Times Two:
The Tenses of Linear and Collapse Dynamics in Relational Quantum Mechanics

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Abstract: The nature and topology of time remains an open question in philosophy, both tensed and tenseless concepts of time appear to have merit. A concept of time including both kinds of time evolution of physical systems in quantum mechanics subsumes the properties of both notions. The linear dynamics defines the universe probabilistically throughout space-time, and can be seen as the definition of a block universe. The collapse dynamics is the time evolution of the linear dynamics, and is thus of different logical type to the linear dynamics. These two different kinds of time evolution are respectively tensed and tenseless. Ascribing tensed semantics to the collapse dynamics is problematic in the light of special relativity, but this difficulty does not apply to a relational quantum mechanics. In this context, while the linear dynamics is the time evolution of the universe objectively, the collapse dynamics is the time evolution of the universe subjectively, applying solely in the functional frame of reference of the observer.

1 Introduction

The concept of tensed time is very attractive, it makes sense of our apparent experience of the moving moment of now. Considerable philosophical argument has been presented both for and against this concept, but on the view presented here both sides of the debate would inevitably find evidence for their preferred mode, since both are present. Turning to physics to settle the dispute it is clear that tensed time is incompatible with general relativity, since any concept of tensed time must be based on a global simultaneity, the now that stands between past and future. This, however, is based on a common but very specific assumption, that quantum mechanics is not purely relational. In a relational quantum mechanics the global frame of reference is always that of a specific observer, global simultaneity is inherent and tensed time is entirely feasible. In this context it is straightforward to make a case for the collapse dynamics of a quantum system as the basis of tensed time. The linear dynamics meanwhile provides an ideal example of tenseless time, since taken overall it provides a static definition of the universe throughout space-time as defined by a specific wave function. Since the collapse dynamics is the time evolution of this definition of the universe, giving rise to a sequence of different wave functions, the two different kinds of time evolution of physical systems are necessarily of different logical type.

2 Two Kinds of Time Evolution

On the standard theory of quantum mechanics according to von Neumann there are two different dynamics that apply to a physical system.

> Dynamics: (a) If no measurement is made, then a system S evolves continuously according to the linear, deterministic dynamics, which depends only on the energy properties of the system. (b) If a measurement is made, then the system S instantaneously and randomly jumps to a state where it either determinately has or determinately does not have the property being measured. ... (Barrett,1998)

After the discontinuous change of the probabilities of the linear dynamics to specificity upon measurement, the 'jump', the system S is in a different state where a new and different linear dynamics applies. Dynamics (a) is the linear dynamics and dynamics (b) is the collapse dynamics, the 'collapse' of the probabilities defined in the linear dynamics. Applying this to the universe as a whole, the linear dynamics is the time evolution of the overall system, defined by a specific wave function. Since this defines the probability amplitudes for events throughout four dimensional space-time it is a definition of a block universe. The collapse dynamics is the change in that four dimensional definition, resulting in a different four dimensional layout of probabilities of events in the universe defined by a different wave function, a change to the linear dynamics giving rise to a different block universe. Given the relationship between the two dynamics they are necessarily of different logical type.

3 Logical Types

Russell (1908) introduced the concept of logical types or ordinality, the basic concept being that a member of a set is of different logical type to the set. An illustrative analogy in the current context is a cinema film, a linear series of frames, each one a two dimensional arrays of pixels. Clearly a single frame of a cinema film is of different logical type to the set of all of the sequential frames on the film making up the whole movie. Similarly to the cinema film, a quantum system can be considered as a sequence of four dimensional 'frames', each one a four dimensional array of probability amplitudes defined by a specific wave function. The linear dynamics defines a system in a specific state, it is the dynamics of a specific wave function; this four dimensional quantum state of the system could be considered to be a four dimensional quantum frame of reference. Collapse is the change in the linear dynamics, the transition from one such quantum frame of reference to another. The collapse dynamics involves a sequence of frames of reference, and is thus of different logical type to a single frame of reference. While the linear dynamics is of the ordinality of a single state in the sequence, the collapse dynamics is of the ordinality of a set, the sequence of states.

Applying this principle to the whole universe, the wave function of the universe defines the four dimensional quantum frame of reference, a four dimensional space-time block universe defined by the linear dynamics, while the change of that block universe is the collapse dynamics giving rise to a sequence of block universes. This provides a simple implementation of Lockwood's suggestion[1] that "the tensed and tenseless theories of time could both be true" (2005,70). This is achieved by simply adopting the linear time dimension of the four dimensional space-time block universe as the tenseless view of time, and adding to this "an overarching march of time, with respect to which this four dimensional block universe itself undergoes change, in the same manner as is envisaged in the tensed view of ordinary time" (70). Thus the time evolution in the linear dynamics, 'linear time', is tenseless, while 'collapse time', the 'overarching march of time', is tensed.

1 Which he also attributes to John Leslie

4 Tensed and Tenseless Time

There are two different types of time evolution of a quantum system, and although the linear dynamics defines change with linear time, with regard to the overall four dimensional quantum frame of reference it is unchanging. Thus with regard to the time evolution of the collapse dynamics each linear dynamics is tenseless while the collapse dynamics itself is tensed. Markosian (2002) provides the following canonical statement of the terms tensed and tenseless.

The Tensed View of Semantics:

i. Propositions have truth values *at times* rather than just having truth values *simpliciter*.
ii. The fundamental semantical locution is '*p* is *v* at *t*' (where the expression in place of '*p*' refers to a proposition, the expression in place of '*v*' refers to a truth value, and the expression in place of '*t*' refers to a time).
iii. It is possible for a proposition to have different truth values at different times.

The Tenseless View of Semantics:

i. Propositions have truth values *simpliciter* rather than having truth values *at times*.
ii. The fundamental semantical locution is '*p* is *v*' (where the expression in place of '*p*' refers to a proposition and the expression in place of '*v*' refers to a truth value.
iii. It is not possible for a proposition to have different truth values at different times.

Throughout the four dimensional quantum frame of reference defined by a specific wave function the definition of the probabilities of events is fixed and static. Thus with regard to the four dimensional quantum frame of reference the tenseless semantics applies, since there is for all points in space-time a fixed truth value, the specific probabilities of events, defined by the proposition, the four dimensional definition of the probabilities of events given by a specific wave function. Although there is a time evolution in the linear dynamics, this time evolution is a fixed property of the truth value of the proposition, because the proposition is a four dimensional space-time proposition for which truth values are given for all positions throughout space-time by a specific wave function. The truth value of this proposition does not vary with regard to linear time, since the entire spread of values for different positions in linear time is subsumed by the specific four dimensional truth value defined by a specific wave function. Thus the tenseless semantics applies. By contrast, with regard to collapse time the tensed semantics applies, since the four dimensional proposition has different truth values at different times in collapse time, as defined by different wave functions. As a result the truth value of the probabilities of events at a specific space-time location may vary with collapse time.

5 No Collapse

On the standard interpretation the time evolution of the universe progresses according to the linear dynamics until there is a collapse, which results in a new version of the wave function and a new quantum definition of the universe. The two different dynamics are thus held to alternate, and since there is no determination as to when the two alternates are to apply this gives rise to a severe problem with the quantum theory, the measurement problem. 'No-collapse' formulations of quantum theory, beginning with Everett's Relative State Formulation, aim to resolve this problem; Everett (1957) claimed that there is no collapse of the wave function, only the appearance of collapse to observers.

A no-collapse formulation does not of course fit the simple cinema film analogy. In a no-collapse formulation there can be no change to the overall linear dynamics of the system, there can only be a change relative to a specified frame of reference. In the no-collapse universe the unitary wave function encompasses all possible versions of the universe at all possible moments, and all possible space-time arrangements of matter and energy exist superposed; this is Everett's view of the universe. On this view there can only be the appearance of collapse. The metaphor is easy enough to adapt. Instead of all of the frames being laid out in sequence, they all coexist. They can be likened to the frames of a movie existing in solid state memory in a computer; the computer makes one frame after another the frame of reference, in succession. Objectively nothing changes except the frame of reference, but subjectively, from the frame of reference of the viewer, or simply from the perspective of the changing frame of reference, there is a succession of frames, a virtual cinema film in operation. Similarly, the changing of the frame of reference from one four dimensional definition defined by a specific wave function to another, from one pre-existing block universe to another, is the exercise of the collapse dynamics of the universe according to a specific frame of reference.

Since in a no-collapse formulation there can be no change in the wave function of the universe itself, the change of the wave function of the universe is only an effective change, the change in the effective wave function of the universe in a specific frame of reference. Thus one achieves the appearance of collapse in a no-collapse universe proposed by Everett. In a many worlds theory the frame of reference is a specific decoherent universe, and in a many minds theory the frame of reference is the world, or effective universe, of a specific observer. In relational quantum mechanics it is the frame of reference defined by the correlations the observer makes with the environment.

5.1 No-Collapse Reality

The concept of a shifting frame of reference is somewhat at odds with the commonly held understanding of the physical world as a physical entity which changes in time. The linear dynamics provides a simple explanation of such a universe; the state of the matter and energy of the universe evolves as time passes, and sporadically there are quantum jumps which alter the basic form of the linear dynamics. This is the natural understanding of the quantum world based on the concept of the time evolution of the changing arrangement of mass and energy of a single pre-Everett universe. Thus one would see the time evolution of a physical system as primarily the linear dynamics, the progression of the four dimensional definition of probabilities as defined by the wave function of the system, punctuated by changes to the system brought about by decoherence, observation, or other mechanism depending on the interpretation. However, in a no-collapse universe the time evolution of the universe can only be understood as the changing mass of a single universe with the proviso that this mass keeps making more and more extra diverse copies or versions of itself, which are somehow 'elsewhere'. However one expresses it there is a dimensionality over and above the four dimensional space-time dimensionality, namely the indexical dimensionality of different versions of the universe, hence the concept of the multiverse. Everett's no-collapse formulation defines a universe which is effectively a multiverse of co-existing and coincident versions of the universe. In this context the exercise of the collapse dynamics can only be an indexical shift from one version of the determinacy of the universe defined by a specific wave function to a different version defined by a different wave function.

6 Which Time Happens?

The wave function can be conceptualised as a wave spreading out in time, like the ripples on a pond, but representing the changing and evolving state of the matter and energy of the universe. However, if one conceptualises the wave function as representing a static four dimensional layout, it is only the change from one layout to the next which constitutes change or 'real time'. Since the wave equation forms the mathematical basis of quantum mechanics it is natural that the linear dynamics is considered the fundamental definition of reality and the collapse dynamics as a subsidiary effect. However, it could be that the cinema film mimics physics exactly, and that physical reality is a series of static frames in rapid succession. On this view it would be collapse time, the change of the linear dynamics, which was the passage of time rather than the time evolution 'internal' to the linear dynamics.

On the standard view the passage of time is the continuous progression of the present moment along the linear time dimension of space-time with the accompanying change in the arrangement and disposition of matter and energy in the universe, as defined by the linear dynamics, punctuated by spontaneous discontinuous change in this arrangement, as defined by the collapse dynamics. On the alternate view the passage of time is a sequence of static frames, each one a four dimensional block universe. Each frame defines the actualities of the moment, and the probabilities of interactions in the future, while new actualities, with attendant altered probabilities of interactions in the future, are the subsequent frames. Each subsequent frame defines probabilities and actualities in accord with the present moment being further along the linear time dimension, thus the sequence of frames results in progressive change in the position in linear time. Naturally the resulting passage of time is effectively movement through the time dimension of space-time, but in this scenario this would be an effect rather than a cause.

6.1 For and Against

In favour of the inverted explanation is the simplification of the explanatory principle, and the need for only one type of process to account for each specific phenomenon; collapse time is change, 'real time', while linear time is static-four-dimensional-layout time. The real time, the ongoing collapse dynamics with regard to a specific functional frame of reference, would be simply and solely the change of the effective wave function in that frame of reference. The obvious difficulty with this explanation is that since all transitions are instantaneous, an observer should pass from beginning to end of the sequence instantaneously! One solution is to assume that each such transition takes a specific amount of time, but this brings in yet another factor of time in direct contravention of Occam's razor. Alternatively it can simply be assumed that the subjective experience of the transition is of the duration of the time interval between the two points in time in linear time. In other words, the collapse that 'spans'[2] a specific time interval in linear time, 'takes that

2 Meaning a collapse comprising a jump from one quantum definition of the universe to a different one where the two define a difference in quantum definition commensurate with a specific span of linear time having passed.

long' to exercise subjectively, whether because this is the actual duration of the collapse in some absolute sense, which is then after all not instantaneous, or because the instantaneous transition is somehow experienced as having duration subjectively. The applicability is, however, limited to the frame of reference of a single observer. Applied to a physical universe of a conventional nature the alternate view is at best highly problematic since there can be no universal simultaneity due to special relativity, and thus no global instantaneous or coherent transition from frame to frame. In relational quantum mechanics, however, the frame of reference is that of a single observer, and a global simultaneity is inherent.

7 Relational Quantum Dynamics

In Rovelli's relational quantum mechanics the system the observer engages with has no definition for that observer other than the information that the observer has about that system, “a complete description of the world is exhausted by the relevant information that systems have about each other.” (16,1996). Thus the effective universe for that observer is defined solely by the information the observer has about the environment system, namely the correlations formed with the environment system. In this context there is a range or spectrum of possible next moments, encompassing all of the possible ways in which new correlations could be formed, defined by the linear dynamics effective in this frame of reference. In this linear dynamics all of these possibilities exist in a future which is a simultaneity of all of them. Subjectively, however, only one of the possible versions of the next moment happens. In each of the possible versions of the next moment a different correlation formed with the environment results in a different version of the observer, and subjectively, in each specific version of the possible next configurations of the effective universe, one specific correlation has been formed, and the others have not.

It could be that objectively there is only the linear dynamics, and that there is no such thing as collapse objectively. In his authoritative examination of the interpretative problem of quantum theory Barrett finds that none of the existing explanations of physical collapse amount to an entirely satisfactory solution, and in summing up he seems to imply that no collapse requires a relational solution.

> ... my money is on the deterministic, linear quantum dynamics making the right empirical predictions all the way up. If we are ever in a position to make the appropriate sort of interference measurement on Wigner's friend, then I have no doubt whatsoever that we would see the interference effects predicted by the standard quantum dynamics. (247,1999)

If this were to be the case it must indicate a relational quantum mechanics at some level; while Wigner's friend is in a superposed state in Wigner's functional frame of reference he clearly is not in this state subjectively. Subjectively each observer makes a specific version of an observation, and adds a specific correlation to the definition of the effective universe. If there is no collapse objectively then it is a purely subjective event.

8 The Static Universe

On this view everything physical is an aspect of a static four dimensional block universe, and thus the Everettian no-collapse universe is the simultaneity of all possible versions of a four dimensional block universe. The collapse dynamics is a change of the functional frame of reference from one indexical version of the block universe to another, a transtemporal process operating in a static no-collapse universe. Environmental decoherence modifies the linear time evolution of the system, but this too is a linear effect. On this basis environmental decoherence would be a phenomenon of definition overlaid on the linear dynamics of the wave equation, producing every possible variation of fine grained physical definition throughout the static four dimensional quantum frame of reference, and thus defining multiple variations of the block universe with great precision. For simplicity the term linear dynamics will be used to refer to the overall linear development of probabilistic definition of possible events in the universe with progression along the linear time dimension of space-time.

The addition of a new correlation to the observer system is clearly a physical event, but in the linear dynamics defining the event in the future all the possible versions of the event are simultaneously existent. Equally clearly the subjective experience of each observer is different in some way to this time evolution, since a direct experience of the result of the linear dynamics would inevitably involve superposed outcomes and superposed identities on occasions, such as when a measurement is made of an observable that begins in a superposition of two eigenstates. If this change is a subjective transition to a different indexical the difference is explained, it is of different logical type to the linear dynamics. The addition of the correlation to the observer results in this 'transition', which is simply a change in the effective universe corresponding to the change in the definition of the observer with regard to the correlations established with the environment. While all possible pathways of this collapse dynamics are physically instantiated in the linear dynamics, the subjective passage from singular moment to singular moment is a process of a different logical type to the time evolution of the linear dynamics. Since, as Rovelli emphasises “Correlation is “information” ...” (1996,9), the difference between the two can be accounted for on the basis that the collapse dynamics is an information process different in nature to the physical time evolution of the universe defined by the linear dynamics. The information process is a sequential process of change in indexical location in the overall system, one that results in ongoing effective progression along the linear time dimension of space-time. Thus, while objectively the time evolution of the system is the linear dynamics, subjectively, in the functional frame of reference of each version of the observer, the time evolution of the effective universe of the observer is a collapse dynamics.

9 Experiential Time

The subjective time evolution of the effective universe of the observer corresponding to the correlations formed with the environment system accounts for the appearance of collapse in a no-collapse universe. This is simply and solely the addition of information to the functional identity of the environment as defined by the observer; in other words, this is an information process, but this alone can account for all observed phenomena. On this view this information process is like the sequential access of structures of data in a solid state memory in a computer, nothing moves or changes except for the functional frame of reference of the observer. The process continually forks giving rise to a branching tree of frames of reference, rather than a single strand of logic, but the physical layout of the no-collapse universe is proposed to be entirely static. This is in accord with Deutsch's view that there is no such thing as the passage of time, since all possible moments exist timelessly and “To exist at all at a particular moment means to exist there for ever.” (1997,263). Deutsch holds that the passage of time is entirely illusory,

> “We do not experience time flowing, or passing. What we experience are differences between our present perceptions and our present memories of past perceptions. We interpret those differences, correctly, as evidence that the universe changes with time. We also interpret them, incorrectly, as evidence that our consciousness, or the present, or something, moves through time.”(263).

Thus time for an observer is simply a measure of change, the distance in collapse time between one subjective situation and another, and whether one moves along this passage of time, as we seem to, or not, as Deutsch asserts, remains moot. The sequence of moments described here forms a static sequence of sequential singular moments in the functional frame of reference of the observer, and should a mechanism be discovered whereby they could be experienced in sequence a transtemporal reality such as we seem to experience would be the result.

10 Objective Time and Subjective Time

If the time evolution of the correlations defining the effective physical environment for this observer is the only change to the system, the two different kinds of time are not only of different logical type, they are the time evolution of the universe in two different kinds of frame of reference, objective and subjective. The linear dynamics of the overall system is laid out in the linear time dimension of space-time. In a no-collapse universe this defines all possible branching sequences of events, and all possible consequent states of a physical universe. This is the dynamics of the universe objectively and it cannot change, it subsumes all possibilities. Whatever effects occur due to decoherence are considered here to be inherent in the overall linear dynamics, thus the four dimensional layout of the no-collapse universe is static. This is in accord with Everett's basic tenet that there is only the appearance of collapse, only the appearance of change of the linear dynamics. Subjectively the effective universe changes as each new correlation is added to the individual system, giving rise to the subjective appearance of collapse and the passage of time, meaning collapse time. If one considers the physical universe to be the simultaneity of all possible versions of a block universe, then this is the transition from one block universe to another, one indexical to another. Since these block universes define the present moment to be at different points along the linear time dimension of space-time the result is an effective movement along this dimension of linear time.

Objectively the time evolution of the universe is linear time, progression along the time dimension of space-time. Subjectively the time evolution of the effective universe is collapse time, the sequential changing of the definition of the effective universe as a succession of new correlations is made with the environment. Thus there are two different types of time evolution in the two different types of frame of reference. Linear time is objective time, the span of time from the perspective of a theoretical observer outside of the system, while collapse time is subjective time, the changing of the effective universe in the functional frame of reference of the observer, resulting in progression in linear time.

11 Conclusion

Strong objections have been raised to accounting for a tensed view of time by attributing to the collapse dynamics an instantaneous change to the whole universe. The problem is the assumption of the validity of the concept of a global simultaneity for all observers while special relativity specifically demonstrates a relativity of simultaneity. In relational quantum mechanics, however, one is dealing with a frame of reference involving only a single observer, and thus there is no difficulty with the concept of a global simultaneity.

Objectively there is no collapse, and the issue of simultaneity does not arise. According to Everett there is no collapse, only the appearance of collapse, and if the appearance of collapse is purely individual and personal a global simultaneity is inherent, it is the subjective now in the functional frame of reference of a specific observer. The collapse dynamics is a change to the linear dynamics, and in a truly no-collapse universe this can only be a change to the effective linear dynamics in a specific functional frame of reference. If quantum mechanics is taken to be relational, such changes are individual to the observer, a progression of subjective moments, changing definitions of the functional frame of reference of that observer. In this context the only change to the definition of the environment system of the observer is the addition of correlations, which changes the definition of the effective universe, and thus the effective linear dynamics. It would appear that only this type of dynamics, a collapse dynamics, operates in this kind of system, the linear dynamics being solely the static layout of probabilities at each point in the progression. The linear dynamics of the overall system is the objective viewpoint, with the time evolution of the system given by progress along the time dimension of space-time, while the linear dynamics in a specific functional frame of reference is a conceptualisation of the objective perspective from a specific point in space-time defined in a specific indexical, the block universe of the probabilistic definition of the effective universe at the present moment of collapse time.

On this view collapse time is the changing definition of the functional framework of the present moment for a specific observer; this tensed time is the ever changing relationship of the individual observer to the world. Linear time is the tenseless array of time stretching out in both directions from the present moment in a manner similar to the extent of the three spatial dimensions stretching out from the location of the observer. In one way the two types of time are the same thing from different perspectives, both result in a progression along the time dimension of space-time. However, while both involve the overall passage of time, change in the location of the point of reference along the time dimension of space-time, they are of different logical type. As Lockwood suggests "... the tensed and tenseless theories of time could both be true, but on different levels." (70). On this view, while objective time and subjective time both involve progression along the time dimension of space-time, they are different logical operations, and are the exercise of the time evolution of the universe at different logical levels of operation of the overall system.

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