

Time and Information

The Origins of 'Time' from Information Flow In Causal Networks and Complex Systems

By

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The '**problem of time**' can be 'solved' *in principle* by taking the viewpoint that *information* created by unstable physical systems or **Feynman Clocks (FCs)** is transferred by signals to detectors as 'infostates' and then used to *construct* 'time' (**Ref. 1**) with a **T-computer**. This constructed 'time' results from the *computational process* of coupling observed signals to standard clock signals into time labeled infostates in an observers' T-computer. The T-computer model is used to define standard 'time coordinates' for 'events' in space-time maps. The 'direction' and 'dimension' of 'arrows of time' follow from the ordering and properties of the numbers used to label event 'times'.

Introduction

information or energy to act on a state to transform it into a configuration we associate with one we have observed, time labeled, and stored in some sort of memory.

Are the irreversible and reversible changes we observe in the universe around us occurring 'in time' or are they creating 'time'? By treating time as a 'dimension' of space-time we lose some of the information about the systems involved. The loss of information occurs when we reduce complex patterns of 'change' into observables. Time's direction and dimension are generally assumed to have fundamental roles like space in our descriptions and models of the evolving universe. Paradoxically, 'time' is not an observable like energy, position, and momentum. Without 'change' we could not define time. We would be stuck in a circular set of arguments if 'change defines time' and reversibly, 'time defines change'. If we assume that 'change' can occur without 'time' then we can examine how 'time' is created by our observation of 'change'.

This is the essence of the 'problem of time'. One approach to solving this problem is to find a way that 'time' can be 'constructed' or 'derived' from a time-independent framework. 'Time' may be a 'construction' or 'map' made by information processing 'systems' like us and 'mapped' back onto a 'timeless' but changing' universe. We will explore this approach in this paper.

The 'Problem of Time'

The 'problem of time' is more than just what is the nature of 'time'. The real 'problem of time' is that we *believe it is a fundamental property of the universe in the same sense that space is*. We know that 'time' is clearly different from space but yet we force them together into space-time. Space-time is a very useful construction for understanding physics.

Why does there appear to be reversible and irreversible properties associated with systems that change or evolve depending on their scale and degree of complexity? Time is first and foremost a tool for ordering events. It is a number that is computed from information 'read off clocks' and then used to label 'observed' information representing the events in some sort of memory. The computation of time involves the creation of 'time differences' represented by these numbers from clocks.

The key to understanding the fundamental nature of 'time' is that signals form causal relationships between standard clocks and observed events. Unstable systems are the source of signals and the 'information' that we use to construct the 'measure' of change that we call 'time'. In order to construct 'time' as a measure of change for reconfigurations of matter in the universe, the conversion of the energy, spatial (directional) information, and matter carried by signals into the 'time numbers' connected with states of standard clocks, differences between time labels must be computed. This computation process also defines 'arrows of time' pointing between the time labels.

The generalization of a local model of time to cosmological systems such as Quantum Growing Networks (see **Ref. 11**) and other network theories applied to the evolution of the universe may be illuminated by understanding the role of the T-computer at various hierarchical scales. The hierarchy of scales range from trans-Planckian primordial nodes to cosmological expansion to investigations into 'clocking' mechanisms related to microtubule and DNA 'T-computers' in cells scaling hierarchically upward to the sense of 'time' and its role in defining consciousness in terms of the mind's awareness of, or 'attention' to 'change'. In the framework of the approach in this paper, '**attention**' refers to the focused or 'directed' computational activities of a causal network or computer that is processing specific infostates in selected causal network circuits or pathways.

Information: The Source of 'Time'

What do we mean by 'information'? We will use a general definition that encompasses the definitions used in quantum computation and classical information theory. Information is any kind of 'label' attached to a physical state of a system. These labels are abstractions created by processing various forms of signals originating in or scattered off an observable system. The source of information is always found in signals. Signals may take the form of particles, photons, atoms, molecules, electromagnetic waves, images, sound waves, and electrical currents for instance. Signals can carry information specific to their sources such as transition energy changes, direction, motion, and type of source. Some of the information content of signals is found in the collective characteristics of various types of signals from the source. An example of this is the 'spectra' of hydrogen. Each emitted photon tells us about a specific transition or state, but all the different photons forming the 'spectrum' tell us about the complex quantum structure of hydrogen as a 'system' with many possible configuration states or 'infostates'. There are many other examples of collective behaviors representing states of systems that are more than the mere sum of the various separate signals that can be generated by reconfiguration processes in these sources.

First we look at a general conception of the infostate as packets or ensembles of information that 'travel' together as a single object, the infostate. An infostate is an extension of the standard interpretation of the wave function for a system representing all the known information about the state of the system. This includes the standard primary or first order observables such as energy, position, and momentum. It also includes secondary or second order observables such as 'images' (e.g. collective surface information), shape, (geometric configurations), material composition and distribution, internal kinetics and motion, chemical processes, internal 'logic', or information processing activities and algorithms, etc. For a system, \mathbf{S} , the infostate is encoded as a 'qword' with 'qubit' entries or other higher order qwords (expanded infostates with additional information acquired by logic operations at various gates or nodes in the computer) representing the primary and secondary information together but as an infostate 'in' a causal network. For example an infostate may be characterized by $\mathbf{I}(\mathbf{S}_n)$ for a given configuration \mathbf{n} , where $\mathbf{I}(\mathbf{S}_n) = \mathbf{I}((\mathbf{n}, \mathbf{E}, \mathbf{m}, \mathbf{p}), \text{first order terms}, \dots, (\text{second order terms}), \dots, \text{etc.})$. The second order terms result from the observer's addition and expansion via entanglement (direct product) of complex secondary information to the primary infostate originating in the source signals. In other words, the expansion of the qword size by the number of qubits of secondary observables representing the net or collective active infostate in the T-computer or other causal network.

The size (e.g. the number of qubit entries in the infostate qword) and content (e.g. states of the individual qubits in the infostate qword) of infostates can be modified by logic operations on them as they propagate through causal networks. The creation of new information and infostates is consistent with a 'conservation of total information law' for the entire universe (see **Ref. 5**). By this we mean that overall the emergence of new infostates as the result of quantum 'logic' (physical) operations on an active infostate of a node or gate in an information-processing network. Where does this information come from? The creation of new information (the reverse process of 'information loss') may be the result of 'decoherence' processes for unstable systems at the interface (event horizon) of matter with the vacuum. This seems consistent with recent work by Claus Kiefer ('Hawking radiation from decoherence' LANL Archive gr-qc/0110070, 15 Oct 2001) for black holes in which he has found that there is no information loss paradox. If the entanglement entropy of the universe is greater than or equal to the conventional entropy, the vacuum is the logical 'reservoir' for the additional 'information' observed in evolving complex systems. The conversion of the entanglement entropy 'stored' in the non-zero energy density of the vacuum into 'observable' information requires further investigation.

Information is represented by the individual qubit entries forming qwords that describe more than one property of the detected 'signal'. In the context of quantum computation, qubits are localized infostates carrying information such as position, momentum, energy, spin states, polarization states, or any other quantum 'observable'. In order to keep these various qubits 'together' as a qword, physical quantum 'registers' or memories are used to allow parallel transport of the collective qword infostate through causal networks. Causal networks are essentially computers. They may be quantum or classical computers depending on the physical nature of the information and the 'logic gates' involved in processing and storing the infostates. In the information model of time (**Ref. 1**), a process of observed and standard clock signals are paired so that the observed signal can become a 'time labeled' infostate in an ordered set of 'infostates' stored in the 'memories' or registers of the observer.

'Classical' information such as the binary states in semiconductor computers, collective representations of thermodynamic coordinates like temperature and pressures, and Shannon's definition based on entropy, are examples of hierarchical mesoscopic and macroscopic states built from microscopic quantum infostates of the atomic and molecular components acting collectively as a single system. The concept of collective excitations represents a bridge between quantum and classical descriptions of complex systems. Collective excitations or infostates indicate plateaus of complexity (POCs) in complex systems in which new behaviors can emerge. The computation of the 'times' associated with 'events' allows us to construct time ordered sets of events and 'arrows of time'. These secondary information structures or maps can be used to define the causal relationships between infostates (e.g. 'memories').

‘Computing’ Time from Information

If time is a number that is computed from information, how is it created and how is it realized as information that can be used by the observer to give a time coordinate to an event? Time can be thought of as a form of *information* about causal relationships of events constructed from signals originating in an observed system. These constructions are sequentially ordered 'maps' that are built from sets of events as the result of the computation and application of 'time labels' to the information states produced in the observer or his/her 'equipment'. The 'computation' process for generating these labels uses signals from a *standard clock* paired with the signals from observed events. This allows us to define the cause and effect relationships between the events in our environments.

In general, the *observed system* (the source of ‘signals’) is a kind of ‘clock’ called a **Feynman Clock** or **FC** (see **Refs. 1, 3, 4**). A Feynman Clock is any unstable quantum system that decays into another state or configuration of the system or into sets of ‘decay products’ such as those created in high-energy particle collisions.

The motivation for this ‘time’ theory follows from the use of Feynman Diagrams in particle physics. ‘*Time reversibility*’ or time symmetry is usually taken for granted at the microscopic scale where Feynman Diagrams are useful. The process reversal of particle interactions is not the same as time reversal since it is the transient excited state of the composite system of incoming particles that decays irreversibly whether or not the incoming particles are exchanged for the outgoing ones and vice versa. The ‘recreation’ of an unstable state of a system is not the same as going ‘back in time’. Since time is created by reconfigurations of unstable systems, the direction of ‘time’ can only be defined by the direction of ‘*information flow*’ or ‘**infostate**’ propagation from sources, via signals, to the detectors and ‘logic’ gates (or nodes) forming ‘*causal networks*’. At the quantum scale, causal networks can be thought of as generalized quantum computers capable of processing a wide spectrum of signals and their energies (e.g. electronic interactions with photons in many-electron atoms) expanding the computing capabilities of matter beyond binary state (e.g. 0’s and 1’s).

Any system in an unstable state, processes incoming information into outgoing information upon its decay, decoherence or reconfiguration. The apparent ‘time reversibility’ of fundamental interactions is due to intervention upon the system putting it into a state that the observer considers the same as some ‘past’ state by comparison of the configuration of this ‘process restoration of some reference state. This requires information in the form of a signal that can be detected by the system and converted into a ‘new’ configuration similar to a ‘past’ one with respect to the observers’ clock.

The theory of time as ‘information’ is *general* and *compatible* with all current established physical theories. It can be applied to any physical system or theoretical model including *second order constructions* of time whose ‘dimensions’ or ‘directions’ use *complex numbers* or *multidimensional* time ‘coordinates’.

Any complex network of physical objects that involves signal generation, signal detection and subsequent ‘processing’ of induced **infostates** in the gates, nodes or devices forming the network, can be understood within the context of this theory. This includes examples such as the particle accelerator systems involved in observations of subatomic particle collisions, complex information processing systems such as optical image formation by eyes and subsequent image processing by brains in living beings.

The **infostate** contains all relevant ‘observable’ information for the system. You can think of this infostate as a sort of ‘word’, in the computational sense, in which each of the ‘n’ entries or bits (qubits etc.) form an ‘n’-tuple. One may use some or all of the information bits or qubits etc. in an infostate for a given purpose or operation. These entries would include information in the conventional sense such as energy, momentum, wavelength, etc. and in a broader sense; ‘images’, material composition, internal logic operations or physical transitions, etc. There may be a conservation of information ‘law’ concerning the abstract ‘magnitudes’ of infostates with respect to the entire universe (see **Ref. 5**), but the infostate paradigm suggested in this paper is applicable regardless of global information creation or loss (e.g. black holes as logic gates).

Feynman Clocks, Signals, and Detectors in Causal Networks

Unstable systems or Feynman Clocks (FCs) create Signals carrying ‘Information’ away from the source to other clock or detector systems in the process of reconfiguration (or decay) to more stable states. Systems of permanent or transient sets of FCs and the signals between them, form causal networks which are the basis for the computation and subsequent creation of the direction and dimension of ‘time’.

The ‘time’ differences associated with the reconfiguration of a system are computed using initial and final state signals. A complex system may have many overlapping reconfiguration processes at work with different ‘lifetimes’ for each one. ‘Time’ can be thought of as the state information representing the configuration ‘differences’ between states of the observed system as labeled by the signals from a standard clock. The process of pairing observed signals with standard clock signals allows the computation of ‘elapsed time’, ‘lifetimes’, and relativistic time contraction and dilation effects. The ordering of these ‘time labeled’ events with respect to the set of real numbers provides the basis for the direction and dimension of ‘arrows of time’ at all levels of complexity.

From Feynman Diagrams to Feynman Clocks

We begin with the example of the conversion of a Feynman Diagram (see **Ref. 6, 7**) of a fundamental interaction into a generalized model I call the Feynman Clock. For example, the strong force or interaction involved in the

scattering of an incoming proton and neutron is mediated by a π -meson with an approximate maximum nucleon separation distance $d_{FC} = 1.5 \times 10^{-15} \text{ m}$ or the approximate ‘range’ of the *strong force* (Figure 1).

Using the Uncertainty Principle, we see that a π -meson can come into existence by violating energy conservation by an amount of energy given by the following relation:

$$\Delta E = (m_{\pi\text{-meson}})c^2$$

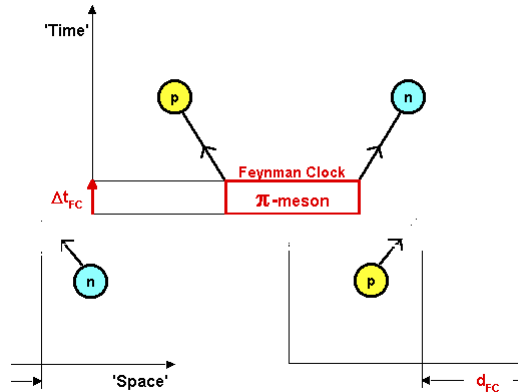


Figure 1. A Feynman Diagram representation of proton-neutron scattering.

The *box* in the space-time diagram below represents the transient Feynman Clock (FC). The *space-time ‘size’ of the Feynman Clock* is ($d_{FC} \times \Delta t_{FC}$) or about $7.5 \times 10^{-39} \text{ m} \times \text{sec}$. Where $\Delta t_{FC} = 5 \times 10^{-24} \text{ s}$ is the ‘lifetime’ of the Feynman Clock. This is also π -meson signal ‘transit time’ mediating the strong interaction and causing the reconfiguration or decay is accompanied by the production of two signals in the form of new proton and neutron trajectories. Now we make an intermediate step towards the causal network representation of a Feynman Clock ‘node’ or ‘gate’ component by observing that the ‘information flow’ through the target space can be viewed as a time-independent map in an ‘info-space’ diagram illustrated in Figure 2.

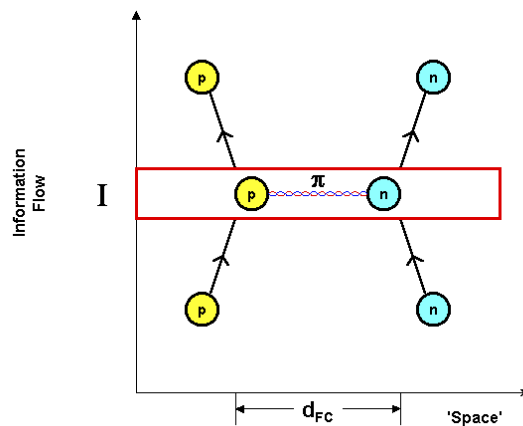


Figure 2. This illustrates a proton and neutron scattering interaction creating a transient π -meson Feynman Clock (box) with a composite infostate, ‘I’, in ‘info-space’.

The ‘info-flow’ diagram for the proton-neutron creation of a Feynman Clock above can now be represented by a causal network’ diagram in which the nodes are Feynman Clocks. Sets of these Nodes and the sets of signals connecting them form the Causal Networks (‘wiring’) that maintain ‘order’ in complex systems. (Authors note: *The ground state or ‘signal detection’ states of a Feynman Clock may be referred to as the ‘detector’ mode of a FC or as a ‘Feynman Detector’*). All systems capable of detecting incoming signals, processing them, and producing outgoing signals represent the general form of a Feynman Clock. The causal network node representation of the above space-time and ‘info-space’ diagrams is illustrated in Figure 3.

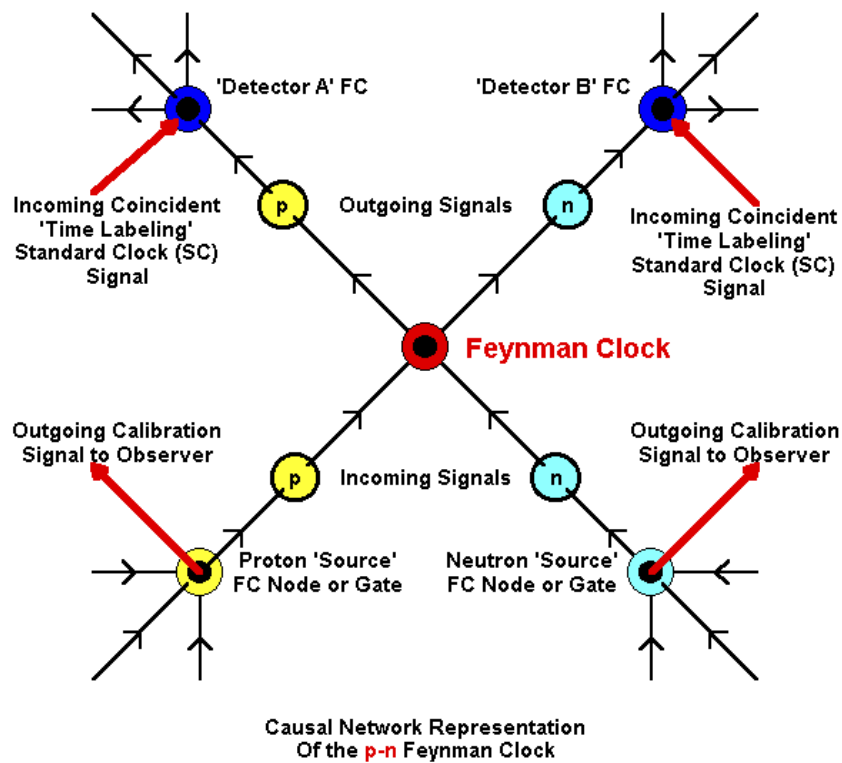


Figure 3. This figure is a causal network node ‘map’ of the interaction of ‘incoming’ proton and neutron ‘signals’. They ‘collide’ to create a transient Feynman Clock (the ‘force’ mediating π -meson is ‘inside’ the FC). The FC ‘computed’ (via conservation of momentum ‘logic’ of the transient FC) outgoing signals follow new trajectories in space (vacuum). The trajectories represent information flow in space. The calibration signals locate and identify the particle signals and therefore the ‘implied’ FC reaction site in space. These signals are sued by the T-computer to time label the calibration signal event representing the spatial location of particles in the transient causal network. The ‘directions’ of the calibration signals in this figure are meant only to illustrate the ideas and have no special orientation in space with respect to the particles under observation. Note that the incoming calibration signals at the lower part of the figure are not shown for simplicity. The time calibration signals at the detectors may be part of a pulse train of signals from a cyclical standard clock. This standard clock may also be coupled to the position detectors that process the outgoing calibration signals of the incoming proton and neutron.

Why invent the ‘T’ Computer model? The T-computer creates ‘time’ labels and causal and temporal relationship between events and computes the ‘time’ that we use in everyday life. It also allows us a chance to see how ‘time’ can be constructed from a ‘timeless’ space in which things evolve. Time is a ‘construction’ derived from the applications of logic, ordered sets, and standard clocks that allow us to locate events in spatial and temporal maps. These maps are the source for the ‘dimension’ and ‘direction’ for ‘arrows of time’. Transient, permanent, and adaptive wiring of network circuitry can occur in sets of logic gates, signals, shift-register-clocks, and memories and clocks can drive information flow or chart its progress.

The T-computer: a ‘Solution’ to the ‘Problem of Time’

In order to ‘solve’ the *problem of time* we must see how ‘time’ is computed in this model. It would be interesting to see how the direction and dimension of time are also computed. The basic computation of a ‘lifetime’ or ‘elapsed time’ involves a physical information processing system I call the ‘T’ Computer. This could be the observation of the creation of a Higgs particle in a very complex and very large accelerator acting as a macroscopic quantum ‘T’ computer or the detection of an ancient photon from a distant galaxy by the rods or cones in the retina of your eye. All ‘T’ computations involve pairing signals from two or more events with co-incident (with respect to the observer) standard clock signals (from atomic clocks to the heartbeat). They also require some sort of ‘logic’ that can compute differences in the ‘time labels’ assigned to the information states representing the ‘observed events’. This is how ‘time’ is created as a ‘secondary map’ (e.g. events in space-time representations) of change in an evolving universe. This concept can be seen in complex biological computations of time perhaps in microtubule quantum computer

components of the neurons forming the increasing complexity of the hierarchically scaled ‘classical’ computers of mesoscopic and macroscopic neural networks in the brain. The computation of ‘time’ via quantum and classical T-computers is essential for the existence of consciousness as a measure of our interaction with our environment. Some of the tools of quantum computation (see **Refs. 8, 9, 10**) have been adapted to illustrate this approach.

T-Computer Principles

The progression of information transfer through the network is mapped by the position of the infostate representing the coupling of the original coincident signals and subsequent ‘processed’ or computed infostates as they are operated on by sequential ‘gates’ in the network. This information propagates through the T-computer from the Feynman and Standard clock sources to a time labeled memory. The final calculation of the ‘time difference’, $\Delta t = t_2 - t_1$, between any two observed events or infostates stored in two different memory locations requires physical ‘logic’ that can find the ‘difference’ between the time labels associated with the stored event information. In the following equations the n^{th} composite state, \mathbf{S}_n , is listed for the entire T-computer acting as a single quantum system (see **Figures 4 and 5**). This state represents a given configuration for the entire system focusing on the ‘active’ infostate in the causal network. In the following, $|\mathbf{Network}\rangle$, refers to the ‘inactive’ *collective* state of the network components not involved with the location of the ‘active’ infostate.

The sequence of *information flow* through a causal network (e.g. T-computer) is tracked by ‘active’ or ‘excited’ (e.g. $|\mathbf{FC}^*\rangle$) infostate representing the spatial location in the network of all the relevant information corresponding to the observed event. The non-active states of the remaining components in the network are summed in the $|\mathbf{Network}^0\rangle$ term. The n^{th} (computational) state of the entire T-computer system is $|\mathbf{S}_n\rangle$. This corresponds to the infostate at a physical gate location in the causal network.

We will assume that the initial configuration of the composite system is given by $|\mathbf{S}_n\rangle = |\mathbf{S}_0\rangle$, for $n = 0$. The standard clock and the ‘observed’ system provide the information (signals) to the T-computer detectors through open space or by closed ‘circuits’ or ‘guides’.

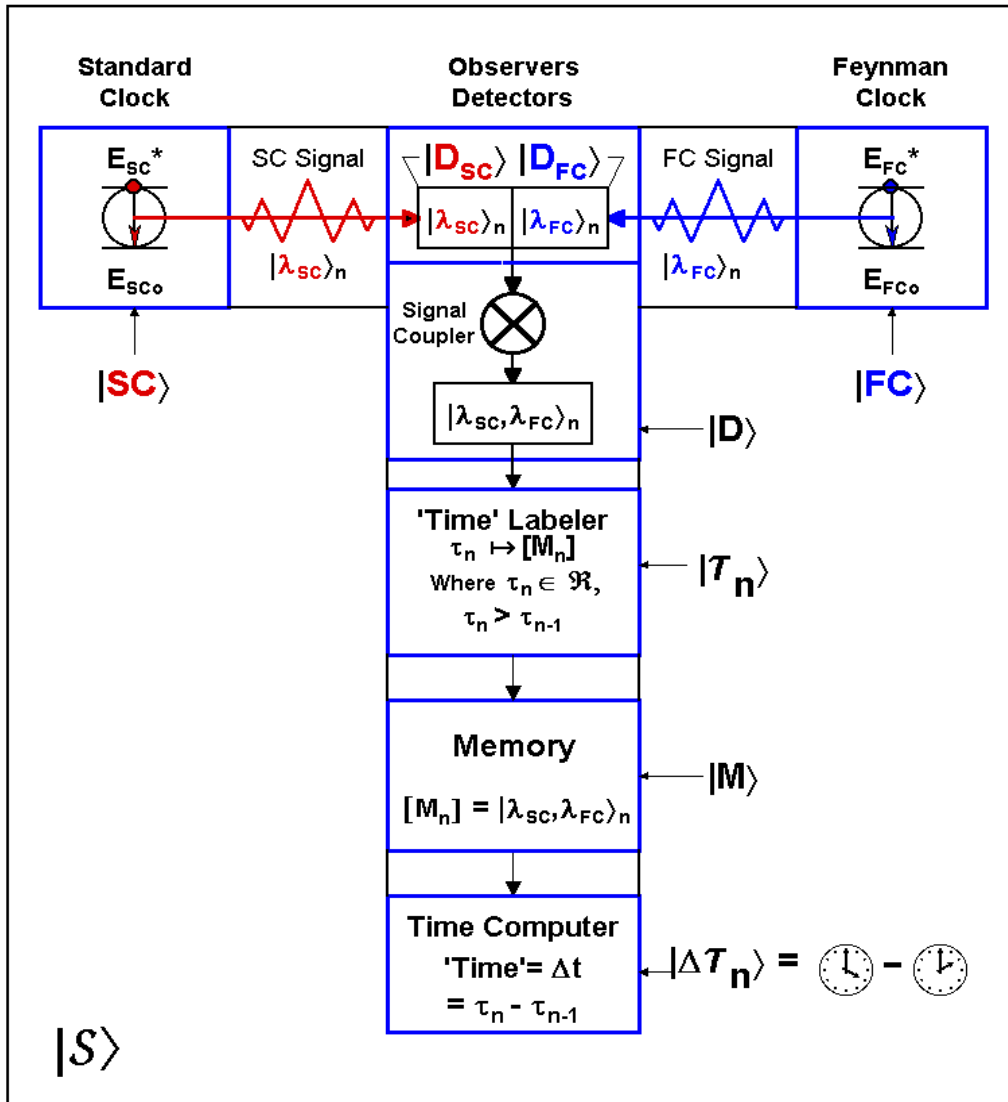
We want to remember that we *implicitly* use *another distinct T-computer* when we assign a ‘start time’ for the flow of information through any causal network or T-computer. Since the point here is that ‘time’ is a bit or qubit of information generated by the T-computer, the *start* and *stop times* can be ignored. We will also ignore any ‘decoherence’ effects on the infostate through its’ interaction with the environment (e.g. vacuum) since the decay ‘lifetime’ of a system due to this coupling is already included in the system start and stop signals processed by the observer. The network will be considered to be robust enough to withstand decay of the local infostate in the active gate or node in the network.

The Flow and Contents of ‘Infostates’ in the T-computer

The equations below are intended to illustrate the general features of the T-computer. The details of the physical ‘logic’ gates and nodes forming a T-computer and the appropriate equations describing them are currently being investigated by the author and will be published at a later date.

We assume that we have an initial configuration of the entire **quantum system**¹ involving the signal sources, however extended or remote in space, and the causal network forming the T-computer given by the **superposition (sum)** of all the **infostates of the components** in the extended system. These are represented by the collective state of the system, $|\mathbf{S}_0\rangle$, defining a reference ‘start’ state of the T-computer where the state index is $n = 0$. The following equations represent the state of the entire system in which the ‘active’ signals, nodes or gates are identified separately from the remainder of the ‘inactive’ components of the network. This allows us to see how the ‘infostate’ is created and propagates through the network. We can see how it changes (‘expands’ with additional qubits into larger qwords or is ‘reduced’ to the selected information needed for a time computation) as it is acted upon by the ‘logic’ of the network.

¹ The causal network forming the T-computer is a ‘quantum’ system. ‘Classical properties’ of a network are the result of mesoscopic or macroscopic collective excitations or behaviors resulting from the composite collective interactions of the quantum sub-systems or sub-networks. The distinction between quantum and classical scale phenomena is mainly a matter of the observers’ choice of what is to be observed. For example, one could measure the ‘classical’ temperature of a gas cell (a ‘thermodynamic’ infostate) or the optical scattering of individual ‘quantum’ photons by the particles in that same gas cell (quantum causal network infostates). The total system is neither quantum or classical alone, but a system with both quantum and classical infostates at various hierarchical levels of complexity.



'T' Computer

Figure 4. Schematic diagram of a simple idealized T-computer. The functions of the logic ‘gates’ or nodes and the signals flowing between them represent a general model of the computation of ‘time differences’ between events in a ‘time-independent’ information space of ‘infostates’, $I(S)$, and the system or causal network forming the time labeling computer is in state $|S\rangle$. This state is the collective ‘infostate’ of the entire network forming the T-computer including the active and inactive components of the relevant computational network. The intent of modeling a T-computer is to show two things. The first point is that ‘time’ is a computational artifact of a signal mapping process that defines ‘time’ as function of the coincidence a clock signal with an event signal. The second point is that the T-computer is a component or sub-network of more complex information processing systems. The T-computer is essentially a quantum computer with classical ‘time’ as an output. The principles in the signal mapping process also apply for larger scale systems that can be treated by classical methods. The key is that all the information used to define time at the macroscopic scale is traceable backwards to the origin of information in the microscopic ‘quantum’ world.

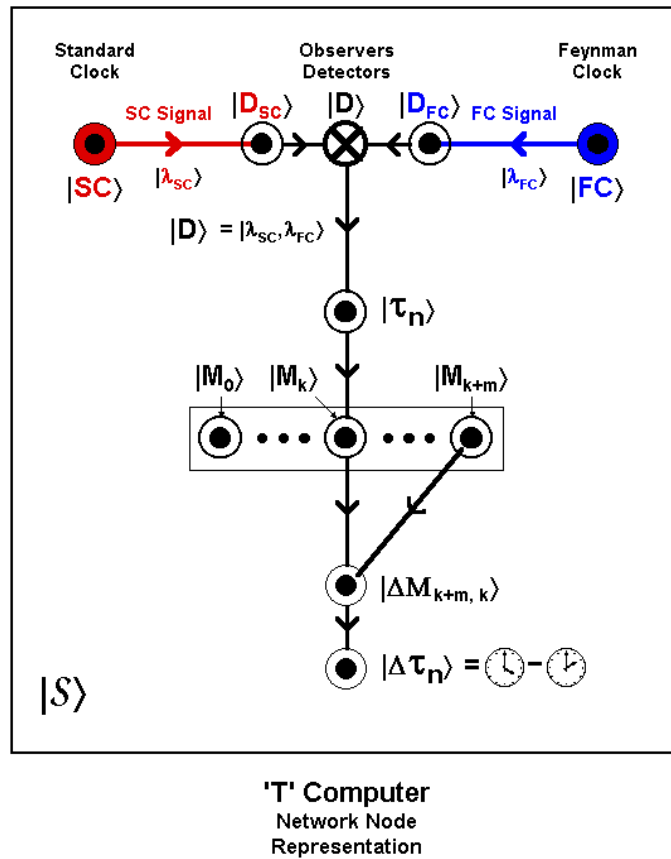


Figure 5. This is a network node representation of the T-computer where the flow of information between nodes and the infostates of the node are indicated. The nodes are the logic gates of causal networks through which information is transferred, modified and created as a result of the interactions of signals with detectors and the signal processing logic of physical systems such as atoms.

The **active** components (e.g. signals, ‘nodes’ or ‘gates’) of the T-computer system (i.e. the ‘current’ location of relevant information from the ‘observed and time labeled’ expanded infostate including additional qubits form any extra information created by processing or logic activities on the incoming infostate) and the remainder ‘inactive’ network for the start state is given by states in Dirac notation².

We begin with the initial state of the T-computer:

$$\boxed{S_0} \quad |FC^*\rangle + |D\rangle + |SC^*\rangle + |\text{Network}_0\rangle .$$

The active (excited) states of the FC and SC are *direct product* states of their respective ‘ground’ states and the ‘potential’ outgoing signal. They are initially entangled until full decay at which point they become a ‘distinct’ linear superposition of quantum systems. When the source and its signal become ‘measurably distinct’ we can consider them to be ‘classically’ separated. This ‘separation’ is represented as a **sum (+)** rather than the **direct product (⊗)**³.

² We note that the Dirac notation lends itself to an oversimplified ‘compact’ representation of the state of a system considered to have a *distinct quantum identity*. We neglect the interactions of components of the system with each other or the environment if they are not ‘active’. ‘Active’ components are defined by the ‘**attention**’ **interaction** of the observer with the T-computer. This interaction is the result of an ongoing coupling or feedback between the information source, a standard clock and the observer.

³ The **superposition** of the quantum states or the quantum components of an ensemble system represents a system that does not support or generate collective excitations as the result of a ‘condensate’ state. The condensate state of an n-body system that generates or supports collective excitations is the result of the coupling of all the components in such a way that they are more than a superposition. The expression of this collective or entangled condensate is the **direct product** of the system states whose whole is clearly more than the sum (superposition) of the parts.

$$\boxed{\text{S}_1} \quad (| \text{FC}^* \rangle \rightarrow | \text{FC}_0 \rangle \otimes | \lambda_{\text{FC}} \rangle) + | \text{D} \rangle + (| \text{SC}^* \rangle \rightarrow | \text{SC}_0 \rangle \otimes | \lambda_{\text{SC}} \rangle) + | \text{Network}_1 \rangle .$$

The decay rates of the FC and the SC may be different. We will assume that the detector will ‘hold’ the FC infostate until the next available signal arrives from the standard clock. When both signals are detected they are converted into a 2-qubit infostate.

$$\boxed{\text{S}_2} \quad (| \text{FC}_0 \rangle \otimes | \lambda_{\text{FC}} \rangle \rightarrow | \text{FC}_0 \rangle + | \lambda_{\text{FC}} \rangle) + | \text{D} \rangle \\ + (| \text{SC}_0 \rangle \otimes | \lambda_{\text{SC}} \rangle \rightarrow | \text{SC}_0 \rangle + | \lambda_{\text{SC}} \rangle) + | \text{Network}_2 \rangle .$$

The collective state of the total system is one in which the ‘signals’ are in transit to the detector while the rest of the network is in its ‘ground’ or signal detection ‘ready’ configuration. Once the ‘classical’ or spatially distinct signals become close enough to their targets to become superimposed and then entangled with the detectors, their identity as quantum signals traveling ‘classically’ through space is destroyed. They are now coupled to the detectors as indicated by the direct product of the infostates of the active front-end components of the T-computer.

The ‘inactive’ components of the network including the FC source and the SC ‘time pulse generator’ are lumped into the superimposed subset of the systems causal network as represent in the last term below. The 2-channel detector is now in a collective excitation state in which two q-words (or qubits) are stored in parallel quantum registers.

$$\boxed{\text{S}_3} \quad (| \text{D} \rangle + | \lambda_{\text{FC}} \rangle + | \lambda_{\text{SC}} \rangle \rightarrow | \text{D} \rangle \otimes | \lambda_{\text{FC}} \rangle \otimes | \lambda_{\text{SC}} \rangle) \\ + (| \text{FC}_0 \rangle + | \text{SC}_0 \rangle + | \text{Network}_2 \rangle \equiv | \text{Network}_3 \rangle) .$$

The composite infostate of the detector is an expanded ‘q-word’ with two q-words concatenated into a larger q-sentence. The q-sentence infostate can now be propagated along the network for used as a ‘time stamp’ for the ‘event’ originating in the FC and labeled by the SC.

$$\boxed{\text{S}_4} \quad (| \text{D} \rangle \otimes | \lambda_{\text{FC}} \rangle \otimes | \lambda_{\text{SC}} \rangle = | \text{D}^* \rangle) + | \text{Network}_4 \rangle .$$

The detector infostate is now given a ‘label’ that will be used later to compute the ‘elapsed time’ between events in memory or the coordinate ‘time’ used in standard space-time.

$$\boxed{\text{S}_5} \quad (| \text{D}^* \rangle \otimes | \tau_n \rangle = | \text{M}_{k,t_k} \rangle + | \text{D} \rangle) + | \text{Network}_4 \rangle \\ = | \text{M}_{k,t_k} \rangle + (| \text{D} \rangle + | \text{Network}_4 \rangle \rightarrow | \text{Network}_5 \rangle) \\ = | \text{M}_{k,t_k} \rangle + | \text{Network}_5 \rangle .$$

At this point a signal from another memory location carrying the ‘time label’ information is shifted into the comparator.

$$\boxed{\text{S}_6} \quad (| \text{M}_{k+m,t_{k+m}} \rangle + | \text{M}_{k,t_k} \rangle) + | \text{Network}_6 \rangle .$$

The ‘time labels’ are qubits in the n-bit word representing the infostates for the processed information from the source and standard clock ‘events’ stored in the various addressable memory locations.

$$\boxed{\text{S}_7} \quad (| \text{M}_{k+m,t_{k+m}} \rangle \otimes | \text{M}_{k,t_k} \rangle) + | \text{Network}_7 \rangle .$$

The interaction of the infostates from the two memory locations takes place in a logic gate that compares the ‘time’ qubits via a ‘subtraction’ operation. This follows from the same kind of logic used in conventional computers that address specific bits needed for a logic operation involved with finding time differences for time labeled events.

$$\boxed{\text{S}_8} \quad (| \text{M}_{k+m,t_{k+m}} \rangle \otimes | \text{M}_{k,t_k} \rangle = | \Delta t_{k+m,k} = t_{k+m} - t_k \rangle = | \Delta \tau_n \rangle) + | \text{Network}_8 \rangle .$$

The processing of the time labels for infostates corresponding to two events results in a ‘time’ infostate whose information ‘content’ is the difference between the labels. We are assuming that real numbers are used here, but complex numbers or any other set of number-like labels may work as long as the physical states of the register in which the computed ‘time’ can be translated into other higher order languages that ‘interpret’ causal relationships between events.

$$\boxed{\text{S}_9} \quad | \Delta \tau_n \rangle + | \text{Network}_9 \rangle .$$

The information encoded in the difference between two time labels for two events is extracted by logic that can evaluate the absolute value of the difference between the two event ‘times’ resulting typically in a real number. *These time label numbers may be physical states such as the number and polarity of charges, analog voltages, discrete binary sets of voltages, polarization states, or spin states. The numerical difference between two time labels corresponds to the physical difference between their physical states in the tubit location of the infostate qword.* The

physical comparison of two states by the logic of the gate in the T-computer results in the following creation of another physical state in a register that can be translated into a number by higher order information processing:

$$S_{10} \quad |$$

high energy accelerators, astronomical observations of intensity and spectral variations in stars, and determination of the expansion rate of the universe to name only a few. Time labeling in biological systems is essential for survival. Responding to the motion and activities of predators and prey of all size scales requires an ability to predict future movements based on those just observed. At a primitive level this means time ordering sensory data in order to respond to changes in the animals environment. We see the interface of instrument and biological T-computers in the medical monitoring of heart and brain activity. A simple but nearly universal example of a biological T-computer system is the eye, the optic nerves, and the time labeling neurological activities in the visual information processing regions of the brain.

Another possible application of the T-computer concept is in cosmology and the structure of the early universe. An approach being explored by *Paola A. Zizzi* looks at the universe as a Quantum Growing Network (**Ref. 11**). The application of network concepts to evolutionary processes from primordial configurations of the early universe to activities in the brain will include hierarchical versions of T-computers wherever change occurs and is ‘observed’ relative to other systems such as ‘clocks’.

T-Computers and Consciousness

In biological systems T-computers are resident in various hierarchical components ranging from individual cells to organs and the neural networks that form the brain. The exact physical structure is beyond the scope of this paper. We can point out one possible example of a quantum scale T-computer that may be a key element in the large-scale ‘collective excitations’ of neural networks that we call ‘consciousness’. These are the microtubules (**Ref. 12**). The primary function of microtubules in neurons may be as T-computers that coordinate the processing of sensory information by the brain. This would give us the ‘sense of time’ necessary for consciousness. In the laboratory, T-computers exist as an integral part of the instrumentation apparatus we invent to extend our sensory range and therefore our conscious perceptions of the world.

T-computers take on a subjective nature since they may be specific to a given system whose ‘rate of change’ is different from other systems. This subjective or individual nature of time labeling events leads us to examination of the *conscious experience* of *speeding up* or *slowing down* of ‘time’. The T-computer ‘clock rate’ in biological systems can vary because of the action of various neurotransmitters that slow down or speed up the information processing ‘speeds’ of our neural networks. The subjective experiences of *time dilation* or *time contraction* may be due to variations in sensory signal sampling rates as well. These rates are a measure of ‘attention’. Attention in this context refers to a variable control of the incoming signal sampling and processing rates.

The rate at which we sample our sense data is compared to our subjective sense of time. This ‘sense’ of the *differences* between each distinct thought in a sequence or flow of consciousness feels ‘constant’. We are unaware of the non-thought ‘time’ width between thoughts. The decay lifetimes of each successive thought may become longer but also the ‘downtime’ in between can be longer with respect to an external standard clock.

This prejudice that the external world is speeding up or slowing down, lies in our belief that our internal reference clock is operating in the same way that an atomic clock does. Our experience of these time effects by our consciousness may be due changes in the information processing rates of our neurons. The rate changes are probably not internal to the neuron but result from the chemical messenger molecules or the physical action of photons and macroscopic electromagnetic potentials on neurotransmitter production and subsequent recovery cycles in synapses. The modification of a T-computers labeling rates and higher order neural states is similar to changing the ‘clock rate’ on digital computers. Consciousness may mislead our sense of the *rate of* ‘flow of time’ since our belief is that our internal clock generates its time labels in a regular and repeatable intervals with respect to external time reference systems like atomic clocks.

In **Figure 6** we see how a **subjective sense of ‘time’** or temporal **‘attention’** to external events is related to information flow from the observers’ environment in the form of light pulse signals from a fixed frequency standard (e.g. atomic) clock driven source. The square wave pattern illustrates a sort of on (‘1’, ‘tick’) and off (‘0’, ‘tock’) state of consciousness in a stream of collective excitation states. The ‘width’ of these states corresponds to the observer’s ‘attention’ or information processing cycle. While the brain may act asynchronously, when ‘attention’ is *given to incoming data* such as the light pulses from the standard clock, the T-computer component of the nervous system is engaged and time labeling of events occurs.

We assume that for this case that one pulse (photon) is emitted for every ‘tick’ or cycle of the standard clock. A person experiencing (i.e. detecting and ‘time labeling’) more events than ‘normal’ such as the 8 clock signals in the ‘Fast Subjective’ frame per internal ‘tick’, believes that the external world is moving *‘faster’* than their memory of a ‘normal’ rate. For purposes of this example, we define the *normal* subjective state to be 4 signals detected per internal ‘tick-tock’ cycle (each complete cycle has a ‘width’ corresponding to the ‘subjective arrows of time’ just below each

figure). Internal clocks calibrate the ‘width of each cycle. For organisms, this might be the heart rate specific to a given species. For devices and instruments, it might be a mechanical, electrical, or electronic clock.

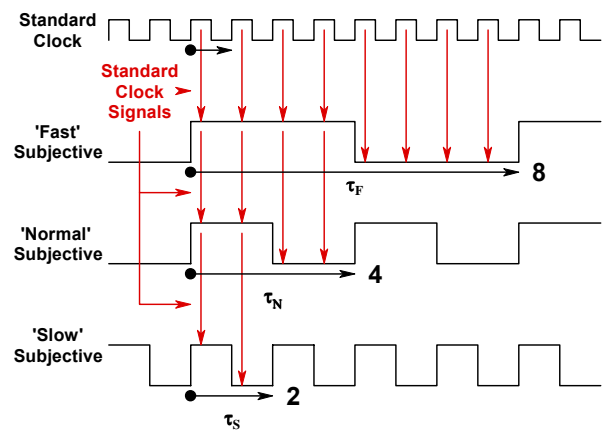


Figure 6. This illustrates the ‘speeding up’ and ‘slowing down’ of the observers sense of external time based on the number of signals detected from a standard clock in each of the three types of subjective ‘time’ frames. The ‘arrows of time’ pointing from left to right, are the created by the relationship between the standard clock, signals, and the observer ‘components’ acting together to form a T-computer in the observers reference frame.

The person detecting fewer signals (2 clock signals detected per internal ‘tick’) is convinced that the external world has slowed down. This is a common experience for people in emergency situations where adrenalin speeds up their metabolism. In all cases, the observers’ reference frame seems *normal* while it is the external world appears to change at different rates. This highlights the fundamental role that an observer or observing instrument has in defining ‘time’. In this example, the T-computer is the composite system created by the interaction of external environmental information with the ‘*internal*’ clock of the instrument, device, or organism that processes information.

We note that τ_F and τ_N and τ_S all ‘feel’ like the same interval to the observer, it is the standard clock that *appears* to change.

Popular ideas about ‘time reversal’ would require *reconstruction of infostates* of the universe as a whole or at least a sufficiently large local infostate for ‘travel’ back in time to an ‘earlier’ state. Since all local systems are entangled with the infostate of the universe as a whole we see that we can only create the illusion of time reversal by construction of a ‘set’ of configurations of matter that *mimic* an earlier configuration of an the irreversibly evolving universe as a whole. At the quantum scale the flow of information is away from unstable systems. To create an unstable system incoming information from the environment is required. In this sense time reversal does not exist.

Time travel has three popular modes of expression. The first is ‘backward’ ‘in time’ as discussed above. The second is ‘instantaneous’ or ‘zero elapsed time’ travel *across* space. The third is travel into the ‘future’ also ‘in time’. All three require access to information about the ‘destination’ space that is assumed to exist ‘simultaneously’ with the traveler and the problem is how to transport an observer into one of these non-local infostates. This requires that past and future *infostates* of the universe ‘exist’ concurrently. The problem here is that previous or past infostates are ‘lost’ as they are ‘computed’ into future ones by the dynamics of the evolving universe *at all hierarchical scales of complexity*. The ‘lost’ (really we mean ‘processed’) information specific to any ‘historical’ infostate means that ‘backward’ time travel is not possible and future infostates have not been computed yet.

We compute our future actions in response to past information in our memories. This allows us to compute ‘time’ in order to predict ‘future’ evolutionary patterns. In this sense we are examples of ‘time machines’. Our ability to ‘travel’ into the past is just our ability to access memories. Our ability to ‘travel’ into the future is our ability to ‘imagine’ evolutionary scenarios based on extrapolation of patterns formed by processing information. It appears that we are stuck in the here and ‘now’.

What about ‘instantaneous’ or ‘zero elapsed time’ travel *across* space via wormholes or some exotic quantum entanglement effect? This may be possible for ‘information’ states in the quantum realm, but it appears that the ordinary real matter we are made of is highly resistant to instantaneous parallel displacement or teleportation in space.

‘Popular’ notions about time travel may be misguided at best since they are the result of our misinterpretations of our *constructed* maps of time rather than originating from a deeper understanding of how we create time from information. This is the source of many philosophical and religious paradoxes relating to the origin and evolution of the universe where our ‘time’ map constructions are projected onto the universe as a space-like ‘dimension’. We may see that the re-conceptualization of ‘time’ as a ‘construction’ or information structure will open doors to a deeper understanding of the ‘changes’ in the universe that we associate with ‘time’.

The Quantum Computing Capacity of the Universe, Non-locality, and Achronological Change

While preparing this paper two very interesting ideas have emerged that reflect the need for the approach outlined above. First is a computational limitation for the universe as it ‘processes’ its evolution (see **Ref. 13**). The second is that non-local phenomena can occur without a ‘chronology’ (i.e. a ‘before’ or ‘after’) (see **Ref. 14**). The computational number of operations calculated in (**Ref. 13**) implicitly assumes the existence of some sort of T-computer in order to assign times to computational events or intervals. This T-computer is integral to the computational activities of the universe as it calculates its future. The non-local experiments described in (**Ref. 14**) concur with the idea of this paper that ‘time’ is a construction and does not exist *a priori*. The confusion about ‘before’ and ‘after’ information transfer in Bell correlations is probably the result of assuming that quantum non-locality occurs ‘in time’. The Bell correlations may be ‘achronological’ or ‘occurring’ without explicit dependence on ‘time’. This is consistent with the idea that ‘time’ is constructed into temporal maps of causal relationships between events. The numerical values of ‘time’ result from the relative *scaling relationship* of observed events calibrated by the observers’ chosen standard clock. The constructed map is then projected back onto ‘reality’ in the form of ‘space-time’. Both of these papers are examples of incomplete conceptual understandings of the nature of time as ‘information’. In order to obtain any kind of consistency and remain free of temporal paradoxes, ‘time’ must be understood in the paradigm of the computational properties of matter in a dynamic universe. The application of the relatively complex T-computer concept may not appeal to adherents of the reductionist maxim of “Ockham's Razor”, but if ‘time’ were reducible to a simple equation or relationship within the frameworks of ‘classical’ or 20th century physics, there would be no ‘problem of time’ at this time.

Future Directions

The ideas outlined in this paper are a *sketch* of an alternative way of looking at the origins of ‘time’ implicit in the operational definitions and devices (clocks) of everyday experience. T-computers at the quantum level may someday be used to drive the information processing activities in *quantum computers, hybrid quantum-classical computers,*

and *quantum biological computers* (e.g. ‘photosynthetic’ see **Ref. 15**). It may be that the current use of system clocks driving large-scale classical computers is unnecessary (see **Ref. 16**). If local T-computers do their job of ordering and time labeling information (where necessary) in such a way that non-local *entangled processing logic* can ‘instantaneously’ perform calculations such as those responsible for complex *meta-infostates* like *consciousness*, we may see much faster classical computers as well as advances in quantum computer architecture when the appropriate devices are finally engineered. The designs for *clockless chi*

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