Insights into The Nature of Time in Physics, and implications for Computer Science

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Time and Computer Science

"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 wavefunction and macroscopic observation."

– Andrew Hodges in: Alan Turing: Life and Legacy of a Great Thinker

Acknowledgments

- This work is based on the work of many others.
  - Core ideas go back to Stückelberg and Feynman*
- *Key influencers include :*
  - Julian Barbour, Lee Smolin, Fotini Markopoulou, Anton Zeilinger, Simone Severini & Stephen Wolfram. They may not agree with anything I have said, but I owe my inspiration to the questions they asked
  - There are countless others who have influenced me. If I have not quoted your work, please let me know
- Talk is targeted for this audience, does not go deeply into the issues

** The idea that time reversal in the photon path provides a logically consistent explanation for entanglement is nicely summarized by Vic Stenger [Stenger 2000]*

Motivation: Computer Science

Making Infrastructures reliable, secure and agile

- Can we think about reliability differently?
- Can we think about security differently?
- Can we think about heartbeats differently?
- Can we think about timestamps differently?
- Can we think about transactions differently?
- Can we think about concurrency differently?

Part One:
The Physics

"We have to bear in mind that all our propositions involving time are always propositions about simultaneous events"

~Albert Einstein, 1905

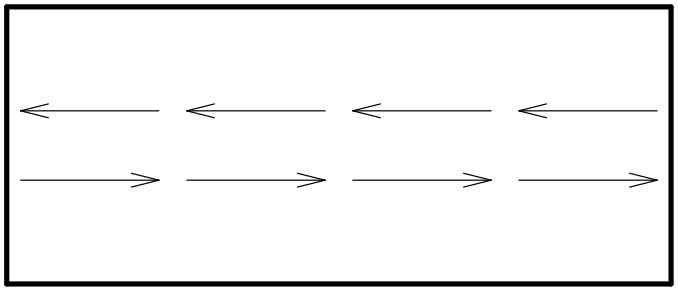
Time: our "sky hook"

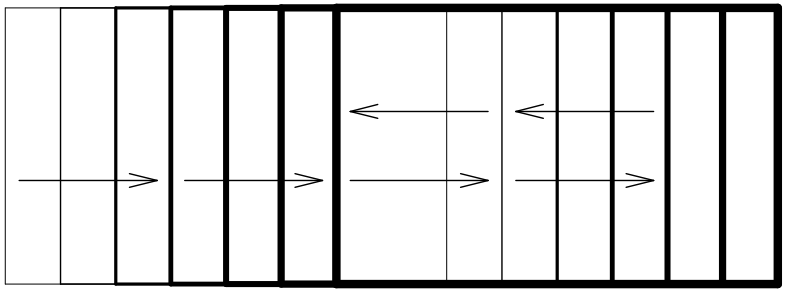
- UTC (Universal Coordinated Time) is ***defined*** as the world time ***standard***
  - Divides time into days, hours, minutes and seconds. Each day contains 24 hours and each hour contains 60 minutes. The number of seconds in a minute is usually 60, but with an occasional leap second, it may be 61 or 59 instead. *Leap seconds cannot be predicted far in advance due to the unpredictable rate of rotation of the Earth, they are announced at least 8 weeks in advance*
  - UTC is therefore ***discontinuous.*** It's not possible to compute an exact time interval between two UTC timestamps without consulting a table that describes how many leap seconds occurred during that interval (Google smears the leap seconds*)
- TAI (International Atomic Time) as a time standard is a ***weighted average*** of over 200 (mostly Ceasium) atomic clocks in over 50 national laboratories, worldwide

http://googleblog.blogspot.com/2011/09/time-technology-and-leaping-seconds.html

Special Relativity (SR)

- A beam of light bounces back and forth between mirrors at the front and back of a moving train
- The time of the roundtrip journey can be used to measure the length of the train, ***but:*** a moving observer and a stationary observer obtain different results





- ***SR Tells us:***
  - The speed of light, c is a constant
  - There are no distinguished reference frames (simultaneity is relative)
  - Space *and* time are *intimately* linked through the speed of of light

Special Relativity (SR)

- From Maxwells Equations:

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

- Time Dilation:

$$\Delta t = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \Delta t'$$

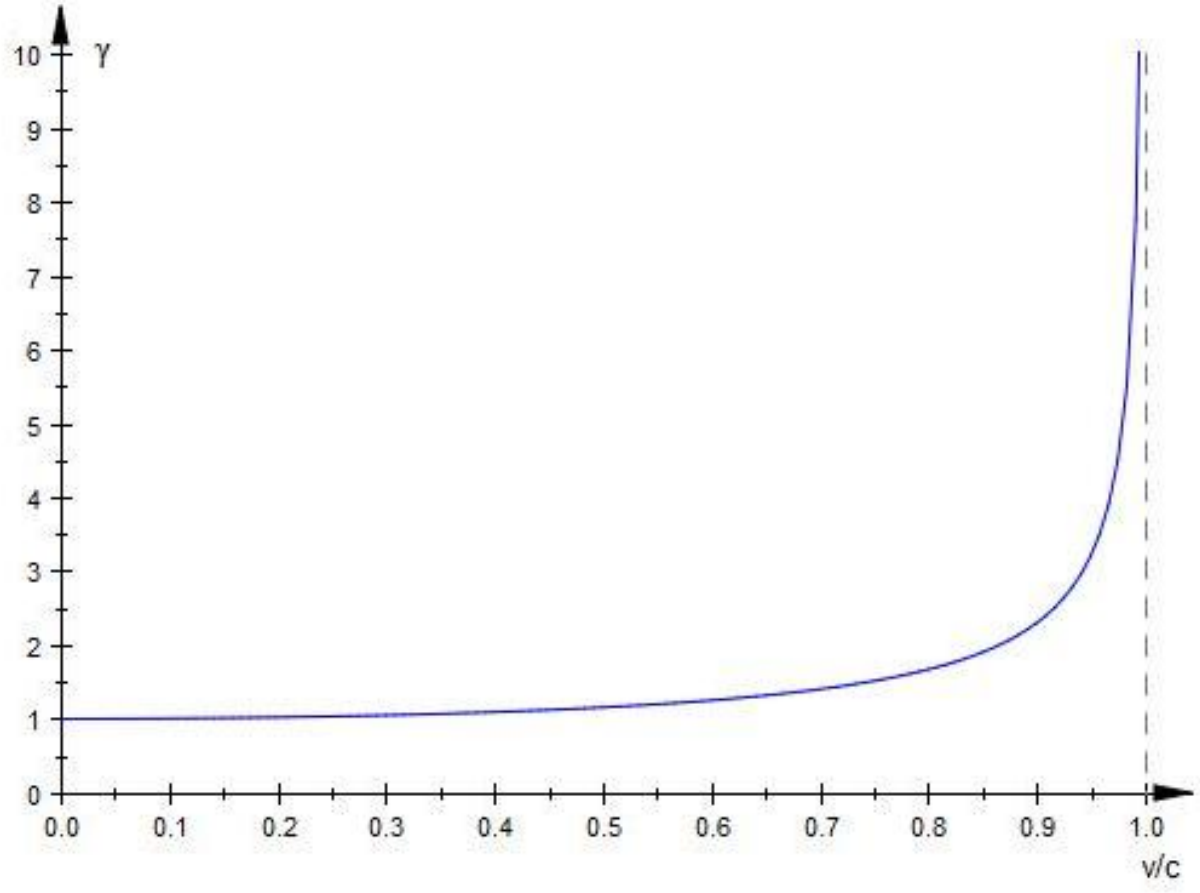
- The Lorentz Boost:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Special Relativity (SR)

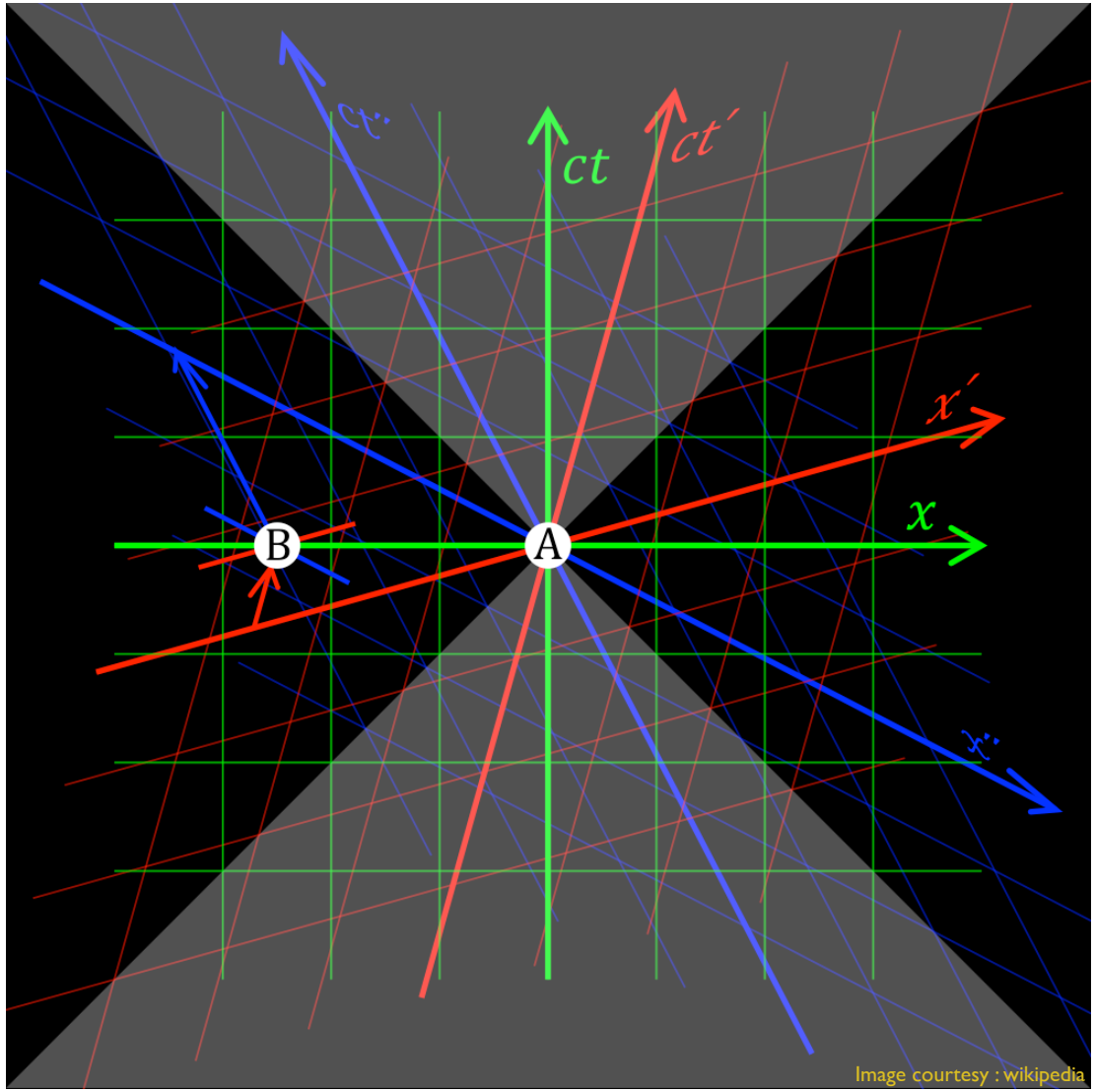
- Lorentz Boost

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$



Light Cones

- A light cone is an ***imaginary*** surface, associated with a point in space-time, comprising the paths of all possible light rays that pass through this point
- Event B is 'simultaneous' with A in the green reference frame, but it occurred *before* in the blue frame, and will occur *later* in the red frame
- Special Relativity is about clocks, not about an abstraction for time
- Photon clocks …



Simultaneity is a Myth

- To determine the time of a distant event: We must know not only the distance between the locations of the two events but also the velocity of the signal by which the comparison of the time indications can be performed. To measure a velocity, however, one has to use synchronized clocks so that the simultaneity of distant events must already be known.*

"Thus we are faced with a circular argument. To determine the simultaneity of distant events we need to know a velocity and to measure a velocity we require knowledge of the simultaneity of distant events"

So much for our "sky hook"

*Quoting Reichenbach, in: "Concepts of Simultaneity. From Antiquity to Einstein and Beyond." Max Jammer(2006)

Inertial Frames are a Myth

- Even without worrying about gravity, the surface of the Earth is not an inertial frame*. ***Knowledge of simultaneity is impossible, even in principle*****

$$t_B = T_A + \varepsilon(t'_A - T_A) \qquad 0 < \varepsilon < 1$$

- Implies: $\varepsilon \in \mathbb{R}$ and a "convention" that $\varepsilon = 1/2$
- Synchronization of clocks represents an attempt to create simultaneity planes
- Computer networks can never achieve (a) the ideal of an inertial frame (or constant velocity of packets), (b) reliability. When networks fail, systems are stuck with local time sources, which are fundamentally *asynchronous* to all other sources of time***

**An inertial frame is, roughly speaking, one in which Newton's laws hold.*
*** The Geometry of Special Relativity. Tevian Dray (2003)*
**** Reichenbach, in: "Concepts of Simultaneity. From Antiquity to Einstein and Beyond." Max Jammer(2006)*

General Relativity (GR)

$$G_{\mu\nu} = 8\pi\kappa T_{\mu\nu}$$

Gravitational Field (Curvature of spacetime)

Energy Density

Matter tells space-time how to curve, and space-time tells matter how to move

- *GR tells us:*
  - Spacetime is a dynamic manifold
  - Acceleration and gravity are equivalent
  - Time stops inside a black hole

- Background independence is the mark of distinction of general relativity [Anderson 2012]

Quantum Mechanics

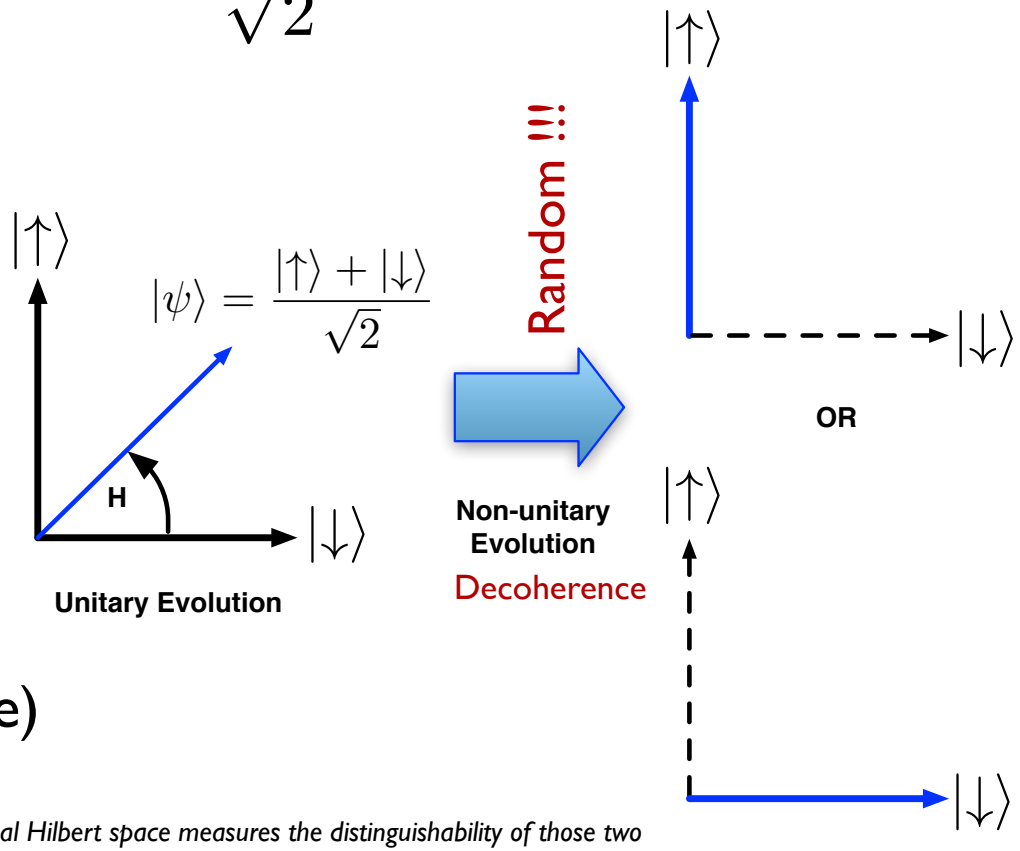
- Two Slit Experiment

$$|\psi\rangle = \frac{|slit\ a\rangle + |slit\ b\rangle}{\sqrt{2}}$$

Sum of two probabilities

  - The ket $|x\rangle$ is a complex vector
  - $\sqrt{2}$ is a normalization factor (combined probability = 1)
  - Measurement is the square (norm)

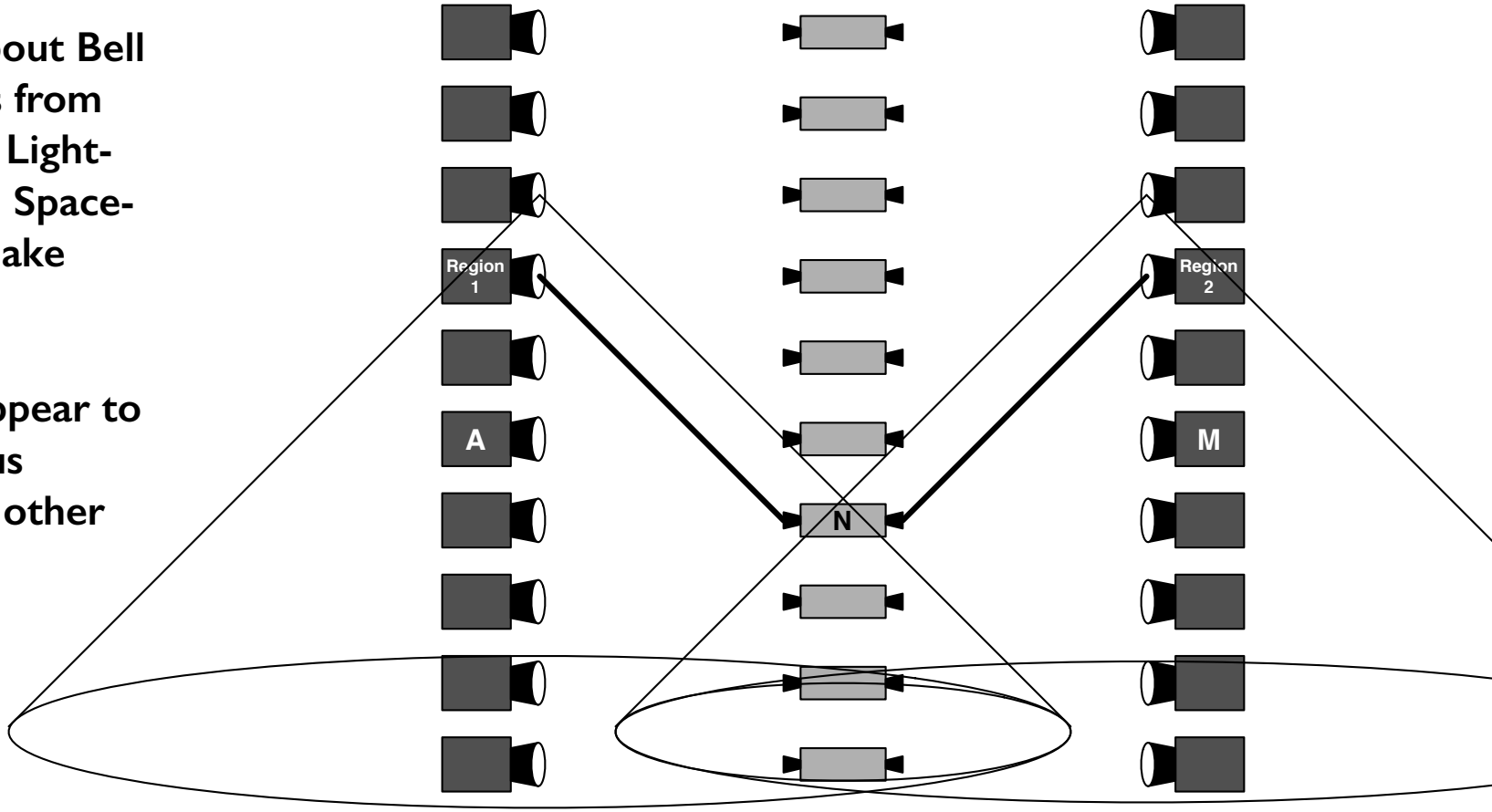
- Quantum Entanglement
  - Two types of evolution
    - Unitary (reversible, linear, lossless)
    - Non-Unitary (irreversible, dissipative)



*The angle between the probability amplitude for those two populations in that real Hilbert space measures the distinguishability of those two populations. One finds oneself forced to probability amplitude by the very concept of distinguishability [John Wheeler, 1999]

Bell State Experiments

- When we think about Bell State Experiments from the Perspective of Light-Cones (Minkowski Space-time), it doesn't make sense …
- Regions 1 and 2 appear to have 'instantaneous influence' on each other



From "Quantum Non-Locality and Relativity" - Time Maudlin, 2008.

The Second Law

- **Boltzmann:** the arrow of time comes from the tendency of nature to evolve into an ever greater disorder.

$$S = -k_B \sum p_i \log p_i$$

PROBLEM: Entropy should increase BOTH going forward in time, and backwards

- Irreversibility in Physics is associated with the second law of thermodynamics: entropy, which measures the degradation of the usable energy in a system, never decreases in isolated systems

- Maccone* shows that entropy in a system can both increase and decrease (as time reversal dictates), but that all entropy-decreasing transformations cannot leave any trace of their having happened. *Since no information on them exists, this is indistinguishable from the situation in which such transformations do not happen at all*

*Lorenzo Maccone. "Quantum Solution to the Arrow-of-Time Dilemma." Physical Review Letters 103, no. 8 (2009)

Information

- Information is what we don't already know. We don't learn much from being told that the sun will rise tomorrow morning, we learn a great deal from being told that it won't. Information quantifies this notion of ***unexpectedness*** [Gershenfeld 2000]

- Entropy, or uncertainty, quantifies the converse: ***expectedness***, i.e. that things inevitably degenerate into randomness, according to the 2nd law of thermodynamics

- The information content of a set $A = \{a_1, a_2, \ldots, a_n\}$ [Shannon 1948] that we collectively call message or an object, each occurring with a discrete probability $p(a_k)$, is given by:

$$H[p] = -\sum_{k=1}^{n} p(a_k) log_2 p(a_k)$$

The Arrow of Time Dilemma*

- The laws of physics are invariant for time inversion. The phenomena we see everyday are not (entropy increases)
- Within a quantum mechanical framework, all phenomena which leave a trail of information behind (and hence can be studied by physics) are those where entropy necessarily increases or remains constant
- All phenomena where the entropy decreases must not leave any information of their having happened. ***This situation is completely indistinguishable from their not having happened at all***
- The second law of thermodynamics is reduced to a tautology: physics cannot study those processes where entropy has decreased, *even if they were commonplace*– ***because the evidence has been erased***

**Lorenzo Maccone. "Quantum Solution to the Arrow-of-Time Dilemma." Physical Review Letters 103, no. 8 (2009)*

Part Two:
Computer Science

"It ain't what you don't know that gets you into trouble,
it's what you know for certain that just ain't so."

~Mark Twain

Orthodox Assumptions

- **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 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.

- ***These orthodox assumptions may mislead us regarding a global background of time***

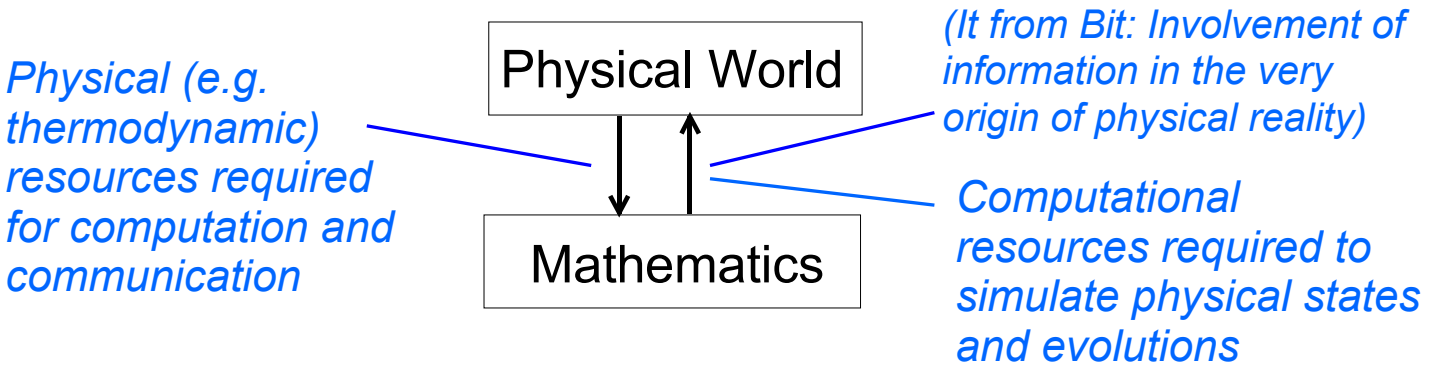
Reversible Computing

- The motive for academic interest* in reversible computing is generally to find ways to minimize the energy dissipation of our machines (exploiting Landauer's Principle)
- Reversible computing is potentially even more valuable as a tool to explore:
  - Alternative paradigms for concurrency control - Performance across WAN's
  - Ultra-reliable transactions - Atomic Information Transfer
  - Security - Use the laws of physics to thwart unwanted snoopers or intruders
  - After all, two-phase commit is a (primitive) form of reversible computing

*ACM *First International Conference on Reversible Computing.* http://www.eng.fsu.edu/~mpf/CF05/RC05.htm

"Information is Physical" Rolf Landauer

"It from bit" John Archibald Wheeler



When Turing, Shannon, von Neumann and their contemporaries formalized the notions of information and computation, they left out notions of reversibility and quantum superposition

reversibility => thermodynamics of computation

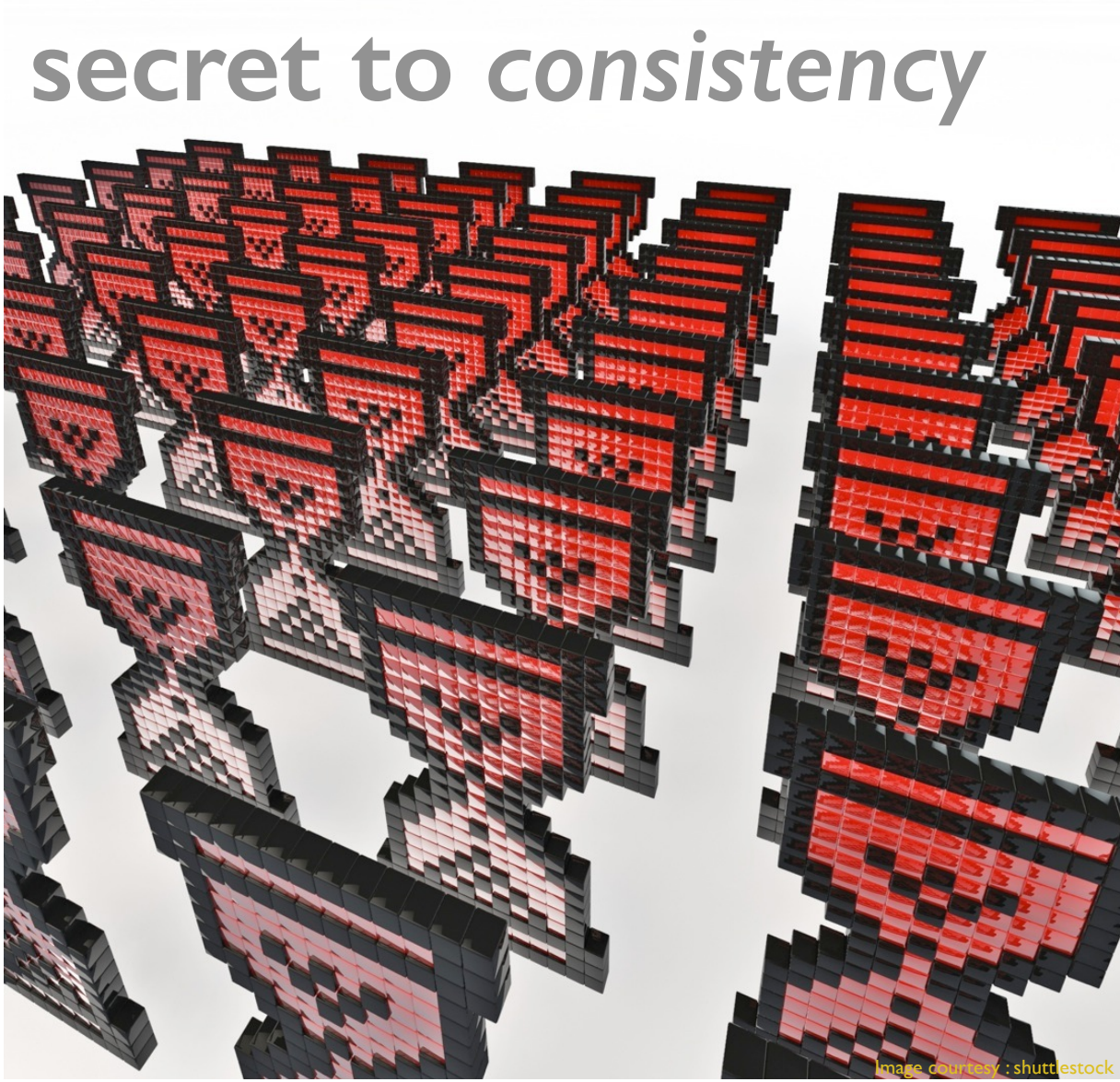
superposition => quantum information/computation theory.

From: Charles H. Bennett IBM Yorktown*

*ACM First International Conference on Reversible Computing. http://www.eng.fsu.edu/~mpf/CF05/RC05.htm

Reversible Time: secret to *consistency*

- Distributed systems today use *Lamport timestamps* as a crutch
- What happens when they go backwards?
- *Google* created the first WAN scale SQL in *Spanner*, by redefining the time API:
  - Uses GPS Clocks
  - Time is no longer a single *scalar*, it is now an *interval that can be tested through an API*



The Computer Science Problem

- In Computer Science, Time is invariably presumed to be a Newtonian background: a smooth, unidirectional flow, with no possibility of reversibility

- Computer Scientists construct models of time by enforcing simultaneity through a logical timestamp and assume the error between one timestamp and another will be no more than a certain bound.

- The principle of Linearizability used for "transactions" in databases, is a model for use inside one computer (GEV of data structures in memory). This forces the implementation of a "master copy". Massive complexity ensues when you lose the master copy, as occurs with failures, disasters or attacks.

- Computational models have to "rebuild" a notion of reversibility (or at least back-tracking) in order to enable database transactions to escape deadlock.

Networks and Virtual Machines

- **Network Time.** IEEE 1588: Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems
- Requires a "Distribution Tree". Ultimately, comes down to a single source of frequency, somewhere in the world (Boulder Co?)
  - A perfect single point of failure (SPOF), and networks fail all the time, particularly the WAN
  - A perfect place for cyber-criminals to attack
  - Propagates the illusion of a simultaneity plane
- Network Timestamps can be used for adding audit information, ***they should never be used for control***

- **Virtual Machine Time.**
  - To be discussed later …

Architecture

Image courtesy : shuttlestock

Get the Observer Right

- *Identity & Individuality:*
  - Human Observer (latency)
  - Multiple Observers (DB Transactions)
  - Background Processing (DP, GC, Compaction, scrub)
- *What it means:*
  - 100% Failure Domain Isolation (if we give up a belief in distant simultaneity)
  - Distributed Transactional Integrity with adaptive ACID
  - Multiple View Versioning (Metadata Tensor on a lattice)

Part Three:
A Potential Insight

"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"

~ Niels Bohr

What is Time?

"That aspect of change that enables it to be counted"

~ Aristotle

"This is a heuristic point of view and not a logically binding conclusion"

Controversial Claims

- **There is no background in time.** We dispense entirely with the notion that a background of time exists, along with any sense of future or past, between isolated entangled systems.

- **Subtime** is *inextricably intertwined with space* along the ***one-dimensional path*** bounded by the photon traversal between emitter and absorber (Shannon transmitter/receiver channel)

- **Subtime** is not new, it builds on the work of many who have dissected this puzzle ahead of me. I have simply connected some dots. See references in the paper, and key influences slide in this presentation.

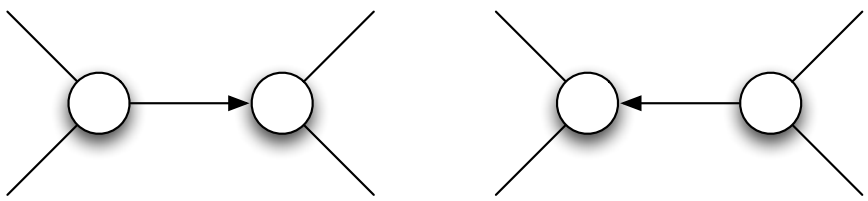
- Subtime provides an alternative model to visualize time, and understand quantum phenomena, such as entanglement, teleportation, the double slit experiment and quantum computing

- This is highly likely to be incorrect, and certainly over-simplified. I am seeking critique and feedback, and have received encouragement by professional physicists

- A revised and extended version of this paper will appear in a new Springer-Verlag book on the foundations of physics later this year

Paradox

- There are two often conflated paradoxes in Quantum Theory:
  - Wave behavior of energy quanta (Interference) when passed through multiple slits
  - Unexplained coincidence in correlated events in the time averaged record of Bell state experiments



The Heisenberg Cut (with apologies to Decoherence Theory)

Minkowski Space-time

- We challenge the assumption of a background of 4D Minkowski spacetime, and replace its implicitly smooth, infinite and global notion of light cones with subtime (t_s) : a local, bounded (quantized), and reversible one-dimensional ***element of physical reality*** to account for increments and decrements of photon information

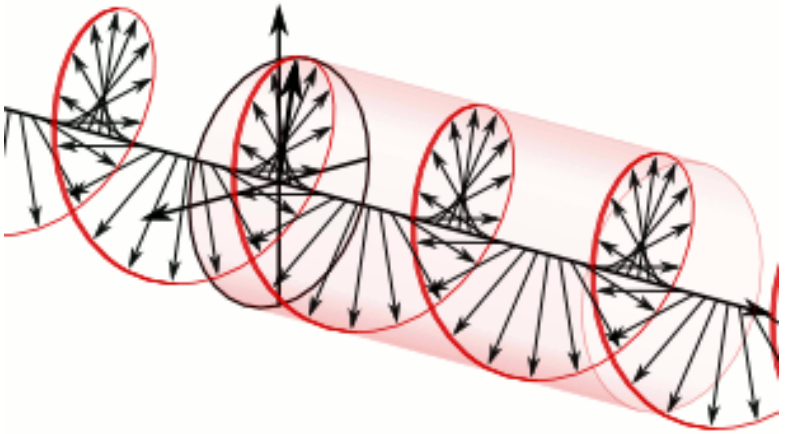
- In t_s , photon information transfer is negative with respect to the transmitter and positive with respect to the receiver. Information and energy are conserved in the entangled systems that we measure in classical time (T_c)

- Minkowski spacetime misleads us that time passes independently of the spatial dimensions

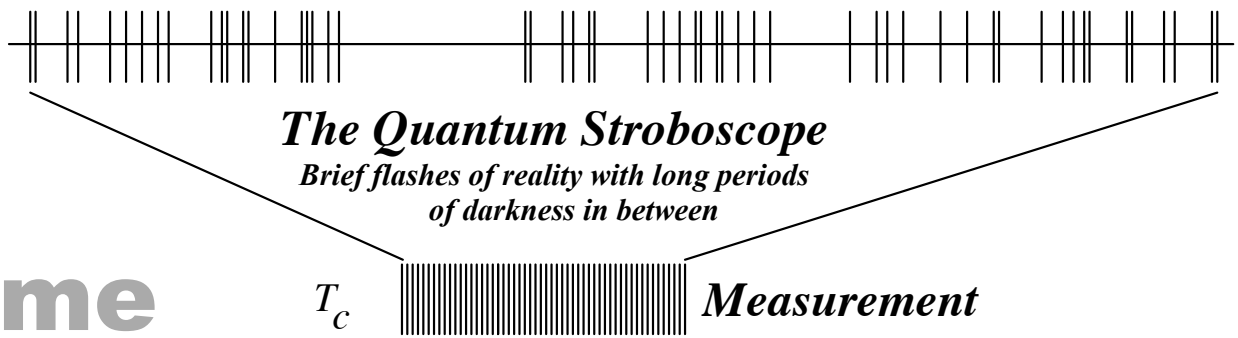
Multiple Slit Experiment

- Is it possible that wave behavior is simply Maxwell's equations (Poynting's twist waves) as helical photon traversals along the one-dimensional paths bounded by emitters and absorbers?

- Phases align with atoms whose reflectivity and absorption matches in the detection plane normal to the experiment, with an intensity proportional to the square of the amplitude at any random (or chosen) orientation



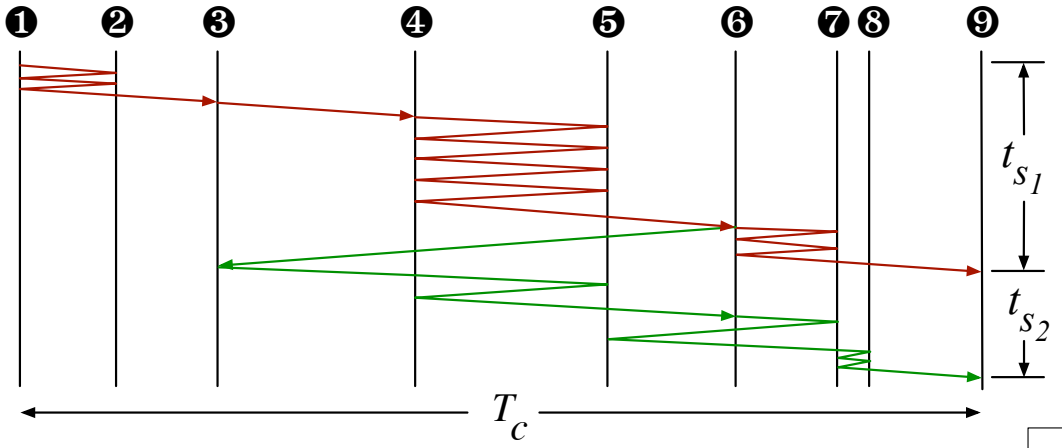
Subtime t_s



Classical Time

Decoherence Events – from the perspective of a single observer

- **Under the Nyquist Hood?**
- Nature appears 'random' because a single quantum observer experiences events at a much slower rate than the accident of sampling by decoherence with the measurement apparatus



Subtime $\sum |\vec{t}_s|$

(sum of absolute subtime elements)

What happens when we are not looking

Classical Time $|\sum \vec{t}_s|$

(absolute value of the sum of subtime elements)

What we, our instruments and computers observe

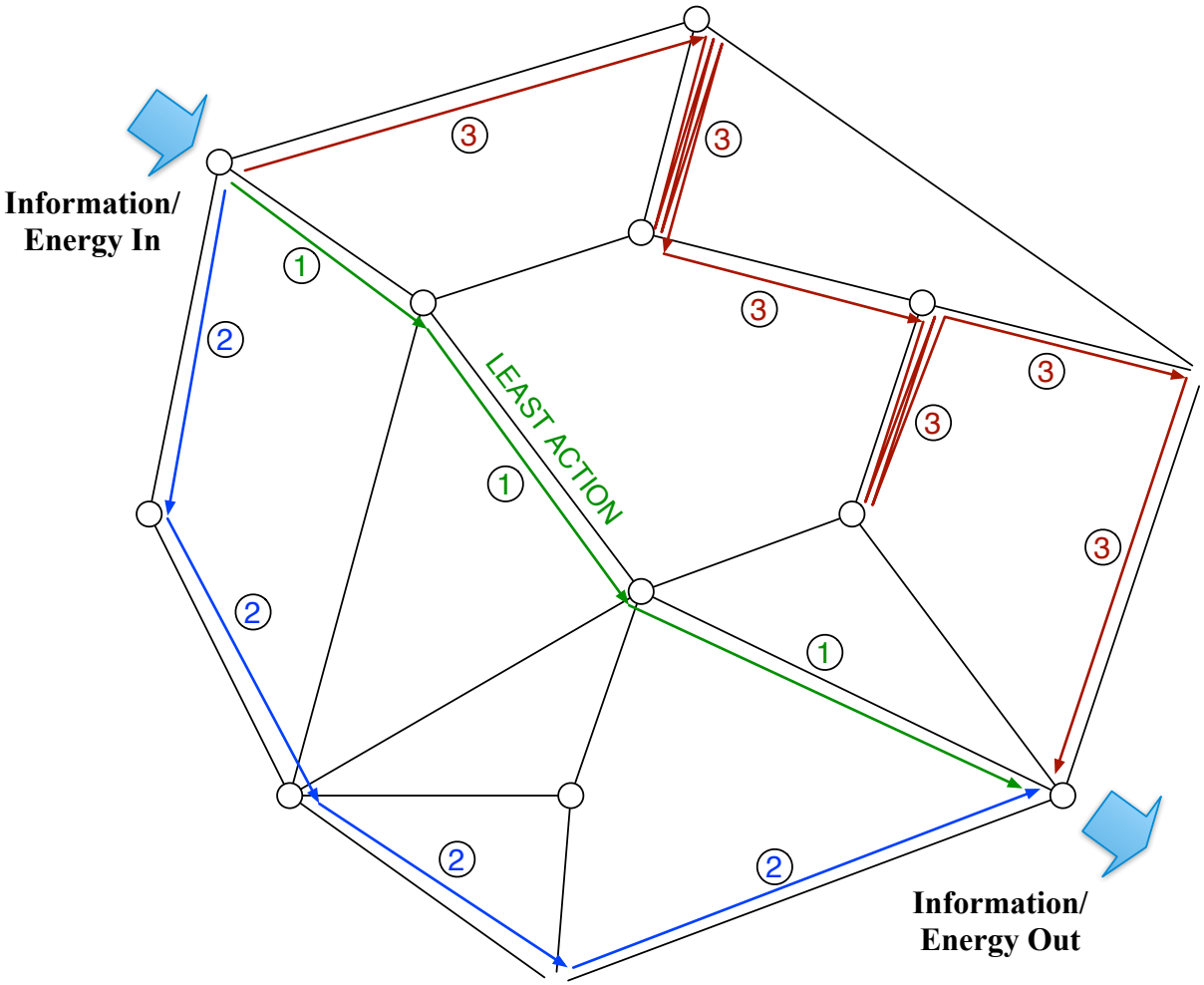
Triangle Identity

$|a+b| \leq |a| + |b|$

Multiple Slit Experiment

- We question the assumption that photons pass once only through both slits ***"at the same time"***

- Instead, photons pass back and forth an uncountable number in subtime (t_s). They appear to traverse once only in T_c because of our inability to measure subtime recurrences

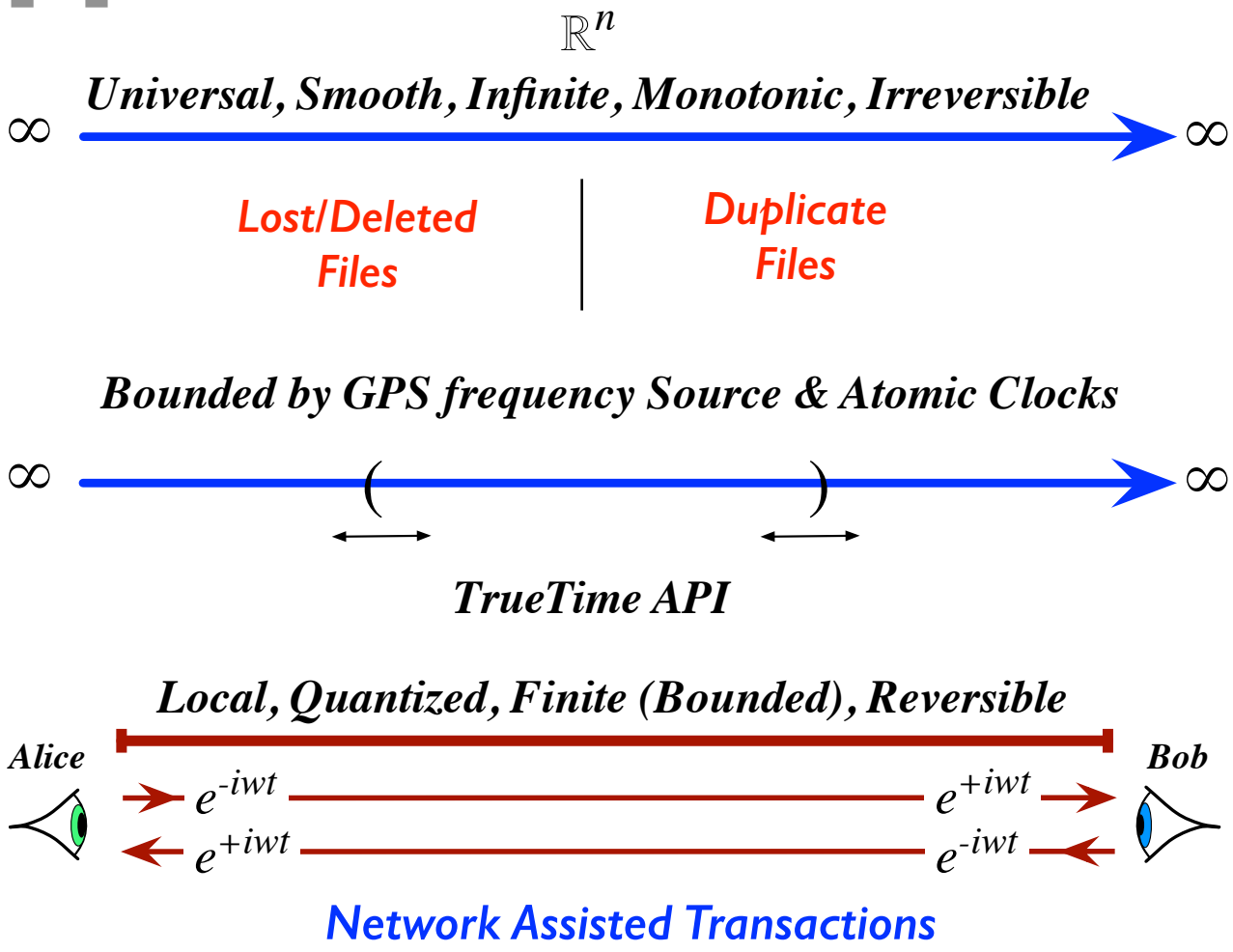


Bell State Measurements

- We address unexplained coincidences in Bell state measurements against an assumed backdrop of T_c by postulating an "element of physical reality" where entanglement may be described as a "hot potato" photon trapped between alternately reflecting atoms. This reversal of time, energy and information may recur an uncountable number of times in t_s, and yet be unobservable (frozen in T_c). Symmetry is broken when an external interaction is prepared, or occurs randomly. This triggers the flow of energy and information – establishing a new seed (root) for a casual and thermodynamic direction.

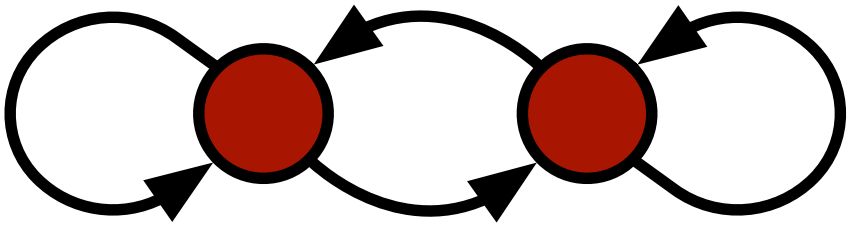
Computer Applications

- Conventional
  - Dropbox
  - Google
  - Apple
  - Microsoft
- Google Spanner
  - TrueTime API
- Alternative Networks
  - Entangled Links
  - Atomic Transfer



Conjecture

- Subtime (t_s) is inextricably intertwined with space along the local, one-dimensional path bounded by photon traversals between emitter and absorber atoms. Subtime is reversed in all ontological respects as the photon is returned to the previous atom. Two atoms exchanging a hot potato photon with each other in perpetuity comprise a bipartite entangled pair. Entanglement (in t_s) will appear 'frozen' in (T_c).

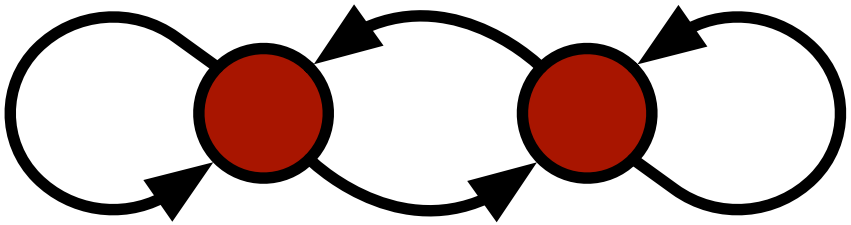


Bipartite Entangled System

Description

- Nature is not only symmetric in subtime at the atomic level, but is capable of reversing itself in perpetuity. *This may account for our failure to explain entanglement based on an immutable causal logic*

- When time (change) happens, we remember; if it happens and then the change is reversed, we don't. Even events that have already decohered in T_c which we might think to be immutable once they have happened can (at least locally) unhappen



- We should expect to see remnants of these reversed "elements of physical reality" as a natural aspect of the (apparently) persistent record we call history. Destructive interference is a state of darkness. ***The photons are indeed there, they are simply bouncing back and forth in subtime, invisible to us and our instruments***

In The News Today

Atomic time lord to battle sneaky high-speed trades *(New Scientist 15 April 2014)*

- "On your wall you will have power, network and time," says the NPL's Leon Lobo. "You just consume it and you know it is correct."
- The NPL's signal will run on high-speed optical fibre that has been leased as part of plans to put atomic clocks on the International Space Station. Time will flow to a data centre in Docklands, the heart of London's finance industry. No other traffic runs over this dedicated fibre, so the NPL can transmit time that is accurate to within a ***microsecond***.
- for the US, it might be too expensive even to build links that run from NIST's atomic clocks in Colorado to the financial hub in New York City. It would make more sense to install a dedicated set of atomic clocks near Wall Street, he says. "That timescale could be the distributing hub for US financial transactions."
- "Recently the FBI confirmed that it is investigating whether high-frequency traders have an unfair advantage over traditional investors. *The obvious solution is to ensure that all financial firms agree on an official time.*"
  - **THE OBVIOUS SOLUTION IS WRONG**
- ***To to do high speed trading, get as close to the source of frequency (the clock standard) as you can. Then you have the lowest uncertainty window. (c.f. Google Spanner)***

Falsifiability

Testable Predictions:

- Atomic clocks will exhibit arbitrary jumps relative to each other (because there is no common background in time, only local manifestations in the quantum interactions)
- We may not be able to extract the hoped for exponential performance improvements in quantum computing
  - Benchmark results on the first 512-qubit machine was published a few weeks ago that showed NO quantum speedup relative to standard desktop computer*
    - A smoking gun, perhaps? Certainly not conclusive — it's far too early to tell

- SPECULATION ALERT : ***This idea has a long way to go to be validated scientifically***
  - However, even if the science proves to be incorrect (or just another equivalent perspective on the measurement problem), the thought process behind it has significant implications for computer science, because unitary evolution (reversible computing) can be ***emulated*** as long as we give up on the idea of preserving distant simultaneity

* *http://www.bbc.co.uk/news/science-environment-25787226 which refers to: http://arxiv.org/abs/1403.4228*

Implications

- Are photons the carrier of time ? ; is the Universe is a network automaton ?
- Entangled systems are dark, i.e., outside of classical time. Entangled systems are unavailable either as emitters or absorbers. Subtime recurrences and their trapped energy/information are unobservable in T_c
- The massive unrealized concurrency under the hood of entangled information/ subtime is reminiscent of the hoped for parallel computation capacity of quantum computing.
- Should we question whether massive concurrency exists in quantum computation, and suggest instead that we have been sampling subtime like a ***stroboscope*** in T_c : ***brief flashes of reality with long periods of darkness in between***
- Is this just another interpretation of the Measurement problem?

Call to Action

- How can we encourage Computer Science as a discipline to take the issues of time seriously?
  - Can we think about security differently?
  - Can we think about heartbeats differently?
  - Can we think about timestamps differently?
  - Can we think about transactions differently?
  - Can we think about concurrency differently?

Questions?

A Short List of References

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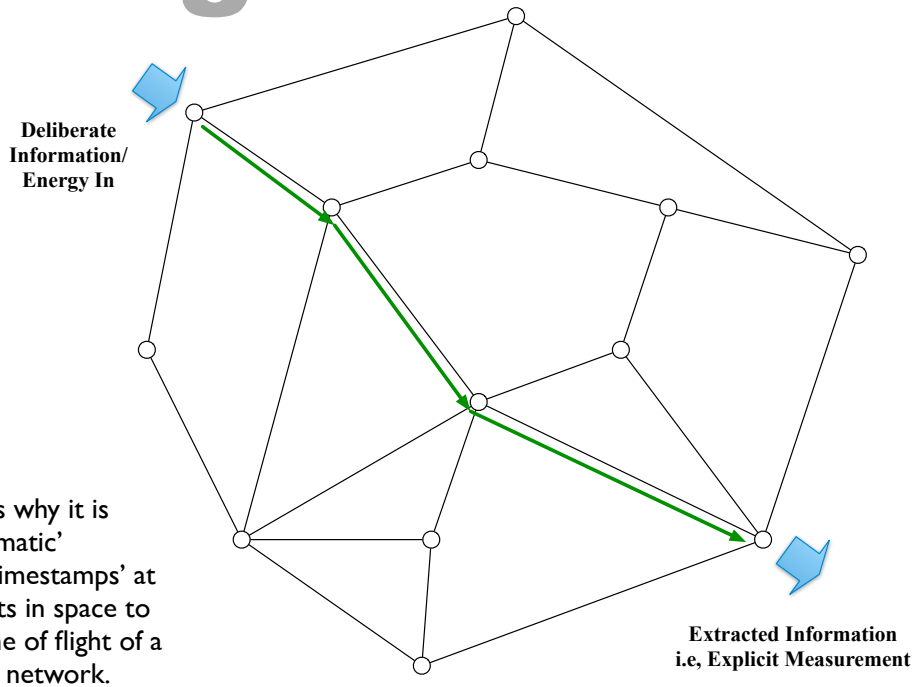
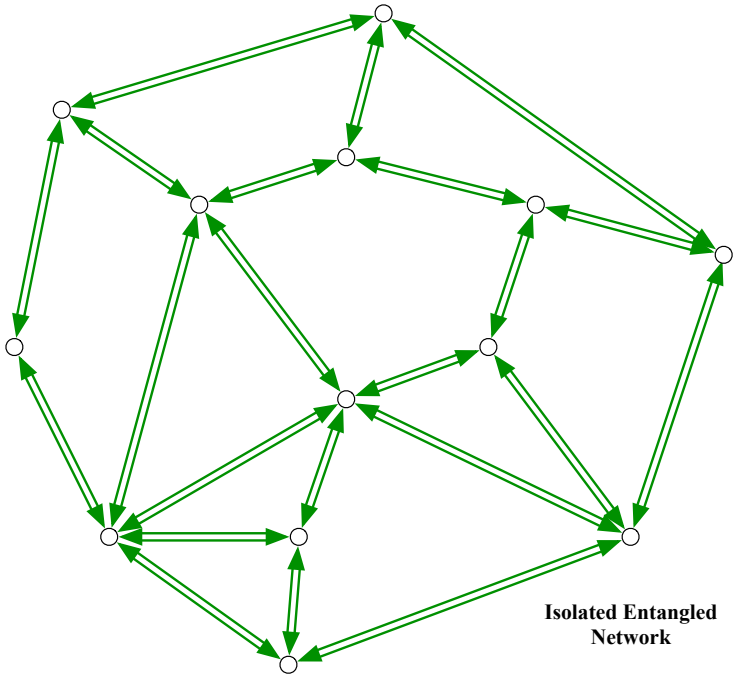
Spare Slides

Entanglement Behavior



Note: this is why it is 'problematic' to depend on 'timestamps' at separated points in space to measure the time of flight of a packet on a network. See discussion on Conventionality of Simultaneity in the next slide.

When we try to measure (Minkowski) Intervals:
Classical Time (Tc) ≐ Subtime (ts)
(Preparation of the measurement stimulates direct energy & information flow)



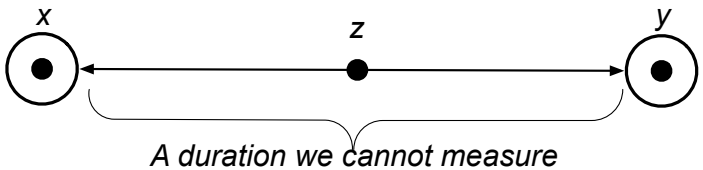
When we are not looking:
Classical Time (Tc) ≠ Subtime (ts)
(Isolaed multipartite entangled system)

Entangled Pair

Simultaneity is a Myth

An Event we can (in principle) measure (departure of a photon)

An Event we can (in principle) measure (arrival of a photon)

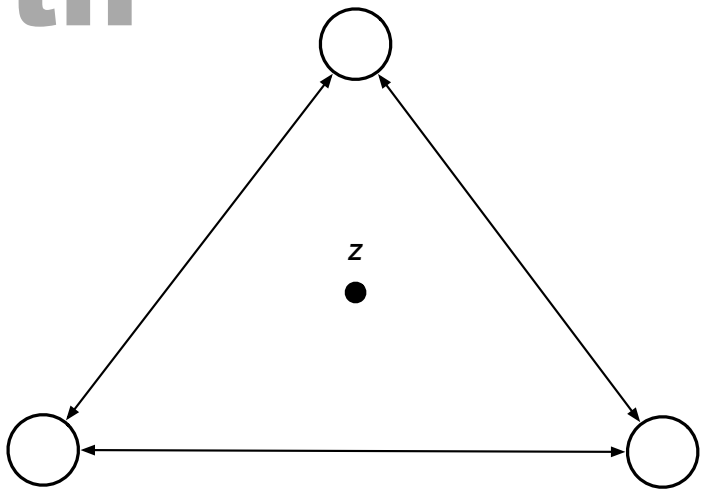


A duration we cannot measure (traversal of a single photon).
*i.e. it is not possible to measure the **one-way** speed of light**

The 'conventionality of simultaneity' : a photon clock

We can: 'by convention' claim that simultaneity is 'defined' at points x, y, or z. But this would be a mistake. There is nothing we can measure at z.

**See: Conventionality of Simultaneity and Reality Vesselin Petkov, and many other references on arXiv.*

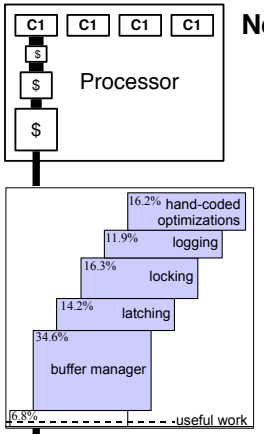


The 'conventionality of simultaneity' : synchronizing three or more entities

*We can: 'by convention' claim that simultaneity is 'defined' any point **z,** anywhere in the 2D plane of three entities. This human created illusion of simultaneity planes is central to the belief in a background of (Minkowski) space-time).*
*TIME (change) is real **only** when interactions occur, and even then, if interactions reverse themselves, reality becomes indistinguishable from them not having occurred at all.*

Concurrency - in the CPU or Network?

Breakthrough Ideas in Networking



Network Virtualization *Decreases* Performance/Scalability & Reliability/Availability

(or why we need direct server to server connections–at least within racks, and maybe between them too)

Performance/Scalability

First problem:
Locking Based Concurrency Control Inhibits Scalability

Figure courtesy: Harizopoulos et. al., "OLTP through the looking glass, and what we found there", Proc.ACM SIGMOD international conference on Management of data, 2008

Second problem:
Excessive Latency in the Network Path

Component	Delay	Round-Trip
Network Switch	10-30μs	100-300μs
Network Interface Card	2.5-32μs	10-128μs
OS Network Stack	15μs	60μs
Speed of Light (in Fiber)	5ns/m	0.6-1.2μs

Table courtesy: Rumble et. al., "Its time for low Latency", Proc 13th Usenix conference on hot topics in Operating Systems, 2011.

Reliability/Availability

Third problem:
Dominant traffic is East-West.
Traffic will soon be in East-West direction instead of the assumed North-South direction due to Network virtualization (SDN) and VM Migration (SDDC)

Gartner: Competitive Landscape: Data Center Ethernet Switches, Worldwide, 2011 Update

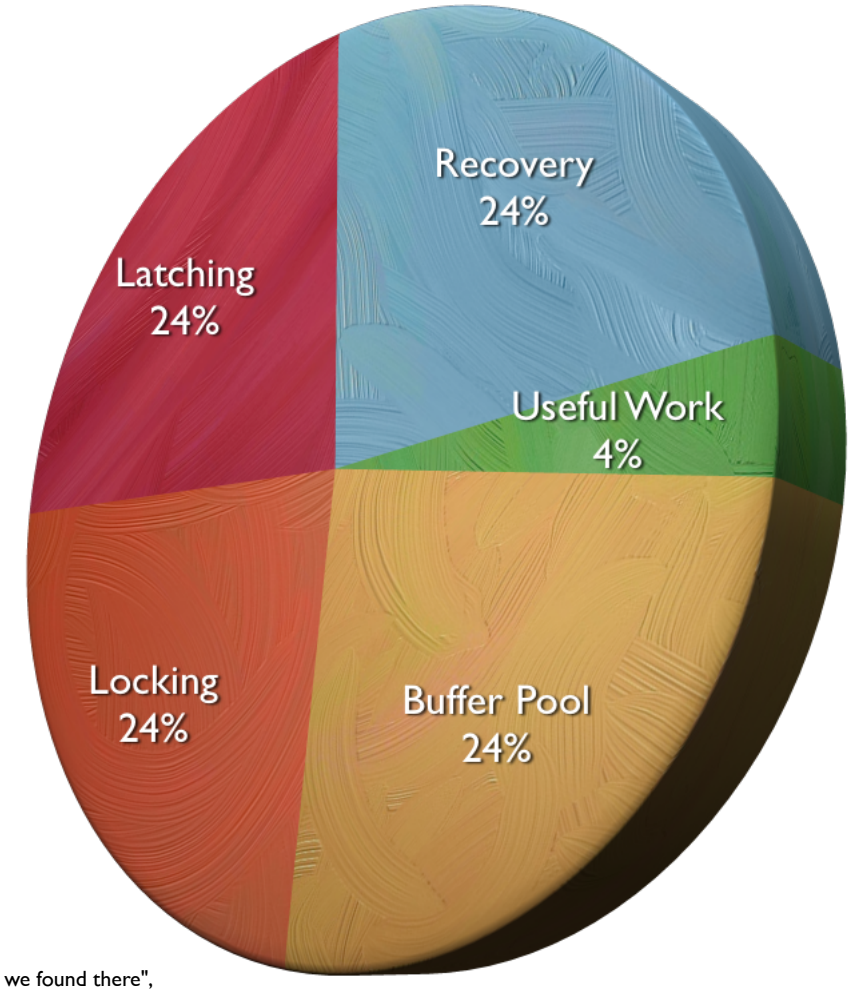
Fourth problem:
Unable to achieve failure domain independence:
severely limits availability. Too many devices in the path for server to server communication.
Reliability issue (Markov Model Calculation)

Networking needs to shed baggage

Wasted Concurrency

- **Latching**
  - In multi-threaded databases, data structures are "latched" during access. *Single-threading improves performance!*
- **Locking**
  - Traditional two-phase locking imposes overhead; access to database structures are governed by a *separate lock manager*
- **Buffer Pool Management**
  - *Main-memory databases* don't need to access pages through a buffer pool; *eliminates level of indirection on record access*
- **Recovery/Logging**
  - Assembling log records for changes slows performance. *Logging not necessary if recoverability provided by other means*

- *96% of CPU Cycles are wasted. Only 4% does useful work.*



* Harizopoulos et. al., "OLTP Through the Looking Glass, and what we found there", Proc. ACM SIGMOD international conference on Management of data, 2008

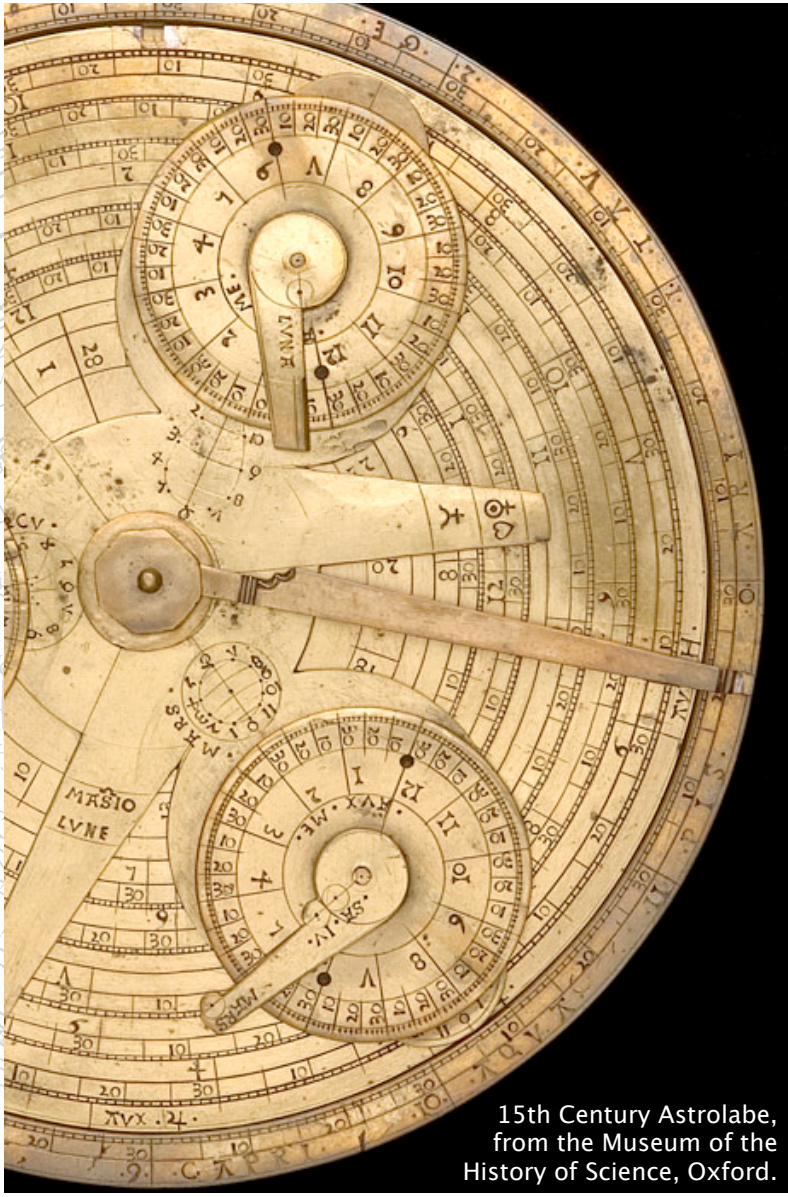
Epicycles?

Epicycles rotated with a period of a Earth year, they were nothing but the shadow of Earth's motion. Other adjustments required still more circles; it took fifty-five circles to get it all to work. By assigning the right periods to each of the big circles, Ptolemy calibrated the model to a remarkable degree of accuracy.

A few centuries later, Islamic astronomers fine-tuned the Ptolemaic model, and in Tycho's time it predicted the positions of the planets, the sun, and moon to an accuracy of 1 part in 1,000—good enough to agree with most of Tycho's observations.

Ptolemy's model was beautiful mathematically, and its success convinced astronomers and theologians for more than a millennium that its premises were correct. And how could they be wrong? After all, the model had been confirmed by observation.*

Then along came Copernicus …



15th Century Astrolabe, from the Museum of the History of Science, Oxford.

*FROM Smolin, Lee. "Time Reborn." Houghton Mifflin Harcourt (2013).

No common reference frame exists in empty spacetime

- Space and (sub)time are inextricably intertwined in Poynting's revolving shaft along the path from transmitter to receiver. We could take Feynman's clocks [QED] literally. Spin being the little hand and orbital angular momentum the big hand. Photons try potential paths in unbounded sequential subtime explorations (t_s), this will appear to occur in parallel in T_c .

- Information is conserved in the photon link between two atoms comprising an entangled system. 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.

- Causality is symmetric . There is no privileged role or direction for the observer-observee 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 (but opposite in sign) for each observer from their vantage point.

- 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 + 1st traversal, i.e., N is fundamentally uncountable.

Decoherence

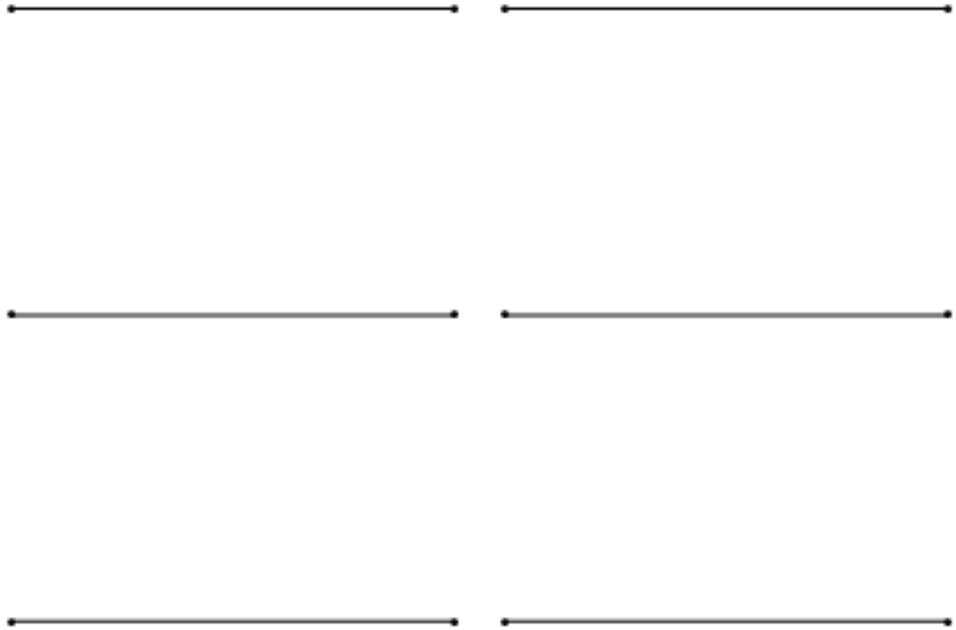
- Decoherence occurs in timescales that are relevant to the speed of our computers and networks. If the Subtime theory is correct, reversibility is happening all the time, and has the potential to repair, or reorder the reception and processing of events that underlie our distributed transactions. This is particularly valuable after a failure, disaster or cyber-attack applications.
- Unitary evolution in either direction will become persistent with selective pressure. I.e. configurations that suit their environment best will tend to persist, while those that do not will devolve back in the opposite direction
- Just as with Evolution, this is *probabilistic*. Each persistent state becomes a foundation for the next. Instead of building a tree of life, it builds a tree of reality.
- This is already understood, and supported by evidence in Quantum Darwinism: the idea that the transition from the quantum to the classical world occurs due to a quantum form of natural selection*
- The theoretical biologist Stuart A. Kauffman proposes, to think of evolutionary dynamics as the exploration in time by the biosphere of what can happen next: the "adjacent possible." The same goes for the evolution of technologies, economies, and societies.

http://phys.org/news192693808.html (Zurek, Ollivier, Poulin, Paz and Blume-Kohout.)

Waves vs particles

Is Subtime Under the Nyquist Hood?

Nature appears ‘random’ because a single quantum observer (emitter, absorber) is much greater than the accident sampling by decoherence with the measurement apparatus



M1: Quantum Stroboscope

- Imagine Discotheque - a stroboscopic light
- Imagine a Quantum (photon version), where an object is not illuminated, unless a photon is *received* from it
- Imagine that entanglement can take place, and that it is beyond our power *within an individual measurement* to discern how many times the photon goes back and forth
- Note: this is different to a conventional (macrosocpic) stroboscope. Every observer will observe something different to every other observer ...
  - This is Relative Quantum Mechanics (RQM)*

* *Carlo Rovelli [ref]*

M2: Quantum Virtual Machine

- Imagine you are a Virtual Machine (the guest type); you have a notion of time that you *believe* you understand
  - *But you can be stopped and started by something external*
  - *What you notice, is "change" (perhaps in your responses to the network time protocol?)*
- What if we (playing Demon over our computers) played games with the set of say *all* the guest VM's:
  - The VM's were started and stopped randomly, they were "on" for a random interval
  - They were off for a random interval

Subtime: What it's not

- NOT Another dimension of time.
  - *If anything, it shrinks time down to a direct 1:1 correspondence with space, in a single "spacetime" dimension*
- NOT A "Time Loophole" theory.
- NOT Quantum Gravity
- NOT Cosmological time
- HAS NOTHING TO DO WITH Planck Scale

SubTime Implications

- If everything were particles. The *illusion of waves* through superposition may be explainable a by leftover "period of new absorption reticence" for photons at the destination, creating the illusion of interference. (Symmetric with the spontaneous emission times for photon excitation of atoms)

- Photons are not isolated particles, but part of a two way continuously related dynamical system between two atoms in SubTime.

- **For the multiple slit experiment:**

  - Did we make a mistake in assuming that we can get "one photon at a time" to go through both slits and therefore interfere with itself?

  - Photons go back and forth in Subtime without regard to direction

  - What if the photon went *back and forth* through the slit(s) not once, but 7 times, or 700 times, or 10^{700} times, making a mockery of what we refer to as a *source* and *destination*?

Notes

- Minkowski space is an illusion. The only thing we can detect is with photons directly, is the emission from one electron (typically bound to an atom) and the absorption by another electron / also typically bound by an atom). The space beyond the emitter (before) and beyond the absorber (after) do not exist. Einstein's SR described photon clocks!
- We contend that the entire temporal reality exists only between these two points, and that it can perpetually reverse, providing an ontology whose time goes back and forth with the experience of "change" by each end of the photon path.
- Time is change, from the perspective of each electron (bound usually to an atom). When change happens, time (information) moves forward, when the change unhappens (e.g. the photon is reflected)
- Simultaneity is relative. Nothing can go faster than the speed of light, even Bell's state measurements do not actually exceed the speed of light; 'our' reality slows down to give the illusion that it might.
- Our problem: measuring the speed of light with a reversible quantum process is problematic. The quantum stroboscope (events on a real line of space) provide an illusion of collapse of a wave function, but this is merely an event—a brief flash of reality with long periods of darkness in between.
- Implications of abandoning Minkowski space include:
  - There will never be an absolute time reference within an entangled system
  - Continuous superposition… is a function of the void not of spacetime. Time is quantized, the void is not,. This, at least, is obvious to our measurement methods.
- 2) The hoped for exponential improvement in quantum computation could be an illusion, in every controlled experiment a classical computer will perform similarly to a quantum computer (with the same algorithm).
- 3) Atomic clocks will not only drift, they will "jump" arbitrarily relative to each other. due to decoherence. Even without the direct due to special (velocity) and general (gravity/acceleration equivalence) relativity we will still be unable to explain their arbitrary jumps, because special and general relativity calculations assume a continuum, and our experience of time through our experiments is discrete, as the photon leaves or arrives on an electron (typically bound to an atom which provides stability to the state).
- Our claim is (a) relativity and locality is Lorentz invariant, and any measurement involving time-correlated events is necessarily flawed (from a basic conceptual aspect) in that we cannot even in principle, measure the (one-way) speed of light in any single measurement.
- We call this the subtime conjecture: the principle that space and time occur together in the flight of a quantum particle, one cannot be distinguished from the other. The speed of light (c) is a constant; a pivot in our equations that provide perfect symmetry.
- The subtime conjecture includes the idea that positive information is associated with he reception of a photon, and negative information is associated with the departure of a photon. A photon reflecting like a hot potato between two atoms will thus exhibit all the properties we have been accustomed to associate with quantum entanglement. We conjecture that this represents local subtime (ts) in a perpetually forward and backward action which is invisible to us in Classical Time (Tc)
- Unlike the classical definition of a Hamiltonian, time cannot go arbitrarily backward or forward on any point on the curve. It can only reverse when encountering an absorbing, entity or reflecting particle, such as an electron (typically bound to an atom) which can restrict the information exchange to reversing at the endpoints only.
- We now proceed to examine the implications of this theory, in the context of computer science
- WARNING: SPECULATION ALERT!!
  - Scientific Theories have a high infant mortality. The subtime conjecture is gathering positive support in the form of experimental evidence, however, it is a long way form being validated as a scientific theory
- WARNING: ENGINEERING EMPIRICISM
  - The following discussion does not depend on the subtime conjecture being correct, (or even equivalent to any other measurement theory)
  - Claim: "Emulating" Quantum processes is independently valuable, and will yield the interesting new results, no matter which interpretation of quantum measurement theory you subscribe to
  - Imagine packets on a network to be equivalent to photons
  - This "optimum" performance does not depend upon any superluminal property of the interaction. It does, however, take full advantage of the rest of 'reality' slowing down in their semi-perpetual states of entanglement in a world of coherent interactions.
  - See: TimeOne PAPER : http://ee380.stanford.edu/Abstracts/140416-TimeOne.pdf