An Insight into Information, Entanglement and Time

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We combine elements of Boltzmann's statistical account of thermodynamic processes in the second law, Poynting's *twist waves* on a photon shaft and Shannon's theory of communication within a background-free conceptualization of *time*; where the departure and arrival of *information* carried by photons bounds "elements of physical reality" as perpetually reversible photon links embedded in an entangled network. Entangled networks become progressively irreversible as decoherence ebbs and flows with the environment. From this, we can begin to formulate a new and logically consistent view of the apparent non-locality revealed in violations of Bell's inequality.

INTRODUCTION

> "Church's thesis and the Turing machine are rooted in the concept of *doing one thing at a time*. But we do not really know what doing is – or time – without a complete picture of quantum mechanics and the relationship between the still mysterious wave-function and macroscopic observation."
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> – *Andrew Hodges in: Alan Turing: Life and Legacy of a Great Thinker* [1]

Our argument[1] brings a new information-theoretic quality to the nature of an *interaction*. A perpetually alternating exchange of information between atoms by a photon at the microscopic level is predictable, yet observation of the current *direction* remains non-deterministic because we cannot know how many times a reversal takes place without disturbing the system. The absurd idea is that *reality is timeless* inside entangled systems[2], i.e., it continually evolves and cycles through its recurrence, bound only by the available number of states. This symmetry can however be broken at the macroscopic level by an observer preparing the system for measurement, triggering a *direction* for the local flow of information, energy and causality.

Subtime (t_s) is introduced as a *reversible* information interchange within an entangled system and we reexamine a conclusion dismissed by Einstein, Podolsky & Rosen (EPR) [4]. We accept the principles of relativity and the constancy of the speed of light c (in t_s), but question our ability to *measure* c with experiments that *presume* a Classical Time (T_c), a smooth, monotonic and irreversible background in time [5].

There is an alternative view in the spirit of Boltzmann indistinguishability: in addition to the indiscernability of particles with identical properties [6] we recognize that states previously visited within a quantum system are *indistinguishable* from reversing *subtime* to that prior state.

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[1] Presented *without* mathematical description because existing formalisms contain implicit assumptions incompatible with this insight. Einstein believed the formalism was a hindrance to reasoning about quantum theory [2].

[2] Inspired by Barbour's timeless reality intuition [3].

Information, Photons and Time

We begin by assuming that information is associated with Poynting's [7] propagation of a photon[3] and postulate that *subtime* is *inextricably intertwined* with *space* along the one-dimensional path bounded by the photon traversal between emitter and absorber atoms (a Shannon transmitter/receiver channel[4]).

We see no need for a four-dimensional (Minkowski) spacetime within which light cones are projected (in an empty manifold) to reason about causality, non-locality and the ordering of events.

In a nutshell, we dispense entirely with the notion that a background of time exists, along with any sense of future or past, *between* isolated entangled systems. Instead, reversible evolution *recurs* perpetually within an entangled system. Only when an entangled system decoheres into the environment of other entangled systems (through new photon exchanges) does time emerge as progressively irreversible, providing persistent evolution of information at the macroscopic scale.

The Absurd Idea

We propose a principle of *retroactive non-discernability* in the recurrence of states in entangled systems. Subtime paths (helicity eigenvalues) are incremented with photon traversals[5] from one atom to another and decremented on their return path resulting in a net zero change in subtime (t_s)[6] while (T_c) *appears to* stand still.

[3] Almost all Bell tests so far have been performed with photons [8]. This description may be applied to any quantum particle with a de Broglie wavelength; information simply travels at the slower rate of traversal of the particle through the apparatus. The helical path description is similar for electrons [9].

[4] Shannon [10] defined the notion of channel capacity in his theory of communication and the notion of a "bit" as the fundamental unit of information.

[5] There are many theoretical and experimental investigations underway regarding the helical nature of photon propagation. Our contribution is recognizing that this is also a reversible action in *subtime*. Photons are also able to transfer multiple bits in higher order angular momentum [11, 12, 13, 14, 15, 16].

[6] Consistent with the advanced and retarded wave solutions to Maxwell's equations.

Instead of the assumed traversal of a photon through the apparatus once only from the source to the detector, imagine a photon traversing backward and forward perpetually within the apparatus an arbitrary (uncountable) number of times before it is finally absorbed by an atom in the detector and passed on as an observation. We would be unable to detect (in any single measurement) how many traversals actually occurred before we registered the event in T_c. This implies:

- Most experimental observations would provide no clue that we were not measuring intervals in t_s. Instead we experience observation events in T_c like a quantum stroboscope, illuminating reality in *quick flashes* with long periods of *darkness* in between.
- Unlimited recurrence can take place within an entangled system in subtime. But (a) we would be unable to discern one recurrence from another from our T_c vantage point and (b) even for large systems of atoms many intermediate configuration states could be visited in their environment and then be reversed to a predecessor state before some external observation registered the state in T_c.
- All configurations may be explored in subtime; only those well suited to their environment would (with selective pressure) *persist* as (what would appear to be) *irreversible change* in T_c.

Entanglement and Recurrence

Two atoms exchanging a photon with each other *in perpetuity* comprise a bipartite entangled pair (Figure 1). Each arrival of the photon (in t_s) at the atoms represents a gain in information and departure represents a loss, i.e., entropy. Information and subtime are incremented along the photon's path from the receiver's point of view, and decremented from the point of view of the transmitter.

Each *entangled system* may evolve through its configuration space an arbitrary (and uncountable) number of times, but is inevitably constrained to a *recurrence* which is temporally indiscernible from any previous or successive recurrence.

Going from one to two atoms mediated by a photon, subtime becomes an isolated temporal experience of that two party system. As we add more atoms to the system, the number of discernible configurations increases nonlinearly. The recurrence of the system becomes richer and more diverse, but the configuration space is still limited by the number of *retroactively discernible* configurations.

Every entangled system evolves independently, or expands as it receives new energy and decays as it decoheres. We expect some power law distribution, e.g., the simplest two atom entangled system would be almost 100% reversible in its state of perpetuity between recurrences. Progressively larger systems of atoms have both a larger space of recurrences as well as a smaller probability of reversing (de-evolving) to a previously visited state, simply because the number of states is so much larger. The *emergence* of irreversibility in T_c would rapidly approach 100% as we observe larger and larger objects up the chain to our macroscopic world.

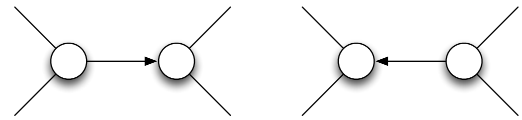

FIG. 1 The Heisenberg Cut - Photons Can Go Both Ways (A Hot Potato Protocol In Perpetuity)

INFORMATION AND QUANTUM MECHANICS

Shannon information and Quantum Mechanics (QM) share a common context: probability. And all probability is conditioned on the actions of an observer, i.e., what binary (yes/no) questions the observer asks, either explicitly or implicitly. In QM, the minimum number of states (yes/no answers) needed to fully describe the system is exposed by the preparation of the measurement.

Our framework for this insight includes:

1. No common reference frame exists in empty spacetime[7].
2. Space and (sub)time are inextricably intertwined in Poynting's revolving shaft along the path from transmitter to receiver[8] [7, 18]. Photons explore any number of bounded subtime elements, an indefinite number of times. This unitary evolution is computationally reversible.
3. Information is conserved in the photon link[9] between two atoms comprising an entangled system.

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[7] There is nothing in nature (or in any measurement carried out so far), supporting a *background of time*, which would allow us to discern temporal relationships between independent entangled systems. If a system has no interactions with other systems, there is no common frame of reference or coordinate system for time. Simultaneity, total and partial orders, are undefined.

[8] We take Feynmans clocks [17] literally.

[9] Each link equates to EPR's "simultaneous elements of reality" [4]. We assume links embedded in a quantum network automata, with each atom representing a vertex of bounded degree. This implies:

- A limit to the number of entanglement neighbors: partners with other nodes in the entangled system or with decoherence partners in the environment.
- Like the valency in atomic bonding, this implies that nature builds a multi-hop entanglement network out into the decoherence environment (similar to Figures 3 & 4).
- Different particles may have different degrees. For example, photons have degree two: one transmitter and one receiver represents a Shannon channel.

Information transfer is negative with respect to the transmitter and positive with respect to the receiver. This symmetry is broken when an observation is prepared which triggers the flow of energy and information – establishing a casual and thermodynamic direction.

4. Causality is symmetric[10]. There is no privileged role or direction for the observer-obsevee relationship. For every action there is an equal and opposite reaction. Just as effects must have causes for them to exist, causes must also have effects for them to exist. Measurements of information will thus be different (and opposite in sign) for each observer from their vantage point.

5. Interactions are reversible. Links comprise a photon bouncing back and forth between a pair of atoms in a perpetual hot potato protocol. It is impossible to discern (in any individual measurement) the first traversal of information from A to B (or vice versa) from the $N+1^{st}$ traversal, i.e., N is fundamentally uncountable.

Information and Entanglement

Entanglement of quantum states is traditionally assumed to be a consequence of the principle of superposition. This phenomenon has confounded physicists since EPR [4] first drew our attention to its paradoxical nature. Insight to explain the experimental evidence that nature behaves quantum mechanically and non-locally has thus far been elusive.

EPR described two possible explanations for entanglement: (a) there was some interaction (simultaneous reality) between the particles despite their physical separation or (b) information about all possible outcomes was encoded in hidden variables. EPR preferred the second explanation because instantaneous action at a distance was in conflict with special relativity.

There is a third explanation: a flaw in the belief that time can be measured as a smooth, monotonically increasing point on a continuum[11].

Time is change. When nothing changes, time stands still. When something changes, and then changes back, it is indistinguishable from time standing still.

Entanglement represents a state of *reversible change*; it is impossible to "count" (in an individual measurement) the number of recurrences within this state. This is one example of (apparent) randomness in quantum theory. It is not truly random (in the sense of being unpredictable). But it is *uncountable* because we cannot distinguish a single (one directional) exchange between two entities from any arbitrary odd number of exchanges; they are fundamentally indistinguishable in the T_c measurement events.

The orthodox assumptions which may mislead us regarding a global background of time are:

The continuum assumption: The experience of an atom (receiver or transmitter of information) is *stroboscopic*; information change occurs abruptly at the instant (in t_s) of emission, or absorption of the photon by an atom. Although *motion* may be continuous (down to the Planck limit), it is the arrival of new information that presents a change of state in the receiver. These discontinuous events in t_s masquerade as a continuous flow in our underlying assumptions in T_c.

The irreversibility assumption: We assume from human experience [19] that time marches irreversibly forward. There is no evidence for this in physics. What we know is that if time (change) happens, we remember: If it happens and then the information reverses its path, we don't. Even behaviors that have already decohered in T_c which we might think to be immutable once they have *happened*, can (at least locally) *unhappen*, within the local T_c state record, along with our memories being reversed also [20].

An indefinite amount of subtime units can be added and subtracted in a quantum network but only the net will be experienced by an observer. Different observers will also experience different measurements, because early observers will extract energy/information which will then be no longer available to other observers. Only a hypothetical witness with perfect *single traversal* properties would be able to detect the difference in subtime units in the system being measured. It is equally likely that the observer is fooled by the same stroboscopic, uncountable but indiscernible phenomena experienced by the system being measured.

Bell Experiments and Virtual Machines

Einstein proved that simultaneity was relative, but when we carry out Bell experiments, we set up our apparatus to detect coincidences with a tacit assumption that our observable measurements in T_c are equivalent to durations in t_s. Testing Bell's inequality requires two independent measurements (at points separated in space). Information regarding these measurements is signaled to a common site where coincidence is analyzed [21].

For the purpose of articulating this insight, imagine that *virtual machines* (VMs) are used to carry out the experiments; one each at the separated points and a third at the common site to analyze the signals from the other

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[10] Solutions to the electromagnetic field equations are symmetric with respect to time inversion. This symmetry is reflected in all our fundamental laws of physics.

[11] This recognition that the logic of the EPR paper was correct but the assumptions were wrong is shared by Nathan Rosen [2].

two for coincidence. These VMs[12] are governed by a clock cycle, orders of magnitude shorter than required to measure and analyze the results (Aspect's atomic clock). In the spirit of Maxwell, imagine a demon[13], which *suspends* and *resumes* each of the VMs (freezing them on a clock cycle) such that their periods of awareness do not overlap, but their computational state remains available while they are suspended and can be read by the others. The VMs have no independent timing reference, and have no idea that they are being time multiplexed in the t_{rt} (real-time) domain; their entire experience is described by the events they observe in the T_{vm} (virtual machine) domain.

Now further imagine that these VMs are capable of reversible computation: the demon can allow the computation to proceed arbitrarily far into the algorithm, but at any point reverse that computation to some prior state visited by that VM. The equivalent of this in the world of computing, is for the VM to be *reset* to some prior snapshot in order to re-acquire some previously consistent state. The VM has no idea it has been reset. Its only clue might be that its hardware time counters now differ from some external source of time that it may acquire from the network.

We can tune the rate of production of entangled photons such that they occur in the timing window of the measurement VMs, and the statistics of Bell states will emerge. However, this says nothing about what happens outside the timing windows, where any number of *internal* events my have taken place, i.e., any amount of forward or reverse computational evolution (non-Landauer [23] reversals or resets).

What is actually happening in the real world of Aspect's [24] Bell experiments? The apparent change in correlation (at distance) as soon as the polarizer is switched is explained simply by the reversal of subtime (the photon bouncing back), and a *rewriting of history* in T_c[25]. Which our instruments and memories would be *unable to remember* [20] – an example where we can catch nature reversing itself even after we have made an observation. This implies that relativistic separability remains intact in t_s, while the temporal artifacts of violations in Bell's inequalities shows up in our T_c record[14].

From this insight, we can now begin to formulate a new and logically consistent *information* view of the apparent non-locality revealed in violations of Bell's inequality without sacrificing the principle of locality.

INFORMATION AND SIMULTANEITY

Since 1905 we often see assertions that – *there is no space without time* – because the speed of light provides a limit to the velocity of information traversal between atoms. We rarely hear the logically equivalent – *there is no time without space* – which is equally concludeable from Einstein's original postulates and argument [26]. Implications of this include:

- The notion of Minkowski space as a 4D manifold can mislead us that *time passes* independently of the spatial dimensions. We postulate that subtime does *not* flow when there is no motion along the path between emitter and absorber.
- Simultaneity surfaces, even in inertial frames, have no basis in reality. There is no common meaning to time separate from motion. They are inextricably tied together.
- Intervals are the physical elements of simultaneous reality, terminated by the atoms on either end of the photon path. Subtime intervals are thus finite. The edges of the subtime graph are summed together to form the emergence of T_c. This is interesting, because *intervals* in time have been described by Barbour as an enigma: identified by Poincaré as an issue but otherwise remaining unresolved [27].
- The only *objective reality* that can be measured is through *interactions* – the ultimate *locality.* Entities must interact (touch, collide, bounce off, be absorbed, emitted etc.) in order to transfer information. However, the internal interactions of an entangled system are, by definition, unobservable. In T_c we observe only those rare events that touch the outside world through decoherence.
- In bipartite entanglements, a photon (and its associated information) is trapped. It is perpetually bouncing between the atoms, just as photons perpetually bounce between the orbiting electrons and protons in the nucleus of an atom.

[12] Virtual machines in computing are software systems that emulate the hardware environment of a real computer, to allow one or many virtual machines (Operating Systems as well as applications) to run on the same physical hardware.

[13] Aspect [22] measured time using randomly switched optical crystals at 50Mhz (20ns), while the spatial extent of the apparatus required more than double that to violate special relativity. This is *not* what we are referring to as a demon.

[14] There is insufficient room in this paper to discuss distinctions with other "time loophole" theories. We draw the reader's attention to the principal arguments: that subtime starts and stops with the emission and absorption of a photon, and is *reversed* in all ontological respects as the photon is returned in the hot-potato protocol. This is one way that we divorce ourselves from the background assumption of time, which is not (as far as we can tell) the case for other time loophole theories.

We assume that information is transmitted between atoms at a finite speed – the maximum being the speed of light – but question our ability to perceive this transmission as a *reversible* information-theoretic process. This creates an illusion of superluminal quantum-mechanical processes in experiments designed with a hidden assumption of an absolute time background, which hinders our understanding of the EPR paradox.

Subtime (t_s)

Subtime is what happens when we are not looking. It is the perpetual alternating direction of information flow through the bipartite interactions of atoms and photons. Subtime is (for our present argument) continuous, and is inseparable from the motion of photons.

FIG. 2 below shows asynchronous events along a t_s line, and the perception of these events back to back in T_c.

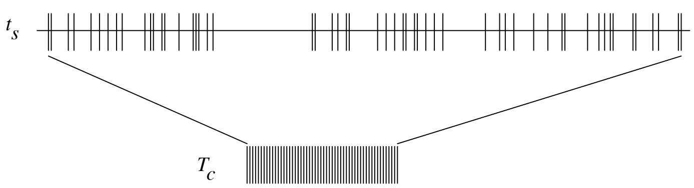

FIG. 2 Asynchronous Events in *Subtime* (t_s) Will *Appear* Continuous In *Classical Time* (T_c)

Subtime is reversible: everything that *happens* in subtime can *unhappen*. A photon that travels from A to B is *usually* followed by a traversal of that same photon from B to A. The state of the system is now indiscernible from that which existed before the first traversal, or indeed any prior or later traversal of the photon between them[15].

We describe subtime as *propechronos* – from the Latin "propinquus"; (of space) near, neighboring, (of time) near, at hand, not far off; and "chronos"; the personification of time. To emphasize its locality (to the next atom in space) and temporally symmetric nature.

Classical Time (T_c)

T_c *appears* successive, monotonic and irreversible and its sign is always positive (because it represents the absolute value of the sum of subtime intervals) in the network *trail*.

[15] From the Lorentz frame of the photon, everything that happens inside the atom, between the absorption and its re-emission, will appear to have a proper time of Zero. The notion of instantaneous is a function of the arbitrary frame in which we chose to perform our calculations [2].

The perpetual *hot potato* photon[16] exchange in entanglement is timeless because we are unable to measure it with our instruments without taking energy out of the system (thus disturbing the state of entanglement).

FIG. 3 shows a photon traversing a chain of 9 atoms. The red path accumulates t_{s1} subtime units. The alternate green path (which continues half way through the red path before branching in a different direction) accumulates t_{s2} subtime units. Both will be experienced in T_c as the *same* interval of time. The order of events observed by different witnesses observing different atoms will therefore be different.

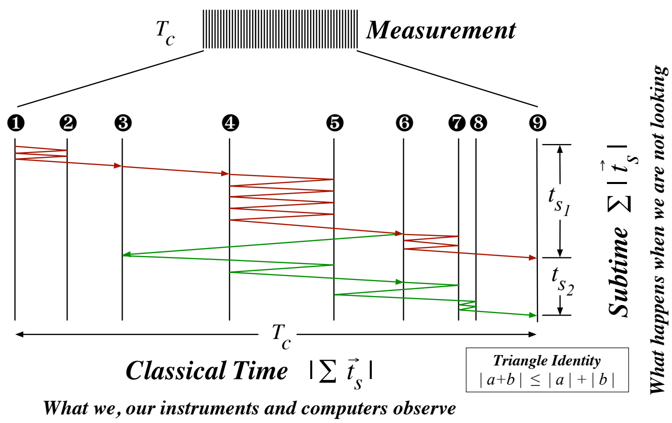

FIG. 3 Different Accumulations In *Subtime* (t_s) Can Appear *the same* In Classical Time (T_c)

Extending the Entanglement Graph

Figure 4 shows a larger system of atoms, with three examples of alternate paths for the photon energy to travel between the energy/information ingress and egress points. The total length of the path defines t_s, but what we observe in T_c will be the absolute value of all the increments (forward traversals) in t_s, minus all the decrements (reverse traversals).

There are two segments of path ③ (second and fourth segments) illustrating entanglement as multiple photon reflections. Remember: an arbitrary odd number of reflections of this photon is indistinguishable from a single traversal. Also there is no way for us to discern (in an individual measurement) whether path ①, ② or ③ has an arbitrary number of photon reflections within them.

- There is no distinction in the passage of time (in T_c) as far as the "outside world" is concerned, with paths ①, ② or ③.

[16] Because photons are indistinguishable, photons in a perpetual hot potato protocol may compete with other photons *taking over* the entanglement [28]. Information and energy may, however, remain trapped within the same entangled system.

- Path ③ includes back and forth passing of the information/energy between the vertices in the graph. The number of passings *back and forth* is *uncountable*. This mixed path shows both temporary entanglement and direct *cut through* of photons through the system.
- There is no global passage of time. Each measurement experiences T_c as the *not yet reversed* receipt (and passing on) of information/energy within the entangled system.

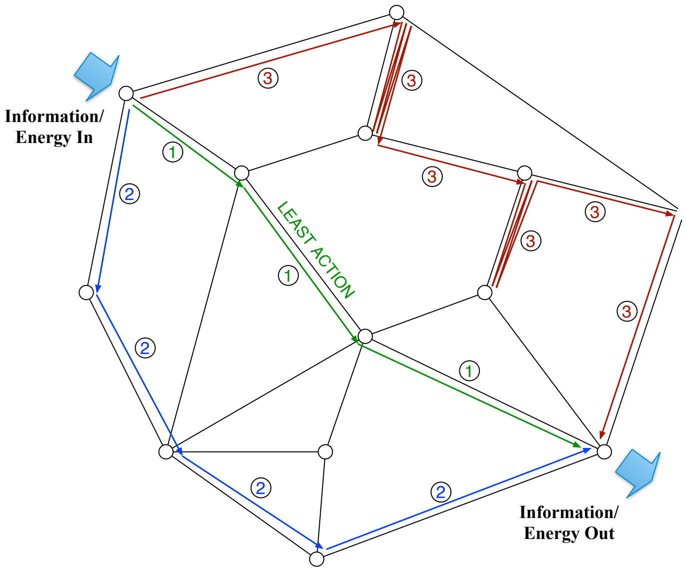

FIG. 4 A Graph (2-D) View of Different Paths In An Entangled System

MULTIPLE SLIT EXPERIMENT

It is commonly believed that if we decrease the intensity of a beam of light, we will eventually reach the point where only one photon is in transit through the apparatus *at a time*. An implicit but unacknowledged belief is that the photon travels only once (one way) through the apparatus from the intended source (transmitter) to the intended destination (receiver) whereupon energy (and information) is captured and the *measurement* is made.

We will use the excellent description by Deutsch [29] as a canonical orthodox description of the multiple slit experiment. Deutsch makes the classic argument (as did Feynman, Greene and many others) that *there is only one photon passing through the apparatus "at a time."* This assumes that we (and our experimental apparatus) experience a continuum of progressive (monotonically increasing) time in T_c.

We offer an alternative perspective: photons enter the apparatus and instead of transversing once only in a single direction and being fielded by the detector, they reflect (or absorb/re-emit) from the detector back to the source, whereupon they reflect again back through the apparatus to the detector. This process continues an uncountable number of times before photons are finally extracted from the system as information/energy representing the measurement. The fundamental uncertainty in this process is not purely Heisenbergian (although it may masquerade as such), it is the uncountability of the reflections. This uncertainty interferes with our ability to accurately measure the *reversed* intervals of backtracking photons in t_s, in any single measurement.

Deutsch explains this phenomena in terms of the Everett interpretation and invokes a huge number of parallel universes to explain the interference without a Copenhagen style *collapse of the wave function*. Within the context of *subtime*, we can see an element of truth in this intuition. Instead of Deutsch's "huge number of parallel universes, each one similar in composition to the tangible one," we can now imagine a many times larger number of *multithreaded* explorations of its t_s environment – between each relative observation event in T_c.

Deutsch enumerates the possible number of universes. The largest area that we could conveniently illuminate with a laser might be about one square meter and the smallest manageable hole size might be a thousandth of a millimeter. So, there are approximately 10^{12} possible hole locations – alternative configurations – which can be explored in this system. It is critical to acknowledge that while this may be an approximate number for parallel universes, or with subtime exploring each location of the one square meter once, the entanglement in subtime expressed by our hypothesis is by its very nature *uncountable*, yet it exhibits a fundamental economy of mechanism and use of resources.

The implications of this include a *massive* unrealized concurrency under the hood of entangled information/subtime which is reminiscent of the hoped for *parallel computation* capacity of quantum computing.

We present a critical change in perspective: Instead of some magical parallel universes being explored, which is somehow beyond the relativistic physics of spatiality separated entities in some Bell-type inequality, we can now see ourselves and our instruments as observing the universe through a *time filter*. This time filter may be like a stroboscope or cinematographic projector. Each frame of the film represents a snapshot of subtime (events in t_s) and we can be fooled by our measurements into believing that there is zero "time" (T_c) between one frame to the next because all the change (the stroboscopic flash of reality) appears to occur at once. In our case, the step from one frame to another may be triggered asynchronously by individual decoherence events.

As the angle between the photon path(s) through the apparatus departs from the nominal 0°, we will observe interference through multiple slits as the phase of the helical photon path impinges on the target, with a "wave-like" probability of dark entanglement and light absorption/detection.

The geometry and mathematics of interference is well known but the mechanism traditionally used to explain it (waves) may now be compared with classical explanations within the *subtime* context. It is not that a single photon (or other quantum particle) is passing through both slits "at the same time," it is passing back and forth with an indefinite number of traversals each reversing the effect in t_s. Appearing to traverse the apparatus only once in T_c because of our inability to accurately perceive intervals (between detection events in T_c) this *appears to* reinforce our assumption of a T_c background being smooth, monotonic and irreversible.

ENTANGLED SYSTEMS ARE DARK

An entangled system explores indefinitely within their *recurrences*, where the system neither gains nor loses energy/information. These are the maximally entangled states. Their existence will be *dark* i.e., *outside of time* – their existence is unobservable in T_c, either as emitters *or absorbers*. The answer to the question, "Is the moon there when we are not looking?" is *yes*; however it hides from us in *subtime*.

In t_s photons may take any and all paths that exist in the apparatus an uncountable number of times between each detection event. Between *detection events* photons are trapped/hidden, thus perpetuating the *state of darkness*. This provides a potentially straightforward (classical) explanation for: interference in the two-slit experiment, Feynman's glass reflector system, quantum erasure, quantum teleportation, the quantum zeno effect and entanglement swapping [28].

FALSIFIABILITY

Many experiments can be conceived to prove this hypothesis incorrect. Below are a small sample of the unique aspects of this insight that may be tested experimentally:

- Separate (non-interacting) entangled systems will develop (evolve their state within the constraints of recurrence) entirely independently. No background of time exists which is common to all systems in the universe.

  Experiment #1: Independent atomic clocks will exhibit random (unexplained) perturbations relative to each other. These jumps will be affected by an increase in electromagnetic coupling to other systems (onset of decoherence).

- The phase of the photon helicity — with respect to path length – is locked into the traversal of the photon. When two endpoints (the atoms) engage in entanglement they will then experience events (information arrival and departure), but will not experience *duration* (the intervals between events).

  Experiment #2: The distinction in t_s and T_c can be exposed by observing that certain observed events in T_c are (perhaps large) integer multiples of the space/time traversal within the geometry of the apparatus. What would we see if we varied the distance between the source and detector in units of wavelength of the quantum particle in a Bell experiment?

CONCLUSIONS

Photons are the carrier of time, and the Universe is a *network automaton*[17]: a graph of evolving relationships where the vertices represent atoms and the edges represent the hot-potato protocol of a continuously (in perpetuity) bouncing back and forth of a photon. The concept of subtime carries many of the hallmarks of *entanglement*.

Photon entanglements represent reversible, bounded *intervals* of reversible subtime. Indeed, the only realistic intervals that can exist are those that span the space/time path of the photon and are *terminated* by the atoms. Intervals in subtime are therefore finite and bounded by the (mostly) symmetric emitter and absorber atoms [30].

What goes on inside entangled systems is both *timeless* and *unobservable*. Only *rare* interactions (observations) with the outside define the order of events that we see. Entangled systems are *dark*.

We question the idea that massive concurrency exists in quantum computation, and suggest instead that we have been sampling subtime like a stroboscope in T_c: we see brief flashes of reality with long periods of darkness in between. We also recognize the intuition behind multiple parallel universes. Instead we imagine entangled systems to exhibit unbounded exploration of the quantum state space in t_s, not dissimilar to a conventional computer "multithreading"[18] the many tasks vying for its physical resources and our apparent *random* selection of the current state of one of the threads through a deliberate (or otherwise) preparation of our observations.

> "We must, therefore, be prepared to find that further advance into this region will require a still more extensive renunciation of features which we are accustomed to demand of the space time mode of description."
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> – *Niels Bohr* [30]

[17] A network automaton is similar to a cellular automaton, but where the cells are vertices in an arbitrary network, and there is an evolving topology of links connecting them.

[18] Multithreading is distinguished from multiprocessing in computer systems, in that *threads* share the resources of a single computer. i.e., we have one universe, not many.

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