Matter and its Configuration States in the Making of Information

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Abstract:
I present compelling arguments for the ontological primacy of matter in the nature of physical reality, by examining the premises of creation, existence and dissolution of information. A clear distinction between matter and its physical states that translates to the distinction between bits and their information states is established to arrive at this result, directly from requirements of quantum measurement. Then it is shown that this alone allows the exponential measure of the information potential of a finite amount of matter. En route the argument, I point out that the consistency of black hole thermodynamics also requires the ontological priority of matter over information. I conclude with a discussion of the universe as matter and its self-referential information landscape.

Introduction

There are perplexing undecidabilities that touch the very foundations of thought and science. While 'chicken and egg' has a vanishing point in the deep recess of evolutionary time scales, questions on whether matter is more fundamental than space and time, fields, information or even consciousness lingers on from time immemorial. Comparing the ontological status of two entities that are both fundamental and familiar presupposes the reality of both - otherwise they would not enjoy the status of familiarity of experience. The familiarity in the case of matter is of sensory experience whereas that of information is at an internal level of awareness. The fact that ultimately both kind of experiences are linked to the human awareness complicates the matter of decision making. While trying to show that matter is more fundamental than information, I do not intent to discuss whether one has a more tangible physical reality than the other. In fact, the view taken here is that the issue of real existence independent of perception is irrelevant for human endeavors like science. What is required is internal consistency and stability of the perceived patterns of nature. While it is reasonable to extrapolate that to an underlying objective reality, it is not a logical necessity for building theories.

Before we discuss the reasons to claim primary ontological status of matter over information, after accepting physical reality of both, it is worth examining how the opposite view, where information is given the primary status, came about. In the ancient wisdoms, it arose in seeing the external world as a projection of the internal mental world. The proverbial serpent and the rope, where a live and lethal reality is perceived in the inanimate coiled rope, exemplifies how reality is constructed out of an interaction between matter and mind. The inseparability of the ontological and epistemological aspects of such reality is in fact the source of the hard problem of realism.

In the modern context of rigorous classical physics, an attempt at formulating dynamics without matter was tried by Newton, and the program failed. The information content of dynamics, in the form of the physical law, was postulated from experience and yet, Newton could not present the arena of space and time for dynamics without referring to matter. The difficulty is evident in Newton's Principia [1]: "Absolute space, in its own nature, without relation to anything external remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces, which our senses determine by its position to bodies, and which is commonly taken for immovable space. But because, the parts of space cannot be seen, or distinguished from one another by our senses, therefore in their stead we use sensible measures of them. For from the positions and distances of things from anybody considered as immovable, we define all places, and then with respect to such places we estimate all motions…" Similar statements are found about 'time' as well.

This situation was addressed again and critically analyzed by Mach who attributed the deciding properties to matter [2]. Einstein's general theory of relativity neutralizes this and attributes equal status to matter and its gravitational information content, as the curvature of space-time.

It is with the necessary Boolean 'yes' or 'no' nature of physical realization of phenomena in quantum physics one comes across the issue of whether 'it' is primary or 'bit' is, in the most discussed context. The actualization of physical reality in quantum physics happens through the device of a measuring apparatus and measurement and hence, there is a widespread tendency to attribute the primary status to the answer, identified as information, over the material entity about which the question was asked. In John Wheeler's often cited description [3], "In some ways, the electron, before the physicist chooses to observe it, is neither a wave nor a particle. It is in some sense unreal..Not until you start asking a question, do you get something...every it - every particle, every field of force, even the space-time continuum itself - derives its function, its meaning, its very existence entirely - even if in some contexts indirectly - from the apparatus-elicited answers to yes-or-no questions, binary choices, bits." The key idea here is the 'actualization' of physical reality on measurement by a 'participatory' observer.

Surprisingly, it is in the context of quantum theory and Wheeler's assertions that we can prove the primary ontological status of matter most easily and convincingly. *Assertions based on reasoning of the kind used by Wheeler incorrectly identifies the physical state of matter with matter itself*. Wheeler identifies the state of the electron with 'it' and the answers in a quantum measurement with 'bit'. Indeed, in an article in honor of Wheeler's 90th birthday in 1992, Zeh wrote [4], "Schrodinger's wave function shows many aspects of a state of incomplete knowledge or *information* ("bit)...Nonetheless, quantum superpositions (such as represented by a wave function) define individual *physical* states ("it")". When this muddle is resolved, the primary ontological status of matter clearly presents itself without ambiguity. If it were for the sake of argument, the proof could be immediate by noting that Wheeler himself presupposes the 'apparatus' for gaining information of the state; information is *apparatus-elicited* in his description. 'Apparatus' in whatever form is matter, loaded with a structure of purpose, which is its information content. However, I do not take that shortcut here. I want to discuss in detail the creation, existence (representation), and dissolution of information and their relation to matter to arrive at a definite conclusion about the ontological relation between matter and information.

Matter, Space and Time

Matter, in our standard description, is all of the fundamental particles including the bosons that are carriers of interaction. The standard model of particle physics is the most structured model of the material world and has a clear classification for matter and their interactions described in terms of matter itself. In the relativistic quantum picture, field is classified as 'material' with energy-mass equivalence. We can include space and time into this picture, for space and time are defined by matter. Without matter anywhere, it is difficult, if not impossible, to deal with concepts of space and time. To quote from Einstein's forward to Jammer's book [5], "...two concepts of space may be contrasted as follows: (a) space as positional quantity of the world of material objects; (b) space as container of all material objects. In case (a), space without a material object is inconceivable. In case (b), a material object can only be conceived as existing in space...Both space concepts are free creations of the human imagination...". In any case, the concept of time is entirely dependent on the existence of matter. There is no clock, even in the abstract, without matter. All our notions of time are related to the difference between two distinguishable configurations of matter. Einstein's equation of the general theory of relativity suggests an equivalence between matter and the properties of space-time (not between matter and space-time, though).

Information

A good signature of what 'information' is may be found by examining the measures of information. All its good measures are proportional to the logarithm of the number of representational configurations. The counting of configurations is an essential feature, and the keyword is 'configuration' itself. From this point of view, matter enters as the primary entity since by configuration, the only sensible meaning we can ascribe is an arrangement, or state, of matter. Empty space, flat and infinite, has no information content. It has zero entropy. One might think that this is an extreme statement since such space has a description in terms of a metric, and isn't that information? We should be rigorous here, and assert that in truly empty space there are no observers or test particles, no scales or clocks, and therefore its metric is an empty concept, devoid of any reality.

Information, in its most general sense, is an attribute of 'something', and the object has the claim to be more fundamental than its attribute, as already been argued in J. Barbour's essay addressing the relation between matter, information and discreteness [6]. What we want to elaborate here is exactly how this attribute is assigned and see whether there is any sense in which one can claim that the creation of the attribute implies the actualisation of physical reality for matter. That is the closest one may come to claim primary ontological status to information. However, we will see that in spite of the attribute providing *meaning* to the existence of matter, a very important and essential feature from anthropocentric point of view, the fundamentality of the ontological status of matter remains intact.

Laws of dynamics and physical evolution

Physical systems evolve and motion or change of relational position in space is the most familiar template for evolution. 'Time' is an essential underlying concept, which itself is an evolution or a generalized motion of a physical system, amenable to some control and standardization. Therefore dynamics in a physical system - the evolution of the configuration of matter - is a relationship or correlation with another configuration of matter, usually isolated enough from the first so as not to be perturbed severely by the former. The next important feature is a 'law of motion'. Newton's law of motion is a familiar example. The law of motion specifies how a configuration or a physical state of matter transforms to another when some external conditions are specified. Hence the key concepts are specification of a physical state of the physical system whose dynamics is monitored and that of the external world. This specification including the law itself may be classified as information.

It is possible to demarcate portions of dynamical evolution as cause and effect, to help in the construction of a world view amenable to analysis. However, it is more appropriate to view physical evolution as a series of transformations on the states (configurations) of matter. A very important aspect to note is that evolution is always a correlation, with another configuration of matter, usually chosen by convention. Indeed, all semantic information is a correlation with a convention. This concept immediately implies time as a physical entity. While the measure and sense of time is determined by the evolution of such a information correlation, the seat of the underlying information templates is matter, like a quartz crystal or an atomic sample. Change requires an object of change. Emptiness cannot change. There are no manifestations of even quantum vacuum fluctuations without any matter present; Casimir force requires the material boundary. In fact, this acknowledgement of matter is necessary because time is affected by gravity and motion, both of which are modified by matter and in turn, affect matter.

The law of motion itself can be ascribed a material basis as in Mach's proposal [2]. A discussion of this with generalization to relativistic dynamics, in the context of presently established cosmology, may be found in reference [7].

There is great amount of inter-convertibility in these configurations as far as description of physical evolution is concerned. For example, the spatial motion of a particle can be described in terms of a correlation with the precession of a spin of another particle, with the precession serving the role of time. However, there is no description of dynamics without at least one such *material* reference configuration.

The relation between matter and information

Our fundamental assertion is that information as a physical entity is in close correspondence with the physical state of matter, rather than in correspondence with matter. We use the terms state and configuration interchangeably in this discussion. A physical state is one where values of measurable or observable attributes are specified on the material particles. We have already clarified that all measurements are evaluation of a correlation with a prior template. The direction of the spin of a particle is an observable attribute. However, a reference direction is necessary for this to make semantic sense. The actualization of information can happen either at the stage of preparation of a state, or at the stage of observation of the state, and both requires material apparatus. This necessity is clear in the context of quantum theory, in which the apparatus is a special entity and high precision in the preparation or measurement necessarily needs apparatus that is as 'classical' as possible, involving a large number of quanta in its existence. Otherwise both preparation and measurement disturb the apparatus, as well as the physical state.

With this preamble, one can examine in detail how information is physically realized. There are three levels of reality we need to consider. One is that of matter, as material particles, with attributes like spin, charge, energy, momentum etc. familiar from the standard model. Second is the physical state of such particles, comprising of *values* these physical attributes can take, like the direction of spin, amount of energy, momentum, position on a trajectory etc. Sometimes the values these physical properties are specified only for a set of particles, as in entangled systems. There is a very clear difference between the particle and its physical state. A material entity, from a fundamental particle to a complex clock, can evolve through a set of physical states, as the law of dynamics allows, in interaction with other material particles without changing its characteristic material nature; an electron remains an electron as it precesses in a magnetic field. The third level of reality is the *representation* of the physical state. This can reside in the same material particles as in classical dynamics, in an abstract quantity as in a wavefunction, or in another system of material particles as in computation. In all cases, the observable representation of the physical state is what accessible information is. It is at this level finiteness and discreteness becomes an integral feature. We do not yet know whether these are also fundamental features of space and time.

So far we have not fixed the ontological properties of these three levels. However, it is clear that the material entity is not the same as its physical state. By this we do not mean that an electron is a meaningful entity without a spin or charge. Given a single unit of such a material entity with spin, charge etc. its physical state has numerous possibilities specified by their relation or correlation with other material entities. Thus, an electron with its spin up relative to a magnetic field (created by a current of charged matter) has a physical state that is distinct and different from one in which the spin is down. It is the property of the *potential* of matter to possess physical states we call *information potential*, or the ability to have information content. *It is precisely this property that endows the material entity, like the electron, the serve as a bit*. However, *information is the physical state* of the 'it', and in turn that of the 'bit'. We now see clearly that *'it' is indeed the 'bit'*, both with information potential. But neither is information itself.

Just as one should not confuse between the material entity and its physical state, one should also not confuse between the holder for information, the *bit*, with information itself. So, while material entities like an electron can be equated to a 'bit', in the sense of possessing information potential, the electron itself is not the same as its physical state or information content. In this sense, the question 'It or Bit?' arises in confusing material entity with its physical state. Matter is distinct from its physical state, and the bit is distinct from its information state.

With this clarification asserted, the ontological priority of matter over information is self-evident, at least in the context of classical physics. Also there is no more confusion in equating 'it' with 'bit', since information is the physical state of the bit and not the bit itself. We will discuss in detail this issue in the context of quantum physics in the next section.

The amount of matter within our causal horizon is limited, and the accessible matter is even more limited. Proliferation of information with limited matter is possible because the number of distinguishable configurations is *exponentially larger* than the elementary material entities that encode or represent the information. This needs the material entities to be independent in a spatially resolved and distinguishable matter. Then the physical state of each can be independently prepared and observed. With just two physical states and N material entities, the maximum information potential is 2^N, equal to the distinguishable configuration states of N bits. However, an atom consisting of a large number electrons, protons and neutrons - all fermions - have information potential that is limited to much smaller magnitude that its maximum, at least in the practical sense, because most of its individual material entities are not accessible for state preparation or observation. Indeed, its interactions with the external world might be determined by just one of its unpaired particle, as in whether the particular atom behaves as a boson or a fermion to the external world. Therefore, what is important is the accessible number of distinct configurations of matter. This dependence of the measure of information on accessible states of matter reinforces our assertion of matter being more fundamental than information.

Another related issue that stresses the primary nature of matter is the importance of order. Ordering in space and time is an essential feature of information storage and retrieval. When this spatial orderings changes, the information itself changes.

Evolution of states and information in the quantum world

All evolution of information can be written as evolution in state space, from an initial state to a final state with an appropriate transformation matrix whose elements may be continuous or discrete. Symbolically,

$$[I]_f = [T][I]_i$$

One may note here that in real terms, there is noise and dissipation in the time evolution of information and also conservation constraints, and these need to be added in the transformation. The vectors $[I]$ are states of matter and a closer inspection reveals that the matrix $[T]$ consists of interaction involving external fields and matter. Indeed, the specifications for the evolution of information in this sense is an equation of motion. At this level, the structure of description is the same in classical physics and quantum physics. The difference arises in how the physical state is specified and what the equation of evolution is. An additional feature of importance is boundary conditions that define constraints, and this necessarily involves specific arrangement of matter itself.

We now discuss an important subtlety about the relation between state, reality and information. Even if we accept and agree about the reality of matter, within any philosophical position on realism, we still need to deal with certain *unobservables* in prescribing the physical states of matter [8]. This issue arises in quantum theory acutely, where the state is specified by a state vector with a spatial projection as a wavefunction - this is an *unobservable* quantity, though often equated to a matter wave in the context of single particle quantum mechanics. The unobservable and often non-localized wavefunction is not matter. Only its relation to probabilities of measurement results are specified by the theory and accessible by measurements. It is reasonable to claim that the wavefunction (or state vector) is equivalent to information. However, there is a real difference between potential information encoded in the wavefunction and the information that is realized after a measurement, which defines a new 'collapsed' wavefunction. The information encoded in the wavefunction is not residing in a material entity and its reference system directly, and the physical state represented by the wavefunction does not have definite values for all possible physical attributes of the material entity. That would go against the uncertainty principle. This is an important difference from classical physical systems.

The role of the observer

The role of an observer in the actualization of the information, during a measurement of the physical state of matter, is always an interaction between matter with matter, with a series of intermediary apparatus for sensing and amplification. Each of these interactions results in an entanglement. Resolution of a final definite state is possible only by postulating a classical apparatus, or an observer who can reduce the entanglement superposition to a single product state consisting of a definite states for the observer and the system. This final state information resides both in the system and in the observer, encoded in very different material configurations. For example, the physical state of the electron spin being up in a coordinate system is the totality of physical states of the constituent particles of the reference frame and the electron, and the observer holds the same information as interconnections of a complex network system of neurons, memory, associations etc. Any attempt to bring in a special role for *consciousness* into this scenario of state reduction is fraught with the danger of excluding consciousness from the scope of the laws of physics. If consciousness obeys the laws of quantum physics, then there is no choice but to participate in the series of entanglements after the interaction. For consciousness to be able to break such entanglement and finally lead to a definite reduction of state, it has to be outside the domain of quantum mechanics. As well known, decoherence within the conscious brain is not enough to effect the final measurement result in individual observations, though it is adequate to account for the averages (density matrix). In this sense, no special role superior than a measuring apparatus can be assigned to the conscious observer in measurement theory. However, the epistemological purpose of observation is complete only when the conscious observer is involved, both in classical and quantum physics.

Gravity, thermodynamics, and information:

There are two contexts where a deep relation between gravity and information is relevant. One is black hole thermodynamics [9] and the other is the view of gravity as an emergent phenomenon [10].

The well known relation between gravity and thermodynamics in the context of black hole physics is considered to be an important pointer to deeper physics. A large body of related work probes the connection between entropy and gravitational information, by trying to identify and count distinct configurations of gravitational degrees of freedom and equate it to the black hole thermodynamical entropy, $A/4l_P^2$ where A is the area of horizon and l_P is the Planck length. In this picture, the surface gravity at the horizon is the temperature of the black hole. Both the area, $A = 4\pi R^2 = 16\pi G^2 M^2 / c^4$ and the surface gravity, $g = GM / R^2 = c^4 / 4GM$ are *determined by the amount of matter*.

The apparent 'paradox' of the entropy reducing to zero as the temperature goes faster to infinity during black hole evaporation is solved in our approach, where matter is given the ontological priority. Only in the case where the two thermodynamic quantities are directly supported by the amount of matter localized in the black hole, rather than by the kinetic energy content of matter (physical state), the entropy (surface area) can go to zero while temperature (surface gravity) goes to infinity, as the black hole evaporates. We then have a consistency proof that in the context of black hole thermodynamics, matter is ontologically primary and information entropy takes its support from matter.

Another issues of relevance here is the 'information loss paradox' [11]. If matter falls into the black hole and thermal radiation is what emerges from it as a result of Hawking evaporation, isn't the evolution spontaneously nonunitary? Statement of this problem in terms of matter that falls under gravity and disappears into the horizon presupposes the ontological priority of matter over information. However, it is very important to note that this is an observer dependent phenomenon. For all observers outside the black hole, not in free fall into the black hole, (which includes the observers of earth) nothing can fall into the black hole because of the general relativistic time dilation factor that diverges at the horizon; matter then takes infinite time to reach the horizon. So, *if information is linked to this class of observers, there is no information loss problem*. (Observers, who are comoving, fall together with the rest of the matter and its information content, and again there is no information loss for them).This is a rigorous general relativistic result.

In a more general view, the equivalence principle implies primacy of matter over information as far as gravity is concerned, by asserting the *universality of free fall of matter independent of its information content.*

In the approach to gravity as an emergent phenomenon [11], one seeks gravity's origin in the thermodynamics of 'space-time' and hence on the configurations of space-time itself. In this view, space-time and its microstructure is primary and matter is secondary. While this program has pointed to certain interesting connections, it has not succeeded in deriving matter out of space-time thermodynamics.

Information decoherence, memory and history.

The ontological priority of matter over information manifests strongly when we consider the dissolution of information, which may be called decoherence because information is a correlation. The second law of thermodynamics is most crucially applicable to information. Useful information always resides in a spatially limited configuration of matter. Hence, any coupling to rest of the matter through any information transfer channels can change the matter configuration thermally, due to fluctuations driven by energy or even phase transfer. This leads to information decoherence and hence, degradation of memory and history. Altered information is also information, but the correlations with previous templates are now different. We see clearly that information decoherence can occur either by decohering the represented information or by decohering the reference template - a correlation is destroyed by decohering either party and this stresses again the material basis of information. What is decohered and altered is the physical state and the material entity is not altered - an electron with its spin remain one with the same spin, but all references to a direction might be decohered.

The importance of stable 'classical' reference templates is then evident. Without a biasing magnetic field that is strong and stable, which in turn refers to the magnitude and stability of a current of charged matter, spins are susceptible to the smallest of perturbations.

Matter, information and the universe

We conclude with a discussion on the big bang universe and the puzzle of how matter was created from nothingness. This necessarily needs to 'materialize' some prior information constraint like the total energy being zero, which naturally leads to a flat space-time universe with matter, as observationally confirmed. However, we do not make a any speculative judgment on the relative priority of matter and information in the singular context of the origin of the material universe. However, it is possible to show, generalizing Mach's idea, that the law of dynamics and relativistic effects follows from the gravity of the matter-filled universe [7]. A self generated universe should also be a self consistent universe where matter and information stably participate in a mutually sustaining evolution.

A true informational representation of the universe is self-referential and leads to an infinite regress. A book on the contents of the universe necessarily will need to include the book itself, initiating the infinite regress. This is similar to P. W. Bridgman's example of the London map displayed inside the city of London [12]. A true representation will need to display the map in its location, which in turn requires a series of 'Russian dolls maps'. This is avoided by resorting to approximation of truncated representation, possible precisely because information as a physical entity takes its support on matter and its configurations. One has to give up exactness of representation when limitations of handling matter makes it impossible to represent information, even in principle. The difference is that in the case of the map, the dilemma can be avoided and 'true' representation can be claimed by taking the map out of the city, whereas there is no such choice in the case of the Universe.

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