Is and What Information Does

In general terms, the discourse on the nature of information has failed to consistently differentiate between what information is and what information does, which are different categories of description. While it has purported to address information's fundamental nature, it has often principally addressed its effects or affordances. In particular, there has been a tendency to conflate information as an objective entity and the process of informing or becoming informed. Both are valid questions, but they are different questions.

The affordances and effects of information are an important function of the discourse in their own right, and often more directly relevant to the issues that information poses on a social or professional level. However, in considering these affordances and effects, the distinction between what information is and what information does needs to be maintained. This has often not been the case. Raber argues that from a subjectivist perspective "information and its effect cannot be separated" [42] (p. 96); this has been a common assumption, particularly in relation to information's subjective aspects, but it is false. It is entirely possible to distinguish between information as a distinct ontological principle immanent in physical things and the subjective and context-dependent effects, reception, or interpretation that it engenders. The former is clearly a matter of the physical properties of the material world, and the latter a matter of the properties of subjective experience.

Information as an objective mind-independent phenomenon is a well-defined, discrete phenomenon that can be understood to arise from established physical laws. Accepting this in no way constrains, delimits or denies its richer affordances and effects, and indeed helps with their explanation. When treated as a subjective aspect of cognition, knowledge, or understanding, the concept of information lacks a clear definition and analytical utility; it neither clarifies the nature of subjective experience nor enhances our understanding of information's objective properties. In such contexts, more precise and well-established concepts, such as knowledge, understanding, emotion or affect, offer greater explanatory power and conceptual clarity. However, there is currently no adequate framework to describe how information, as a basic constituent of nature, gives rise to complex and often richly meaningful phenomena. Starting with an assumption concerning the objective mind-independent nature of information allows a clearer differentiation between information as a simple phenomenon and the complex effects and affordances to which it gives rise, and the opportunity to construct a better understanding of these different levels of description.

4.4. Information and Prior Causes

Shannon's account of information remains one of the most influential models of information's ontological structure, yet it is incomplete. While its mathematical formalism is universally applicable, it does not fully capture all dimensions of what information is or does. Notably, Shannon's theory excludes subjective aspects and does not explicitly connect information to the underlying physical principles that give rise to it as an objective and independent phenomenon. Nevertheless, the widespread applicability and robustness of Shannon's framework place strong constraints on any foundational theory of information.

Dretske's theory of information defines information as the basis for making reliable inferences about prior causes in the physical world [72]. Moving beyond purely structural accounts, he emphasises the semantic content of information—its role in indicating or representing states and events. Grounded in physical causal relationships, Dretske's account naturalises information without invoking metaphysical assumptions, highlighting how information functions to connect causes and effects independent of any particular

observer or interpreter. The role of prior causes is evident across many domains: reading a text involves inferring the intentions behind its creation; the state of a logic gate reflects electron flow causes; ice core patterns record historical climatic events; and DNA sequences embody biological processes. However, extending this insight into a universally applicable model remains challenging. The association of information with the trace of prior causes highlights information's retrospective temporal orientation—that information testifies to prior causes, and provides a potential foundation for constructing a foundational theory of information. However, Dretske's reliance on a propositional framework arguably does not achieve that extension because of its reliance on traditional analytical accounts of meaning.

4.5. Semiotic and System Complexity

As noted, the role of complex systems and emergent phenomena may play a significant role in understanding both the nature of information and its affordances, effects and potentialities. While there have been several accounts treating information itself as an emergent phenomenon [82,98–100], this risks conflating information with the phenomena that arise from it, such as meaning, intentionality and perhaps consciousness. It seems more plausible to treat information as fundamental and its secondary affordances and effects as emergent. This distinction preserves the universality and measurability of information while acknowledging that its semantic and phenomenological dimensions arise only through interaction with observers or complex systems. By separating the fundamental nature of information from its emergent effects, this approach avoids reductionism and provides a more comprehensive framework for understanding information's multifaceted role across disciplines. It seems plausible that semiotics and systems complexity may provide a solid foundation on which to build, from the nature of information as a trace of prior causes to a theoretical description of its complex affordances and effects. Nevertheless, this is not itself an explanation, but merely a description, and the theoretical work that develops such a model remains to be conducted.

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