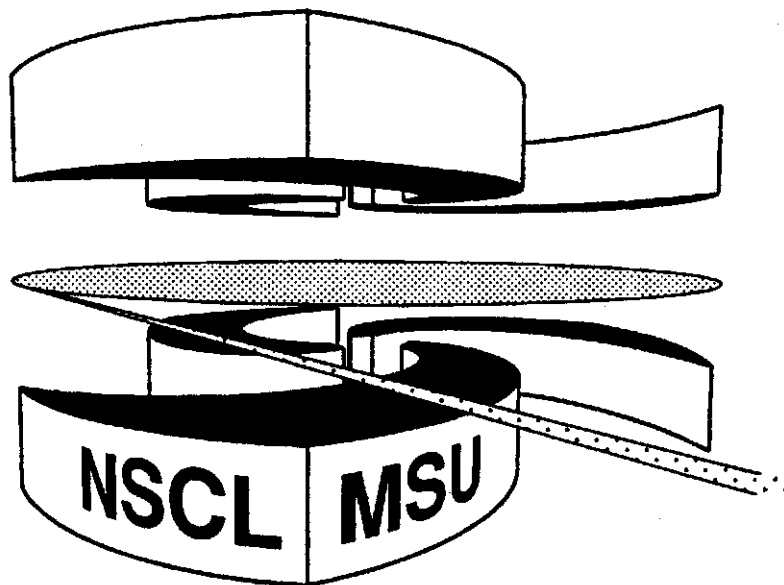


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**QUANTUM CLOCKS AND THE ORIGIN OF TIME IN  
COMPLEX SYSTEMS**

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# **Quantum Clocks and the Origin of Time in Complex Systems.**

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## Abstract

The origin and nature of time in *complex* systems is described with a special and a general theory of time. The special theory of time describes quantum *clocks* and their role as sources of signals (e.g. decay or collision products). The method of Feynman diagrams is used to define a Feynman *clock*. The general theory of time describes *networks* of quantum or Feynman clocks and their signals. These networks form the basis of evolution in complex systems.

A temporal correspondence principle describes *temporal phase transitions* from *collective excitation* to *discrete* n-sum representations of quantum clocks in a network. *Temporal phase transitions* mark the emergence of classical properties of systems such as *irreversibility*, *entropy*, and *thermodynamic arrows* of time in the evolution of the universe.

The general concept of *time* is translated into the lifetimes of unstable configurations of matter. The application of the special and general theories of time to quantum cosmology are discussed. (Revised February 20, 1999).

**Keywords:** The Problem of Time, the Arrow of Time, Time asymmetry, Entropy and Time, Collective Excitations, Time Measurement, Atomic Clocks, Many-Body Problem, Complexity and Nonlinear Systems, **Fractal** Time, Cellular Networks, the Wheeler-Dewitt Equation, Instantons, and Quantum Cosmology.

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## 1 Introduction

Time is one of the most important features of our changing world. The cause and effect relationship between events is thought to be guided by irreversible 'arrows of time' pointing from 'what was' to 'what is' and then to 'what will be'. These irreversible changes define the course of our lives and the evolution in the world around us. The *cause* of this change and the time associated with it is one of the least understood aspects of our universe. In spite of this lack of understanding about the origin of time we have developed 'quantum' or atomic clocks to a very high degree of accuracy [1], [2]. We use them to 'measure' change, control our activities and define our perceptions of reality.

Time is often viewed as a 'parameter' in the description of dynamic quantum systems [3]. As a parameter 'time' does not have the same properties as other quantum observables. In general relativity time is converted into a 'spatial' measure of the distance between events. This spatialization of

time arises when two distinct causally connected events are mapped onto separate hypersurfaces where the 'time' between the events is transformed into a 'distance' (*lapse function*) interval [4], [5]. The *time* created in this way implicitly assumes the result (directionality of time) that is to be proved ("petitio principii"). This paradox can be resolved by *defining* time as a *lifetime*.

The quantum world is the *source* of all the irreversible changes we observe. The *special theory of time* is based on the finite *lifetimes* of *unstable* quantum systems or *quantum clocks*. Quantum clocks may be created from the decay of a particle or the collisional interactions of particles in a volume of space  $V_{qc}$ . The lifetimes of these systems can be calculated using the methods of *Feynman diagrams*. These systems will be called *Feynman clocks*.

'Unstable' applies to any *isolated* system (quantum or classical) in an excited, perturbed or non-equilibrium state. The decay of an unstable system is *caused* by the asymmetric distribution of its masses and charges under the influence of repulsive and attractive fundamental interactions (e.g. strong, electromagnetic, weak, gravitational forces or their combinations at high energies in the early universe). An unstable *discrete* initial state decays to another discrete reconfiguration state from within a *continuum* of possible states [6]. This new state of the system may subsequently decay as part of a chain reaction. These chain reactions form the basis of *networks*. Networks map the evolution of complex systems as sequences of causes and effects. A set of *axioms* define the properties of Feynman clocks. In modified *cellular networks* [7] the vertices are Feynman clocks and the arcs are signal trajectories. With the following substitutions, Quantum or Feynman clocks for nodes and Signals for bonds (along with modifications of the assumptions of the space-time picture; see axioms), the Cellular networks of M. Requardt [8] provide an excellent mathematical framework for the exploration of the evolution of complex systems. These *Feynman networks* are used to develop a *general theory of time* that describes the *emergence* of *macroscopic lifetimes* in *complex systems*. Once the axioms are applied, the tools already developed by others for dealing with these networks can be applied to model *message* (i.e. information content of network signals) transmission in many body networks [9].

The decay process may also result in shape or positional changes of the reconfigured system with resulting signals in the form of *images*. The image can be the combination of *emitted* and *scattered signals*.

Reconfigurations of macroscopic systems can be detected as changes or

transitions in *thermodynamic* coordinates such as temperature, pressure and volume changes, etc. The lifetime of the states associated with these thermodynamic transitions is determined from the network of  $n$  quantum clocks acting together as either a single *collective quantum excitation* or a classical sequential sum ( $n$ -sum) of clock and signal lifetimes. The *temporal correspondence principle* determines which description is needed based on the magnitude of the 'action' for the system and the strength of the *coupling* between the quantum clocks. A *temporal phase transition* occurs when a complex interactive system in a collective excitation state *decouples* into a set of distinct uncoupled quantum clocks. The transition may be created by increased spatial separation of components due to a change in the potential energy between clocks. At a *critical distance* the clocks then decouple. A *critical energy* for system may be reached by energy losses translating into decreased interaction strengths between clocks. The decay of a phonon state resulting in system energy loss through the scattering of a signal can return a system to a decoupled state.

The largest example of a quantum clock may be the universe. Its 'decay' from an unstable state of extreme high energy is the 'first cause' for the creation decay products such as matter, space (the vacuum), and the complex evolving systems we observe today (see Section 5).

## 2 Quantum Clocks

The special and general theories of time based on quantum clocks in networks begins with the following axioms:

**Axiom 1** *A clock is an unstable system or source that decays with a finite lifetime.*

**Axiom 2** *A quantum clock is a system that requires a quantum mechanical description. This occurs when the 'action' (energy  $\times$  time) of the system is of the order of Planck's constant ( $\hbar$ ) [10].*

**Axiom 3** *Clocks emit or produce signals when they decay. Signals can be detected by absorption in another system which may become unstable resulting in the creation of another signal. An unstable system can also become stable with no further signal creation.*

**Axiom 4** Two types of time are associated with quantum clocks. **Intrinsic time** is the sum of the **decay lifetime** of an excited state of a **clock** and the **initialization lifetime** of the preparation or reconfiguration process that sets up the excited state of the clock. The initialization lifetime is the lifetime of the **reconfiguration message** created in the detector by its carrier signal. Note: decay lifetime is used interchangeably with intrinsic lifetime henceforth unless otherwise noted. The other time is the **signal lifetime**. This is the lifetime starting with the creation of the signal by the source and ending with its absorption at a detector. This is equal to the classical translation time of an object or signal in space.

**Axiom 5** Sources may be created by collisions of particles or the merging of two or more systems. The decay products connect emission sources to detection sites with signals that form a **network**.

**Axiom 6** Clocks may be **reset** to an unstable configuration by **detection of signals**. **Feedback** can reset a system many times exhibiting cyclical **self-regulation**. Regular repeated detection of signals is the basis for a **standard clock**. The number of reset-decay cycles for a clock can range from 1 to infinity. A **zero order clock** is a system that decays once and is not reset (e.g. the initial state of the universe).

**Axiom 7** There are two '**arrows of time**'. The **intrinsic arrow** always 'points' or maps energy changes causing the decay of **unstable states** to lower energy **decay states**. This is the lifetime associated with network **vertices**. The **signal arrow** always 'points' from the **source system** to a **detector system** (or **sink** in the case of empty space). This is the lifetime associated with the signals or **arcs** connecting vertices in network.

**Axiom 8** For networks with  $n$  vertices and  $n$  arcs, the total lifetime or  **$n$ -sum lifetime** is a **classical sum** of the lifetimes for the individual clocks and signals acting **sequentially**.

**Axiom 9** The '**collective excitation lifetime**' is a **quantum** description [11] of a system of  $n$  quantum clocks acting **collectively as a single unstable quantum system** (e.g. phonons, plasmons, etc.).

**Axiom 10** The  **$n$ -sum** and **collective excitation** descriptions make a **temporal phase transition** when the signal path distances or **bond energies** between quantum clocks reach critical values. At this scale the **temporal**

*correspondence principle* defines the transition boundary conditions for **decoupling of a collective excitation quantum clock into an  $n$ -sum set of quantum clocks**. Isolated and collective quantum clocks along with their signals can create complex macroscopic networks with classical temporal features.

It is important to note that in general, interpretation of the information content in signals involves comparisons with **standard clocks**. The lifetimes of unstable signal generating systems are 'measured' through a process of **signal mapping** to a standard (quantum) clock. Note that  $\hbar = c = 1$  unless they are expressly shown in the following equations.

### 3 The Special Theory of Time

The quantum clock is the building block of all macroscopic and large scale structures in the observable universe. A simple quantum clock is described using **time independent perturbation theory**, **Fermi's Golden Rule**, and a **time-independent Hamiltonian** transforming a **discrete resonantly coupled (excited) state** to another state from within a **continuum** of the **possible reconfiguration (lower energy) states** after decay. The initial discrete state decays **irreversibly** with a **finite lifetime**. This is the point at which directional causality appears.

Two important points are made here. First a **time independent process** creates a 'time' which for a quantum clock is the **lifetime** of that process. The key to this **dimensional conversion** of the **energy-momentum reconfiguration** of a quantum clock to a **temporal representation** is **Planck's constant**,  $\hbar$ . This dimensional conversion represents the subtle connection between temporal irreversibility of complex reconfiguration processes and the interactions of energy and matter.

The second point is that the **continuous nature** of the set of possible final reconfiguration states **causes the irreversible decay**. The **intrinsic arrow of time** is directly the result of this resonant coupling of the initial state to the continuum. The **finite lifetime** of the initial state is *caused* by this coupling to another state of the **same energy** in the continuum set. This coupling to states of **different energy** causes the **energy shift**,  $\delta E$ , in the initial discrete state energy. This shift defines the location of the center ( $E_{discrete} + \delta E$ ) of the *Lorentzian energy distribution* of the final states after



decay. This distribution maps the dispersion in the energy of final states from which the probability for the system to be in a given reconfiguration state is determined. The *full width at half maximum* of this distribution is  $\Gamma$ . The **lifetime** of this process is the *inverse* of the width of the final Lorentzian energy distribution (see Complement D<sub>XIII</sub> in [6] for details of this description):

$$\tau = \frac{\hbar}{\Gamma} \quad (1)$$

This simple decay lifetime is generalized for the many-body problem by looking at the *momenta* of the components of quantum clocks. In this case a decay process begins with the initial momentum,  $\mathbf{p}_0$ , of the discrete unstable state. The general equation for the intrinsic lifetime [12] of this isolated quantum clock is given by:

$$\tau_{qc} = \frac{\hbar}{\Gamma_I} \quad (2)$$

$$= \frac{\hbar}{\int \cdots \int_{q_n \cdots q_1} \left[ \frac{V^{n+1}}{(2\pi)^{3n+4}} \mathbf{P} \cdot |\mathbf{M}_I|^2 \delta_4 \left( \mathbf{p}_0 - \sum_{j=1}^n \mathbf{q}_j \right) \right] dq_1 dq_2 \cdots dq_n} \quad (3)$$

where  $\Gamma_I$  is the decay rate (in *MeV*).  $V$  is the 3-space volume of the quantum clock. The permutational factor  $\mathbf{P}$  keeps track of the number of identical particles produced by the process. The reduced matrix element,  $\mathbf{M}_I$  is equal to the usual  $S$ -matrix element, apart from the  $\delta$ -function for overall energy-momentum conservation. The index  $I = s, em, w, \text{ or } g$  represents the strong, electromagnetic, weak, or gravitational forces while including the possibility of *coupled* fundamental interactions (e.g. the electroweak or GUTs epoch unified interaction in the case of high energy states in the early universe). The  $\mathbf{M}_I$  matrix contains all the physical information for the decay process including the way in which the fundamental interactions drive the reconfiguration. If the reconfiguration term:

$$\mathbf{M}_I = 0 \quad (4)$$

then the 'lifetime' of the transition is *infinite* (i.e. no decay occurs). The initial momentum for the unstable system is  $\mathbf{p}_0$ . The momenta of the decay products (*signals*) are  $\mathbf{q}_j$ .

The lifetime,  $\tau_{qc}$ , of a decay transition between configurations represents the intrinsic 'tick' (lifetime) of the clock. This 'tick' is transformed into state

information carried by the *signal* produced in the decay process. An example of this process is the creation of the universe from the irreversible decay of an unstable initial *non-stationary* state due to an 'initiation' perturbation (quantum fluctuation) in the total energy (see Section 5).

A general description for the **intrinsic lifetime** of an unstable system produced by decay or **collisions** (a **Feynman clock**) is the same as above except that the initial state with momentum  $\mathbf{p}_0$  is a composite discrete unstable state *created* in the space of volume  $V$  by the interactions (collisions) of the incoming momenta  $\mathbf{p}_i$ . With the substitution

$$\mathbf{p}_0 = \sum_{i=1}^m \mathbf{p}_i \quad (5)$$

we have the **lifetime** for a **Feynman Clock** given by:

$$\tau_{fc} = \frac{\hbar}{\Gamma_I} \quad (6)$$

$$= \frac{\hbar}{\int \cdots \int_{q_n \cdots q_1} \left[ \frac{V^{n+1}}{(2\pi)^{3n+4}} \mathbf{P} \cdot |\mathbf{M}_I|^2 \delta_4 \left( \sum_{i=1}^m \mathbf{p}_i - \sum_{j=1}^n \mathbf{q}_j \right) \right]} dq_1 dq_2 \cdots dq_n} \quad (7)$$

where the  $\mathbf{q}_i$  are the signals (or scattered momenta). When using this method a Feynman clock is defined by the incoming and outgoing momenta in a specified volume  $V$  with *overall energy-momentum conservation*.

The outgoing particles of momenta  $\mathbf{q}_j$  (signals) created by a Feynman clock have a **signal lifetime** given by the distance,  $d_{q_j}$  (geodesic path length calculated with an appropriate metric for the space) traveled from the **source** to a **detector** divided by the propagation velocity,  $v_{q_j}$ :

$$\tau_s = \frac{d_{q_j}}{v_{q_j}} \quad (8)$$

### 3.1 Signal Paths Between Events

The incoming momenta in a Feynman clock are time-independent in an *operational or empirical* description of a system. An example of this is a spectrogram. Energies and momenta of photons are *determined* from the spectral distribution function created by interpretation of events recorded by a detection system. The *information* created after the *detection* of a set of spectral signals is causally and temporally independent of their sources.

For this reason the decay or signal momenta are treated as 3-momenta in a 3+0 space (without 'time'). The Minkowski 4-metric for a 3+1 spacetime geometry transforms from

$$ds_4^2 = c^2 dt^2 - dx_1^2 - dx_2^2 - dx_3^2 \quad (9)$$

to a 3-metric for the space alone:

$$ds_3^2 = dx_1^2 + dx_2^2 + dx_3^2 \quad (10)$$

since the *spatialized time term* ( $c^2 dt^2$ ) becomes 0 when transforming events into a *3-space* reference frame using the *lifetimes* of quantum clocks and their signals to map the evolution and reconfigurations of systems. This assumption applies to any metric that couples time to space. Relativistic corrections can be applied to these systems when the signal and decay 'lifetimes' are substituted for the relativistic or proper 'time' between **events**. The *locations* of the signal emission sources and signal detection systems in this time-independent 3-space are the *events* of conventional *spacetime*. The signals from these unstable systems provide the basis of causal connectivity between events (source and detector quantum clocks).

The intrinsic and signal lifetimes are real numbers associated with the vertices (events) and arcs (signals) of a causal network. By transforming the spatialized time term into a lifetime we can prepare the foundation for developing a "*background-free*" [13] theory of time. Time is neither a coordinate or dimension in this case but the magnitude of an intrinsic or signal lifetime originating from an unstable system.

## 3.2 Virtual Quantum Clocks and Signals.

A special case arises for a spatial scale (of the order of the Planck length or about  $1.6 \times 10^{-35}$  meters [13], [7]) where intrinsic lifetimes overlap signal or transit lifetimes. This occurs in the '*spontaneous*' creation of extremely short lived virtual particles (or 'universes') due to the Heisenberg uncertainty principle. The *lifetime* of one of these particles is the '*characteristic lifetime*'. An example of this form of particle creation occurs in a '*vacuum fluctuation*' in which an electron-positron pair is produced with a lifetime of approximately  $10^{-21}$ seconds (before decaying back into the *vacuum*).

For virtual particles with energy  $m_{virt}c^2$  which is less than the uncertainty  $\Delta E_{virt}$  in its total energy, the characteristic lifetime of this *virtual quantum clock* is given by:

$$\tau_{virt} = \Delta t_{virt} \approx \frac{\hbar}{\Delta E_{virt}} = \frac{\hbar}{m_{virt}c^2} \quad (11)$$

This is the time scale at which the characteristic lifetime and the signal lifetime merge if you consider the emergence of the particle out of the vacuum with velocity  $v_{virt}$  and its subsequent decay back into the vacuum as a signal along an trajectory of a finite distance,  $d_{virt}$ . The *virtual signal lifetime* would then be given by:

$$\tau_s = \frac{d_{virt}}{v_{virt}} = \tau_{virt} \quad (12)$$

This can be interpreted as a fundamental transition scale in which signals with enough energy ( $\geq \Delta E_{virt}$ ) can be distinguished from a source. It is also the energy at which information can decouple from a source and be *transmitted* as a signal.

## 4 The General Theory of Time

A general model of time is developed for complex systems composed of networks of interacting quantum clocks. With network theory [14] a quantum clock is treated as a vertex connected to another quantum clock by signal paths or arcs. The network model uses the method of Feynman Diagrams [12] to calculate lifetimes of states for complex systems approaching the classical scale.

Feynman Diagrams are modified by treating the incoming and the outgoing 3-momenta trajectories as *arcs* (signals) between *vertices* (clocks) in a space of volume  $V$ . The 'distance' between the clocks is given by the time independent metric above. The *lifetime* of the signal on the arc is given by a weight function.

The network in this case is a digraph  $\mathbf{D} = (\mathbf{V}, \mathbf{A})$ , where  $\mathbf{V}$  is the set of vertices, and  $\mathbf{A}$  is the set of connecting arcs. The *signal lifetime weight function*  $\tau_s : \mathbf{A} \rightarrow \mathfrak{R}$  maps the arc set  $A$  to the set of real numbers,  $\mathfrak{R}$ , giving the *lifetimes* of the signals between the vertices.

The quantum clocks represented as the vertices in the set  $\mathbf{V}$  have an *intrinsic lifetime weight function*  $\tau_{qc} : \mathbf{V} \rightarrow \mathfrak{R}$  that maps *intrinsic lifetimes* to the set of real numbers. This weight function is just the inverse of  $\Gamma_{qc}$  (or  $\Gamma_{fc}$ ) calculated for each quantum (or Feynman) clock as calculated above.

The separation distance  $d_{i,i+1}$  is found from the *metric function* defined by  $\mathbf{d}_{metric} : \mathbf{A} \rightarrow \mathfrak{R}$ , where

$$\mathbf{d}_{metric} = \int_{\mathbf{r}(v_i)}^{\mathbf{r}(v_{i+1})} \mathbf{r} \cdot d\mathbf{r} \quad (13)$$

is the path distance between vertices as travelled by a signal. Signal trajectories may be non-Euclidean in case of the *curvature* of *space* due to massive objects. The signal lifetime is equivalent to the intrinsic lifetime of an unstable clock whose decay is a spatial ('orbital') transition.

The *out-degree* at vertex  $\nu \in \mathbf{V} = \{\nu_1, \nu_2, \dots, \nu_n\}$ , is the *number* of arcs (signals such as decay products) directed away from the quantum clock. The *in-degree* of a quantum clock is the number of arcs (signals creating or triggering a quantum clock) directed towards the vertex (detector or scattering space). In general these two are not equal but the sum of the  $j$  **out-degree energy-momenta**,  $\mathbf{q}_i$ , and the sum of the  $k$  **in-degree energy-momenta**,  $\mathbf{p}_i$ , are equal since total energy-momentum for each individual quantum clock is conserved:

$$\left[ \left[ \sum_{i=1}^j \mathbf{q}_i \right]_{out} - \left[ \sum_{i=1}^k \mathbf{p}_i \right]_{in} \right]_{\nu \in \mathbf{V}} = 0 \quad (14)$$

## 4.1 Collective Excitations in Networks

The equation for a collective or elementary excitation (phonon) lifetime of a *coupled* or *continuous* set of n-quantum clocks in a network is:

$$\tau_{ce} \equiv \frac{\hbar}{\Delta E_{ce}} \quad (15)$$

where  $\Delta E_{ce}$  is the broadening (dispersion) in the energy levels  $E_{ce}$  of the elementary excitations based on Heisenberg's uncertainty principle for the phonon model (see page 345 [11]). The set of coupled clocks in a collective excitation have a non-zero potential represented by a *bond*. Collective excitations of sets of coupled quantum clocks acting as a single unstable quantum system result in signals (e.g. Brillouin scattering). The classical analogue is the sound wave.

When the *coupling distance* associated with the *bond* [7] is exceeded then the collective excitation system *jumps* from a *continuous* system to a *discrete* system composed of a set of decoupled quantum clocks.

## 4.2 Networks of Discrete Quantum Clocks

The lifetime of *n-sequential uncoupled* or *discrete* quantum clocks within a larger network is the *n-sum lifetime*. For uncoupled set of clocks the potentials between them are zero. The sequence lifetime is given by:

$$\tau_{nsum} \equiv \left[ \sum_{C=1}^n \left( \frac{1}{\Gamma_C} \right) \right] + \left[ \sum_{s=1}^n \frac{d_s}{v_s} \right] = \left[ \sum_{C=1}^n \tau_C \right] + \left[ \sum_{s=1}^n \tau_s \right] \quad (16)$$

where  $C$  is the clock number (also the network *vertex* number),  $\Gamma_C$  is the natural width of the Lorentzian energy distribution of the final states after reconfiguration of quantum clock  $C$ . Between clocks  $C$  and  $C + 1$  the signal number is  $s$  (also the network *arc* number),  $d_s$  is the distance between emission and detection by a quantum clock, and  $v_s$  is the propagation velocity of the signal along the arc. The first term in the equation is the sum of *intrinsic lifetimes* and the second term is the sum of the *signal lifetimes*. The net lifetime,  $\tau_n$ , from clock  $C = 1$  to  $n$  is the lifetime of a signal propagating from clock 1 to clock  $n$ .

If  $n$  is not known then the emission of a signal appears to be created by a single system. This signal is not the result of the decay of a collective excitation of the system but represents the decay of the last clock in a chain in the network.

## 4.3 The Temporal Correspondence Principle

Coupled and uncoupled sets of quantum clocks are distinguished by the presence or absence of **bonds** respectively. The *critical bond distance*,  $l_{crit}$ , represents the scale at which a **temporal phase transition** occurs between the collective and discrete representations of quantum clocks (e.g. chain of coupled harmonic oscillators) in a network. This assumes a single bond length for the simple case of regularly spaced clocks in a network (e.g. crystals). For variations in clock separations (bond lengths) collective excitations can be treated as the superposition of spatially oriented phonons (w.r.t. the network reference frame).

Below critical separation distances, the bonds couple the clocks into a single system with quantized energies which can be regarded as a set of phonons. Above the critical distance, the clocks are decoupled and can act like discrete clocks in a network. At the critical distance the two representations overlap.

This is the **temporal correspondence principle** which states that the collective excitation and discrete n-sum representations allow the superposition of states at the critical bond distance.

A superposition of many different collective excitations can exist for a system. Rotational and vibrational states can occur simultaneously. A spectrum of collective excitations may occur if the substrate network of coupled quantum clocks can support it.

The critical bond length represents a boundary condition (i.e.  $l = l_{crit}$ ) at which the two representations meet. We have the following (weak form):

$$\tau_{ce} \iff \tau_{nsum} \quad (17)$$

where the double arrow indicates a phase transition. The two lifetimes are not equal if the physical phase transition from a coupled state to an uncoupled state is disjoint. In this weak case, the unstable intermediate transition state decays in a lifetime equal to the decay lifetime of the *last* excitation resonance that can be supported collectively by the network before the system decouples into a discrete configuration.

In the strong form of the temporal correspondence principle the transition is continuous at the critical bond length (at the boundary condition, the descriptions are 'equal'). This implies:

$$\tau_{ce} = \tau_{nsum} \quad (18)$$

where the lifetimes are equal. The physical meaning of the strong form is confused by the possibility of the superposition of phonon-like excitations in nearly discrete n-sum sets of causally connected clocks in networks. The dispersion in the lifetimes of superimposed collective excitations supported by the coupled network creates an uncertainty in the distinction between coupled and uncoupled states of the system.

#### 4.4 Functions of 'Time'

Virtually any *time* variable calculated as a function of *time-independent* parameters and observables can be *interpreted* as the *lifetime* of a *transition* between two (or more) states of an unstable system [15].

For example the classical time associated with the total energy for a two-

body central force (see eqn. 3-18 [17]):

$$\tau_{classical} = \int_{r_o(\varphi_0)}^{r_f(\varphi_f)} \frac{dr}{\sqrt{\frac{2}{m} \left( E_I(r) - V_I(r) - \frac{l^2}{2mr^2} \right)}} \quad (19)$$

can be interpreted of as an intrinsic lifetime for an 'orbital' clock possibly in a network. The mass,  $m$ , maps the reconfiguration transition of the system from an initial state  $\varphi_0$  to a final state  $\varphi_f$ . The 'lifetime' is evaluated at the limits of integration. The initial position,  $r_0$ , is a function of the initial excited state  $\varphi_0$  that 'decays' with a finite 'lifetime',  $\tau_{classical}$ , to the final orbital radius,  $r_f$ , with a final state  $\varphi_f$ . The 'signals' created by this clock are the *images* of the orbital transitions of the mass.

#### 4.5 Fractal Time, Feedback, and the Messages in Signals

*Signals* generated or caused by these transitions take many forms ranging from photons and elementary particles to nerve impulses to the expansion of the universe. The detection of signals by systems within networks is essential for dynamic processes such as life. *Detection* in a broad sense becomes a *cause* for the evolution of complexity. The emergent patterns of coupled and uncoupled quantum clocks in a network may have fractal like behavior mapping *fractal time* [18], [19], [20] within emergent stochastic resonance structures [21].

It is assumed in these models that the signals in these systems do not interact with each other. If the signals interact then *signal quantum clocks* are created by these 'collisions'. These clocks expand the network size (i.e. number of effective clocks in the sequence) and complexity. The treatment for interacting signals in networks is described elsewhere [9].

The *n-sum representation* emerges as the components creating collective excitations decouple into discrete non-interacting clocks. The decoupling may arise from increased spatial separation, increased 'action', or changes in the physical properties and complexity of the distinct clocks. The decoupling can lead to the emergence of increased system complexity and *feedback* [22]. *Feedback signals* allow system configurations to be reset or initialized to maintain dynamical or evolutionary processes. The lifetime associated with



the feedback signal added to the lifetime of the signal processing and generating system (e.g. standard clocks, cells, engines, etc.) gives the net feedback cycle lifetime. Cells are examples of systems with many superimposed levels of feedback in which the quantum and classical models overlap in complex chemical and metabolic networks (pathways).

These systems may be non-linear. In such cases, they appear to be cyclical for a finite number of 'cycles'. As the behavior of the system diverges from cyclical feedback, fractal patterns of cause and effect can emerge. Complexity with deterministic chaos may lead to the emergence of *fractal lifetimes* for the evolving signal pathway patterns in networks.

For a network composed of quantum clocks, the lifetime of an unstable configuration is determined by the set of discrete (uncoupled) and continuous (coupled) clocks acting as a single composite system. The *messages* in  $n$ -body networks [9] are carried by signals from clock to clock. They contain the information about reconfigurations and signal generation processes of subnetworks.

Networks with feedback form the foundation of 'memory' structures. Memory structures process signals and generate messages containing repeatable temporal and configuration information. *Message propagators* in these temporal networks define the signal transmission process from emission to detection and can be mapped back to their source Feynman propagators at the quantum clock level [9].

Messages can also create *reconfigurations* in their targets by the detection of the carrier signal (see section 2, axiom 5). They can encode and create new temporal structures by modification of the detector systems physical properties. The *lifetimes of the messages* are then the *initialization lifetimes* of the reconfiguration process of the detector.

## 5 The Universe as a Quantum Clock

An example of the 'largest' (although originally the 'smallest') quantum clock is the Universe [24]. Treating the initial state of the universe as a quantum system with an initial wave function,  $\Psi_{U_0}$ , the subsequent evolution is described by a modification of the general features of the Schrödinger wave equation. An example of this modified equation is the **Wheeler-DeWitt equation (WDW)** [26], [25], [23], [29] given by:

$$\mathbf{H}_{wdw} \Psi_{U_0} = 0$$

based on the presumed existence of a minisuperspace. There is some questions about the validity of this assumption [27]. If this equation is modified for the case of **pure decay** of a non-stationary discrete initial state coupled to a continuum of decay states then we have:

$$\mathbf{H}_{wdw} \Psi_{U_i} = \mathbf{E}_i \Psi_{U_i} \neq 0$$

where  $\Psi_{U_i}$  is the time independent wave function for the universe,  $\mathbf{H}_{wdw}$  is the Hamiltonian, and the energies,  $\mathbf{E}_i$ , represent decay transitions. The *Big Bang* can be treated as a **zero-order quantum clock** with a finite lifetime (e.g. for the series of temporal and physical phase transitions such as in inflationary scenarios). This *initial state* represents the '*first cause*'. The initial state is *not a metastable* state. The inflationary phase is not quantum tunneling, but a true decay process with decay products (e.g. mass-energy structures mapped with an evolving spatial distribution function). The *pure decay* of the initial state of the universe can be treated as a *Feynman Clock* permitting the use of *modified* Feynman diagrams. The modification is that 'time' is omitted as a dimension in the diagrams, but the 'lifetimes' associated with the trajectories of signals emitted by Feynman clocks remain. **Signals** (such as the microwave background radiation) result from the interactions between particles and energy mediating the reconfigurations of the universe.

The '*instanton*' model proposed by Hawking and Turok [28] is similar to the idea of a 'pure decay' except that time is still implicitly coupled with space. Spatialized time remains and the nature of causality is masked by time-implicit solutions to the conventional Wheeler-DeWitt equation.

Time independent Feynman diagrams can then be used to map solutions to the Wheeler-DeWitt equation. Evolving structures in the early universe are marked by temporal phase transitions (e.g. decoupling of fundamental interactions) along with global configuration changes. The implications of these proposals with examples of modified Feynman Diagrams will be explored in a future paper.

## 6 Conclusions

It has been speculated that 'time' in the conventional sense is a *lifetime* associated with reconfigurations of systems and networks of systems. By partitioning 'time' into intrinsic and signal lifetimes, a general theory for the description of complex temporal processes can be developed using the results of network and systems theory [9], [7].

The special and general theories of time accommodate all scales of phenomena from micro to cosmic. The thrust of this exploration has been to look at time in a new way. The result may be a shift in a philosophical viewpoint rather than a modification of existing paradigms. It is hoped that these ideas will bring a new approach to looking for a solution to the 'problem of time'.

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