Feynman Clocks, Causal Networks, and the Origin of Hierarchical 'Arrows of Time' in Complex Systems from the Big Bang to the Brain'

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A theory of **time** as the '**information'** created in the *irreversible decay process of excited or unstable states* is proposed. Using new tools such as **Feynman Clocks (FCs) [1], [2],** [3], **Feynman Detectors (FDs), Collective Excitation Networks (CENs)**, **Sequential Excitation Networks (SENs), Plateaus of Complexity (POCs), Causal Networks,** and **Quantum Computation Methods** [4], [5], [6] previously *separate* '**arrows of time**' describing change in complex systems ranging from the Big Bang to the emergence of consciousness in the Brain can be 'unified'. The '**direction**' and '**dimension**' of time are created from clock ordered sets of real number 'labels' coupled to signal induced states in detectors and memory registers. The '*Problem of Time*' may be 'solved' using the fundamental *irreversible* **Quantum Arrow of Time (QAT)** and *reversible* **Classical Arrows of Time (CATs)** to 'map' information flow in causal networks**.** A pair of communicating electronic Feynman Clock/Detector units were built and used to demonstrate the basic principles of this new approach to a description of 'time'.

1 Introduction

Should we be prepared to see some day a new structure for the foundations of physics that does away with time?...Yes, because "time" is in trouble.-John Wheeler [7].

It has been suggested by Julian Barbour that 'time' does not exist [8] thus adding one more complication to the '*Problem of Time*'. It is the position of this author that 'time' in fact 'exists'. 'Time' is a different 'property' of evolving systems than has been previously assumed. This problem was explored last year at the XXII International Workshop on High Energy Physics and Field Theory by *C. Marchal* [9]. I will take a different approach that will in principle provide a basis for the 'statistical' or 'ensemble' *arrows of time* of Poincaré as the result of n-body causal networks of fundamental quantum systems called **Feynman Clocks** or **FCs**.

The 'Problem of Time' is two fold. First there is the problem of *what* is 'time'? Second is the problem of the *apparent irreversibility* in a macroscopic world built on the *apparent reversibility* of the microscopic world. The first question can be answered by identifying '**time**' as a form of **information**. The second question can be answered by identification of an *irreversible* **Quantum Arrow of Time (QAT)** and *reversible* **Classical Arrows of Time (CATs).** The QAT and CATs are **pointers** mapping information flow between quantum systems and their environments in hierarchical causal networks. QATs are pointers generated by transformations between quantum states in a finite 'lifetime'. CATs are pointers whose 'endpoints' are the 'time labels' for events. The causal separation between these events is the classical 'time difference' interval or the *magnitude* of the CATs.

The *correspondence* between the various separate biological, cosmological, psychological, radiative, and thermodynamic '*arrows of time'* [10], [11], [12], [13], [14] is achieved with *causal networks.* Hierarchical **Plateaus of Complexity (POCs)** emerge at various size scales (e.g. atoms, molecules, and cells). Feynman Clocks (a general form of a 'quantum clock' [3])**, Collective Excitation Networks or CENs (see Fig. 1),** and **Sequential Excitation Networks or SENs (see Fig. 2)** are the '**nodes**' and '**gates**' used to build causal networks.

We begin with the idea that **time is a number created by the processing of 'energy of reconfiguration' information** (with dimensions of 'energy') carried by '**signals**'. The signal information represents the endpoint of a geometric and energy configuration change of the matter in a source system. Understanding the internal structure of a system by interpretation of it's signals requires more than one *bit, byte* or **qubit** of information in order to identify the '*geometry*' of the matter. A good example of this is the *deduction* of the Bohr energy level model for the Hydrogen atom based on the emission line spectra of photon 'signals'. These signals are the key to mapping the discrete quantized energy levels of the electron and proton system. It is clear that more than one spectral line is necessary to understand this system as a *whole.*

In the case of the QAT, scalar division of Planck's constant by the energy of reconfiguration creates a *real* number representing the '**lifetime**' of the decay process (with dimensions of 'time' or seconds) in a **Feynman Clock**. The *information* coupled to the **signals** emitted by **Feynman Clocks (FCs)** is transferred to the FC's 'environment' (e.g. the vacuum) through which it propagates. The trajectory of the signal may end at a **Feynman Detector (FD)** where it is converted into an 'excited' state by 'absorption'. The FD is the signal absorption mode of the FC and unless otherwise indicated 'FC' will be used to represent these two modes of a *single system.* The conversion of this state information is called **Signal** or **State Mapping (see Fig. 3)**.

This mapping process can be either a 'quantum' or classical computation in a *connected* set of logic 'gates' or 'nodes' forming a causal network. This process couples or **entangles** a '**number state**' or '**time label**' with a '**standard clock signal' (pulse)** *and* the **signal induced state** in a detector or memory register. This new composite **coherent 'entangled'** or **triplet state** *encodes* the '**event time**' of classical and relativistic mechanics (**see Fig.4**). The conversion of this entangled state into a real number representation of the 'event time' results from a selective decoupling or disentangling measurement on the 'number state' with an attendant loss of information about the two other states.

In order to create a conventional 'time' for an 'event' the label part of the triplet state must be measured. The 'signal state' and the 'standard clock pulse' information is lost as part of the *measurement induced* **decoherence** [11], [15], [16] of the triplet state. This loss is indicated by an increase in the 'entropy' of the environment or the gate in which the processing of the triplet state occurred. The resulting numerical label is a singlet state that can be used to **build** the conventional 'dimension' and 'direction' of 'time' in space-time using ordered sets of labeled singlet states representing the causal order of detected events with respect to a standard or internal clock.

The FC model may be applied to quantum cosmology and the Big Bang origin of the universe up to a point at which the vacuum appears as an 'environment' decoupled from the rest of the matter and energy. At this point, 'freezing out' of the vacuum decouples the FC-Universe QAT into 'local' QATs associated with all the various quantum subsystems distributed throughout the universe. Classical CATs emerge from the interactions of information provided by the environment to these quantum systems. The separation of these quantum systems in space is necessary for 'classical' behaviors to emerge. This separation also gives rise to hierarchical networks of matter and energy formed, in part, by gravitational clustering and *information enrichment* in local regions of space such as the life-forms on our planet's surface.

The expansion of space leads to classical 'entropy' and thermodynamic considerations defined by separation and unavailability of signals to reset or create new unstable states of quantum systems. The Big Bang starts as a quantum system but branches into locally complex quantum and classical systems spread through out space. The evolution of these systems into hierarchical networks of ever increasing complexity leads to local high information density structures of matter such as the brain. The complex states supported by biological systems can create information 'spikes' in space in contrast with extreme gravitational information 'spikes' in which information is localized but trapped in objects like black holes. A balance of gravity and information flow through a 'system' such as the Earth's ecosphere is necessary for the emergence of 'consciousness' from hierarchical causal networks of elements formed in a Big Bang Feynman Clock model and evolved in the complex neural network systems of the Brain.

2 The Quantum Arrow of Time (QAT)

The **Quantum Arrow of Time** or **QAT** is defined by the *irreversible* 'decay of a discrete unstable state resonantly coupled to a continuum of final states' [17]. The unstable state of a system originates in the fundamental geometric asymmetry of non-equilibrium spatial configurations of particles with 'charge', 'spin', and other quantum properties. The instability is characterized by *finite* '**lifetimes**' of these states. The irreversible QAT is observed in the decay of radioactive nuclei, excited electronic states of atoms through 'autoionization' (emitting a 'free' electron) or photon emission for example. The decay of these quantum systems can be described with '**time-independent**' perturbation theory;

> "For example, a system, initially in a discrete state, can split, under the effect of an internal coupling (described, consequently, by a time-independent Hamiltonian W), into two distinct parts whose energies (kinetic in the case of material particles and electromagnetic in the case of photons) can have, theoretically, any value; this gives the set of final states a continuous nature...We can also cite the *spontaneous emission* of a photon by an excited atomic (or nuclear) state: the interaction of the atom with the quantized electromagnetic field couples the discrete initial state (the excited atom in the absence of photons) with a continuum of final states (the atom in a lower state in the presence of a photon of arbitrary direction, polarization and energy)."[17]

These decay modes are not restricted to atoms and nuclei. We will see that these *Feynman clocks* are *time-independent irreversible systems* that can be created in space by *apparently* 'time' reversible particle collisions. *The key to the irreversibility in quantum systems is the creation of an **unstable** configuration of matter and energy in space.* This is the '*first cause*' for decay. *Instability* is a measure of the *geometric asymmetry* of the mass-energy distribution of the 'components' as they are driven to 'more stable' configurations by the fundamental interactions (forces) between each other.

We will see that apparent 'time' reversibility and irreversibility are compatible and necessary aspects of quantum systems. The '*Program of Decoherence*'[11], the entanglement of quantum states, and the emergence and decay of novel collective excitations provide tools [18], [19], [20] for understanding the common roots of all arrows of time for unstable configurations of hierarchically scaled clusters of matter in an evolving universe. This scaling leads to the emergence of collective 'classical' or macroscopic aspects of reality. The definitions used in this new approach to the problem of time are:

'**Time**' is a **form** of '**information' created by the mapping of signals to real numbers**.

The **irreversible Quantum Arrow of Time (QAT)** is always defined as a **pointer** from the **unstable state** to the **decay state** for any **unstable quantum system**.

Signals created by **reconfigurations** of **unstable states of quantum systems (Feynman Clocks or FCs) carry 'Information' to other systems (Feynman Detector mode of a FC) in Causal Networks**. Signals can be used to 'reset' an unstable state of a system which will 'decay' irreversibly.

The '**energy' of reconfiguration** represents the **information content** of the transition from the initial to final wave-functions via the reconfiguration operator or Hamiltonian. The energy of reconfiguration is converted into the '**lifetime**' of the **unstable state** by division into **Planck's Constant**.

The signal induced state **information** in a FD or memory register is converted or 'computed' into a **time number** or **time label** by **signal** or **state** '**mapping**'. The signal induced state is mapped to a '**standard clock pulse**' and a concurrent '**number state**' creating a new **composite** or **entangled coherent** '**triplet**' state. This triplet state can then be converted into a single real '**event time' number** by **disentanglement** due to a **measurement** or **decoherence** process. This real event time number is the time label used to find the **classical time difference** between two time labeled events.

The **ordered set of real numbers** extracted from triplet states created by signal events can be used to construct the '**dimension**' and '**direction**' of the **conventional time** used in classical and relativistic physics by mapping of the set onto the geometric real number line.

3 Signals

A **signal** is any '**system**' (e.g. photon plus vacuum) that conveys *state* **information** from one system (e.g. FC) to another (e.g. FD). The creation of a excited state in a detector from a signal state is the end process of information transfer originating in a spatially distinct source FC. The state information transfer causes the reconfiguration of the detection system resulting in an unstable state of 'excess' information. This information can then be converted into the 'time' of detection of the signal through the signal mapping process.

The classical *transit time* of a 'signal' is given by the 'distance' travelled by the signal divided by it's velocity. This transit time is a **classical time difference** determined by comparison of two signals. One of the signals is generated at the point of creation of an unstable state of the observed system. The other signals is created upon decay of that state accompanied by the creation of any other decay mode signals. The mapping of these signals to a 'time' label for each requires that the observing system pair standard clock signals to them upon detection. This new state is the 'direct' product of the two signal states for each observed event. The observing system can then process the time difference by comparison of the 'time' label number differences. This process maps signals to ordered labels such as integers or real numbers. If necessary, complex numbers may also be used for labels since it is the *ordering of the labels* coordinated with standard clock signals that determine how events are mapped to 'timelines'. The timeline or axis of space-time constructions has one 'dimensions' and a 'direction' determined by the intrinsic order of the set of real numbers.

4 Feynman Clocks (FCs)

We will be using the 'decay rate' method and appropriate Feynman Rules [25] for particle processes to calculate the 'lifetimes' of FCs. For a general system described with Feynman diagrams, where m **incoming signals** colliding with a target, if any, we have the total time-independent 3-momentum, $\mathbf{p}_0$, (including the initial target system momenta, $\mathbf{p_T}$, if any) for the initial system momentum given by;

$$\mathbf{p}_0 = \sum_{i=1}^{m} \cdot \mathbf{p}_i \tag{1}$$

The resulting total 3-momentum, $\mathbf{q}_0$, of the decayed system is the sum of the n **outgoing signals** (including the momentum of the remnant target, $\mathbf{q_T}$, if any) is given by;

$$\mathbf{q}_0 = \sum_{j=1}^{n} \mathbf{q}_j \tag{2}$$

A 'transient' Feynman clock system can be created by decay of the unstable configurations of the matter and energy in the composite system. The creation and decay of the system may be driven by strong, electromagnetic, weak, or gravitational fundamental interactions (indexed by $I = s, em, w, g$ respectively). We will look at the case The **'lifetime'** of the decay from the excited state to another reconfigured state of lower energy for system modeled in the Feynman Diagram representation is given by the **'Veltman' decay lifetime (vdl)** for the particle collision creation of unstable states [25];

$$\tau_{FC_{net}} = \frac{\hbar}{\Gamma_{FC_{net}}} = \frac{\hbar}{\int\limits_{q_n \cdots q_1} \cdots \int \left[\frac{V^{n+1}}{(2\pi)^{3n+4}} \mathbf{P} \cdot |\mathbf{M}_I|^2 \, \delta_{\mathbf{3}} \left(\mathbf{p}_0 - \mathbf{q}_0 \right) \right] dq_1 dq_2 \cdots dq_n} \tag{3}$$

$$= \frac{\hbar}{\int\limits_{q_n \cdots q_1} \cdots \int \left[\frac{V^{n+1}}{(2\pi)^{3n+4}} \mathbf{P} \cdot |\mathbf{M}_I|^2 \, \delta_{\mathbf{3}} \left(\left[\sum_{i=1}^{m} \mathbf{p}_i \right]_{in} - \left[\sum_{j=1}^{n} \mathbf{q}_j \right]_{out} \right) \right] dq_1 dq_2 \cdots dq_n} \tag{4}$$

If there is no reconfiguration of the incoming signals and target (if any) in this region of space, then a clock has not been 'created' and the reduced fundamental interaction matrix element M_I (Note: equal to the S-matrix (the 'scattering' matrix) except for the δ-function for overall energy-momentum conservation) is zero:

$$\mathbf{M}_I = 0 \tag{5}$$

The above equations for the Feynman diagram method for FD/FC 'lifetimes' represent the creation of 'lifetime' information from a scattering process that in general is very difficult to compute for complex systems. The idea here is that a 'collective excitation' of a system can be created by the incoming signals. This unstable configuration decays irreversibly with the production of outgoing signals.

The general lifetime of a Feynman Clock, τ_{FC}**,** is:

$$\tau_{FC} = \frac{\hbar}{\mathbf{\Gamma}_I} \tag{6}$$

Note that the denominator is usually referred to as the 'decay rate', $\mathbf{\Gamma}_\alpha$, which represents the reconfiguration process. It has units of 'energy' but encodes much more than just that. The initial state, the transformation Hamiltonian specific to the system, and the final state information is needed to 'understand' how the system processes configuration and reconfiguration information into a 'lifetime' interpreted by detection of a carrier signals and other knowledge about the geometry of the system creating the signal.

The **classical time** is the *'measured' difference* between the *detection event 'times'* connected with at least *two independent signals* from the two separate events **as seen** by a detection system of an observer. For the detection events α and β triggered by two signals, the observed 'lifetime' or 'elapsed time' between these two (signal detection) events is the 'difference' or 'classical' time between signal detections with respect to a standard clock;

$$\tau_{\alpha\beta} = \Delta\tau = \frac{\hbar}{\mathbf{\Gamma}_\alpha} - \frac{\hbar}{\mathbf{\Gamma}_\beta} \tag{7}$$

If $\tau_{\alpha\beta} < 0$ then event α is mapped onto the observers n-th standard clock pulse and event β is mapped onto the $(n+1)$-th pulse. The observers arrow of time pointing from the n to $n+1$ pulses would lead to a causal relation where event β's signal was detected 'before' event α's signal. Any corrections for transit time of the signals, relativistic or geometric effects would be made using other 'secondary' information such as the 'distance to' and type of sources (e.g. spectral information giving energies of transitions and red or blue shifts in the signals) relative to the observer. If $\tau_{\alpha\beta} > 0$ then event β is mapped onto the observers n-th standard clock pulse and event α is mapped onto the $(n+1)$-th pulse. If $\tau_{\alpha\beta} = 0$ then event α and β are both mapped onto the observers n-th standard clock pulse indicating simultaneity of signal detection in the observers frame. The key to defining causal relationships between events is the process of signal mapping by the observer using a standard clock in conjunction with other information about the intrinsic properties of the signal sources may be needed to establish any causal relationships if any. For two or more independent sources the 'time' ordering of detected signals is a reflection of the subjective ordering by the observer relative to the observers frame.

The perception of the existence of an external causal network as seen by the observer requires more information that just 'time labeled' signals. This may require a geometric map of the 'clocks' in the network and the types and trajectories of the signals between these 'nodes' or information processing gates. Herein lies the need for an understanding of 'lifetimes' of unstable states and the differences between labels for the detectors states created by two or more signals. It is the differences between detected signal events that is implicitly used in almost all treatments of 'time' as a 'dimension' in physics. It is obviously a very effective way to map events onto an arrow of time 'constructed' by the observing system from the signals generated by a standard clock but it masks the intrinsic nature of time as information flowing through networks. Conventional 'time' is the difference between two or more 'numerical' labels one of which may be defined as a 'zero' point.

We can also use the standard lifetime for decay of an unstable state based on the Fermi-Dirac Golden rule [17]:

$$\tau_{FC_{net}} = \frac{\hbar}{\Gamma_{FC_{net}}} = \frac{\hbar}{2\pi\rho(E)\left|\langle\Psi_f\left|H_{i\to f}\right|\Psi_i\rangle\right|^2} \tag{8}$$

Where the initial excited state of the system decays to a final state by means of a Hamiltonian $H_{i\to f}$. The density of final states is $\rho(E)$ evaluated at intersection of equal energy states for common energy of states $|\Psi_i\rangle$ and $|\Psi_f\rangle$. In the case of particle collisions the determination of the general initial and final wave functions may not be possible and the Veltman decay lifetime can be used to characterize the lifetime of a state of a system created by incoming signals and information which then result in a decay of the excited state. This produces outgoing signals and information 'processed' by the fundamental interaction driving the reconfiguration of the Feynman Clock.

5 Collective Excitations and Entangled States

The key to single collective behaviors of many quantum systems coordinated by signals and then acting as 'classical' objects are **collective excitations (CEs)** of **quasiparticles** (also called 'elementary excitations') [26], [27], [28], and **entangled states**. **Phonons**, **excitons**, and **plasmons** are examples of CEs that exhibit mesoscopic system behaviors but are still quantum phenomena [29], [30]. Entangled states are observed in correlated behaviors of photons in non-locality experiments in which their initial coupling at the source of their creation remains even though their physical space separation is so large that 'signals' travelling at the speed of light are too slow to account for the communication of state information between the distant photons when one or both of them are 'measured'[33], [34].

One of the fundamental questions about collective excitations is what are the maximum distances between CEN components that will still support collective behavior? The emergence of 'quantum' excitations in mesoscopic (quasi-classical) and macroscopic CEN systems requires resonant communication or '*synchronized*' *entanglement* of the states of all the relevant components. **Entanglement** of the quantum states of two or more components provides a composite complex state that can represent a collective excitation of two 'isolated' but 'historically' coupled signals.

The 'entanglement of states' of nodes in causal networks that have space-like separations is an essential aspect of behaviors of large numbers of coupled systems acting as a single collective system with collective excitations that define the system arrow of time. The entanglement of states is represented by the 'Direct' or 'Tensor' Products of the individual states of the components forming the Composite Quantum system. For the case of a composite system, $|T_j\rangle$, composed of three entangled subsystems $|t_j\rangle$, $|q\rangle$, and $|\Psi_j\rangle$ the '*direct'* or *tensor product* is:

$$|T_j\rangle \equiv |t_j\rangle \otimes |q\rangle \otimes |\Psi_j\rangle \,. \tag{9}$$

For the case of the *triplet state* in Fig. 4 the **pulse counter label state** $|t_j\rangle$ is a *singlet* state (e.g. 'time label') such that $t_j \in \Re$, where $\Re$ is the set of Real Numbers.

The **standard clock pulse** or '**qubit' state** $|q\rangle$ is a *superposition* of two standard clock pulse states, $|0\rangle = |'off'\rangle$ and $|1\rangle = |'on'\rangle$, where $\alpha_1$and α_2 are the complex amplitudes of the clock pulse basis states, and $|\alpha_1|^2 + |\alpha_2|^2 = 1$. The clock state *induced* in the detector is:

$$|q\rangle \equiv \alpha_1 |0\rangle + \alpha_2 |1\rangle \,. \tag{10}$$

The *detected signal* is *registered* as the *direct product* of the *n-body energy eigenstates of the detector,* $|\Phi_\gamma\rangle$, with the *induced excited state* or *phonon-like CE state,* $|CE_\gamma\rangle$, of the *entire n-body system.* Examples of these kinds of systems are the 'giant' multi-pole resonances of nuclei [28] and phonon behaviors (e.g. '*Brillouin scattering'*) in crystals [29], [30].

The configuration information of the mass-energy distribution is *encoded* in the state of the system which can be '*measured*' to give a conventional 'event time' label. The **excited n-body state** of the component is given by:

$$|\Psi_j\rangle \equiv |\Phi_{n-body}\rangle \otimes |CE_{n-body}\rangle \,. \tag{11}$$

The **entangled triplet state** of this Feynman Clock is a composite system of the three states above. The pulse counter 'labeled' and standard clock pulse calibrated excited state is given by:

$$|T_j\rangle \equiv |t_j, q, \Psi_j\rangle = |t_j\rangle \otimes |q\rangle \otimes |\Psi_\gamma\rangle \tag{12}$$

$$= |t_j\rangle \otimes (\alpha_1 |0\rangle + \alpha_2 |1\rangle) \otimes (|\Phi_{n-body}\rangle \otimes |CE_{n-body}\rangle) \tag{13}$$

which is an '**entangled** *triplet state*' (see for example the Feynman Clock Triplet state in **Fig.4**) and cannot be reduced to a simple linear sum of discrete states. It represents the entangled state of the whole system which is the result of the system acting as a Feynman Gate with 3 input signals and one output signal.

The disentanglement of these states occurs by a classical *intervention* [31], [32] or *measurement* of the entangled state resulting in the extraction of the *event time label* as a real number. In the case of signal mapping, the processing of the triplet state signal occurs in a 'gate' or FC that disentangles the event time from the other information in the triplet state. The **disentanglement operator**, D, acts on the triplet state via a *classical intervention* causing the decoherence of the coherent entanglement of the triplet state:

$$D\,|T_j\rangle = t_e\,|t_j, q, \Psi_j\rangle \tag{14}$$

where t_e is the **event time** corresponding to the *classical time* label for the moment of signal detection in the FD mode of the target FC system. This is not the same as the *lifetime* of an unstable state but a '*time label*'. The triplet state may someday be experimentally verified in the actions on neural signals in microtubule causal networks in which molecular conformation states represent the qubit states of 0 or 1, the collective phonon resonance state of the microtubule represents the n-body and its CE, and the counter label state is the number of neurotransmitters in a chemical accumulator vesicle in the pre-synaptic membrane.

Recent work on the synchronization of quantum clocks provides a model for CEs as entangled states in widely separated systems through a "*quantum clock synchronization scheme*" (QCS) [33]. This model can be expanded for Feynman Clock Synchronization (FCS) over 'classical' distances where the FCs are virtual clocks (entangled 'time' independent *signals*) until 'measured' or decohered from an atemporal global CE state into 'actual' FC states of the nodes in a causal network. These synchronized nodes create a CEN without the exchange of 'timing information'. Evidence of CEs over great distances is found in photon entanglement experiments.

Experimental observation of two 'energy-time' entangled photons separated by more than 10 Kilometers [34] provides an example of the *decay of a collective excitation* of a vary large spatially extensive quantum system *if* we look at the entire experimental setup as a 'SEN' system from the 'Geneva FC' to the Bellevue/Bernex 'CEN'. The 'Geneva FC' produces two 'coherent' photon signals that traverse large distances on separate fiber optic paths (8.1 and 9.3 km). The 'transit lifetimes' of the signals are functions of the velocity of the signals in the medium and their distances to the FDs in the Bellevue/Bernex CEN. Signal mapping of the FD/FC detection events in the CEN via a 'clocked' memory system linking the two 'node' leads to causal ordering. The entangled photons remained 'correlated' even though separated by 10.9 kilometers, upon their detection 'decohere' with the production of 'classical' information (i.e. the emission of 'signals' or the creation of 'states' in memories) upon measurement.

The CEs of systems may act as measurements on the internal states by the surface environment. This surface represents a plateau of complexity for these systems. These plateaus have collective behaviors including irreversible transitions to new configurations of matter and energy in expanding space. One can artificially ascribe scaled arrows of time for these plateaus. These system dependent arrows are derived from the quantum arrow of time. They '*correspond*' to the quantum arrow through the collective excitations and behaviors of the networks of clocks and signals throughout the hierarchical clusters of information processing subsystems.

6 Collective Excitation Networks (CENs)

Collective behaviors of systems composed of discrete but connected components need to be characterized in order to understand how 'arrows of time' emerge at POCs in complex systems. The concept of 'collective excitations' in the many-body problem [26] and in phonon behavior in solids [29], [30] provides the basis for modeling reconfigurations in POCs. When a set of subsystems (local networks) in a complex system are 'wired' together in a network, they can support coherent superposition of states capable of new collective system behaviors (**Fig.1**). These collective states have finite lifetimes and decay with the production of 'signals' (e.g. phonons, solitons, plasmons, 'sound waves', etc.).

The first level of complexity emerges when sets of *coupled* Feynman clocks act collectively as a single system with new system energy eigenstates (e.g. molecular spectra) whose unstable excitation modes decay with finite lifetimes. This system is a **Collective Excitation Network** or **CEN**. These CENs can support new *collective excitation states and signals.* They can also act as 'gates', memories, or registers creating and processing signals (information) when embedded in larger networks. This process of 'nesting' of subsystems with collective excitation states provides a means for deriving various hierarchical 'arrows of time' connected with plateaus of complexity. Individual Feynman clocks and CEN units can interact to form higher level CEN 'circuits'. These CEN circuits can become 'gates' with *multiple signal inputs and outputs.* These 'integrated' CEN circuits now generate new POC states.

The 'lifetime' of the 'clock' mode of a general CEN is given by:

$$\tau_{CEN} = \frac{\hbar}{\mathbf{\Gamma}_{CEN}} = \frac{\hbar}{2\pi\rho(E_{CEN})\,|\langle\Psi_f \mid H_{CEN} \mid \Psi_i\rangle|^2} \tag{15}$$

where the excited 'clock' state of the CEN decays via the reconfiguration transformation function, H_{CEN}, with the creation of a signal, S_{out}. This is the 'lifetime' of a phonon resonance over a crystal array of atoms for instance. The density of states, $\rho(E_{CEN})$, is for the collective excitations for the entire system.

The initial state of the CEN in the above equation is created by the detection of an incoming signal, S_{in} , by the CEN composed of a set of j-coupled FCs. This 'system' configuration state, $\mid \Psi^*_{CEN}\rangle$, is the *direct product* of the states of each of the components:

$$\mid \Psi^*_{CEN}\rangle = \left[\bigotimes_{i=1}^{j} \mid \Psi^*_{FC_i}\rangle\right] \bigotimes \mid \Psi_{S_{in}}\rangle. \tag{16}$$

The state of the CEN after decoherence ('decay' or 'decoupling') of the CE over the set of FCs results in the emission of a signal, S_{out} . The 'reconfigured' state of the system is:

$$\mid \Psi_{CEN_0}\rangle = \left[\bigotimes_{i=1}^{j} \mid \Psi_{FC_i}\rangle\right] \bigotimes \mid \Psi_{S_{out}}\rangle. \tag{17}$$

The decohered FCs may still be bound in a lattice or other n-body configuration ready to detect the next phonon-like signal.

7 Sequential Excitation Networks (SENs)

A SEN is a composite network of FCs and CENs coupled in such a way that information and signals moves from node to node sequentially (see **Fig.2**). The SEN has a net 'lifetime' representing the sum of all the of the FC, CEN and signal transit 'lifetimes from the initial signal input to a final signal output. The SEN 'lifetime' for this process is given by:

$$\tau_{nsum} \equiv \sum_{k} (\tau_{FC_k} + \tau_{S_k}) \tag{18}$$

where, τ_{FC_k}, is the 'lifetime' of the k-th FC (or CEN) in the sequence and τ_{S_k} is the signal lifetime between the k-th and $(k+1)$ nodes.

Feedback, feedforward and **cyclical flow of signals (information)** is also possible in the SEN. This provides a mechanism for the resetting of unstable configurations necessary for quantum computational algorithms. It also provides for adaptive behavior in relatively closed systems like cells. These 'control' mechanisms can be realized by defining signal trajectories or 'circuits' connecting various nodes into hybrid linear and cyclical causal networks. All of the combinatorial possibilities for 'connecting' systems and subsystems together by signal loops provide a means for modelling complex self-adjusting or adaptive behaviors. The transformations of the local states or network configurations in the component FD/FC, CEN, and SEN nodes produce different computational 'lifetimes' for the information 'currents' propagating through them.

8 Plateaus of Complexity (POCs)

As we have seen above, collective excitations are the markers for new levels of complexity in hierarchically connected systems. Solitons represent 'classical' wave packet signals in macroscopic scale systems. Their origins are found in the **Plateaus of Complexity or POCs** of the subsystems from which they are composed. Since CEs are the result of the superposition of *quantum states resulting in another quantum state,* classical states emerge as the result of the interaction of this system with an *environment.* Plateaus of complexity are the interface between the quantum properties of the system and its environment. This is how quantum systems in CENs and SENs can create 'classical' signals and behaviors as a result of the environmental measurement by an observing system in which it is embedded. The environmental component makes the quantum system 'open' to classical signal production. If the environment is the boundary condition on the quantum system it may be 'closed', but still act like an open system which can decohere (e.g. decay of FC mode of the initial state of the universe in Big Bang scenarios).

POCs are configurations of complex systems from which **simplicity** emerges. Simplicity of behaviors means that collective excitations provide a way for classical physics to describe global changes without the need for a complete description of the many individual systems contributing to the overall 'simple' state. This is already evident in the success of classical or Newtonian mechanics etc. POCs give rise to the behaviors and signals associated with classical arrows of time and represent the basis for a paradigm leading to a '**simplicity theory**' as a *model* for the *emergence of hierarchical intermittent sets of simple POC states punctuating the deterministic chaos intrinsic to* '**complexity theory**'. Simplicity theory would then describe phenomena emerging as simple large scale behaviors within complex systems.

9 Signal Mapping and Processing State Information into 'Time'

"The Map is not the Territory". - Alfred Korzybski [35]

Signal mapping is the process by which signals carrying state information are detected and their 'information content' (induced state in detector) put into ordered sets with respect to a standard or internal clock (see **Fig.3**). This involves creating states in a 'memory' so that their causal relation to other events can be 'read' and interpreted. 'Time' emerges as the functional value of the energy eigenstates in the detectors as information 'bits' assigned to a detected signal from an 'event' (FC created signal) in 3-space (possibly an n-space at the Planck scale for n higher dimensional quantum modes of 'strings' etc.). The magnitude of the states (in 'bits') are determined by the conversion of state information by a detector and kept in a memory register as a mirror state of the original source state created by the decay of the signal generating FC. The state in the memory can be 'scanned' (measured) by a shift or parallel data register through the action of an internal or standard clock. This is similar to data ordering in classical computational hardware.

The process of signal or state mapping resulting in a 'time' number label for a signal induced state in memory is the result of *processing* a 'triplet' state (**Fig.4**). The creation of this entangled state results in a new state that encodes a label referenced to a standard clock register for the 'time of detection' for the creation of an FD state:

$$\mid T_j\rangle = \mid t_j\rangle \bigotimes \mid 1\rangle \bigotimes \mid\Psi_j\rangle = \mid t_j, 1, \Psi_j\rangle. \quad (19)$$

A 'disentanglement' measurement, D, on this state gives the number representing the 'time' label for the detection of the signal event with respect to a standard clock (e.g. cyclical FC powered by regular signals from the 'environment'). The measurement gives the 'time label' eigenvalue j in the equation below:

$$D \mid T_j\rangle = D \mid t_j, 1, \Psi_j\rangle = t_e \mid t_j, 1, \Psi_j\rangle. \quad (20)$$

This value is the 'classical' time for the event where $t_e \in \Re$ (set of real numbers). The disentanglement of this triplet state requires a quantum computer gate that 'selects' the 'label' state and can transfer this extracted information to a symbol or word in a language to be communicated to other systems. The exact physical situations that can produce such entanglement and disentanglement will be explored in future work.

The key point here is that all of the systems (FC, Signal, FD, Memory and cyclical data sequencing clock) may be 'quantum' systems with microscopic or classical sizes. In this way, the relative order and magnitude of the conventional 'time' interval *between events* is the result of the processing of state information in the 'gates' of a *quantum computer*.

10 Examples

10.1 The 'Big Bang' as a Feynman Clock

Can the Big Bang Singularity be modeled as a FC? The 'diameter' of the FC universe at that point was of the order of the *Planck Length* or about 1.61605×10^{-35} m indicates that the methods of quantum mechanics are appropriate for the description of the Big Bang initial state [36], [39]. The Wheeler-DeWitt Equation is a starting point for 'quantum cosmology'. The inflationary Big Bang scenarios are designed to accommodate an extremely high energy density singularity [37], [38], [39], [40], [41] as the source for all structure observed today.

The initial 'excited' unstable state of the universe is a singular unstable high energy-density Feynman Clock with '**decay products**' *such as* the '*vacuum*' (space), various forms of matter, the fundamental interactions between particles, and evolving complex systems in causal networks. The emergence of the 'vacuum' at the end of inflation creates an 'environment' which decoheres the previously coherent pre-inflation superposition of configuration states from the continuum of all possible ('future') coupled decay states for the initial singularity [43].

The initial unstable state is the direct product of all the coherent modes of a 'pseudo-stable state' coupled to a global collective excitation in the form of a phonon-like perturbation in the mass-energy density function of the initial singularity. This phonon-like perturbation is frozen out into spatially distinct mass-energy density enhancements when the vacuum 'signal' decouples from matter at the end of the inflationary epoch resulting in the first Feynman Clock '*tick*' of the Universe. These density enhancements evolve into complex systems through '**quantum' source and 'classical' sink** *non-equilibrium competition* between the strong, electromagnetic, and weak interactions of matter in the continuously *stretching* vacuum **versus** the local gravitational clustering of mass in the form of galaxies, stars, and planets. The gravitational clustering of matter is essential for the emergence and evolution of complex systems of matter (e.g. the ecosphere and the life within it) driven by energy sources such as stars.

We propose that an initial 'triplet' state of the Universe is modeled with an entangled state built from the **coherent set of FC configuration states** $\mid \Psi_i\rangle$, the **global collective excitation state** $|\Psi_{CE}\rangle$ over this system *and* the **Planck Scale FC counter state** $|t_U\rangle$. The resultant initial entangled triplet FC state of the non-tunneling decay mode of the Universe is:

$$\mid \Psi_{U_i}\rangle = \left(\bigotimes_{i=1}^{\infty} \mid \Psi_i\rangle\right) \bigotimes |\Psi_{CE}\rangle \bigotimes |t_0\rangle \tag{21}$$

decohering via 'self-measurement' from the CE 'Environment'. This forces a 'phase transition' producing an inflationary Big Bang FC evolutionary causal network in the vacuum with a **first cause** decay mode 'decoherence lifetime' of:

$$\tau_{BigBang} = \frac{\hbar}{\mathbf{\Gamma}_{U_{FC}}} = \tau_{PlanckTime} = 5.39056 \times 10^{-44}\,\mathrm{s} \tag{22}$$

where:

$$\left|\Psi_{U_{Inflation}}\right\rangle = \left(\bigotimes_{k=1}^{\infty} \mid \Psi_k\rangle\right) \bigotimes |\Psi_{Vac}\rangle \bigotimes |t_P\rangle \tag{23}$$

and $D_{U_{PlanckTime}}$ is the **time-independent** FC-Universe reconfiguration operator. The 'energy of reconfiguration' term, $\langle\Psi_{U_{Inflation}} \mid D_{U_{PlanckTime}} \mid \Psi_{U_i}\rangle$, is encoded in the '**expanding universe signal**' seen as the creation of a *global expanding vacuum environment* with *gravitationally created FC systems* formed by the clustering of matter and energy into *local* information 'sources'. As this mass-energy-information density 'locally' increases in the form of 'sources' such as galaxies, stars, planets and humans, we see that the density of 'signals' and therefore available information (states) forming causal links between these spatially distinct systems decreases as particle, atomic, and molecular *FC density* of space declines due to expansion of the universe. The increase in local POCs is in stark contrast with the increasing unavailability of energy sources in an expanding universe.

The fundamental interactions between particles emerge from the destruction of the coherence of configuration states as the 'interference terms' between topological inhomogeneities in the energy density function. The evolution of the FC-universe into a hierarchy of complex systems of causal networks forming a 'quantum computer' is a topic for further speculation [24]. The quantum computer analogy may be explored by taking the position that the initial early universe was a FC or CEN that decohered to a configuration of matter and energy that then 'decayed' in an inflationary SEN of branching, subdividing, and hierarchically connected FC, CEN and SEN 'gates'.

The continuous evolution and *branching* of causal networks of matter and signals makes it difficult to treat the universe as a 'single' quantum computer system representing all of the emergent structures in the universe throughout its reconfiguration history. The branchings are in one system and do not need the many distinct universes to 'branch into'. This does not mean that the universe itself is not a 'quantum computer', but that it might be a FC-quantum computer which can accommodate the complex hierarchical causal networks and the signal mediated information flow in them evolving into differentiated 'classical' structures in which the quantum component systems are subsumed.

10.2 'Unification' of the Fundamental Interactions

Is it possible to *unify* the strong, electromagnetic, weak and gravitational forces using 'time' as a common term? Any one or a combination of the strong, electromagnetic, weak and gravitational fundamental interactions can drive reconfiguration processes in FCs, CENs and SENs. In this sense all of these interactions have 'lifetimes' and therefore information generating capabilities in common and are therefore 'unified' in an *information space* [42]. For a FC reconfigured by the strong interaction we have a decay or decoherence lifetime τ_U:

$$\tau_U = \alpha\tau_{strong} = \frac{\hbar}{\mathbf{\Gamma}_{strong}} \tag{24}$$

For a FC system driven by the weak interaction (or 'electroweak') we have:

$$\tau_U = \beta\tau_{weak} = \frac{\hbar}{\mathbf{\Gamma}_{weak}} \tag{25}$$

For a FC system driven by the electromagnetic interaction we have:

$$\tau_U = \delta\tau_{em} = \frac{\hbar}{\mathbf{\Gamma}_{em}} \tag{26}$$

and for a gravitational FC system we have:

$$\tau_U = \epsilon\tau_{grav} = \frac{\hbar}{\mathbf{\Gamma}_{grav}} \tag{27}$$

where the lifetimes are related by real scalar constants α, β, δ, and ϵ. The unified 'lifetime', τ_U is then:

$$\tau_U = \alpha\tau_{strong} = \beta\tau_{weak} = \delta\tau_{em} = \epsilon\tau_{grav} \tag{28}$$

These four prototypical systems are reconfigured by different forces but their signals provide a rather obvious and perhaps trivial way of establishing an ad hoc unification of the fundamental interactions of matter. The key to this type of unification is recognizing the dimensional equivalence of the 'lifetimes' and therefore the **reconfiguration information** *common* to all unstable systems. Note that these are the 'QAT lifetimes' of states in FC systems. The signals carrying information from two different types of the FCs above to a detection systems or observer are converted into CAT differences between the detector events.

10.3 Time 'Dilation' and 'Contraction'

Time intervals between events (CATs) and the *'lifetimes' of unstable systems* (QATs) are subject to '*dilation*' and '*contraction*'. These correspond to two cases: 1) relativistic motion and energy effects, and 2) **Quantum Zeno Effects** [4] for 'classical' (including 'relativistic') and 'quantum' systems respectively.

For the 'classical' case of dilation or contraction of *time intervals* where relativistic corrections for source-detector motion are required, the signals from two space-like separated 'moving' FCs (or a *second signal* from the same FC) may appear to be increased or 'dilated' for objects moving away from the observer. They may appear to be decreased or 'contracted' for motion towards the observer. These signals may originate as *quantum processes* in the FCs but they are *processed* ('signal mapping') as two separate detector triplet state events in the observer system. The *triplet states* created in the detectors are '*time labeled*' and the computation of the *differences* between two or more of these 'event times' using the standard or internal clock of the observing system is subject to appropriate relativistic corrections depending on the geometry and motion of the sources with respect to the observer. The relativistic corrections are *computed* after signal processing and 'time difference' maps have been created in a 'memory'.. These 'computed' relativistic '*time dilation/contraction*' effects between detection events represent an '*interpretation' process* which is a *map in information space* that gives the causal relationships of the sources and the detectors and based on other information about the systems whether the signal time separations were due to their geometric relationships or other local processes. This is necessary to 'understand' whether relativistic phenomena have been observed based on the detected signals.

The case of dilation or contraction of 'lifetimes' of unstable states in quantum systems refers to the modification of the intrinsic decay process by interventions inducing more or less stability in the state. More stability means that the system will stay together longer before decay thus dilating the 'intrinsic lifetime'. More instability contracts the intrinsic lifetime and shortens the life of the unstable state. It should be noted that both dilation and contraction effects of the quantum lifetime are really the lifetimes of *new hybrid entangled states* in a *composite system* of environment (e.g. incoming signals) and the FD mode of a FC. This is the quantum Zeno effect which can act to slow or speed up a decay process depending on the nature of the interaction of the environment with the quantum system. The interventions of drugs upon the brain for instance can induce time 'dilation' and 'contraction' effects on the *consciousness CE state* by '*spreading out*' or '*squeezing'* the CE state respectively (see below). Dilation of this state means that more signals than normal per CE state lifetime are processed thus creating the sensation that the world is moving faster. Contraction of the CE state means that less signals than normal are processed per CE lifetime and therefore the rapid sequence of CE states creates the appearance that the world is moving slower. this is the case for the 'adrenaline rush' experience of people in crisis situations who experiences time slowing down. The use of chemicals that trigger Quantum Zeno effects in neurons may be present the possibility for experimental verification of CEN quantum states in neural networks such as the brain.

10.4 The Emergence of Consciousness

How does *consciousness* emerge in the complex neural networks of the brain? There is some question about whether the Brain needs to be modeled as a quantum computer or system [44], [45]. It appears that the brain has both quantum and classical information generating and processing properties depending on the size of the subsystem under examination. *Coherence* of the many individual states of neurons seems to be necessary for the creation of a single large scale 'thought'. The coherence mechanism may be classical such as the release of energy stored in a **many-body** neural network creating phonon-like CE 'brain waves' [46]. This however ignores the possible complex interactions of the internal structures of neurons at the quantum level [47], [48], [49]. It has been proposed that **quantum gravity** is involved with consciousness and quantum computational processing of 'holographic' patterns of information at the Planck scale [50], [51], [52]. It is likely that 'consciousness' is the result of both quantum and classical information processing and storage.

At the neuron level, microtubule structures in the cytoskeleton may act as **qubit** [5], [6] processing gates in a molecular quantum computer [50]. The resulting states in these neurons may be synchronized with other neurons in a neural network by entangled states mediated by internal photon and external phonon-like collective excitations. They may also be synchronized by classically mediated neurotransmitter release and uptake at pre- and post synaptic membrane sites via diffusion and electrochemistry. Macroscopic electromagnetic properties seen in brainwaves and NMR images of active regions of the brain may not need a quantum explanation but yet may still be the result of classical POC collective excitation states resulting from the synchronization of the quantum chemical causal networks with FC, CEN and SEN information processing gates. The quantum and classical properties of the brain giving rise to 'consciousness' may meet at the mesoscopic realm of the synaptic gap. The neuron may be a quantum computer connected to many other quantum computers forming a classical computer neural network.

There are many open questions in this difficult and complex problem. What we propose here is that QATs in neurons may give rise to CATs in neural networks through hierarchical POCs. If time is a form of information then the information processing capabilities of neurons (or 'gates') in networks may be required for the ordering and time labeling of events in the world around us. The exploration of the fundamental nature of time leads naturally to the problem of consciousness.

If neurons are local quantum computers in networks then the irreversible processes in them should give rise to QATs pointing along the paths of 'information flow'. If microtubules in neurons can be *synchronized* into 'single' collective excitation states either by entanglement of signals coupled by **faster than light 'information' communication** [21] or by a **vacuum induced entanglement** [53] then there is the possibility for a quantum description of 'thoughts' as classical electromagnetic phenomena emerging from spatially extended entangled quantum systems such as those in neural networks of the brain.

A recent analysis of EPR experiments in Geneva indicates a lower bound of $\mathbf{1.5 \times 10^4 c}$ for '**communication**' between two *entangled* photons with space-like separations of 10.6 km [22]. This may pave the way for understanding how photons and phonon like resonances in individual and network microtubules might support a 'quantum state' of consciousness. Less spectacularly, resonance effects of large scale classical electromagnetic 'brainwaves' may coordinate the quantum states. The quantum or classical CE states of neural networks emerge and decay with characteristic 'lifetimes'. The superposition of these 'local' CEs generated by overlapping CENs can synchronize even larger sets of neurons into a large scale CE. This may give rise to the distributed collective state over a large set of neurons supporting a singular but continuously transforming 'consciousness' state.

The 'lifetime' of any given 'thought' as a net CE state configuration resulting from the transformation $B_{1\to 2}$ of a decaying CE; Ψ_{CE_1} to another overlapping emergent CE; Ψ_{CE_2} forms a SEN of **POC states of consciousness** is:

$$\tau_{SEN_{1,2}} = \frac{\hbar}{\mathbf{\Gamma}_{SEN_{1,2}}} = \frac{\hbar}{2\pi\rho(E_{Brain})\left|\langle\Psi_f \mid B_{1\to 2} \mid \Psi_i\rangle\right|^2} \tag{29}$$

The brain is 'quantum' only in the sense that complex states (e.g. consciousness) can be viewed as collective excitation state of casual networks built from neuron based Feynman Clocks, CENs, and SENs. The building of these complex interacting neural networks give rise to 'classical' global collective excitations such as brain waves. The collective excitation states in the brain may be created by the adaptive rewiring of some neurons among relatively fixed function neurons allowing a continuity of historical memory information while processing new information generated by the sequential emergence and decay of novel CEN states. The ultimate 'collective excitation' may be consciousness (see **Fig.5**). As far as we know it is the Brain that maps numbers onto events and constructs the dimension and direction of time from a changing world that cares not for the numbers we use to define our lives.

11 Summary

It has been postulated that **time is a form of information**. Information ultimately takes the form of labels, words, and language in complex systems such as the brain. The source of all information is the initial unstable collective excitation state of the Feynman Clock Universe. The purpose of the theory presented above is more 'explanatory' than 'predictive'. The 'triplet' state necessary for the creation of 'time' labels for the signal induced events in detectors or memory registers may eventually be 'observed' in the microstructure of neurons. The understanding of the fundamental nature of time as information rather than as it's *constructed* 'dimension' and 'direction' may lead to resolution of 'time' related causality paradoxes in quantum mechanics and relativity theory.

The information processing properties of complex configurations of matter and energy in quantum computers may lead to an understanding of the emergence of the brain and it's most powerful state- 'consciousness'. The flow of information in the form of signals between emergent hierarchical patterns of matter map the evolution of the universe. It is hoped that the novel ideas, models and tools presented in this paper will help contribute to the answers to the 'age' old questions about the origins of the universe and how a 'brain' could emerge from the Big Bang (Big Brain?)...*after all*, **understanding the Brain is the ultimate test for any theory of 'everything', 'anywhere' at 'anytime'!**

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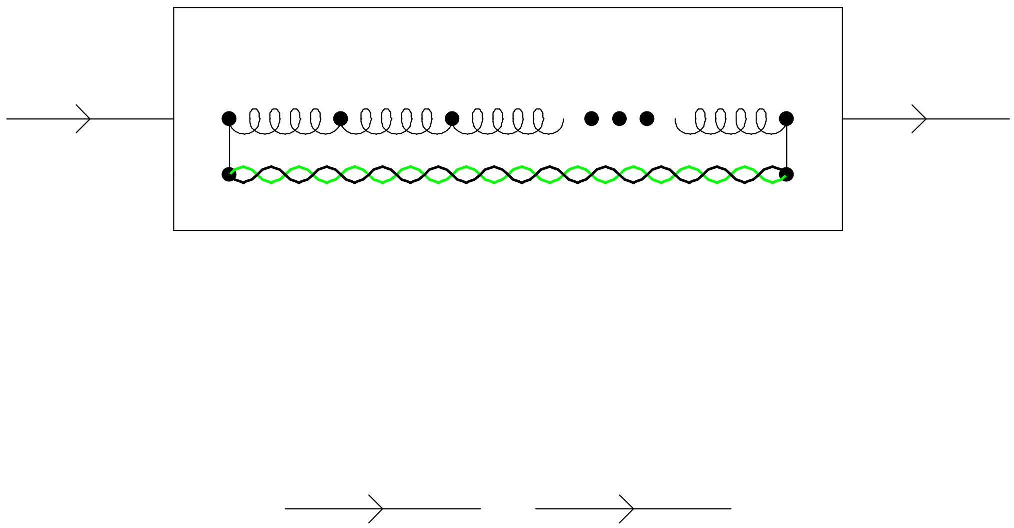

Figure 1: (a) A general Collective Excitation Network or CEN 'node or 'gate' as an 'entangled' or coupled system of 'J' Feynman Clocks with a Collective Excitation CE1,J. (b) The simplified causal network node notation.

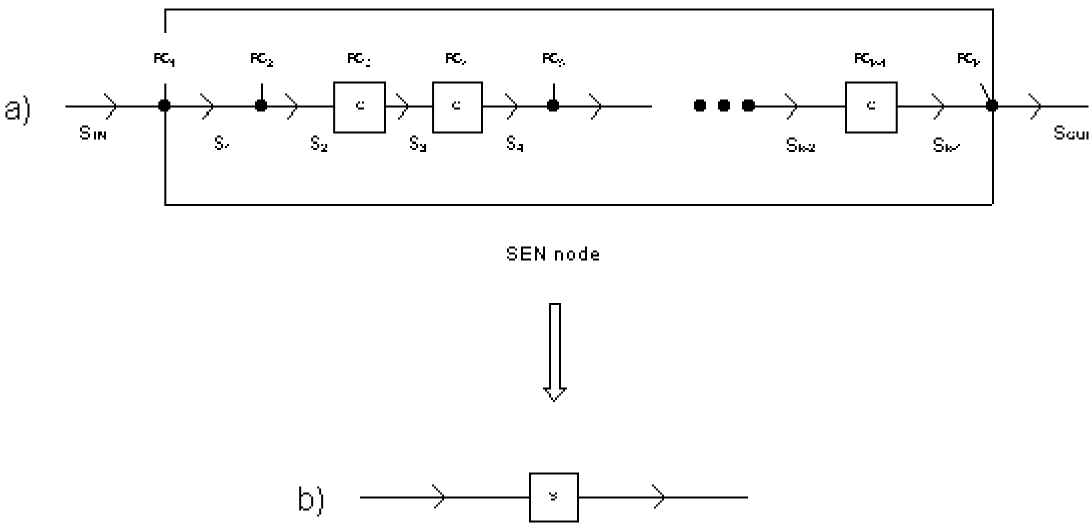

Figure 2: A general Sequential Excitation Network or SEN 'node' or 'gate' as a sequence of 'k' Feynman Clocks or CENs and 'k+1' signals. Information flows from left to right with a 'classical' lifetime equal to the sum of the lifetimes of the nodes and the inter-nodal signals (transit or decay lifetimes). The simplified causal network node notation is shown below.

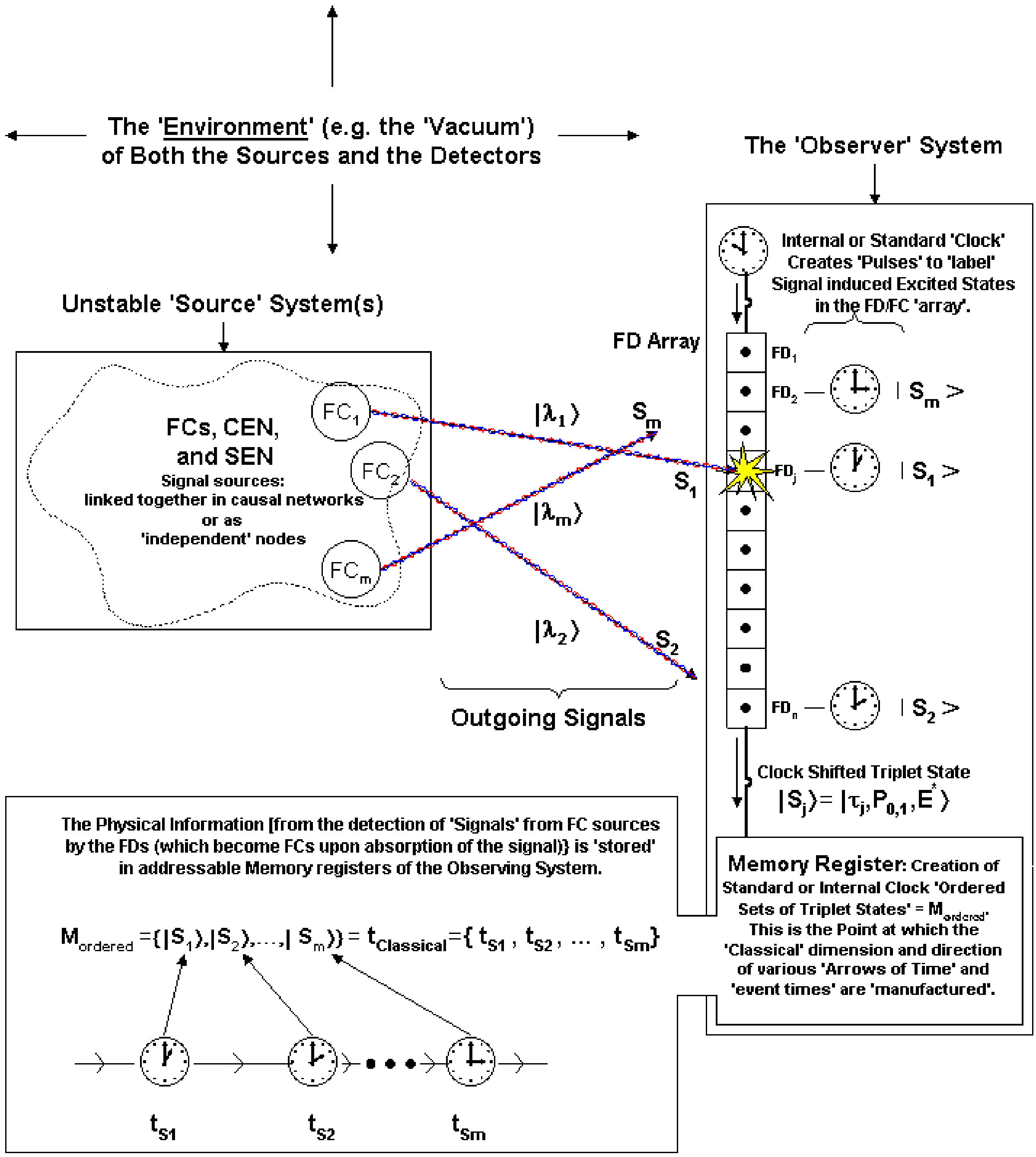

Figure 3: The Signal Mapping process in which 'event' signals originating in FCs are detected in FD arrays (the FD 'mode' of FCs in an array) creating states that are entangled with standard or internal clock pulse signals, event counter labels, and signal induced detector states (see Figure 4). These are stored in memory or processed further to extract the number that is used to label a 'time' with an event.

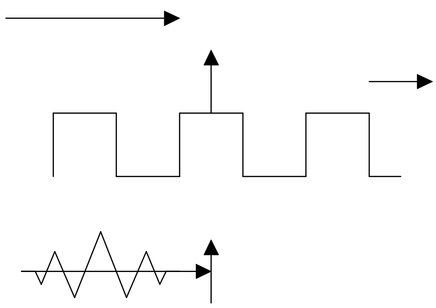

Figure 4: The creation of an entangled 'Triplet' State that couples a detector state with a standard clock pulse and a 'time' label (typically an integer or real number) generated by a pulse counter.

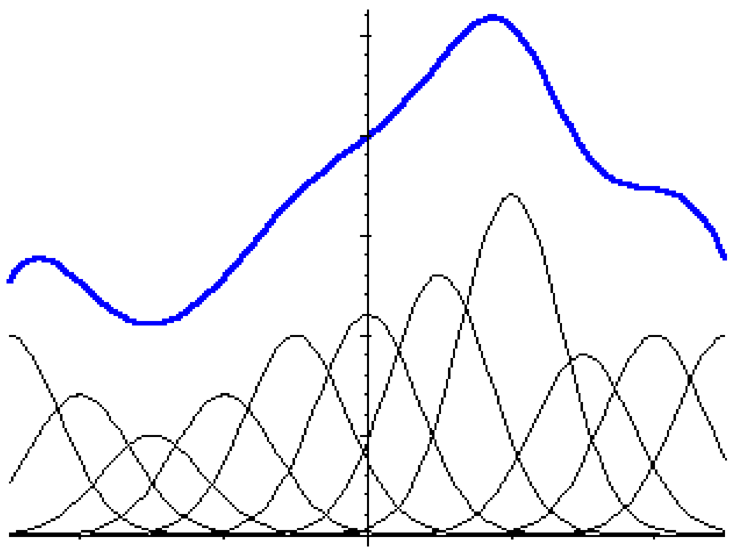

Figure 5: The 'Consciousness CE' (top curve) state due to a SEN progression of CEs through a neural network. This vertical 'now' axis represents the net CE state of the observer.

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