It, Bit, Object, Background

Armin Nikkhah Shirazi*

University of Michigan
Ann Arbor, MI 48109

June 27th, 2013

Abstract

In recent years, the notion that information may be the basis for reality, rather than the other way around, has become more popular. Here we consider the issue within the context of a general relation between the role of physical objects against the background in shaping the pattern of distinctions that can then be translated into information. It is found that from this perspective, in classical physics substance is more fundamental than information, while in general relativity they are on an equal footing. Quantum superposition and collapse, on the other hand, introduce new considerations. A foundational principle is introduced to give an explanation for quantum superposition, and from this principle it becomes evident that to the extent that one frames the nature of quantum objects in terms of this dichotomy, in quantum theory information is more fundamental. This implies that the description of quantum objects in a superposition is dependent on features of the background, as these features set boundary conditions on such manifestations. Thus, if this principle really does underlie quantum mechanics, it means that the term "background independent quantum theory" has to be considered a contradiction, which has implications for the search for a quantum theory of gravity.

1 Introduction

In recent years, the idea that, at a very deep level, information might underlie reality itself has gained increased traction. This appears to be due to developments that led to a deeper understanding both of the nature of information and the nature of reality as described by physics.

On the information side, such developments could be said to have begun with Claude Shannon's 1948 article *A Mathematical Theory of Communication*, later expanded into a book [1]. Though the article was focused mainly on signal processing, it introduced concepts which could be applied much more broadly. For example, the concept of Shannon Entropy, a measure of the uncertainty of a random variable, found applications in cryptography, natural language processing, statistical inference and other areas. Intriguingly, it has the same mathematical form as the concept of entropy in physics, and this greatly facilitated the recognition of parallels between information theory and physics.

On the physics side, the advent of the theory of quantum mechanics in the mid 1920's with its interpretational difficulties opened the door for taking such an idea seriously. Niels Bohr, one of its founding fathers, is famously said to have remarked that "Physics concerns what we can say about nature"[2]. The central idea of quantum mechanics relevant here is that a physical system does not have a definite state because it must be described in terms of what is called a quantum superposition of states, until one attempts to make an observation or measurement of the system. As more of the theory's predictions became confirmed and led to practical applications, such as quantum cryptography and quantum information processing, this further raised the possibility that, in a sense, having definite information about a quantum state leads to its having a definite state. This line of thought is concisely summarized in John Wheeler's famous quip "It from bit",

*armin@umich.edu

that substance (i.e. matter and energy) arises from information[3].
This paper will attempt to show that the nature of the relation between substance and information depends on the domain of physics in which this relation is considered because each general domain relates a physical object differently to the background against which it exists, and these differences affect the relation between it and bit. After proposing a very general formula that relates the arrangement of matter and energy to patterns of distinctions, we will examine the application of this formula to each of the domains of classical physics, general relativity and quantum physics. A principle will then be introduced and described which provides a principle-based foundation for quantum superposition, and which clarifies how the general formula is to be applied to the domain of quantum theory. An important implication of this principle is that, if it in fact underlies quantum mechanics, quantum superposition inherently requires objects in the theory to be defined against a background. This categorically dooms all contemporary efforts to find a background-independent formulation of quantum gravity.

2 Patterns of Distinctions vs. Material Arrangements

Although we already understand some things about the quantitative relation between it and bit, it seems (at least to this author) that there is still a gap between this and an understanding of how these notions are implemented at the most foundational level. To help fill this gap, our starting point will be more basic than what is already assumed in information-theoretic treatments. In particular, we consider a prerequisite to the existence of information some pattern of distinctions. Distinctions are necessary for contrast and to make it possible to put whatever information is encoded in some context.
If we attempt to numerically encode a physical situation in a world characterized by the complete absence of distinctions, an arbitrary single value for a number would exhaust the possibilities, whereas a bit, the smallest unit of information, requires the existence of the possibility that a number can take on one of two distinct values. Indeed, in presenting this scenario, we already assumed a distinction, namely that some situation in such a world could be distinguished from others, but since that contradicts how we characterized this world in the first place, the distinction would be entirely arbitrary i.e. not grounded in anything physically real. A world without distinctions could then be arbitrarily encoded by a sequence of numbers of the same value, depending on how many situations one cares to arbitrarily distinguish, with the possibility that any of the numbers could take on a different value precluded by the global absence of distinctions. This means, in particular, that whether one considers such a string a sequence of single digit numbers, or just a single number by itself, or anything in-between, is completely arbitrary. Insofar as the numerical encoding of such a world falls short of even a single bit (because none of the digits have the possibility open of taking a different value), we may consider distinctions to be a prerequisite for the definition of information. We need distinctions before we can have information.
Given that the presence of matter and energy introduces distinctions in our world, intuitively the relation between them and information seems very straightforward: it is always possible to consider any local material arrangement to form a pattern of distinctions, and this pattern can then be formatted to yield information. The general relation can be expressed as

$$(\text{Pattern of Distinctions}) = (\text{Constant}) \times (\text{Arrangement of Substance}) \tag{1}$$

where by 'substance' we mean to employ a general term that comprises both matter and energy. Since under this conception the pattern of distinctions is determined by the arrangement of objects with substance in space and time, it may still be a dimensionful quantity, and there is more than one way to convert this into pure information. The simplest is to just multiply the expression for the pattern itself by some arbitrary constant with a value and dimensionality chosen such that the resultant numerical values are conveniently formatted.
To give a very simple illustration, suppose we wish to arrange a cubical bricks of side l, mass m and density ρ in a straight row, then arrange b rows of bricks next to each other to create a layer of bricks, and then stack c layers to finally create a cuboidal brick structure. Equation (1) specialized to this situation becomes

$$ABC = \frac{1}{\rho} \sum_{c} \left(\sum_{b} \left(\sum_{a} m \right) \right) \tag{2}$$

Where $A = al$, $B = bl$, $C = cl$ are the three length dimensions of the geometric shape formed by this arrangement; it is the pattern of distinctions formed by a very simple arrangement of bricks. The simplest way to convert this into pure information is to divide the product on the left by some volume element that is regarded as a unit volume. While it is convenient to define l^3 as such a unit volume, so that the information associated with this particular arrangement is just the product of the numbers a, b and c, there is by no means an intrinsic requirement that one choose this, it just depends on what definition is most convenient for the task at hand. For instance, a unit volume of $(2l)^3 = 8l^3$ might be more convenient if a, b, c, are multiples of 8 and we were just interested in the relative ratio of the dimensions of the object.

3 It vs. Bit in Classical Physics

The same idea as above can be straightforwardly applied in classical physics to any arrangement of matter and energy to re-express it in terms of information. The beautiful shape of a snowflake, the shifting wave patterns on the surface of the sea, and the configuration of individual molecules of a gas are all amenable to this kind of approach, though the much greater complexity of these arrangements of substance entails, correspondingly, that the information associated with these systems will be much greater.

In classical physics, a world without substance would be characterized by empty space, so it is reasonable to think of it as a "background" against which the material arrangement introduces patterns of distinctions. By characterizing space as a background, it might seem that we are giving the property of position a special status, but it should be emphasized that this need not be so. One can apply the same concept to any physical property such as velocity , momentum, Energy etc., though the property that one considers then determines what one should consider as a "background", i.e. the default in the absence of any distinctions. For example, if we are examining the momentum distribution associated with a particular arrangement of substance, then the appropriate background is momentum space, and though by the principle of relativity there is no value of momentum which can in an absolute sense be considered a default, it is for many purposes convenient to define the default value as zero momentum in some frame.

Let us now examine the question of whether within a classical context substance or information is prior. So far, implicit in our discussion has been the viewpoint that substance comes before information because we have presented substance as the "thing" that gives rise to a pattern of distinctions. This is not an accident, for consider how one can conceptualize in classical physics substance arising from information: it seems that to do this, one must consider information as a deviation from the background, independent of whether the deviation is associated with the presence of objects with substance or not. This is somewhat analogous to the situation in which, say, a cavity in the ground signifies a configuration that can be expressed in terms of pure information, regardless of whether it is actually filled with water or air (i.e. objects that have 'substance') or not.

But, after a moment of reflection one notices that this conception of the background tacitly assumes that the background itself is composed of some kind of substance, for if it wasn't, what else could it be that gives rise to a pattern of distinctions? This is not a problem for classical physics because the Newtonian view of space as the container of all objects with an existence in and of itself is already compatible with it. Indeed this view is sometimes called *substantivalism*[4]. From there it does not seem a big step to associate to any kind of background in classical physics the properties of a substance, for one can then attribute the same dynamic properties that characterize substance to space itself.

This conception of space is a problem for considering substance and information on an equal footing because in classical physics the background is not dynamically affected by the objects in it. Ascribing to the background the dynamical properties of a substance therefore introduces an asymmetry between information and substance: All patterns of distinction can be ascribed to some arrangement of substance (re-defined now to include space itself in addition to matter and energy), but not all arrangements of substance can be ascribed to some pattern of distinctions. There exists under this conception a subset of arrangements of substance (namely those associated only with space itself) which cannot be expressed in terms of a pattern of distinctions because such a pattern cannot be identified via interactions with matter and energy, our only means of putting material arrangements and the corresponding patterns on a physically real footing.

Of course, in classical physics, one can have patterns of distinctions introduced by fields, but this does not help: Fields ultimately require sources somewhere in space in order to be considered physical, and the

sources are just what we would consider substance. On the other hand, in classical physics fields are not considered a property of the background, they are considered as objects that exist independently in space. Therefore, one can think of fields as extensions of the concept of substance without impacting the problem that a dynamically inert background has been ascribed substance properties.
For these reasons, it does not appear that classical physics supports the notion of patterns of distinction in the absence of a corresponding material arrangement. This seems quite in agreement with our intuitions: historically, it has been intuitive to imagine how information can come out of matter and energy, probably because it is easy for us to think of information as arising from a pattern of distinctions in otherwise formless substance. Thus it is very easy to create a "map" that takes us from the former to the latter in classical physics, but the reverse is not true. It seems very difficult to imagine how, in the absence of any substance whatsoever-and especially substance associated with the existence of a dynamically inert background-one might arrive from information to substance. One might call this the"problem of the map".
In short, in classical physics, it does not appear that it and bit are on an equal footing because a dynamically inert background is otherwise endowed with unverifiable dynamical properties of a substance. Substance seems to be more fundamental than information.

4 It vs. Bit in General Relativity

Einstein's theory of gravity, the general theory of relativity, is our most fundamental theory of nature applicable to large scales. At the heart of this theory are the Einstein Field Equations, a set of 16 partial differential equations [5]:

$$G_{\mu\nu} = 8\pi \frac{G}{c^4} T_{\mu\nu} \tag{3}$$

Here, $G_{\mu\nu}$ is the Einstein Tensor, $T_{\mu\nu}$ is the energy-momentum tensor, G is the gravitational constant, and c is the speed of light. It is striking how much the field equations can be thought of as a specialization of equation (1): the arrangement and flow of matter and energy is given by the Energy momentum tensor, and the pattern of distinctions is given by the Einstein Tensor, a purely geometric quantity that can very roughly be thought to indicate the local curvature at a spacetime point. It has the dimensionality of inverse area, and by choosing a suitable but arbitrary constant with dimensions of area it is easy to convert the Einstein Tensor into an array of dimensionless numbers.
The most groundbreaking feature of the field equations is that the background itself is shaped in accordance with the distribution of substance, and as such is both dynamically affected by it and dynamically affects it. This is in stark contrast to relations like equation (2), which tacitly assume an unchanging background not affected by the presence of substance. That kind of background no longer exists here, and closely related to this is that in general relativity it is natural that the laws of physics are expressible in a way that is completely independent of any coordinate system, i.e they are *generally covariant*. For these reasons, general relativity is considered a *background-independent* theory [6].
Within the context of it vs. bit, general relativity addresses the problem of the map in classical physics by erasing in some sense the boundary between object and background. It seems that when we consider an object in space over some duration, we are by these equations equally well entitled to claim that what we were considering was actually some deformation in a local region of the background spacetime.
This opens up two diametrically opposite approaches to conceiving the relation between it and bit: According to what might be called the *substance-oriented approach*, since the background itself conforms to the arrangement of substance, any pattern of distinctions in the background can be more fundamentally thought of in terms of an arrangement of substance. By this approach, all is substance and information is derivative. According to what might be called the *information-oriented approach*, since any arrangement of objects with substance is really a way of describing a pattern of distinctions in spacetime, any substance properties we ascribe to spacetime objects more fundamentally reflect just such patterns. By this approach, all is information and substance is derivative. The dual approaches to framing the relation between it and bit are on an equal footing, yet it is probably fair to say that most have a greater intuition for the substance-oriented approach. This may be because practically any situation describable by general relativity that falls within the range of our direct experience is one in which the classical physics is adequate as an approximation, and, as mentioned above, classical physics considers substance to be more fundamental than information.

5 It vs. Bit in Quantum Physics

It is in quantum theory that the question of it vs. bit becomes most subtle, and this is due to a certain peculiar feature that is completely absent in classical physics and in general relativity. To briefly review, the state of a quantum object must be described as a vector in an abstract vector space called the Hilbert space, which is coordinatized by unit-directional vectors that correspond to possible outcomes of a particular measurement. If the different possible outcomes are endless in number, then the Hilbert space is infinite-dimensional. Prior to a measurement, the state is usually in a superposition of basis vectors, and since the outcomes to which these correspond are mutually incompatible, this means that prior to a measurement, a quantum state must be characterized as though it has more than one mutually incompatible property at the same time. This is called quantum superposition. According to the orthodox interpretation of quantum mechanics (the only one that we will consider in this paper), this is not an epistemological phenomenon (i.e. due to our lack of knowledge or information about the state) but an intrinsic characteristic of the state. A measurement, however, results in just one outcome of the possible ones, and hence the state is said to "collapse" to one of the basis vectors[7].

When one attempts to apply the quantum superposition principle to equation (1), then it immediately implies that somehow in quantum theory superpositions of arrangements of substance must be related to superpositions of patterns of distinction. Mathematically, the appropriate space in which to describe this kind of relationship is configuration space, and for n particles, it is $3n$-dimensional. But let us stop and consider whether it is not possible to find some fundamental principle which would render this extremely counterintuitive characterization of objects more intuitive.

The advantage of having such a principle is that it can clarify how one is to think of the relation between substance and information more deeply and guide application of the quantum superposition principle beyond the present domain of quantum theory. Without it, one is left with a non-intuitive description as a starting point, and, not knowing the "why" behind it, one can only grope in the dark on how to extend is application to other regimes, such as gravity.

6 A Foundational Principle for Quantum Superposition

There exists an arguably fundamental principle in mathematics which, perhaps because it is so obvious, is to this author's knowledge not even articulated. Let us call it the *default specification principle*:

The absence of an explicit specification entails all possible default specifications

.

To build some intuition for this, consider first a less mathematical but perhaps psychologically more easily relatable analogy: If you, dear reader, have not committed yourself to a specific path to follow in life, then all the paths that are possible for you to follow by virtue of your personal characteristics and circumstances are open to follow. That is, by not explicitly specifying ahead of time one of these possible paths, your future can by default be characterized as a superposition of all these possibilities. Of course, as you go through life, you continually "collapse" these possibilities to the path that you actually take in life but you can already "collapse" your future by committing yourself to follow, i.e. explicitly specifying just one particular path to follow.

An application of this principle closer to the context of this discussion is the fact that an equation like $x = 3$, while in $\mathbb{R}^1$ representable as a point, must be represented in higher-dimensional spaces as a 1-dimension lower surface. Thus, in $\mathbb{R}^2$ it is represented by an infinite line parallel to the y axis because the absence of an explicit specification of a value for y entails that it be represented in $\mathbb{R}^2$ by all possible values by default, and in $\mathbb{R}^3$ it is represented by an infinite plane because the same principle applies to z as well. The surfaces represent the superposition of all of the possible values the point $x = 3$ could take on in that space if, in addition to x, the other variables were also explicitly specified.

Let us contrast the representation of $x = 3$ in $\mathbb{R}^2$, with the explicit specification of an infinite number of ordered pairs (x, y) such that $x = 3$ and y takes on a different value in each pair. We then find that default specification differs from explicit specifications in several respects, and to label this difference, an object specified explicitly will be called an *actual* object and an object specified by default an *actualizable* one.

1. **Actualizable lines obey metrics distinct from those obeyed by actual lines:** The metric interval that characterizes distance relations obeyed by $x = 3$ is just that of $\mathbb{R}^1$ i.e. $dr_1 = dx$, whereas the line in $\mathbb{R}^2$ created from the ordered pairs obeys the metric interval $dr_2 = \sqrt{dx^2 + dy^2}$, where the subscript indicates the dimensionality of the space in which the interval is considered.

2. **An actualizable line is not locally displaceable:** If we change x to some other value, the entire line in $\mathbb{R}^2$ is displaced. On the other hand, for the actual line it is possible to define a finite interval in $\mathbb{R}^2$ such that x has a different value only in that interval. Hence the line formed from the ordered pairs in $\mathbb{R}^2$ is locally displaceable.

3. **Distance relations between actualizable lines are not directly defined:** If we consider, say $x = 3$ and $y = 4$ separately (i.e. not as an ordered pair), then each manifests itself as an infinite line in $\mathbb{R}^2$. Although the representation of these lines makes it appear that the lines are perpendicular to each other, the metric interval each obeys does not define a relation between dx and dy. Without an expression which includes both dx and dy or the additional information that $\mathbb{R}^2$ is the Cartesian product of their respective spaces, the metric relation between them is not directly defined. On the other hand, for the ordered pairs, the metric that governs them directly defines a relationship between dx and dy.

4. **Actualizable lines can collapse:** Upon the assignment of some value $y = c, c \in \mathbb{R}$ to the equation $x = 3$, so that one can form an ordered couple out of these, the infinite line representation of $x = 3$ collapses to the point $(3, c)$ in $\mathbb{R}^2$. No analogous collapse process is possible for the ordered pairs because all possible values for y are already explicitly specified.

The proposition here is that the default specification principle underlies quantum mechanics in a manner that is consistent with the orthodox interpretation. According to this interpretation, a quantum object does not have a definite state prior to being measured. If it is really the case that it completely lacks a property such as 'Energy' or 'position' prior to a measurement, then application of this principle permits us to conclude that, before it is "measured", by default it has to be represented in terms of all possible values for that property if it were attributed that property. A 'measurement' attributes to the object something it is inherently lacking to make it into a new (i.e. a spacetime) object, analogous to the attribution of a definite value$y = c$ to the equation $x = 3$ to create the ordered pair $(3, c)$, and as such underlies the transformation from a superposition of actualizable objects to a single actual object.

Although standard quantum theory recognizes no intrinsic distinctions between pre-measurement and immediate post-measurement states, a recent argument suggests that an intrinsic distinction is necessary to avoid a logical inconsistency in standard quantum mechanics [8].

A theory based on the default specification principle exists, and the free-particle Feynman path integral has been derived from it [9][10]. In that framework, called the *Dimensional Theory*, the distinction between actual and actualizable objects is applied to the concept of mass [11], and while actualizable objects are not identified with information but rather considered as an intermediate kind between substance and information for which there exists no familiar classical analog, to the extent that one frames the relation between them as a dichotomy, the nature of an actualizable object is much closer to information.

The reasons that a consideration of the substance aspect cannot be eliminated are that *a*) there is still the existence of 'something' as opposed to 'nothing ' prior to a quantum measurement, even though this 'something' does not have properties of spacetime objects prior to a measurement, and *b*) the spacetime manifestation depends on the background, which is itself much closer in conception to the classical than the general relativistic one. This is the reason that the distinctions that underlie information here are not the same kind as in classical physics: There, the *presence of an object* forms patterns of distinction which can be formatted into information whereas here, *there is no object in spacetime prior to a measurement* so the patterns of distinctions are just due to the default specifications allowed by the background. If only two default specifications are permitted, then the quantum object can be represented in terms of a superposition of these, and formatted in terms of information it is called a *qubit* [12].

7 Background-Independent Quantum Theory: A Self-contradiction?

Applying the default specification principle to quantum theory implies that prior to a measurement, there is no arrangement of substance in spacetime associated with a quantum object. Consequently, the pattern of distinctions given by the superposition of properties is entirely determined by the features of the background because it is the background which enables the superposed properties to manifest themselves. To understand this, consider first the original analogy: if instead of $\mathbb{R}^2$ we consider the actualizable line to manifest itself on a curved Riemannian manifold, then the line would warp according to the curvature of the background. Or, if we consider $x = 3$ just in a subspace of $\mathbb{R}^2$ curtailed by $-y_0 \leq y \leq +y_0$, then it would manifest itself as a line of length $2y_0$ instead of an infinitely long one. Notice that the representation of the default specifications can change even though the underlying explicit specification remains unchanged.

Applied directly to quantum mechanics, this means that the spacetime manifestation of quantum objects is determined by the features of the background. For instance, if it is really true that prior to a manifestation an electron has no such property as 'position' in space, then its spacetime manifestation prior to a measurement is entirely determined by the features of the background because it is these which determine the possible positions in space it could have if it were attributed the property of position (i.e. 'measured'). Thus, the pre-measurement spacetime manifestation of a single electron (which in this case happens to coincide with its configuration space representation i.e. its wavefunction), say, inside an infinite square well is completely different from that of a free electron.

It turns out that at a mathematical level this is already well-understood: it reflects itself in the fact that the boundary conditions of the Schrödinger equation determine its possible solutions. But since under this distinction the boundary conditions are due to actual spacetime objects (in contrast to the quantum object itself), they must be counted as features of the background. By virtue of this, the default specification principle turns this mathematical fact into an implication with grave consequences for current efforts to find a quantum theory of gravity. It is currently thought that the property of background independence is highly desirable, if not absolutely essential, for any quantum theory of gravity [13]. If the default specification principle underlies quantum superposition, then the possible solutions of a quantum gravitational analog of Schrödinger's equation are determined by boundary conditions. But if these are due to actual spacetime objects, this implies that the possible solutions depend on the features of the background.

It might be argued that in principle it may be possible to overcome this problem if the boundary conditions depend on the solutions, analogous to how in general relativity the shape of spacetime is interdependent with the distribution of substance. This can be done e.g. by associating a probability amplitude with the background just as with the quantum state. Perhaps so, but then this means that the default specification principle does not underlie quantum superposition. In that case, one really does need to associate superpositions of metrics with superpositions of matter distribution. In contrast, if this principle underlies quantum superposition, it implies that an object in quantum superposition does not produce a corresponding pattern of distinctions in spacetime, and hence produces no gravity field. This was discussed in greater detail in a work submitted to the 2012 FQXi essay contest [14]. The two possibilities are obviously in principle empirically distinguishable, but as a practical matter, it may be a long time before the technology is developed to do a test sensitive enough the detect the gravity field of an object in a quantum superposition.

8 Conclusion

This paper attempted to show that the answer to the question 'it from bit or bit from it?', when considered in terms of the relation between material arrangements and patterns of distinctions, depends on which domain of physics one considers: In classical physics, substance is more fundamental, in general relativity, substance and information are on an equal footing and in quantum physics, if the default specification principle underlies quantum superposition and one dichotomizes the state of a quantum system in terms of substance vs. information, then information can be argued to be more fundamental, though whereas in classical physics information is associated with objects, in quantum physics it is associated with the background. The latter conclusion is important within the context of quantum gravity, because it undermines the possibility for a background-independent formulation of quantum theory.

References

[1] C Shannon *A Mathematical Theory of Communication* Bell Syst. Tech. Journ., 27 (1948)

[2] A Petersen *The Philosophy of Niels Bohr* Bull. Atom. Scient. Vol. 19, 7 (1963)

[3] J Wheeler *Information, Physics, Quantum: The Search for links* Proceedings III International Symposium on Foundations of Quantum Mechanics, Tokyo (1989)

[4] L Sklar *Space, Time, Spacetime* University of California Press (1977)

[5] S Carroll *Spacetime and Geometry: An Introduction to General Relativity* Addison-Wesley, San Francisco (2004)

[6] G Belot *Background Independence* arXiv:1106.0920 [gr-qc] (2011)

[7] R Shankar *Principles of Quantum Mechanics, 2nd ed.* Springer Science, New York NY (1994)

[8] A Nikkhah Shirazi *Asymmetry Due to Quantum Collapse* Deep Blue:http://hdl.handle.net/2027.42/97779 (2013)[last access: 06/27/2013]

[9] A Nikkhah Shirazi *A Novel Approach to 'Making Sense' Out of The Copenhagen Interpretation* in Quantum theory: Reconsideration of Foundations 6 AIP Conf. Proc. 1508, 422-428 (2012)

[10] A Nikkhah Shirazi *A Dimensional Theory of Quantum Mechanics* Deep Blue: http://hdl.handle.net/2027.42/83865 (2011) [last access: 06/27/2013]

[11] A Nikkhah Shirazi *Are the Concepts of Mass in General Relativity and in Quantum Theory the same?* http://hdl.handle.net/2027.42/87999[last access: 06/27/2013]

[12] B Schumacher *Quantum Coding* Phys. Rev. A 51(4) 2738-2747 (1995)

[13] L Smolin *The Case for Background Independence* arXiv:0507235 [hep-th] (2005)

[14] A Nikkhah Shirazi *The Mythos of a 'Theory of Everything'* submission to 4th FQXi essay contest http://www.fqxi.org/community/forum/topic/1431 (2012) [last access: 06/27/2013]