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# Supporting Concepts for Understanding Time

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**Abstract**

Understanding the nature of time requires more than philosophy and geometry. Past, present, and future are defined through event sequences and state transitions. Communication and the construction of geometry are key elements for constructing time. Special and general relativity bring together the effects of communication and geometry in understanding time. Quantum theory and particle-to-force relationships underscore the need for precise definitions of time. Time and information flow are inextricably entangled. Significant challenges lie ahead for physics, time, and information science.

**Keywords:** Time; Relativity quantum theory; State-machines; Information theory

## Introduction

Philosophers and scientists have struggled with the concept of time throughout the ages. What are the foundations upon which concepts of time can be constructed? Significant work, such as has been done in this area, but much more needs to be done, specifically regarding the nature of state transitions and metrics associated with communicating and recording exchanged information. Much confusion and difference of opinion still exists in physics and philosophy communities. Surveys [1] and popular treatises [2,3] bare witness to continuing interest in Time. Here we examine some points of confusion and offer one other solution based on a logic foundation. This provides a simple, straightforward, unpretentious foundation for a theory of time that unifies perceptual science, information theory, control theory, relativity, and quantum theory. The range of subject matter for background is not contained in standard curricula [4]. The theory does offer resolution to some fundamental questions and short-comings of presently accepted foundations. Understanding is enhanced by an understanding of the physical nature of information [5]. This paper does not pretend to be a formal proof, but a series of compelling observations, providing a very compelling foundation for a theory of physics.

### The ambiguity of time

The equations of physics provide no compelling reason for why we feel as though we live in the present, remember the past, and do not "remember" the future. For example, the proper-geometric-time of relativity, as, $\tau_2 = -X_0^2 + \sum_{i=1}^{i=3} X_i^2$ accounts for the present only by designating the intersection of light-cone axes as the present. No explanation emerges as to why we live in the present and remember the past. The second law of thermodynamics cites entropy-increase to explain why time moves from the past towards the future, but self organizing systems tend to counter this approach. We can substitute -t for t in the equations of Newtonian dynamics and achieve apparent validity. We can view Feynman diagrams of particle interactions from any angle of the page and seemingly arrive at valid particle interactions. All of these approaches leave us with the uncomfortable feeling that we are missing a significant part of the picture. Quznetsov illuminates the heart of the matter by showing that time does not reverse, because of the nature of event recording. However, we need to take a step further back into fundamentals [6].

### Solutions for ambiguities

Entropy increase was a meaningful, valiant effort at reducing the ambiguities of time direction, however, this is not enough. Does complexity always increase in nature? There is something else at the heart of the issue. Entropy and complexity-increase skirt around and touch one critical phenomenon -- information-flow Shannon's metric, $I=\Sigma_i p_i \log^2 p_i$ [7], explains the link, showing that increased complexity, in the form of many equal probabilities $p_i$ of events, requires more information, I, for exposition. On its surface, information theory does not reveal the nature of time. Digging deeper shows us that the truth is deep within. Follow the path persistently and find that information-flow requires source and sink, that is, a transmitter and a receiver. Therein lies the secret of time.

What is Time but a sequence of events? To utilize this concept, we postulate or acknowledge individuals x in the set of entities $E, \exists x | x \in (E)$ having attributes $a_i$ in a set of characteristics C with values $v_i$, such that energy pattern action Δ(energy) is implied by a change in attribute value.

$$\forall a_i \in C_x \left(\exists\left(\Delta a_i = \left(v_j \text{-}> v_k\right)\right) \supset \Delta(\text{energy})\right)$$

We define the collection k of attribute values as the *state* $S_{xk}$ of the entity x, as:

$$S_{xk}=(v_i(a_1), v_j(a_2),..., v_m(a_n)).$$

A change of state becomes:

$$\left(\Delta_{k->m} S_{xk} => S_{xk}\right) \supset \left(\exists a_n \in C_x \middle| \left(S_{xk} = \left(V_i\left(a_1\right),\right.\right.\right.$$

$$v_j(a_2),...,v_g(a_n),...,v_m(a_n))=>$$

$$(S_{xm}=(v_i(a_1), v_j(a_2),...,v_h(a_n),...,v_m(a_n))).$$

The cause of a state change, or value change $V(C_x a_i)$ of a in C, is a *stimulus* signal $\sigma(a_m)$: $(v_i\text{->}v_k)$, so that:

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$$\exists(\acute{o}(a_m):(v_i - v_k), v_i, v_k \in V(C_x a_m))$$
$$\&\left(S_{xk} = \left((V_a(a_1), V_{a+1}(a_2), .. V_i(a_h), ..., V_m(a_n)\right)\right)$$
$$\&\left(S_{xl} = \left((V_a(a_1), V_{a+1}(a_2), .. V_k(a_h), ...., V_m(a_n)\right)\right)$$
$$\supset (\sigma(a_m):(S_{xk} -> S_{x1})$$

Further, we define a *response* $R_{xkj}(S_{xk} \geq S_{xl})$ as any signal (if it exists) resulting from a transition from state $S_{xk}$ to state $S_{xl}$ within the entity x. We postulate or acknowledge that some response exists for some state transition of some entity x, i.e.

$$(\exists x \in (E) \& \exists R_{xkj}) | \sigma(a_m):(v_j(a_m) -> v_q(a_m)) \supset (R_{xkj}(S_{xk} -> S_{x1}) = R_{xkj})$$

We now find, we can define a *state machine* i,

$SM_i \equiv <\Sigma, S, s_0, \delta, F>$ as an entity having a set of states $S=S_{xk}=(v_i(a_1), v_j(a_2),...,v_m(a_n))$ identified by values v of attributes a, a set of stimuli from an alphabet $\Sigma=\sigma(a_m):(v_i \geq v_k)$, a start state $s_0$, a final or accepting state $F=S_{xl}$, which generates a response $R_{xkj}(S_{xk} \geq S_{xl})$, and a transition function δ defined by a state transition table $T_x:(\sigma_i \text{ X } S_{xi})$.

This is a standard model described in computer science texts, for example [8]. Particles are described as state machine using notation such as $<q_F|e^{-iHT}|q_I>$, for the path of a photon as it transitions from location-state $q_I$ tolocation-state $q_F$.

*We define Time Passage Δt as any sequence of state transitions $S_{i..k=}(s_i, s_{i+1},..., s_k)$ within a state machine entity.*

Before we can advance very far, we must investigate the stimulus signals, $\sigma(a_m):(v_i \geq v_k)$, which cause attribute-value changes, and thus state transitions. The concept is abstract, but, in reality, any such stimulus is patterned energy, similar to, for example, a patterned wave-form $\Psi=\Sigma_j \xi_j \exp(i2\pi k_j \omega_j t)$. The patterned energy produces a state-transition, thus generating Time. The patterned energy must be of precise nature, called the input alphabet of the state machine, such that the specific present state is changed to a specific subsequent state. Any such patterned energy is coded information in the information-theoretic sense. Information flow generates time through state transition sequences. When an entity is stimulated by patterned energy, such that state-transitions occur within the entity, we say the entity has observed the event producing the stimulus, and effect of the stimulation is called the observation.

## Present, Past, and Future

The highest priority in a theory of time is establishing the meanings of past, present and future. This becomes possible using the concepts of state-machines and state-transitions in response to stimuli.

### Present

As patterned-energy causes attribute-value changes, state-transitions respond to the actively changing stimulus environment. During this process, the entity is experiencing the present. We define the present as the on-going sequences of state-transitions. As we will see below, many definable activities are taking place in the present, such as recording event sequences, exercising pattern recognition algorithms, and generating cause-and-effect scenarios. The present is happening now.

### Past

Generating the past requires an enhanced state-machine. To generate recordings of state transition event-sequences, the machine must have memory. We define a state-machine with memory $SMM_i$ as a state-machine $SMM_i \equiv <\Sigma, \Gamma, S, M, \omega_c, \omega_s, \omega_r, s_0, \delta, \omega_0>$ such that an input-stimulus-sequence is processed and a corresponding output-response-sequence is produced, where

Σ is the input stimulus set,

Γ is the output response set,

S is the set of states within the machine,

M is a set of reserved states which can preserve a record of input sequences,

$\omega_c$ is a compare function whereby two preserved records in M can be compared.

$\omega_s$ is a save function whereby machine state can be saved in M.

$\omega_r$ is a recall function whereby a preserved record can be retrieved from M.

$s_0$ is an initial state.

δ is a state transition function, δ: S x Σ ≥S, and

$\omega_o$ is an output function, ω: S x Σ ≥ Γ, or ω: S ≥ Γ.

Strictly speaking $\omega_c$ and $\omega_r$ are not required to produce history, but they are required to perceive or make use of it. Then we define *the past* as the collection of records, which have been recorded by our extended state machine with memory.

There are many enhancements, which could augment the capability of our state machine- with-memory. For example, one could add a capability to recall sequences from memory and compare them. When sequences match we could generate a response called recognition. Also, we could provide a cycling clock mechanism within our machine, so that time stamps could be recorded with event sequences, thus generating history. A scenario is defined as a well-defined sequence of events within a record. Enhancements can be postulated which compare and recognize scenarios. History and scenarios are recordings of observations.

Using our model, memory records are not required for the existence of time, but state transitions are. Some would argue, with some validity, that the state-transition structure constitutes memory records. Being concerned with foundations, we prefer to discriminate. Many particles do not record their history as they progress through a series of state transitions. On the other hand, trees certainly do.

### Future

Generating the future requires a further enhanced state-machine-with-memory. Our machine must have a set of state-transitions forming a sub-machine such that it can collect from memory a set of sequences which are nearly the same, but diverge at a specific event. The device must be able to select the most likely subsequent event for a specific event. The most likely event for the subsequent event is called *the future*. The predicted future becomes the most likely subsequent scenario, which is verified or not by observation. The predicted future is not guaranteed to happen. In some cases, the comparison engine can build generalized models and record them, and the result is called cause-and-effect analysis. Using this model, it becomes obvious that the future is simply determined as it unfolds. There is predestination only in the sense that long chains of events conspire to constrain subsequent events. This is not to say that events can not be predicted with a great amount of precision. It does say that events following a long chain have

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their associated probabilities. Often there are too many possibilities for subsequent stimuli, making prognostication very difficult. A Kalman Filter, as is used in radar to predict target trajectories, is a prime example of statistical scenario prediction.

Thus we have past, present, and future with specific definitions and implications. In particular, even though state-transition sequences can reverse, time is not reversible. There is no going back in time, as is permitted by block-time theories like General Relativity, and there is no "traveling into the future", since the future is not a geometric place. However, time is highly relative, and it depends to a great extent upon geometry, which is also constructed by our state-machine. We ultimately find out that, for the most part, special and general relativity actually work out in the end (to our great relief).

## Communication and Geometry

Communication of information and the construction of geometry are key to understanding what time is and how it works. Quznetsov and others have addressed the issue of time, information-flow, and geometry, however, we must go a bit deeper into the foundations [9]. How do entities generate and respond to patterned energy flow? Since all entities use time-delay and distance in some way, how is distance determined by an entity with only a local perspective? We must go beyond clocked and recorded data-streams.

### Communication

Up to this stage, our state-machines could be singular and isolated, responding to any stray energy fluctuations from within or from external sources. Communication requires at least two members, $x_1$ and $x_2$, of the set of entities (E), as in:

$$\exists x_1, x_2 \in (E) | x_1 \neq x_2 \ .$$

Between two such machines, there must be a medium through which patterned energy can travel. The medium could be another state-machine or a linkage through which energy can propagate from one to the other. For communication, we need transmitter and receiver mechanisms composed of transducers, encoders, and decoders.

**Sensors and emitters:** First, we must postulate, observe, or invent the existence of transducers. A *transducer* is defined as a device, which can transform patterned energy from one form to another. A photo-electric device stands as an example, since it changes electro-magnetic radiation patterns into electrical current patterns. A flashing light converts mechanical keying into electro-magnetic radiation patterns. For our foundation we say there exists a member, tr(k→l), of the class of entities (E), such that it converts patterned-energy p, in the form $\Psi_k$, of type k, into an equivalent patterned energy p in the form $\Psi_l$ of type l, as in:

$$\exists \mathrm{tr}(\mathrm{k} \to \mathrm{l}) \in (\mathrm{E}) | \mathrm{p}(\Psi_\mathrm{k}) \to \mathrm{p}'(\Psi_\mathrm{l}).$$

We must postulate, observe, or invent the existence of encoders and decoders. A *decoder* is an entity, $\mathrm{de}(\mathrm{p}' \to \alpha)$, which changes (as best it can) an energy pattern p into an alphabet sequence α, in the target state-machines stimulus set $\Sigma_x$, so the target state-machine x can react or not with an appropriate state transition. We will need to assume for some state-machine and some medium:

$$\exists \mathrm{de}(\mathrm{p}' \to \mathrm{a}) \in (\mathrm{E}) | \mathrm{p}'(\Psi_\mathrm{l}) \to \alpha \in \sum_x .$$

Conversely, an *encoder* is an entity, en(β → p), which changes (as best it can) a response β in the response set $\Gamma_x$ of the state-machine x, into energy pattern p, to be sent to a transducer, as in:

$$\exists \mathrm{en}(\beta \to \mathrm{p}) \in (\mathrm{E}) | \beta \in \Gamma_x \mathrm{p}(\Psi_\mathrm{l}).$$

Sometimes we refer to the combination of transducer and decoder as a sensor and the combination of encoder and transducer as an emitter. We can picture conceptually a combined transceiver mechanism as a state machine including transducers, encoders, and decoders (Figure 1).

Since we are only interested in foundations here, we leave the implementation details to the experimental physicists and the engineers.

State-transitions, and thus Time T according to our definition of Time, is required for the operations of receiving and transmitting energy patterns.

$$T_{total} = T_{medium} + T_{transducer} + T_{decoder} + T_{processing} + T_{encoder} + T_{transducer} + T_{medium},$$

All time is local and unidirectional.

**Messages:** Messages open the possibility of non-local time. We define a message as a sequence of stimuli Msg=($\sigma_1$,...,$\sigma_n$). A message can be a sequence of stimuli generated as a sequence of responses generated by one entity $x_1$ and received by another $x_2$. Whether the message can be decoded (or is significant) to the second entity depends on the state-transition architecture of the entities involved. Messages can be sequences of stimuli representing scenarios. An entity $x_2$ can receive a scenario from another entity $x_1$ describing an observed scenario that both entities have independently observed and recorded, whereupon $x_2$, if it has the build-in mechanism, can compare the two scenarios. We will discover several reasons why these recordings, particularly recorded time stamps, will not match. Here in lies the crux of geometry and geometric temporal relativity.

**Metrics:** At the heart of all metrics is the counting of state-transitions. We postulate or observe state machines that can count internal state transitions. Such devices have been constructed, such as the machine used in creating this document. We observe or construct a sub-entity that can cycle through and count state-transitions based upon sequences of internal stimuli. We have define a count of these transitions as *local time*. A *clock* is a machine that counts such state-transitions and thus measures time. A clock can measure the time associated with sending and receiving messages. We can also measure time by counting the number of recorded observed scenarios in the memory of a state-machine with-memory, or by comparing time measurements embedded in recorded scenarios. At this point we have established entities that receive and record stimulus sequences and

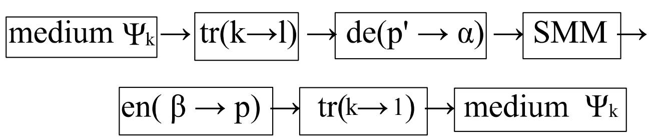


**Figure 1:** A transceiver.

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thereby construct local time. There are entities that can record time by counting state transitions. There are entities that can exchange messages containing observed scenarios. These scenarios can be compared. We must now establish distance and motion.

## Geometry

Up to this stage our state-machines could be contiguous. We construct or observe two communicating entities labelling them $x_1$ and $x_2$, each with its own clock $c_1$ and $c_2$ respectively. Entity $x_1$ emits a stimulus and initializes and starts its clock at $c_1=0$. Entity $x_2$ receives the stimulus message and sends a response message back to $x_2$, which includes a record of internal delay time $d_2$ as measured by $c_2$. Entity $x_1$ receives the return message and subtracts it own internal delay $d_1$ and also $d_2$ from its clock reading $c_1=T_t$, giving the travel time $T_d$, as $T_d=(T_t - d_1 - d_2)/2$. We define the resulting $T_d$ as the distance $d(x_1, x_2)$ between $x_1$ and $x_2$. The distance, according to $x_1$, is one half of the time the message spends in the round-trip through the medium. We say that entity $x_1$ has measured the distance between $x_1$ and $x_2$. The ambiguity of $d_2$ is often minimized by $d_2$ being much less than $T_t$, so it can be treated as insignificant in the calculation and not needed for the distance estimate. Further definition of distance requires directional sensors.

**Directional sensors:** We postulate or observe entities $x_o$ that can discriminate between two remote entities $x_1$ and $x_2$ and measure the respective distances $d(x_0, x_1)$ and $d(x_0, x_2)$ to the two entities. We further postulate or observe that $x_0$ can identify lines of- sight to the two objects and measure an angle θ between the lines-of-sight, as long as the lines of sight do not coincide. “Line-of-sight” and “angle” assume direction discrimination and are left undefined. Practically speaking, physical mechanisms and phased arrays can measure angles and lines-of-sight. We say that $x_0$ has at least one directional sensor. The Euclidean distance $d_0(x_1,x_2)$ perceived by $x_0$ between the two remote entities $x_1$ and $x_2$ is given by:

$$d_0(x_1,x_2)=(d_2(x_0,x_1)+d_2(x_0,x_2) -2d(x_0,x_2)d(x_0,x_2)\cos\theta)1/2,$$

which, of course, is simple euclidean distance measured by state-transition-based Time at $x_0$. In a practical sense, all measurements remain local to the observer $x_0$. This may not be the distance measured between $x_1$ and $x_2$ by $x_1$ or $x_2$, depending on the curvature of space between the entities.

**Coordinates:** We postulate or observe entities $x_o$ that can discriminate between three remote entities $x_1$, $x_2$ and $x_3$ and measure the respective distances $a=d(x_0, x_1)$, $b=d(x_0, x_2)$, and $c=d(x_0, x_3)$ to the three entities. We further postulate or observe that $x_0$ can identify lines-of-sight to the three objects and measure an angles $\theta=\theta(x_1,x_2)$, $\varphi=\theta(x_2,x_3)$, and $\gamma=\theta(x_3,x_1)$, between the lines-of-sight respectively, as long as the lines of sight do not coincide. Call line-of-sight $x_0$ to $x_1$ the coordinate axis *x*. Add a definition for a rectangular plane through $x_0$, $x_1$, and $x_2$ and call it the *x,y* plane. Define a direction z perpendicular to the *x,y* plane. Then define a rectangular coordinate system (x,y,z) relative to the four points such that:

$$A=(a, 0, 0)$$

$$B=(b\cos\theta, b\sin\theta,0)$$

$$C=(c\cos\varphi, c((\cos\gamma - \cos\theta \cos\varphi)/\sin\theta),$$

$$c(\sin 2\theta - ((\cos\gamma - \cos\theta \cos\varphi)/\sin\theta)2)1/2),$$

where A, B, and C are called the *positions* of $x_1$, $x_2$, and $x_3$ respectively. Of course, this is one of many possible ways of constructing euclidean coordinates. The goal here is establish coordinates from a strictly local point-of-view. Once one frame is established, many other options are derivable for calculation convenience. Each entity would construct its own coordinate frame.

At this point, we could follow some standard procedure to further develop the relationships between coordinate systems. For example, following [10], use a coordinate system $(x_1, x_2)$ to cover a small patch of locally euclidean space, then examine a distance ds from $(x_1, x_2)$ to $(x_1+dx_1, x_2+dx_2)$. In this local space, we find ds can be expressed as:

$$ds^2=g_{11}(x_1, x_2)dx_1^2+2g_{12}(x_1, x_2)dx_1dx_2+g_{22}(x_1,x_2)dx_2^2,$$

with an alternate coordinate system $(\xi_1, \xi_2)$, with $ds^2=\xi_1^2, \xi_2^2$, with $g_{ij}$ defined as:

$$g_{11}=(\partial\xi_1/\partial x_1)^2+(\partial\xi_2/ \partial x_2)^2$$

$$g_{12}=(\partial\xi_1/\partial x_1)(\partial\xi_1/\partial x_2)+(\partial\xi_2/\partial x_1)(\partial\xi_2/\partial x_2)$$

$$g_{22}=(\partial\xi_1/\partial x_2)^2+(\partial\xi_2/\partial x_2)^2$$

thus relating two coordinate systems so the geometry can be extended to the next local patch. The metric $g_{ij}$ characterizes the local geometry and demonstrates the inner properties of the metric space. We can further characterize the local geometry by expressing what is called the affine connection $\Gamma^{\sigma}{}_{\lambda\mu}$ in terms of the metric $g_{ij}$ as:

$$\Gamma^{\sigma}{}_{\lambda\mu}=(g^{\nu\sigma}/2)[(\partial g_{\mu\nu}/\partial x^{\lambda})+(\partial g_{\lambda\nu}/\partial x^{\mu})-(\partial g_{\mu\lambda}/\partial x^{\nu})],$$

which will be useful later in discussing implications for physics. The super- and subscripts refer to contra variant and covariant components respectively, as described in standard texts. Ultimately, we need to express how the affine connection changes as entities change location, and for this we introduce the Riemann tensor $R^{\lambda}{}_{\mu\nu\kappa}$ in terms of the relationships and changes in the affine connection as:

$$R^{\lambda}{}_{\mu\nu\kappa}=(\partial\Gamma^{\lambda}{}_{\mu\nu}/\partial x^{\kappa})-(\partial\Gamma^{\lambda}{}_{\mu\kappa}/\partial x^{\nu})+\Gamma^{\eta}{}_{\mu\nu}\Gamma^{\lambda}{}_{\kappa\eta}-\Gamma^{\eta}{}_{\mu\kappa}\Gamma^{\lambda\nu}{}_{\eta},$$

then projecting to a local surface then to a scalar,

$$R_{\mu\kappa}=g^{\lambda\nu}R_{\lambda\mu\nu\kappa}, \text{ and } R=g^{\lambda\nu}R_{\lambda\nu}.$$

Combining these then, it is customary to characterize local space by defining the Einstein Tensor *E* as:

$$E=R_{\mu\nu} - g_{\mu\nu}R,$$

which turns out to be very useful in physics.

The goal here is to establish a foundation, for generalized local geometry, that is based upon the concept of state-transitions within an observing entity. This has implications for remotely measuring geometric relationships of distant, moving, or accelerating entities. For comparison, a number of treatises have been written on time and geometry [11-14].

**Remote observations:** We define *motion* as a change in position manifested as a distance during a time interval, speed as a measured change in distance during a measured time interval, *velocity* as speed with a specified direction, and *acceleration* as a change in velocity during a measured time interval, more precisely, motion=$d_2$-$d_1$=Δd,

$$\text{speed}=\Delta d/\Delta t,$$

$$v = \Delta d\angle\theta/\Delta t,$$

$$a = \Delta v\angle\theta/\Delta t.$$

In this paradigm, motion, speed, velocity, and acceleration are measured relative to some state transition sequence within an observer $x_0$. Such measurement are recorded as scenarios and can be encoded into messages for transmission to other entities. Transmission of energy patterns can be in mechanical or radiation form, depending on the communication medium. Cause-and-effect phenomena are revealed through examination of recorded scenarios. Values of certain attributes of entities are also revealed through examination of recorded scenarios. For example, change in momentum can be derived from recorded scenarios revealing entity behaviour in conjunction with acceleration of observed particles. The potential for change in an entity's momentum-attribute under conditions of acceleration is defined as force, and is manifested as a change in the energy attribute of the observed entity. Positive acceleration adds to the energy attribute of an entity and negative acceleration reduces it. The energy attribute of an entity is generally expressed as its Hamiltonian, as energy is H=kinetic and potential energy=$p^2/2m+mgz$. Ultimately, momentum is measured by the effects of one particles on another, by some sort of energy exchange.

Once Newtonian physics and euclidean geometry are established as a result of state transition mechanisms and message communication between observers, signal frequencies, Doppler effects, cause-and-effect reconstruction, time dilation from velocity and acceleration, and light cone geometry are easily constructed.

The summation of mutual force effects within a local geometry combine into a convenient form. Let $G^\alpha(x,t)$ be the sum total of forces measured, according to momentum changes, by an observer looking at position x at its local time t. Let the observer scan the local vicinity $\partial x^\beta$ of x, observing the changes in force as the observed position changes. The quantity that changes as the observation point changes, namely $\partial T^{\alpha\beta}/\partial x^\beta=G^\alpha(x,t)$, is called the energy momentum tensor $T^{\alpha\beta}$ or stress-energy tensor $T$. Experimental observation of the geometric effects of T lead to the classic Einstein field equation:

$$E=-8\pi G T,$$

where G is the, so called, universal gravitational constant. Other constants, such as the cosmological constant $-\lambda g\mu\upsilon$, also appear in discussions as an added term in the equation to account for cosmic expansion effects.

**Entity sensitives:** Different entities are subject in different ways to messages from other entities. State transition mechanisms respond to specific sequences of stimuli, that is, different sequences of patterned energy. Table 1 summarizes the basic particle-to-messenger relationships. Experiment reveals that particles can exhibit state changes based on receipt of patterned energy. Specifically, between particles there are messages, which determine the state transitions of the particles as Table 1.

Quantum Field Theory explains the interactions of particles and fields. With this study, we can see the relationships of energy, geometry, and time in a more precise way. This explanation will closely follow

| Particle | Messenger |
|---|---|
| Any | Graviton |
| Charged | Photon |
| Quark, Gluon | Gluon |
| Quark, Lepton | $Z^0$ |
| W+,W-,$Z^0$ | $Z^0$ |
| Down Quark | W- |
| Electron, Muon, Tao | W- |
| Neutrino | W+ |
| Charged Leptons, Quarks, W&Z, H | Higgs |

**Table 1:** Fundamental particles are entities, which have state and communication capabilities.

and interpret the exposition of particle interactions of non-interacting vibrational structures where Gaussian path integrals apply [15].

First consider a photon as it transitions from location-state $q_I$ to location-state $q_F$. The state transition is written as $<q_F|e^{-iHT}|q_I>$, where T is the event-sequence ensemble marking time during the state transition, and H is the Hamiltonian, representing the energy structure of the photon particle, namely,

$$H=p^2/2m+V(q).$$

The $p^2/2m$ and V(q) are the kinetic and potential energies of the particle respectively. The $e^{-iHT}$ term is actually interpreted as a sequence of N state transitions making up the events along the multiple paths of the path integral from $q_I$ to $q_F$. The continuous path integral is achieved by taking the limit as N becomes very large and the respective event intervals come correspondingly small [16-18].

For convenience $\int dq(t)$ is defined as:

$$\int Dq(t) = \lim_{n\to\infty} (-i2\pi m/\delta t)^{N/2} \prod^{N-1}{}_{j=0} \int dq_j$$

That is, for incremental transition events, δt, the effects of each change of the particle wave are accumulated (with the factor $(-i2\pi m)^{1/2}$. The effect is:

$$< q_F \left| e^{-iHT} \right| q_F >= \int Dq(t) \exp\left(i \int dt L(q,q)\right)$$

wherein L(q.,q) is the Lagranian,

$$L(q,q)=p^2/2m - V(q),$$

and thus ∫dtL(q,q) is the action S(q) for the particle. So, state $q_I$ becomes state $q_F$ based on all energy/state changes taking place as the event sequence unfolds. The particle accumulates information energy packets as it goes through intermediate state changes. However, much of the information is lost by subsequent events (there is no history-memory). So last to first change in state characteristics remains the only indication of information exchange during transition [19].

Even at rest particles undergo changes as expressed by:

$$Z=<0|e^{-iHT}|0>,$$

which indicates particle vibrations around its zero point. When we add other effects, J(x), which are simply energy-information packets acting on a system within which the particle resides, then:

$$Z=D\varphi \exp(i\int d^4x[+1/2(\partial\varphi)^2 - V(\varphi)+J(x)\varphi(x)].$$

The term $+1/2(\partial\varphi)^2$ is the energy, which is positive indicating the forward progress of time in the action. So then, V(φ) is the potential, and J(x) is the source function- information-packet acting on the particle, φ(x). All influences add in the context of the changing environment of the particle at its zero point, and the particle 'feels' and 'reacts' to the influence-messages. We measure the information of the transactions using the Shannon metric on the square of the probability amplitude Z as:

$$I=Z^2\log Z^2.$$

The term Dφ is called the propagator of the action. The square of the propagator, $(D\varphi)^2$ is the probability for the disturbance J(x) to go from the origin to the point x. From point y to point x, the propagator is:

$$D(x-y)=\int d^4k/(2\pi)^4[\exp(ik(x-y))/(k^2-m^2-i\varepsilon)].$$

Note that the exponent of d is 4 since the time dimension is

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included and will be separated out subsequently. The infinitesimal term $\varepsilon$ was added to make the integral possible and will disappear as $\varepsilon \geq 0$. The information of propagation, again using the Shannon metric, is:

$$I=(D(x-y))^2\log(D(x-y))^2.$$

As Zee points out, we can imagine a discrete division of the potential field framework and call the lattice spacing a. Then $\partial\varphi(ia) \geq 1/a$. Then we can use a matrix operator $M_{ij}$ for intermediate micro-transitions and then write:

$$(\varphi_{i+1} \geq \varphi_i)=\Sigma_j M_{ij}\varphi_j.$$

Finding the eigenvalues, $€_{ii}$, of $M_{ij}$ provides another way to measure the total information involved in the state transitions of $(\varphi_{i+1} \geq \varphi_i)$ as:

$$I_{transition}=\Sigma_i\, €_{ii}\log €_{ii}.$$

In the finite model, time is represented by the sequence of transition intervals, a, counted for the virtual transition events.

We can further characterize the role of time in the transition process as follows. The transition amplitude Z can be written in terms of the energy potential as:

$$Z(J)=Z(J=0)e^{iW}(J),$$

which defines W(J). This leads ultimately to W(J), between potentials $J_1$ and $J_2$ located at points $x_1$ and$x_2$ respectively, expressed as:

$$W(J_2-J_1)=-1/2\int d_4k/(2\pi)^4 J_2(k)^*(k^2-m^2+i\varepsilon)^{-1}J_1(k)$$

$$=(\int dx^0)\int d^3k/(2\pi)^3\exp(ik.(x_1-x_2))/(k^2+m^2)$$

$$=(time)(E),$$

which separates out the $\int dx^0$ time dimension contribution from the d3 space-contribution potential- energy, E, between potentials $J_1$ and $J_2$. This $\int dx^0$ time dimension contribution reflects the rate of time-sequence passing as the transition occurs. It is also clear from this expression that potential energy drops off with distance as 1/m and 1/k. The bottom line here is that the virtual 'message carrying' particle of mass k propagates from the source to the sink carrying this message we interpret as force [20].

If we introduce electromagnetic forces characterized by $F_{\mu\eta}$ for charged particle of mass m in a vector potential $A_\mu(x)$, we have Lagrangian L as:

$$L=-1/4\, F_{\mu\eta}F^{\mu\eta}+1/2\, m^2A^\mu A^{\mu+}A_\mu J.$$

Assuming conservation of current $\partial_\mu J^\mu=0$, then propagation energy W(J) turns out to be:

$$W(J)=+1/2\int d4k/(2\pi)4\ J2(k)^*(k^2-m^2+i\varepsilon)^{-1}J_1(k),$$

where the+sign indicates that like charges repel. The message exchanged between particles tells them to repel each other.

Furthermore, we can relate the propagation energy, in terms of gravitons of spin 2, using the stress-energy tensor $T^{\mu\eta}$. For masses with energy density $T^{00}$,

$$W(T)=-1/2\int d^4k/(2\pi)^4T^{00}(k)^*(g_{\mu\lambda}g_{\upsilon\sigma}+g_{\mu\sigma}g_{\upsilon\lambda}-g_{\mu\upsilon}g_{\lambda\sigma}/2)(k^2-m^2+i\varepsilon)^{-1}T^{00}(k),$$

$$=-1/2\int d^4k/(2\pi)^4T^{00}(k)^*(3/4)(k^2-m^2+i\varepsilon)^{-1}T^{00}(k),$$

with a negative sign indicating gravitational attraction messages between massive particles.

Summing things up, spin o particles share attraction messages in the strong force, spin 1 particles share repel messages through the electromagnetic force, and spin 2 particles share attraction messages through gravitational forces.

Message carriers speak - particles listen Transitions take place - time passes.

## Why is this Approach Worth Considering?

There are a dozen or more reasons for considering a state-machine information-based approach to the logical foundations of physics, for example:

1. Time is defined,
2. Time metric is separated from space geometry,
3. Past, present and future are defined,
4. The direction of time is accounted for,
5. Time does not need a direction,
6. The connection between time and entropy is explained,
7. It gives a new perspective on force,
8. Emphasis changes to communication and control,
9. Relativity and quantum field theory still stand,
10. Multi-dimensional reality is not required,
11. Statistical nature of quantum mechanics is explained.

Other considerations could be included in this list, but how many are needed to spur a further examination of the possibilities?

## Conclusions

Event sequences, communication, and geometry are essential elements in understanding time. Philosophically, we would say that there must be something outside of ourselves that keys into our internal mechanism for perceiving time and space. There are external clocks and external event sequences, then there are internal state-transition, recording, and interpreting mechanisms. These mechanisms are enhanced by an appreciation of the physical nature of information [5].

To establish a logical foundation, we must start with entities, which can process information sequences though state-transition structures, create organized time-stamped message records, then match them statistically to subsequent incoming information sequences. Ultimately, event sequences generate information sequences as results of patterned-energy outputs of the originating state-transitions. Physics enters the picture when metrics are assigned to event sequences, through state-transition records, allowing for cause-and-effect analysis with known precision. The foundation logic must support each phase of the model-building progression. The progression is state change, energy pattern response, time construction, event recording, event analysis, coordinate system construction, geometry-time relationships for mechanics, statistical prediction of event sequences, generation of new event sequences. The logic must also provide a robust enough foundation to construct the subsequent structure of information-coding analysis, communication signal analysis, and, ultimately, applicable control theory mechanisms. Logic supports the physics, which in turn supports the engineering. Each element is essential: philosophy, science, and engineering. A more complete expose' of these foundations and the construction of dependent principles is contained in a dissertation which is currently under construction.

Our point of view presents specific challenges, such as:

1. Re-evaluating physical experiments like particle interaction,
2. Refining the definitions of the nature of various state-machines which generate time,
3. Defining languages accepted by specific particle state-machines,
4. Defining metrics of the capacity of state based memory technologies,
5. Investigating metrics related to time/communication for red shift, dark matter, dark energy,
6. Refining modifications in relativity and quantum field theories for information flow,
7. Developing quantitative information metrics for particle/entity interactions,
8. Investigating and integrating control theory into entity interaction, and
9. Increasing the precision of the axiomatic notation and logic construct.

There will be other opportunities for contributions as well, especially in the area of simulations of interacting entities as provided by the automated state machine simulation software technology such as [Grable 2016].

In the next couple of decades, physics will undergo significant re-orientation. It is the belief of this author that state-machine based technology will play a significant role.

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