

IT from BIT considering fluctuations in a quantised space

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John Archibald Wheeler "It from Bit. Otherwise put, 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."

Abstract

In the spirit of John Wheeler this essay explores an alternative view of the geometry of space and how it could relate to matter. A time "BIT" emerges which is fundamental to the geometry creating a physical universe. In doing so a quantised space-time can be related to gravity.

1. Unifying space and matter

The desire in physics to relate matter to the geometry of space has been long standing. It began in the early 20th century when Einstein following his General Theory of Relativity went on to explore the use of curved space to unify gravity with the electromagnetic force^[1]. His approach was based on a unified field theory. It was revitalised in the 1950s by John Wheeler who developed the theory of Geometrodynamics^[2]; the study of the geometry of curved empty space and its evolution with time according to the equations of General Relativity; masses and fields are built out of the geometry itself. As part of this theory Wheeler developed the concept of the "Geon"^[3]; an entity that is constructed out of electromagnetic or gravitational radiation which will hold itself together by its own gravitational attraction for a long period of time. A geon is built from curved empty space and has radiation content and mass. Geometrodynamics was shelved when it failed to explain spin $\frac{1}{2}$ fermions. Following this work Wheeler went on to develop the concept of "quantum foam" where the curvature of space arises as an averaging of small scale complicated geometries. The concept of vacuum fluctuations forming a space-time foam is still relevant today.

John Wheeler continued to develop novel ways of thinking about the Universe. He developed the Participatory Anthropic Principle that led to Wheeler's phrase of "IT from BIT"^[4]. This builds on the idealist philosophy, as argued by Kant^[5], that space and time lack substance and there is no existence of objects beyond the mind. This is in contrast to the realists, such as Hume^[6] and Popper^[7], who assert that the knowledge of an object does not determine its existence.

In Wheeler's Participatory Anthropic Principle information is the key to understanding the Universe. In asking questions we get binary yes/no answers, BITs, which result in a measurement of the "ITs" (matter, fields, forces). It is the asking of the question that creates the Universe around us. Until something is measured (or questioned) it is unreal; it only becomes something real, an "IT", when a yes/no "BIT" has happened, therefore "IT from BIT". This view embraces the measurement paradox of quantum mechanics; the measuring of a wavefunction, with probabilities of multiple outcomes, fixes the wavefunction to become a single definite outcome. The act of measuring the probability wavefunction can be viewed as creating the real world.

Wheeler went on to ask "how does something arise from nothing?"; the creation of "mass without mass", "charge without charge", "field without field"^[8]. Wheeler's questions go to the heart of the fundamental philosophical debate about what is space and time. Is it real or ideal, is it relative or absolute, does it exist beyond the human mind or a measured moment, what does space and time mean, what is it's structure, is space-time a substance?

2. Much ado about nothing

Wheeler "How does something arise from nothing?"

Starting from the premise that from nothing you get nothing then there must be something in the Universe. A reasonable starting assumption is that there exists space and there exists energy. A fundamental tenant of physics is that energy is conserved; it cannot be created nor destroyed, therefore it must always exist somewhere. Without energy there can be no matter and no Universe. Space is the place that the energy exists in, so if you have energy you need to have space. An assumption made here is that space is also conserved.

Axiom 1: Space and energy exist and are conserved.

The aim of this paper is to visualise space in a way that could bring together the very small, the quantum, and the very large, gravity, and to explore a quantised approach to space. Therefore the second axiom is that space is quantised.

Axiom 2: Space is quantised; it is made a up of discrete units.

If we think of a small part of nothing, say a cube of nothing, then that nothing becomes something which we shall call space. (Imagining nothing becoming something could be said to support the Participatory Anthropic Principle. My view is that this is a model we create in order to understand matter. Space and energy exist even if we do not understand it. In fact I would argue that we do not understand space and time, yet it still exists.) If we now think of that piece of nothing having some energy then, using our current understanding of what energy is, that piece of nothing must move. Energy in the Universe is always seen as movement; when there is no movement it is at absolute zero, i.e. nothing. So by

imagining a moving piece of nothing we have created space and energy.

Our knowledge from General Relativity is that space can move and expand and contract so lets assume that a space quantum can expand and contract with the size of the space quantum varying depending on it's energy. The simplest way for the “piece of nothing” to move is to vibrate, and the simplest form of vibration is harmonic oscillation. Harmonic functions occur frequently in physics.

Axiom 3: A quantum of space vibrates harmonically, the amplitude of which is determined by the energy of the quantum.

The units of space can vary in shape and size and position, they are not fixed. However an important assumption is that each quantum has to be contiguous with it's surrounding quanta so that space makes a continuum. This constrains the quanta within a network but the whole network can move. The quantum of space cannot jump from place to place discontinuously, it can move from place to place but all the surrounding quanta have to move with it. The vibrations of the quanta are random but contiguous quanta must be synchronised. The moving quanta create a dynamic curved space continuum both at the quantum, local level, and at the very large, global level.

Axiom 4: Quanta of space are contiguous and continuous; a space quantum cannot move from one part of space to another discontinuously and all space quantum are joined together.

In this model there is no fixed space, the network is constantly moving, globally (at low frequencies) and locally (at high frequencies). This is in keeping with General Relativity; space is invariant. It also brings together the global and the local, in keeping with Mach's conjecture (the motion of the distant stars is related to the local motion of an object).

3. A BIT of time

When there is something that moves then the time for that movement to happen can be measured, there is a start of the movement and an end of the movement, and hence time emerges. As a quantum of space expands and contracts it creates a time period. Since the space is oscillating, time is symmetrical; there is no unique direction of time.

The time period of the space quantum will determine the maximum speed at which information can transfer from one quantum to another. The quantum of time becomes the BIT that enables information to flow across the space network. Whatever the curvature of space or the shape of the quanta or the amount of energy contained, there is a minimum time at which any change in oscillation can transfer from one quantum to another. This will be the limiting factor for information to move across the space network.

An harmonic oscillation has a fixed time period that is independent of amplitude. As the energy in a space quantum increases the size of the space can increase but the time period will stay the same. Time is discrete; there is a BIT of time that exists. The time period of the harmonic oscillation becomes a fundamental minimum time unit.

Axiom 5: Time is discrete and a quantum of time has a fixed time period.

Since the space quantum moves within the surrounding network it would be reasonable to assume that the local space quanta move with the same time period. From Special Relativity it is our understanding that light travels at a fixed speed regardless of it's frame of reference. Therefore it would also be reasonable to assume that the speed of light is fixed by the time period of the space quantum making it a global time period. That is not to say that the time period does not slowly change over the Universe, only that we cannot know if it does.

The time BIT leads to a maximum speed of travel of information that is independent of the geometry of space. It is reasonable to assume that the maximum speed is the speed of light. The maximum speed of travel in the Universe would apply to everything in the Universe including the speed of gravity.

4. Resonances are IT

Wheeler "Einstein's inspiring vision that curved empty space-time is all of physics"

Just as Einstein showed that gravity was geometry, Wheeler asserted that matter could also be geometry, "mass without mass". From an oscillating space-time network it is possible to envisage resonances forming within the network. The resonances form because the quanta are coupled and synchronisation of the quanta in the network is a necessary consequence. Resonances can naturally occur in randomly vibrating coupled networks. The resonances can be 1D such as strings, 2D such as loops, as well as 3D to form and create matter leading to the IT of the Universe.

Resonances by definition only occur at fixed energies that will be determined by the vibration constraints of the space-time quantum network. An analogy would be an atomic array. In such an array the atomic vibrations are random yet coupled and add up to produce resonances and complicated patterns and, significantly, produce solitons (fast moving wavefunctions) and phonons (slow moving stable wavefunctions). Similarly resonances can form in the space-time network starting from random vibrations (c.f self-organising systems) which could be a moving wave (photons) or a stable wavefunction (matter).

Resonances can only form with discrete energies determined by the constraint of the space network. Resonances are continually created and annihilated within the space-time network and these would form the vacuum fluctuations of the space-

time foam that Wheeler proposed. Resonances would mostly be small and transient with some larger, stable resonances forming.

A resonance can move to another part of space and look exactly the same (space invariance). However space somewhere else must look different to accommodate it. All space must move when the resonance moves. There is a space “lag” from the surrounding space expanding/contracting causing inertia. From inertia there is mass. The bigger the resonance the more space would have to move to accommodate any change and therefore the more inertia and mass.

Since a quantum of space can move in any direction it will have a linear and rotational part. Space invariance would require the conservation of momentum of the linear movement. Similarly, resonances would rotate and rotation invariance would require the conservation of angular momentum. This would give rise to the charge of a mass and the conservation of charge.

5. A Clouded view

The following section is a proposal of ideas that could follow from the axioms above based on considerations of scale, probabilities and entropy.

When two resonances come close together the touching space-time quanta will have to vibrate in synchronisation in order to avoid discontinuities. This would create an attraction between the resonances creating a force. Such a force would only be an attractive force and it would be possible for the effects of space distortions from multiple resonances to spread out to large distances. Since the force will only occur as a function of the surface area of the touching resonances the force would follow a $1/r^2$ law. These are the properties of gravity. Hence gravity emerges from the model and becomes the dynamic movement and synchronisation of the space-time quanta.

It has already been proposed by Verlinde^[9] that gravity is an entropic force. Verlinde's proposal is based on the holographic principle and asserts that gravity is caused by information changes in a material body as it moves away from an holographic screen. In this essay it is proposed that gravity is an entropic force that is created from the synchronisation of the space-time quanta.

When considering the size of a quantum of space it is reasonable to take the Planck length as being the smallest possible unit, 10^{-35} m. The difference between a quantum of space at 10^{-35} m compared to an elementary particle of matter such as an electron at 10^{-15} m is of the order of 10^{20} . This is comparable to the size difference between an electron and the Earth. A small number of elementary particles combine to develop matter as we know it, but they combine in many ways to give us the complexity of life and the Universe. In the same way resonances at the quantum space level could combine together to form the elementary particles. An electron would then be made up of a “cloud” of resonances that are held

together by a stable overall wavefunction. This would be analogous to a gas where the individual gas particles are the same but they are not fixed to a unique position. In the same way as asking the position of a particle of gas is unnecessary, since individual positions do not affect the macroscopic properties of the gas such as temperature and pressure, asking the position of the individual space quantum in an elementary particle is unnecessary since individual positions or energy of the quanta at any one time do not affect the macroscopic properties of the particle.

A “cloud” of resonances would become a statistical entity rather than a fully determined entity. This “quantum cloud” would change size and shape following the global space-time and local curvature changes. If the energy in the cloud remained the same then the cloud could be considered as the same particle. For example an electron would remain an electron even when it is a single entity, maybe a sphere shape; when it is within an atom, maybe as a hollow sphere; or when it is in a Cooper pair, maybe as an elongated structure.

Such a statistical “quantum cloud particle” would behave quite differently than a fixed single resonance. It would make interactions at an elementary particle level a probabilistic one. What we observe are the overall properties of the “quantum cloud”. When we make a measurement the “cloud” is “frozen” to a particular state (i.e. the position of the individual resonances). After the measurement the resonances are free to move again into a multitude of possible energy states.

Entropy becomes a consequence of the statistical behaviour of the “clouds”. Looking at it from an entropic point of view, a space-time network with uniformly distributed energy has a unique single state which has a very low probability of occurring. A randomly vibrating network containing resonances has an extremely high number of possible states and hence the probability of occurring is very high. The formation of matter may be purely a consequence of probabilities.

At the level of a quantum of space, time is symmetrical, vibrations can be considered as +t and -t from t_0 . As local resonances create and annihilate, and space globally moves (curved space-time), a statistical nature of the Universe emerges and time could become asymmetrical.

6. Does IT exist?

A BIT could be the starting point for a Universe to exist. A space-time BIT created from an oscillating space quantum contains information in the form of how much energy it contains and, more importantly, it is the means by which the energy is transferred; the transference of energy between quanta becomes information moving through the space-time network. This 'information' comes together as resonances allowing IT to form.

Wheeler's “IT from BIT” refers to information defining the Universe; that by using information we are in some way creating the Universe. This assumes that we have

a unique place in the Universe and that without us the Universe does not exist – an idealist viewpoint. The alternative view is that substances can exist without human intervention - the realists. This debate has been around since Plato and is as strong as ever today. As physics delves further into the realms of the very small and the very large, and the observed phenomena become further from our everyday experience, rather than shedding light on this metaphysical debate, physics is intensifying it.

This essay takes the realist view; the BIT of information contained in the space-time quantum can exist regardless of an observer. It does not rely on the Anthropic Principle. However, Wheeler's concept of "IT from BIT" can be considered as possible in the sense that matter, photons and forces could be created from a quantum BIT of fluctuating space-time.

References

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