**Braneworlds, Presentism, the Arrow of Time, and the “Now” Problem**

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**Abstract:** For millennia physicists and philosophers have debated the nature and properties of time, including the “arrow of time” and the nature of the “now” moment, but so far there is no consensus theoretical agreement on these matters. However the recent development of string theory and M- or Brane theory has provided us with novel theoretical concepts that were not available to earlier theorists, concepts that may have a direct bearing on problems of the nature of time. These new string or brane theories showed that general relativity and quantum mechanics can be unified in an eleven-dimensional space-time, a realization that could produce an even greater revolution in our concepts of space and time than the one produced by relativity theory in the last century. And brane theorists have suggested a “braneworld” model in which the universe is a 3-brane that moves along a time axis. In such a braneworld the local “now” moments could be defined as the intersection of each spatial point in the brane with that time axis. Further, the motion of the brane itself in the time direction could provide the necessary asymmetry in time that is required to produce an “arrow of time.” Such temporal asymmetry is not found in any of the fundamental physical laws that operate inside the brane, but the motion of the brane itself does not necessarily depend on the physical laws that operate inside the brane. Resolution of the problems of the “now” moment and the “arrow of time” may force us to think “outside the brane.”

**1. Introduction**

The “now” problem can be stated succinctly: Each of us constantly perceives a special moment in time that we call “now,” a point in time that appears to separate a determined past from an undetermined future. Whether the future is actually undetermined is a matter of some controversy, of course, but the asymmetry between the past and the future is clearly seen in the fact that all of us have memories of the past but none of us have any memories of the future. Carnap stated that Einstein was bothered by the “now” problem and thought that it lay outside the realm of science (Carnap 1963, pp. 37–38; see also Greene 2004, chapter 5 and especially p. 141, and Smolin 2013, pp. 91-92). Of course this “now” moment is not a fixed point in time. It moves from the past toward the future, a motion that is called the “arrow of time.”

The difficulty with the “now” phenomenon is that there is nothing known in conventional physics, including Quantum Mechanics (QM) and General Relativity (GR) and even Newtonian physics, that would allow us to specify any particular “now” moment in time. Nor is there any known way to allow such a “now” point to define the fulcrum of the asymmetries between the past and the future. And there is no known way to force or even allow this “now” moment to move from the past toward the future. As Einstein himself said: “For us believing physicists, the distinction between past, present [“now”] and future is only a stubbornly persistent illusion” (quoted in Calaprice 2000, p. 75).

I suggest that the reason for this “stubborn persistence” is that the “now” moment is not an illusion, rather it is an observed fact that gives us important information about the nature of time and space, information that may provide observational evidence for some aspects of modern brane theory. The idea of a “braneworld” gives us novel concepts that appear to at least provide a context in which a solution to the “now” problem and the problem of the “arrow of time” could be sought.

**2. The Braneworld Model**

To recap briefly: The original string theory showed that the equations for quantum strings have no sensible solutions unless they are combined with the Einstein metric equations for GR in a ten-dimensional space-time with nine spatial dimensions and one time dimension. To explain why we perceive only four dimensions of space-time the additional six dimensions were postulated to be curled up or “compactified” into structures called Calabi-Yau spaces that are roughly the size of the Planck length (~1.6 x 10-35 meters) and are thus too small to be perceived in any experiment using present-day technology (see, *e.g*., Susskind 2008, pp. 336-339).

The newer eleven-dimensional M-theory or brane theory extends the idea of one-dimensional strings to N-dimensional “branes,” where strings are one-branes, but there are also two-dimensional branes (“membranes,” the origin of the word “brane”), and three, four, five . . . dimensional branes, up to a maximum of nine dimensions. A brane is an N-dimensional object that can propagate through a higher dimensional space (Greene 2004, p. 385).

In brane theory the universe that we observe might be modeled as a three-brane that is moving along a time axis. As Greene put it: “Could it be that the four-dimensional spacetime developed by Minkowski and Einstein is actually the wake of a three-brane as it evolves through time?” (Greene 2004, p. 388). “String theorists call this the *braneworld scenario*” (Green 2011, p. 114). Susskind adds: “Could the real world . . . all take place on a brane? To the majority of theorists working on these problems, it seems the most likely possibility” (Susskind 2006, p. 281). It is important to understand that these “braneworld” models are constructed to be completely consistent with both GR and QM.

If we therefore assume that the universe that we observe is actually a 3-brane that is evolving through time we could explore some of the implications that this assumption would have for our philosophical difficulties in understanding the properties of time. The braneworld concept introduces a new physical object, a brane that moves in time, whose properties were not known to earlier theorists who were attempting to understand the nature of time. And perhaps the greatest weakness in these earlier attempts to understand time in terms of conventional GR, QM or even Newtonian physics is that none of these three theories has any clear way to define a “now” moment. In contrast the braneworld model has a natural definition of the local “now” moment in time as simply the time value of the intersection of the local or nearby part of a three-brane with the time axis.

It might be helpful here to try to visualize this braneworld definition of the “now” moment. However, most of us have some difficulty picturing a rippling three-brane that is moving in time, so for purposes of visualization it might be convenient to drop down to just two spatial dimensions and picture a two-brane model for the universe instead of a three-brane. Imagine then that we have two spatial axes, *x* and *y*, in a horizontal plane, and a time axis, *t*, in the vertical direction. Then for visualization purposes imagine that this model is filled part-way up with water, so that the rippling surface of the water (the surface, not the water itself) represents a two-brane that moves in the vertical or time direction. Of course the water surface is not an M-theory two-brane: It is governed by the differential equations of hydrodynamics rather than the equations of brane theory. Nevertheless it is a two-dimensional surface that is sufficiently familiar to be useful for visualization even if its detailed behavior is not exactly the same as an M-theory two-brane.

The “now” moment that is defined by the time value of this “brane” at any spatial point (x,y) ripples with the water surface and it must also move from the past toward the future, the so-called “arrow of time” that can be observed by anyone sitting quietly with a wristwatch. To visualize this upward motion of the water surface we could imagine further that there is a firehose pouring in water below the surface so that the average surface moves vertically faster than the largest negative velocity caused by the ripples in the water surface. Then the surface that represents the brane and depicts the local “now” moment at each spatial point will move with a varying velocity that always has the same sign in the time direction, and the overall motion of the surface (brane) will define the arrow of time.

This simple two-brane model makes clear why the “now” phenomenon exists at all: Because the two-brane is two-dimensional with both dimensions spatial, it has no thickness or extent in the vertical or time direction. It therefore occupies only a single point in time at each spatial location, a point that we can call “now.”[[1]](#footnote-1) If the brane had any significant thickness in the time direction it would not define a unique “now” moment at that spatial location. In effect the presence of a moving two-brane breaks the symmetry between the three (x, y, t) dimensions of this model. Time may have been the same as space until a spatial two-brane that ripples and moves in the time direction was introduced that confines all observers to its two spatial dimensions. The moving intersection of the brane with the time axis then gives us a clear and precise local definition of the “now” point in time at every spatial location. It is a definition that will provide us with a solid foundation for understanding the properties of both the “now” moment and the arrow of time as well as the reason why this “now” point defines the dividing point between the past and the future.

Any explanation of the arrow of time must begin with this kind of careful definition of the “now” moment since the arrow is defined by the motion of the “now” moment. As noted above, lack of a precise definition of the “now” point is perhaps the most important failing of past attempts to explain the arrow of time in terms of the physical laws that operate inside the brane including, for example, Eddington’s explanations in terms of the direction of the increase of entropy. These “internal” explanations all lack a clear definition of the “now” moment, presumably because to see and understand the intersection of the brane with the time axis you need to think “outside the brane” as this two-brane model is designed to facilitate.

One problem with this model involves the kinematics of the motion of this surface. It should be obvious here that the observed vertical motion of a “now” moment along the time axis is nonsense in any conventional physical theory based on standard space-time with only a single time axis, because in order to express any motion, say the motion of an object along the *x*-axis of a coordinate frame, you require a time axis that is separate from the axis under consideration. For a simple example the position of a body that is moving with a uniform velocity *v* along an *x* axis might be written as:

*x(t) = x0 + v t*

Without a time axis (or *t* variable), *i.e*., if there is only an *x*-axis, we might have to try to express the *x* position of the body as a function of *x, x(x),* which is nonsense. But it is related to the nonsense of trying to express the “motion” of a point in time, the “now” point, as a function of time: *t(t)* makes no more sense than *x(x)*.

The 11-dimensional brane theory may be able to resolve this difficulty because the additional seven dimensions of the theory are not necessarily spatial dimensions—some of them might be time-like. The possibility of additional extended time dimensions has been discussed (see, *e.g*., Bars, 2001) but I believe that the relation of additional time dimensions in brane theory to the “now” problem has not been thoroughly explored.[[2]](#footnote-2) We might refer to an additional time dimension as *t\**. The requirement for a second or *t\** time axis is quite general. It holds for any model that includes a special “now” moment in time that moves along the time (*t*) axis, both a universal and constant rate of time flow as in Newtonian physics as well as models that have a local rate of time flow that depends on velocity and gravitational potential, as in GR. For example, Lubashevsky has discussed two-dimensional time in the context of ordinary Newtonian physics (Lubashevsky 2016).

In our simple two-brane model we could label the time value (the vertical position) of the surface of the water at any spatial point *tnow*. It will move vertically with a velocity *dtnow/dt\** that is always positive upward. Thus this model makes clear the need for a *t\** axis to express the motion of the *tnow* point along the time direction. Without a *t\** dimension there would be no way to speak of any motion of the *tnow* point or the velocity *dtnow/dt\**.

The value of *tnow* agrees with the basic properties of our observed local “now” values in time that move with a speed that can be different at each spatial point but is always upward or forward in time. In fact the braneworld model has an explanation for all of the observed properties of the “now” moment, including the so-called “arrow of time.” The arrow of time simply reflects the motion of the brane along the vertical time axis, produced in this visualization model by the fire-hose analogy above. The motion of the brane in the time direction provides the necessary asymmetry in time needed to produce the observed arrow of time, and it is an asymmetry that is not found in the laws of either QM or GR nor indeed in any of the “equations of fundamental physics” (Greene 2004, p. 13). Indeed, the overall motion of the brane along the time axis does not necessarily depend on any of the details of its internal composition or the physical laws that operate inside it.

Exactly why the brane moves in one direction along the time axis is not perfectly clear at present. Perhaps it is simply a form of inertia: The brane initially moved in one direction in time and there is no force to stop it. Or perhaps there is some force, possibly akin to gravity, that is pulling the brane in a particular direction. But although the reason for the motion of the brane in the time direction is not presently clear, the fact that the brane is moving in a particular direction in time can be observed by anyone sitting quietly with a wristwatch.

Furthermore, the observed asymmetries between the past and the future have a natural explanation in terms of a three-brane that is moving along a time axis with motion that is a function of the second time axis, *t\**. The past is simply the set of points in time that the local part of the three-brane has already visited, and the future is the set that the three-brane has not yet visited, with “already” and “not yet” specified in terms of *t\** and not *t*. Finally, the observed motion of these local “now” moments along the time axis *t* provides observational evidence for at least one (*t\**) of the seven additional dimensions (beyond the 4 of conventional space-time) that are required by the eleven-dimensional brane theory. As noted above, the “now” point could not be observed to move in the time direction (*dtnow/dt\**) without this *t\** axis.

**3. Further Properties of the “Now” Moment**

It is important to understand that the “now” moment defined by the time value at a spatial point on a three-brane is defined locally on the three-brane. It is not a Newtonian-style universal “now” moment that would be the same everywhere. “Now” will generally be different at each point on the three-brane with differences that are specified by the differential equations (presumably brane theory equations) that define the brane. The fact that there are small differences between the “now” moments of nearby observers poses no conflict with observation so long as the observers are close enough in time (and space) to be able to exchange information using photons and phonons exactly as they are observed to do.

In fact, one of the important properties of the “now” phenomenon is that everyone perceives essentially the same “now” moment locally to the accuracy that perception allows. In classical Newtonian theory this presents no difficulty because everyone in the universe always experiences exactly the same “now” moment. But in GR all observers should be experiencing their own “now” moments that “move” at rates that depend on their relative velocities and gravitational potentials. And because those “now” moments are moving at different speeds (measured against *t\**) we should expect observers to become separated in time, with everyone experiencing a different “now” moment as expressed by the readings on their respective wristwatches. Similarly, if two observers are moving along a spatial axis with different speeds, we should expect them to become separated in space.

The time differences between the separated “now” moments for different observers could be arbitrarily large. For example, suppose that Bob stays on Earth while Alice has a spaceship that can reach nearly the speed of light. She travels to a star that is ten light years away and then returns. Further suppose that elapsed time on the ship is, say, one week, while for Bob the elapsed time until the return of the spaceship is about twenty years. When Alice returns, why is it that that her “now” moment is still synchronized with the one back on Earth? Since she has experienced only a week of elapsed time, why isn’t her “now” moment twenty years or so in the past of the Earth-bound observers? But if it were, then by waiting twenty-odd years here on Earth she should be able to observe her own return as seen from the Earth-fixed frame. Clearly that would not happen because, among other things, it would involve a violation of conservation of energy, a duplication of the mass-energy of the spacecraft (see the discussion below). But what does happen? It seems somewhat odd that everyone’s “now” moment would remain locally synchronized even though their respective wristwatch readings do not agree.

GR makes no reference to a “now” moment and therefore has nothing to say about the matter, as Einstein was aware. But brane theory may be able to resolve this problem because branes are “sticky.” They hold on to things. As Greene says: “Branes are the only locations where the endpoints of string snippets can reside . . . String snippets can freely move within and through a brane, effortlessly gliding from here to there, but they can’t leave it . . . In a braneworld, the strings that make up you and the rest of ordinary matter, are snippets. While you can jump up and down, throw a baseball . . . all with absolutely no resistance from the brane, *you can’t depart the brane*” (Greene 2011, p. 116; Greene’s italics).

Therefore in the model of the universe as a three-brane that is moving in the time direction (moving with respect to *t\**) all observers will be confined to that brane, and confinement to the brane will be sufficient to synchronize the “now” moments of nearby observers in the brane, as observed, regardless of the readings on their individual wristwatches. All nearby observers on the brane will be close to the same “now” value because any discontinuity or step function in the local “now” values would constitute a discontinuity in the brane (see, *e.g*., the two-brane model above). But we know that branes cannot have discontinuities because they are solutions to the differential equations of brane theory, and continuity is the one property that is possessed by all of the solutions to every differential equation, as Poincare noted when he developed topology. Therefore the observation of local synchronization of the “now” moment may provide observational evidence not only for the existence of an additional time dimension but also for the existence and properties (continuity) of branes themselves.

In a braneworld model this “now” moment is not just a reading on a clock, it is a real physical thing, as real as a pencil or the planet Mars. This idea of a physically real “now” moment makes no sense in relativistic mechanics or quantum mechanics (as Einstein was aware). None of these physical models have anything at all to say about a special “now” moment. But the idea does make sense in a braneworld model because the brane is a real physical object. The temporal location of the nearby part of the brane is similarly real and provides a local definition of a “now” moment, a definition that is completely consistent with both QM and GR because the braneworld equations were set up for consistency with QM and GR.

But as we have seen with the spaceship model above, in order to make this assumption of a physically real “now” moment work it will be necessary to divorce that “now” moment from the readings on individual clocks. It was a mistake in the arguments above about Bob and Alice to assume that the readings on a clock can define or are even related to this “now” moment. The linkage of the “now” moment to clock readings is a common and longstanding assumption which in fact is reasonably accurate locally so long as velocities are small and gravity fields are weak. This assumption was actually one of the main motivations for developing clocks and wristwatches in the first place. For example, considering Bob and Alice again, they could synchronize their wristwatches at noon and agree to meet at a café when both of their watches read 3:00 PM. Bob then immediately goes to the café and reads an e-book until his watch reads 3:00 while Alice flies around in her private jet at no more than 600 MPH and returns to the café when her watch reads 3:00. When they meet neither one notices that their watches are slightly out of sync even though their “now” moments are not out of sync. Thus the idea that a “now” moment can be defined by readings on individual wristwatches works reasonably well in all normal human experience.

But as noted above, if Alice flies around in her spaceship at close to the speed of light then their rendezvous situation changes dramatically Alice might return to the café when her watch reads 3:00 and find that Bob has aged 50 years waiting for her to return. Alternatively, Alice could monitor her speed and calculate exactly how to return when Bob’s watch reads 3:00. At that point her watch might read only a few minutes after noon. In both cases Bob and Alice return to a common “now” moment at the café, but that moment is not well defined by the readings on either wristwatch. Thus the linkage between the “now” moment and wristwatch readings is only a local and often useful approximation that works reasonably well if relative speeds are low (and gravity fields are weak) but it has no fundamental significance. (Notice that all of the relativistic equations that Alice needs to calculate clock readings in different reference frames still hold in the braneworld model, because the branes were designed to be fully consistent with both GR and QM.)

A century ago researchers had to adjust to the realization that space-time is a physical thing that has mass and can be bent by gravity fields. Now it appears that we need to further adjust to the idea that the local “now” moment is also a real physical thing and is not just a clock reading. It is defined by the present position of the brane along the time axis (where “present” is expressed in terms of t\*). And these “now” moments are essential to the fundamental idea of conservation of energy. Conservation of energy is deeply linked to the “now” concept, as many discussions of time travel fail to consider.[[3]](#footnote-3) In particular, if a time machine were transported a year into the past then its mass-energy would be lost in the “now” moment, and it would appear suddenly one year in the past and conservation of energy would fail at both points of time. Also the spacecraft behavior in the example described above would produce a similar violation of conservation of energy if its “now” moment were not synchronized among local observers. But if everything in our observed universe is confined to a three-brane then problems of conservation of energy would appear to be tractable—no mass or energy can move off the brane, and the brane has no thickness or extent in the time direction. Therefore no observer can move away from the local “now” moment. It therefore appears that the simplest way to make sense of both the “now” moment in time and conservation of energy would be to assume that we are confined to a three-brane that is moving in the time direction in a higher dimensional space.

To better understand this braneworld model it might be helpful to try to recast Newtonian mechanics in terms of a brane that we might call a Newtonian brane or an Nt-brane. An Nt-brane is an object that has three spatial dimensions and zero thickness in the time direction (in order to qualify it as a 3-brane, a 3-dimensional “membrane”). The three spatial dimensions of an Nt-brane are Euclidean-flat (no curvature) and all the spatial points in an Nt-brane have the same time value (“now” value) and thus all have the same “arrow of time” that is produced by the motion of the Nt-brane in the time direction. An Nt-brane does not satisfy the strictures for the branes from M-theory, of course; in other words an Nt-brane is a brane that is not consistent with GR and QM, as M-theory branes must be, but it can still be useful for visualization purposes. In the two-dimensional model we could consider an Nt-brane to be a water surface that is calm and flat (no ripples), and that moves in the vertical direction while keeping the same time value (“now value”) at all spatial points. I have called it a Newtonian brane because it was used implicitly and worked quite well for Newtonian physical calculations during the time between Newton and Einstein (and sometimes later than that), although generally it was not stated explicitly as a brane.

But theorists including Lorentz, Einstein, *et al*., realized that, with the advent of Maxwell’s electrodynamic equations that specify a velocity for light, the Newtonian model did not respect the principle of relativity, the idea that physical laws including Maxwell’s electrodynamics should be the same in all inertial reference frames. So the implicit Nt-brane model was discarded and with it the idea of a “now” moment that separates the past from the future (see, *e.g*., Rovelli, 2019). What these theorists failed to realize is that it is possible to modify the Nt-brane model by changing the Euclidean-flat Newtonian “brane” to a topologically equivalent brane from M-theory that respects GR (and therefore the principle of relativity), and as an added bonus it is required to include QM as well, while still preserving a useful definition of “now” moments. (It is difficult to fault twentieth-century theorists for not anticipating the development of an eleven-dimensional brane theory a century or so ahead of their time.)

The M-theory brane is not Euclidean-flat, of course, and its time values (“now” values) are not identical across the brane, but they form a continuous and smooth surface (because no discontinuities or “jumps” in time are allowed across small spatial displacements.). This smooth and continuous surface of “now” values serves to define the difference between the past and future both locally and globally. Further, to match local observations, the M-brane model must approach an Nt-brane locally under the usual approximations of small velocities and weak gravity fields so that Newtonian dynamics (implicitly based on Nt-branes) provides a reasonably accurate model for calculating the local behavior of thrown baseballs, launched spacecraft, and the orbits of comets, asteroids and other astronomical bodies.

Some theorists have argued against the idea of the existence of a sensible “now” moment by using straight lines and flat Euclidean planes to try to extrapolate such “now” moments across the universe (for example the “slices” in the discussion in Greene 2004, p. 135). But these flat planes do not and indeed cannot produce sensible results for connecting the “now” moments of different locations in the universe because, although the argument may be technically correct, what it really demonstrates is that it is not reasonable to use flat planes to try to extrapolate anything across a curved universe. To connect the “now” moments at different places in a braneworld you have to extrapolate those local “now” moments along the brane itself at some specified value of *t\**, and the brane is definitely not a flat plane.

A minor technical issue might be resolved by the existence of a second (t\*) time axis. In the original formulation of 10-dimensional string theory the six additional dimensions beyond the standard three-space plus one time dimension were thought to be compactified into a 6-dimensional Calabi-Yau space. With brane theory’s 11 dimensions there are 7 dimensions that would have to be compactified. But we do not know of any 7-dimensional Calabi-Yau spaces. We know how to construct them only in spaces of complex dimensionality which translates into an even number of real spatial dimensions. Whether the absence of odd-dimensioned Calabi-Yau spaces is a real property of these spaces or simply reflects a deficiency in our current analytic techniques is not presently known (See Yau and Nadis 2012, p. 150). But if there are two extended time dimensions then there are only six remaining dimensions (out of 11) that might need to be compactified into a six-dimensional Calabi-Yau space.

But of course the model of the universe as a three-brane that moves in time provides a different answer to the question of why we perceive only three spatial dimensions in an eleven-dimensional universe, an answer that does not require compactification of the additional dimensions. Observers who are confined to a three-brane would not be able to observe any additional dimensions that might exist, regardless of whether those dimensions are compactified or not because those observers and their observing tools, such as photons and phonons, cannot leave the brane. (Cf. Greene 2004, pp. 392-393).

However, although the braneworld model does not strictly require that the additional 6 spatial dimensions (beyond the four of space-time plus the *t\** dimension) be compactified, the observed behavior of gravity within the three-brane might require their compactification. The problem is that the particle that carries gravitational force, the graviton, is known to be a closed loop of string, and branes only hold on to the ends of open-loop strings. Gravitons should therefore be free to move along any extended dimensions. But the strength of gravity would be diluted by these additional dimensions. In particular, the inverse-square dependence of gravity with distance that Newton discovered should happen only in three dimensions. Each additional dimension will add one to the exponent in the denominator, so in a four-dimensional space gravity would have an inverse cube dependence on distance (see the discussion in Susskind 2006, pp. 281-283). One possible solution to this problem would be to compactify the six additional spatial dimensions. Gravitons then could still move into these dimensions, but they would not contain enough volume to dilute the gravitational force significantly.

Another possible solution to this problem would be to find a different kind of brane that holds on to closed-loop strings as well as the ends of open-loop strings. Note, for example, that in conventional 4-dimensional spacetime models gravitons do not move freely along the time direction but are confined to the “now” moment (the brane location), otherwise conservation of energy would not be observed. Gravitons that can move freely in the time direction would “leak” energy from the present into and out of the past and the future. So adding yet another timelike dimension does not necessarily allow an additional (timelike) degree of freedom for gravitons.

**4. Philosophical Implications**

A century ago Einstein revolutionized our understanding of space and time by showing that they could be understood in terms of a non-Euclidean 4-dimensional spacetime continuum governed by the Einstein metric equations. Modern brane theory promises to create an even greater revolution in our understanding of space and time with the discovery that an eleven-dimensional continuum is needed to unify GR and QM. The further exploration of braneworld models gives us an entirely new perspective on problems of space and time, a perspective whose philosophical implications have barely begun to be explored. As Randall noted: “String theory’s extra dimensions might be a nuisance, but they might also prove to be an opportunity for finding new ways of addressing old problems. . . .These dimensions might help explain underlying relationships that are relevant to observed phenomena.” (Randall 2009, p.74).

For example, the moving three-brane model provides a natural context for the school of philosophy called “presentism,” whose fundamental idea is that the past and future do not exist, only the present or “now” point in time actually exists. In the three-brane model the brane that defines the “present” (the set of “now” values across the brane) is all that actually exists, at least so far as can be observed from inside the brane. Romero and Perez note that: “The compatibility of presentism with the theories of special and general relativity was much debated in recent years” (Romero and Perez 2014). But, as we noted, GR has nothing to say about the “now” moment. In other words, in debating the compatibility of presentism with GR, philosophers were in effect trying to understand the properties and behavior of the “now” moment by using a theory (GR) that provides no information about the “now” moment. Therefore any discovered or purported inconsistency between GR and presentism may well represent a deficiency in GR rather than in presentism, a deficiency related to the inadequacy of 4-dimensional models to encompass or explain the behavior of the “now” moment in time. The model of the universe as a three-brane moving in a higher dimensional continuum requires the full formalism of brane theory, and therefore any discrepancies with GR should be resolved in that formalism and are not necessarily permanent objections to presentism.

Discussions of the “now” phenomenon in the literature often fail to appreciate the need for an additional time dimension to deal with the motion of the “now” moment in the time direction. Additional dimensions were seldom considered prior to the development of string/brane theories in the late twentieth century, with the notable exception of 5-dimensional Kaluza-Klein theories. And even today the eleven dimensions of brane theory are not uniformly accepted by theorists considering the “now” phenomenon. For example, in his recent book about “now” Muller calls eleven dimensions “crazy” (Muller 2016, p. 149). Of course it is possible that the idea of eleven dimensions is wrong but it is certainly not crazy. Any such prejudice against the idea of additional dimensions will probably inhibit any understanding of the “now” phenomenon, since, as noted above, the “now” point cannot move along a time axis unless there is an additional time dimension.

The model of the universe as a three-brane that moves in the time direction resolves the old philosophical difficulty of the observed asymmetry between space and time, that we are free to move in three spatial directions (subject to some constraints), but, although we do move in the time direction, we are not free to choose our motion in that direction. In particular, we cannot move away from the local “now” moment in time. Such an asymmetry is a natural consequence of living in a three-brane that is moving in time. We are free to move in three spatial directions without leaving the three-brane, but the brane has no extent in the time direction so any attempt to move away from the “now” point in the time direction would involve leaving the brane, which is not permitted. We are therefore forced to simply move along with the brane as it moves along the time axis. Notice that in this brane-world model “time travel” is impossible because we cannot move away from the “now” moment, and all of the familiar paradoxes of time travel do not arise.

Einstein’s difficulty with the “now” problem may center on the fact that classical 4-dimensional spacetime is inadequate to resolve the problem. Einstein was aware of the possibility of additional spatial dimensions beyond the 4 of space-time at least since Kaluza’s introduction of a fourth spatial dimension. But I am not aware that he ever considered the possibility of additional timelike dimensions, or the possibility that such timelike dimensions might be needed to specify the motion of a “now” moment along the conventional time axis. And the idea of the continuity of a three-brane moving in a higher dimensional continuum was a half-century or so ahead of his time.

**5. Summary and Conclusions**

This brane-theory model is consistent with the following five observed facts about the “now” phenomenon:

1. There is a local, physically real “now” moment that is observed constantly by every waking person.
2. This “now” moment moves “forward” in the time direction, as measured locally by a stationary wristwatch.
3. The “now” moment is the point in time that appears to separate a determined past from an undetermined future. The asymmetry between the past and the future is perhaps best seen in the fact that all of us have memories of the past, and none of us have memories of the future.
4. Observers who are close together in three-space will also be close in their “now” values on the time axis, despite possibly sizeable differences in the readings on their respective wristwatches.
5. Observers are free to move in three spatial dimensions but are not able to move away from the moving “now” moment in the time direction.

These facts can be confirmed by personal observation and none of them are addressed by either conventional GR or QM. But all of them can be neatly explained by the model of a three-brane moving in the time direction. Indeed it is somewhat astonishing that although neither GR nor QM separately have any information about the “now” phenomenon, the theory that successfully combines them, brane theory, does contain a natural explanation not only for the existence of the “now” phenomenon, but also for all of its observed properties.

To elaborate on this explanation we can take our simple two-brane model and convert it to the full three-brane model by first restoring the missing third spatial dimension of the brane (while maintaining zero thickness in the time direction) and then replacing the hydrodynamic equations of water ripples with the differential equations of brane theory that define a three-brane. We will then have a three-brane model whose spatial points each occupy a single point (“now”) in the time direction, a point that moves with a local velocity (*dtnow/dt\**) specified according to the brane equations. This three-brane model is first of all a model that is consistent with both QM and GR. That consistency with QM and GR was a difficult combination to accomplish but it is exactly what the brane equations of brane theory were designed and constructed to do. The model has a natural explanation not only for the existence of an observed “now” moment at every spatial point but also for the observed asymmetry between the past and the future: The past is the set of time points that the local part of the brane has already visited, and the future is the set that it has not yet visited, with “already” and “not yet” expressed in terms of *t\**. The model also explains the fact that observers who are close in three-space will observe “now” moments that are close in time. Furthermore, the motion of the brane along the time axis provides the temporal asymmetry that is necessary to produce the “arrow” of time. And the model provides a natural explanation for the fact that observers are free to move in the three dimensions of the brane, but are unable to move in the time direction away from the local “now” moment.

None of this is handled in conventional QM or GR. The model therefore fills a gap in conventional physical theories while remaining completely consistent with those theories: The idea of three-brane that is moving in the time direction is the principal idea that was missing from attempts to explain the “now” phenomenon and the “arrow of time” in the past. And finally, the observed motion of the “now” moment along the time axis *t* provides observational evidence for at least one (*t\**) of the seven additional dimensions required by brane theory.

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1. If we are making measurements at the Planck scale then this discussion might need to be modified slightly: The thickness of the brane in the time direction is probably not less than the Planck time (approximately 5.39 × 10 −44 s), because in brane theory generally it makes no sense to talk of time durations smaller than this. However for the discussion here the Planck time is an adequate approximation to a zero time interval. [↑](#footnote-ref-1)
2. Skow and others discuss an additional time axis (sometimes called “supertime” or “hypertime”) in the context of a “moving spotlight” model for the motion of the “now” point or present time, rather than in the context of an extra time dimension in a braneworld model. But Skow calls the idea crazy and insane, and goes on to say: “In the face of the proposal that there really is such a thing as supertime I can only stare incredulously” (Skow 2015, p. 47). In the discussion here it will be convenient to refer to the additional time dimension as simply *t\**. [↑](#footnote-ref-2)
3. The deep connection between time and conservation of energy was explored by Emmy Noether in her justly famous set of theorems that connect symmetries of space-time with conservation laws. Noether showed that conservation of energy is implied by the invariance of physical laws over time. Fundamentally, conservation of energy means that the energy in a closed system at any particular “now” moment will be the same at the next “now” moment and any “now” moment, and it is thus deeply connected to the concept of the “now” moment. [↑](#footnote-ref-3)