

Editorial

Information and Energy/Matter

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1. The Necessity of an Agent (Observer/Actor) for Knowledge Generation

What can we hope for from studies of information related to energy/matter (as it appears for us in space/time)? Information is a concept known for its ambiguity in both common, everyday use and in its specific technical applications throughout different fields of research and technology. However, most people are unaware that matter/energy today is also a concept surrounded by a disquieting uncertainty. What for Democritus were building blocks of the whole universe appear today to constitute only 4% of its observed content. (NASA 2012) [1] The rest is labeled “dark matter” (conjectured to explain gravitational effects otherwise unaccounted for) and “dark energy” (introduced to account for the expansion of the universe). We do not know what “dark matter” and “dark energy” actually are. This indicates that our present understanding of the structure of the physical world needs re-examination.

However, by connecting two much debated sets of ideas—information and matter/energy—can we hope to gain more clarity and some new insight? I believe so! This special issue contains contributions with beautiful examples of clarity and strength of argument, which helps us in assembling the jigsaw puzzle of relationships between information and energy/matter.

One of the approaches discussed leads to formulating physics in terms of information. The idea goes back to Wheeler’s “it from bit” [2], developing the idea that, for us, information is the fabric of the universe. Our reality results from the processing of information of multimodal signals coming through our senses in combination with information processes in our bodies and brains.

Informational reality is the subject of a steady stream of new books; prominent examples are [3–8].

2. Reality (for an Agent) Is an Informational Structure

Matter and energy are higher order concepts derived from interactions of an observer, or a network of observers, with the universe, including mutual interactions among agents. This does not mean that the reality is just an agreed upon imagination. A world exists on its own with human agents in it and

we discover its structures and processes, patterns and laws, by interactions and via self-structuring of information obtained through the interaction. This is the most rigorous approach to scientific knowledge production that not only models the world but also the agents researching the world, as the reality being experienced by cognitive agents is built upon the information available to them and their own information processing capacity. The reality of an amoeba or a robot differs from the reality of a human.

Understanding the observer-based (also scientific-community-based, theory-dependent) character of scientific knowledge does not question its scientific validity, but opens our eyes to the fact that under different conditions, for a different cognitive structure and theoretical framework, the same reality reveals different facets. So specifying how (scientific) knowledge is actually produced helps us to better understand how knowledge is constructed based on informational reality.

Informational approaches go one step deeper than our present day level of understanding of scientific process, building a layer beneath the structures of the currently used matter/energy-in-space/time paradigm. This does not mean that current sciences are thereby invalidated or become subjective fictions as some wrongly fear. *Observer-dependent does not equal subjective!* Placing a well defined observer (agent) in the center of the model of reality makes explicit what in classical physics was implicit. As Goyal in this issue aptly explains, an observer in classical physics was a highly idealized omnipotent agent looking at the world from nowhere (or, in Fields's words, also in this issue: a "Galilean observer", a bare "point of view"), able to observe and conceptualize the world without affecting it or being affected.

3. Information is both Discrete and Continuous

One of the many confusions surrounding the idea of informational reality and interpretation of the "it from bit" slogan is that information is sometimes supposed to be a discrete yes/no answer to questions, that seems to be the original Wheeler view. However, not all information for an agent is observed as coming in discrete chunks, some of it appears as continuous signals. For example, discrete and continuous views of protein structure are complementary and protein structure space is discrete on an evolutionary level, but it is geometrically continuous. In general, the question of continuity/discreteness depends on the level of analysis. For an agent (observer) with a coarse resolution, even grainy systems will appear continuous. Being continuous is relational—it is relative to the observer. On a quantum-mechanical level the wave/particle duality is unavoidable." Qubits are also known as "quantum two-state systems" (though this is a rather misleading term because, like all quantum systems, *a qubit has a continuum of physical states available to it*) [9].

Floridi [10] explains why informational structural realism implies discrete and continuous, analog and digital ontology: "The most reasonable ontological commitment turns out to be in favor of an interpretation of reality as the totality of structures dynamically interacting with each other."

4. It from (Qu)bit

The first topic in focus in this special issue is physics as science of information in which papers of Goyal, Vedral, Fields and Zenil can be placed. The essential goal of Goyal's paper is to examine the "it from bit" idea from the point of view of quantum theory, to clarify why and how information acquires

a central role when moving from classical physics to quantum physics, and how precisely the information point of view is allowing us to more deeply understand the nature of quantum reality (both through using quantum theory to implement informational protocols, and through trying to formulate and use information-inspired principles to derive predictions of quantum theory).

Vedral contributes with a discussion of the question of what comes first, physics or information, arguing that both physics and science of information profit from interaction with each other. Zenil's article presents a survey of some characteristics of the thermodynamics of computation and relates information, energy, computability and statistical mechanics. He finally suggests research into information and computation applied to biology, which until now successfully resisted the famous "unreasonable effectiveness of mathematics in the natural sciences" [11] proclaimed by Wigner. Fields investigates the consequences of the physics understood as information science, elaborating the question of the nature of an observer modeled more realistically than the Galilean "point of view". He shows how the observations recorded by an observer that satisfies the requirements of classical automata theory will display the characteristics predicted by quantum theory.

When studying the physical character of information, it is good to remind oneself that the physical "has a variety of overlapping meanings (a Wittgensteinian family resemblance). For example, Quine takes the physical to be anything accessible to the senses or inferences thereof. Ladyman, Ross, Collier and Spurrett take the physical to be the most fundamental laws of our (part of) the universe. (...) Information is at least physical in both of these senses. Quine's approach might make it entirely physical. I prefer to relate it to the causal, which always has physical parameters, as far as we know. But there are many ways of approaching this issue, and disentangling them will be a major advance in foundations of information theory", as argued by Collier [12].

Luhn, in this issue, follows this approach to information grounded in physics as the causal and explains novelty as compositional. This proposed concept of information is developed based on ideas of Burgin, Brenner and Floridi.

On the quantum mechanical level of physical reality there are qubits, "So, what does that leave us with? Not "something for nothing": Information does not create the world *ex nihilo*; nor a world whose laws are really just fiction, so that physics is just a form of literary criticism. But a world in which the stuff we call information, and the processes we call computations, really do have a special status." by Deutsch [9]. This emphasis on the dual nature of information/computation is found in Dodig Crnkovic [13] as well as Zenil [14].

5. Self-Organized Complexity, Jaynesian Observers and Logic in Reality

Apart from the direct answers to the question of physical nature of information and informational nature of physics, the topic of this special issue provoked responses ranging from the role of an observer in the self-organized complexity, mechanisms of chemical affinities relevant for the origins of life, to the issues of representation and logic. All of the articles touch upon the role of an observer or rather an agent undergoing interaction with the world, be it a cognizing agent as a researcher generating theory, or a simple physical system like a chemical molecule interacting with its surroundings.

Matsuno and Salthe's "observers" (agents) are molecules involved in two types of interactions used for studying chemical affinity as material agency for naturalizing contextual meaning. An important natural example of this material agency is suggested as responsible for the origins and evolution of life.

Yoshitake and Saruwatari see the interaction of an agent with the world as an act of measurement. They address articulation of information from the physical world via interactions alone, generalizing the extensive measurement theory.

Brenner's take on representation in information theory contains a discussion of the limitations of the standard theories of representation and argues for a more realistic picture of informational systems based on information as an energetic process. Brenner proposes an extension of logic to complex real phenomena in his Logic in Reality (LIR), which provides explanations for the evolution of complex processes, including information. Rather than via structural relationships, information in Brenner's approach is identified by its dynamics, or better, by the fact that its structure is dynamic. This approach can be compared with the Dodig-Crnkovic view of information and computation as two complementary principles [13], where information corresponds to structure while computation stands for dynamics. This approach "unpacks" Brenner's information into its structural and dynamical aspects.

Brenner contributes to this special issue even with an informative review of Mark Burgin's book *Theory of Information: Fundamentality, Diversity and Unification*.

An information-based, epistemic, inductive probability was developed by physicist E. T. Jaynes who used the maximum entropy inference (or logic) to convert prior information for an observer into prior probability distribution. While Jaynes applied probability theory to the problems of inference facing scientists (notably in statistical mechanics), both Phillips and Fiorillo, in separate articles, consider the implications of Jaynes's work for our understanding of how the brain can perform inference.

Phillips's paper studies how complexity can be adaptively self-organized by using probabilistic context-sensitive inference. Jaynes's probabilistic inference is seen not only as the logic of science; but generally as the logic of life. Phillips concludes that the theory of Coherent Infomax specifies a general objective for probabilistic inference, and that contextual interactions in neural systems perform functions required of the scientist within Jaynes's theory.

Fiorillo, too, argues for Jaynes's approach, in which probabilities are always conditional on a state of knowledge of an agent through the rules of logic, as expressed in the maximum entropy principle which provides the objective means for deriving probabilities, as well as a unified account of information and logic (knowledge and reason). Fiorillo's article suggests how to identify a probability distribution over states of one physical system (an "object") conditional only on the biophysical state of another physical system (an "observer"). Even though the aim is to show "what it means to perform inference and how the biophysics of the brain could achieve this goal", this approach exquisitely exemplifies the idea of relational information as defined by Hewitt [15].

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