# Information is Protophysical

Douglas J. Matzke
Texas Instruments
Dallas, Texas
matzke@daldd.sc.ti.com

## Abstract:

*Thought experiments led Einstein to discovering that gravity and acceleration were identical, which lead to his famous theory of relativity. Thought experiments can also be used in critical thinking and understanding about the relationship between physics and computation. This paper will discus several computational oriented thought experiments related to spacetime (or gravity) that surfaced during the planning of the PhysComp 92 and PhysComp 94 conferences. Thought provoking questions will be developed from these thought experiments, as well as other questions people asked during this period. These thought experiments and questions will be discussed in light of actual research supporting those issues, and the result will be the view that information laws are topological constraints that precede physical laws and therefore are protophysical.*

## 1.0 Introduction to information and spacetime:

When Dr. Landauer argued that information was physical [1] he turned the concept of information from a mathematical exercise into a physics reality. In principal therefore, information is just another kind of energy or matter (or visa versa). This notion of information does not exactly jive with the information theory view of information being a mathematical measurement for modeling communication systems or the computer engineering and computer architecture ideas that computation is defined as physical spatial (memory in Mbytes) and temporal (CPU in Mips) resources, with the actual energy cost a technological dependent variable.

Computer science has traditionally been concerned with the abstract costs of computation, where as engineers have been concerned with the physical mechanisms and physical costs of computing. As computer technology continues to scale there will be less of a clean separation between the abstract and physical computational layers. Also as computer scientists continue to demand exponentially more computing resources for tough problems, we are faced with the reality of computing resource technology limits looming in the future.

For these reason, many scientists are looking at quantum computing as a solution to providing more computing power than semiconductor scaling alone will provide. In a similar vein, perhaps computational leverage could also be obtained by looking at relativistic notions of space and time and observer frames.

This approach of looking at relativity theory may not seem like the most obvious approach, but much work has been done combining relativity and information theory with quantum mechanics. For example, the black hole work of Schiffer and Bekenstein [2] led to the understanding that black holes are gigantic "bit buckets" with a bit being the intrinsic quantum increase of surface area. Likewise the generalization by Unruh [3] showed that gravitation fields, impact information transfer rates due to gravitationally induced thermal noise. Empty space itself also represents an intrinsic zero point energy potential to support quantum fluctuations, and must therefore also represent intrinsic computational potential since information and energy are related. Even the big bang must have started as a very special entropy state to allow the universe to keep running ever since then towards a thermodynamic oblivion of uniform heat death or big crunch.

Connections between gravity and computation are expected if both deal intrinsically with spacetime and energy. Is it possible to take this kind of thinking to the next step and find some connection between computation and gravity, where computation can be viewed as information dynamics? Hopefully this understanding would also generalize to include the non-standard spacetime metrics obtained by quantum computing leverage.

Most of the unified field theories propose multiple dimensions of space to solve super symmetry constraints [4]. Interestingly, many of the most successful computer science concepts also deal with supporting higher dimensional semantics and mechanisms. For example, virtual memory pointers can be thought of as spatial microcode that allow representation of high dimensional topologies using the zero dimensional topology of virtual memory space. Likewise coding theory, content addressable memories, neural networks, and object oriented programming all deal with efficiently supporting mechanisms for high dimensional semantics. Again, it is no surprise that topology is the essence of gravity as well as information and computation theories.

The major difference between gravitational and computational spacetime is the difference between actual physical spaces and simulated spaces. The most obvious is simulated spaces do not have real energy, or a simulation of a nuclear reactor would destroy the computer and building. Less obvious is that physical spaces have real "time" metrics and isotropy. Isotropy is the ability of a system to behave consistently independent of the axis of observation of movement. High dimensional simulated spaces will demonstrate anisotropic metrics when measured against physical time (vs. virtual time metrics).

With this introduction the rest of the paper will discuss several thought experiments and many thought provoking questions to elicit more understanding about the relationship between computation and spacetime.

## 2.0 Spacetime Thought Experiments

Conventional thinking about exponential algorithms leads to the classical understanding of NP-complete problems known today. If this thinking is put into the context of a physics thought experiment the following description applies. NP-complete problems are those problems that scale exponentially based on the number of elements in the solution. For very large problems, when one limits the amount of spatial resources (defined as the number of computing elements), the time to solve the algorithm takes more time that the predicted life of the universe. This outcome remains a fact independent of technology scaling.

Another more interesting variant of this thought experiment was shared by a person contacted for PhysComp 92. His thought experiment turned this solution on it's side and suggested a time bound solution to the problem. Imagine an answer to a very hard computation problem is desired within a time T. Based on the speed of light, this time limit places an upper bound on the size of the computer based on the distance light can travel during that time. This time bound also determines the number of computing elements that must be used to produce the answer based on the exponential number of subsolutions. Assuming that each computing element has a mass, it is possible to define the total mass of this verysupercomputer. Fitting this mass inside the previous size constraint would result in exceeding the mass density limit for a black hole event horizon. No one will fund this effort.

Spatially bounded solutions to exponential problems appear to have a mathematical interpretation but temporally bounded solutions seem to suggest a very strong physical interpretation. Both of these thought experiments actually have the same physical interpretation, namely that exponentially hard problem solutions do not fit into our physical universe. Leverage obtained by quantum computing is so interesting because it is based on superposition principles, which effectively exists outside of the spacetime of conventional deterministic computers.

The second thought experiment, called the twin paradox, is an early relativity thought experiment regarding time dilation. This thought experiment involves a pair of twins in the space program. The first twin was onboard an advanced space ship and accelerated toward a distant star to a large percentage of the speed of light, then decelerated, turned around, and returned to earth in a similar fashion. The second twin stayed on earth. When the twin returns from his trip he has not aged very much compared to his now much older twin brother who stayed on earth. The inflight twin not only got to see the universe, but effectively aged more slowly as a result of it.

The alternative version of this thought experiment is to use twin computers. The stay at home computer will be working on a problem that will take the length of the trip. The other computer bound for space is also working on the same problem. When the inflight computer returns it is only partially complete and the stay at home twin has solved the problem already. It seems like an advantage for humans to stay younger but for computers remaining young is a disadvantage.

The analysis of the twin computer paradox suggests that the optimal manner for computing an answer is to not go through any large accelerations. This leads to ask the question,

> **"Is there any kind of motion that can accelerate the computation rate of a computer?"**

The answer to this question is to accelerate the rest of the universe away from the stationary computer. If this was done simultaneously for all three dimensional axis then the computer would be more efficient than another computer inside the universe. Of course to accomplish this, the universe would have to move on a higher dimensional axis orthogonal to our normal three dimensions of space. If this motion is completely relative, instinctively we can believe moving relative to the known 3 axis of space may give computational leverage. In other words, higher dimensional computers may be more efficient than lower dimensional computers, especially for mapping higher dimensional applications. This is certainly true in the limit of computer scaling [5].

This thought experiment begs the question regarding higher dimensional spaces, What are the time properties of higher dimensional spaces (most likely without mass since this is a property of 4space)? As demonstrated by time dilation for photons themselves and Bells theorem, it is obvious that higher dimensional systems (outside 4space) are comparatively atemporal. This is expected since our time emerges as a result of consistency constraints from relativity and quantum mechanics.

Just as high dimensional semantics are important to computation, higher dimensions go one step farther beyond simulated spaces by reintroducing isotropy, redefining temporality, and also locality (since they are strongly linked notions). Compared to the energy metrics of 4space, the atemporal and nonlocal notions of higher dimensional spaces appears to be more like an information metric, where every inertial frame and quantum interaction can be viewed as a large system of information constraints.

## 3.0 Thought Provoking Questions

One of the earliest questions asked by a PhysComp colleagues was, “How heavy is a bit?” As a result of Bekenstein's work we can now answer that question as roughly Planck's area worth of energy/matter. The next version of that question is, if a bit is heavy, how many bits does it take to define each the primitive particles of physics?

This question can be approached from a computer science perspective, as if each particle was a token of a message, and the particles defined the symbol set of nature. Unfortunately this abstract solution does not comprehend the complete picture, since these particles are not of equal probability in the message. (Physics experiments can be thought of as information dynamic simulations). Additionally, since information is physical, this approach must comprehend energy dynamics due to fields and also include Bekenstein's work. Lastly, quantum constraints and zero point energy constraints (energy potential of free space) must also be comprehended as information.

This question is supported by the work of Noyes and Kauffman [6] where they start out with the assumption that physics laws are derived from discrete information dynamics. Supersymetry solutions are also topologically oriented and related to knot theory, which has a strong basis from topological constraints. All of these solutions are higher dimensional solutions. John Wheeler understood this relationship between information and gravity [7] and also proposed a pregeometric way of thinking [8]. More work must be done to answer this question.

The quantum probability solutions and higher dimensional solutions beg other questions besides atemporality. Can we have information encoding as topologies without using matter/energy structures? Another way to pose that same question is, What is the information encoding mechanism of quantum probability distributions (and other fields)? or, Can information be encoded directly as topological spacetime without thinking of them as a particle (i.e. graviton)?

These questions are supported by the notion that spin is a property independent of energy properties, but effectively represents an informational oriented property that must be preserved in the face of black holes. Likewise, quantum coherency in EPR is like an acausal constraint, where either part can be influenced and effect the coherent whole. Just labeling new concepts such as Qubits and Ebits is useful, but what does it mean from an information encoding mechanism behind physics constraints? All conservation laws must be built on top of some more primitive consistency mechanisms, that must have topological properties and information dynamics.

Another provoking question is the subtle aspect of simulating real spaces. In order to simulate the dynamics of relativity, a model of an inertial frame must be represented in the computer. In order to generate the relativistic view of other elements and fields, this data representation must contain information regarding velocity, direction, position, etc. to be used in the computation task. But more important, the inertial frame represents information state associated with the observer.

Therefore, if information is physical, then inertial frames must also be physical. Unfortunately, physicists treat inertial frames as pure mathematical abstractions with no physical reality. This is simply proven by the fact that inertial frames can not be acted upon. Another observation is that inertial frames can not actually be used as an inertial frame for photons, as if the frame had some mass associated with it.

This line of thinking is very fundamental, because inertial frames formally define the observer for relativity just as quantum collapse is the observation mechanism for quantum mechanics. Processes (running on CPUs) can be thought of as the observer frame for computation, causing the computation to unfold at decision points. Can all three notions of an observer be combined to make a comprehensive "observer" abstraction that is consistent with information, quantum, and relativity theories.

It is clear that giving equal weight to information mechanics as well as energy mechanics within physics raises very interesting questions. This is very similar to the kind of process that happened initially with particle/wave duality at the beginning of this century. Information/energy duality will most likely be the dominant paradox that must be resolved next. Unified field theories that do not explicitly included computational and informational perspectives will most likely be incomplete.

## 4.0 Conclusions

This paper does not give many answers, but the questions raised about the intrinsic informational properties associated with spacetime, and physical "conservation" constraints supports that universe is a large constraint system. Physical laws must be supported by some information mechanism with topological properties that give rise to isotropy, 4space energy metrics, coherency, nonlocality, atemporality, and acausal characteristics. The exact mathematical solution is unclear at this time, but these thought experiments and questions suggest that unified theories using higher dimensional solutions must have an information metric orientation and not just more of the 4space energy metric thinking. Therefore, information within 4space is physical, but information is protophysical for mechanisms outside our 4space bounded energy metric.

## 5.0 References

[1] Landauer, Rolf. 1992. "Information is Physical." Proceedings of the Workshop on Physics and Computation. IEEE Computer Science Press.

[2] M. Schiffer, 1993, “The interplay between Gravitation and Information Theory”, Proceedings of the Workshop on Physics and Computation, PhysComp 92, IEEE Computer Society Press.

[3] Unruh, W. G. 1976, “Notes on black-hole evaporation”, Phys. Rev. D14, 870

[4] Kaku, Michio. 1994. Hyperspace, A Scientific Odyssey Through Parallel Universes, Time Warps, and the Tenth Dimension. Oxford University Press

[5] Franco Preparata, May 1993, “Horizons of Parallel Computation”, Brown University, Technical Report No. CS-93-20.

[6] L. Kauffman and H. P. Noyes, 1996, “Discrete Physics and the Derivation of the Electromagnetism form the formalism of Quantum Mechanics”, Proc. of the Royal Society **A 452**, pp. 81-95

[7] Wheeler, John. 1989. "It From Bit," Proceedings  3rd International Symposium on Foundations of Quantum Mechanics, Tokyo.

[8] C Misner, K Thorne, J. Wheeler, Gravitation, pp. 1203-1212. W. H. Freeman and Company. New York.