Einstein's Road Not Taken

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Abstract

When confronted with the challenge of defining distant simultaneity Einstein looked down two roads that seemingly diverged. One road led to a theory based on backward null cone simultaneity and the other road led to a theory based on standard simultaneity. He felt that alone he could not travel both. After careful consideration he looked down the former and then took the latter. Sadly, years hence, he did not return to the first. In the following we investigate Einstein's road not taken, i.e., the road that leads to a theory based on backward null cone simultaneity. We show that both roads must be traveled to develop a consistent quantum theory of gravity and also to understand the relationship between the gravitational and electromagnetic fields.

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The Road Not Taken

Two roads diverged in a yellow wood,
And sorry I could not travel both
And be one traveler, long I stood
And looked down one as far as I could
To where it bent in the undergrowth;

Then took the other, as just as fair,
And having perhaps the better claim,
Because it was grassy and wanted wear;
Though as for that the passing there
Had worn them really about the same,

And both that morning equally lay
In leaves no step had trodden black.
Oh, I kept the first for another day!
Yet knowing how way leads on to way,
I doubted if I should ever come back.

I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in a wood, and I?
I took the one less traveled by,
And that has made all the difference.

– Robert Frost [1]

In his groundbreaking paper on special relativity, Einstein [2] argued that a practical definition of distant simultaneity can be achieved by synchronizing clocks using light signals and assuming that the one-way speed of light is identical to the experimentally measured two-way speed of light. This method of synchronizing distant clocks results in a simultaneity relation now commonly referred to as *standard simultaneity.* It is less well known that Einstein also contemplated another method of synchronizing distant clocks, namely, the method that leads to a simultaneity relation that is now called *backward null cone simultaneity* [3, 4]. Indeed, Einstein wrote in the paragraph immediately preceding his description of standard simultaneity [2]:

> We might, of course, content ourselves with time values determined by an observer stationed together with the watch at the origin of the co-ordinates, and co-ordinating the corresponding positions of the hands with light signals, given out by every event to be timed, and reaching him through empty space. But this co-ordination has the disadvantage that it is not independent of the standpoint of the observer with the watch or clock, as we know from experience. We arrive at a much more practical determination along the following line of thought.

Evidently, one reason Einstein favored standard simultaneity over backward null cone simultaneity was its property of being a "much more practical" method of synchronizing distant clocks. In addition, Einstein objected to synchronizing clocks via the backward null cone method because of its dependence on the location of the observer, claiming that this conflicts with experience. We now address both of these assertions.

With respect to standard simultaneity being more practical, we note that the equations of a theory based on standard simultaneity are indeed less complex than the equations of a theory based on backward null cone simultaneity. However, this advantage comes with a significant cost because the only way to achieve standard simultaneity is to insert into the theory the additional and unproven assumption that the one-way speed of light is equal to the experimentally measured two-way speed of light. This high cost is underscored by the observation that this assumption has not been experimentally confirmed even though more than a century has passed since Einstein's seminal paper. All experimental efforts to measure the one-way speed of light independent of a synchronization scheme have failed. Furthermore, this assumption has led to a long-standing, and still unresolved, debate in the literature regarding the conventionality of simultaneity [5, 6, 7, 8, 9, 10, 11, 12].

Regarding Einstein's concern that the position dependence of backward null cone simultaneity is inconsistent with experience, we note that this position dependence is no more troubling than the velocity dependence of standard simultaneity. Indeed, standard simultaneity and backward null cone simultaneity are complementary ways of describing nature. Whereas standard simultaneity is independent of an observer's location, backward null cone simultaneity is independent of an observer's velocity [3]. Experience does not require one choice over the other, although a theory based on backward null cone simultaneity does not suffer from the disadvantage of introducing the unmeasurable one-way speed of light. In conventional relativity, the dependence of standard simultaneity on an observer's velocity does not preclude the equations of motion to be formulated in a velocity-independent manner. On the contrary, relativity theory demands Lorentz-invariant equations in order to be consistent with experience. Similarly, the dependence of backward null cone simultaneity on an observer's position does not preclude the equations of motion to be formulated in a position-independent manner. On the contrary, a theory based on backward null cone simultaneity demands equations that do not depend on an observer's location in order to be consistent with experience. The group of transformations that transform the position of the observer is the fundamental symmetry group of a theory based on backward null cone simultaneity just as the Lorentz group is the fundamental symmetry group of standard relativity.

We argue that backward null cone simultaneity is closer to reality than standard simultaneity and other simultaneity relations because it eliminates the unmeasurable one-way speed of light from the mathematical formalism. Indeed, the one-way speed of light according to backward null cone simultaneity is a measured quantity. This is a significant advantage over Einstein's choice of standard simultaneity since all attempts to measure the one-way speed of light independent of a synchronization scheme have failed. Nevertheless, backward null cone simultaneity has received very little attention in the literature. Presumably, the complexity of the mathematical formalism that results from the backward null cone simultaneity relation along with no obvious advantages of adopting this formalism, have discouraged many from investigating it further. Notable exceptions include Sarkar and Stachel [3] and Ben-Yami [4]. Sarkar and Stachel [3] demonstrated that backward (forward) null cone simultaneity satisfies Malament's criteria [8] for defining simultaneity once the assumption that any simultaneity relation must remain invariant under temporal reflections is removed. Ben-Yami [4] explored some of the advantages as well as the kinematic and dynamic aspects of backward null cone simultaneity.

In addition to eliminating the unmeasurable one-way speed of light of standard relativity, the backward null cone simultaneity framework helps illuminate the origin of quantum physics as well as the electromagnetic field. Consider an observer O at position[1] $\{x^i_O\}$ and a colocated clock that records t_O. We assume that the observer O attributes events according to backward null cone simultaneity, using the spherical coordinate set $\{t_O, r, \theta, \phi\}$ to describe the null cone structure of space-time. According to backward null cone simultaneity, the two-way speed of light is c and therefore the observer at O records the time $dt_O = \frac{2dL}{c}$ for two-way light propagation along any infinitesimal distance dL. The one-way speed of light according to backward null cone simultaneity is no longer forced upon us as an assumption, being a measured quantity that depends on the angle, α, between the direction of light propagation, $\hat{n}$, and $\hat{r}$. Specifically, for light propagating radially towards (away from) observer O the one-way speed of light is infinite ($c/2$). For light propagating

[1] Greek indices run from $(0 \ldots 3)$ and lowercase Latin indices run from $(1 \ldots 3)$.

transverse to the observer the speed of light is c. To emphasize, these values are measured quantities and not assumptions of the theory, in contrast to the one-way speed of light of standard simultaneity, which can never be measured. Generally, the speed of light $\tilde{c}$ according to observer O is:

$$\tilde{c} = \frac{c}{1 + \hat{n} \cdot \hat{r}} = \frac{c}{1 + \cos\alpha}. \tag{1}$$

Whereas the Lorentz transformation follows from the invariance of the one-way speed of light for all observers in relative motion in conventional relativity, Equation (1) follows from the invariance of $\frac{2dL}{c}$ for all observers in space that attribute events according to backward null cone simultaneity.

For infinitesimal light propagation at constant radius (i.e., in the $\hat{\theta}$-$\hat{\phi}$ plane), the null cone structure according to observer O is equivalent to the null cone structure of Einstein's flat space-time because transverse light propagation according to backward null cone simultaneity is equal to c. However, for radial light propagation, the null cone structure of O differs from the null cone structure of the relativistic observer at rest in the same inertial frame. Indeed, in order to reconstruct the null cone structure of relativity from observers that attribute events according to backward null cone simultaneity, one must introduce an infinite number of observers that view light propagation in the $\hat{r}$ direction from a transverse vantage point. In other words, the flat space null cone structure of relativity for radial light propagation requires an observer O' at each position $\vec{r}$ that attributes events according to backward null cone simultaneity and is situated with local $\hat{r'}$ in the local $\hat{\theta}$-$\hat{\phi}$ plane.

Therefore, we immediately see the correspondence between relativity and a theory based on backward null cone simultaneity. The flat space-time metric of relativity can only be constructed by an infinite number of observers that attribute events according to backward null cone simultaneity. In addition, for every collection of infinite observers there is an infinite number of transformations that lead to another set of infinite observers due to the invariance of rotation in the $\hat{\theta}$-$\hat{\phi}$ plane. Indeed, consider the scalar field $\psi(x^\mu)$ that defines the angle of each backward null cone observer in each local $\hat{\theta}$-$\hat{\phi}$ plane. One may contemplate the transformation:

$$\psi(x^\mu) \to \psi'(x^\mu) = \psi(x^\mu) + f(x^\mu), \tag{2}$$

where $f(x^\mu)$ is an arbitrary scalar field that leads to another equivalent set of observers.

By reconstructing the null cone structure of Einstein's inertial frame using observers that attribute events *according to backward null cone simultaneity we are led to an infinite number of observers as well as a* $U(1)$ *invariance embedded in flat space-time.* Naturally, we identify the $U(1)$ invariance with the fundamental invariance group that, when gauged, produces the electromagnetic field. Charge results from introducing a set of observers that cannot be achieved by the simple transformation (2). Furthermore, we see that Einstein's inertial frame possesses an intrinsic non-locality due to the requirement that an infinite number of non-colocated observers is needed. Herein we see the connection between classical and quantum physics. The observer assigned to a particular Einstein inertial frame is indeed an infinite number of observers that attribute events according to backward null cone simultaneity, and the problems encountered in describing the quantum domain with classical relativistic concepts are a result of our insistence on using a space-time built from standard simultaneity. It is important to point out that according to this interpretation, a mass, m_0, with de Broglie frequency, $\nu_0 = \frac{m_0 c^2}{h}$, is equivalent to introducing a rotation of the observer in the local $\hat{\theta}$-$\hat{\phi}$ plane at a frequency ν_0.

Returning to Equation (1), we note that the angular dependence of the speed of light leads to observable consequences that are not predicted by standard relativity. We consider light propagating from a point A in space to the observer O. In order to ascribe the conventional values of wavelength and frequency to light in the backward null cone simultaneity framework, we must reconstruct Minkowski space-time along the propagation path using observers that attribute events according to backward null cone simultaneity, as described above. Therefore, we consider an infinite number of observers along the propagation path, each with a line of sight perpendicular to the vector $\overrightarrow{AO}$. In other words, each observer, O', along the propagation path must be situated with local $\hat{r'}$ such that $\hat{r'}$ is perpendicular to the vector $\overrightarrow{AO}$. When light travels from point A to O in a straight line, the wavelength at emission and wavelength at reception are identical since according to this set of observers, the phase of light is:

$$\frac{2\pi}{\lambda}(n - ct), \tag{3}$$

where n is the local coordinate along the direction of propagation, $\hat{n}$, and we have ignored an arbitrary phase constant. However, if light leaves A and arrives at O but is deflected along the path, such as via gravitational lensing, so that $\hat{n}$ is no longer parallel with $\overrightarrow{AO}$ at the point of emission, then the observers introduced above do not view the propagation from a transverse perspective at O, the point of reception (see Figure 1). According to the observers at the point of reception, the speed of light follows from Equation (1), which is achieved by a transformation of time such that:

$$t \to t - \frac{\cos\alpha}{c} n + t_0, \tag{4}$$

where t_0 is an arbitrary constant. Therefore, the phase of the electromagnetic wave according to observer O is:

$$\frac{2\pi}{\tilde{\lambda}}(n - \tilde{c}t), \tag{5}$$

where $\tilde{\lambda} = \frac{\lambda}{1+\cos\alpha}$, $\tilde{c} = \frac{c}{1+\cos\alpha}$, and we have discarded the arbitrary phase shift due to t_0. We see that transformation (4) leads to the correct transformation of the speed of light. Since $\alpha = \frac{\pi}{2} + \delta$, where δ is the deflection angle in free space, we obtain:

$$\begin{aligned} \tilde{\lambda} &= \frac{\lambda}{1 - \sin\delta}, \\ \tilde{c} &= \frac{c}{1 - \sin\delta}. \end{aligned} \tag{6}$$

Therefore, backward null cone simultaneity predicts a wavelength shift that is not predicted by standard relativity when light does not follow a straight path in free space. It is important to point out that the frequency of the wave remains constant under transformation (4), such that $\tilde{\nu} = \nu$. Assuming $\sin\delta \ll 1$, the shift in wavelength is:

$$\Delta\lambda \approx \lambda\delta. \tag{7}$$

According to the backward null cone simultaneity framework, astrophysical wavelength shifts will be observed when light is deflected in free space. This wavelength shift will appear to be anomalous to the relativistic frame that ignores the backward null cone simultaneity framework. The wavelength shift of Equation (5) is not predicted by standard relativity because standard relativity assumes the speed of light is c in all direction. Backward null cone simultaneity, on the other hand, avoids this assumption and therefore recognizes that the standard 'frame' of relativity along the path of propagation is composed of an infinite number of observers that attribute events according to backward null cone simultaneity. This frame is defined by the direction of light emission. A change in the propagation direction that is not due to mechanical means (e.g., mirror) changes the angle of propagation of the light relative to this frame. This manifests itself in a change in wavelength at reception, but not a change in frequency. The frequency of light can be understood physically as a rotation of the observers that attribute events according to backward null cone simultaneity around the axis of propagation. Evidently, this rotation of observers corresponds to the transport of energy, $E = h\nu$, in flat space-time. It is reasonable to conclude that Equation (7) is responsible for a wide range of observed astrophysical wavelength shifts, such as those measured on cosmological scales. Indeed, backward null cone simultaneity predicts wavelength shifts from stationary sources without resorting to ad-hoc mechanisms such as an expanding universe, dark energy, or dark matter. All astrophysical observations are based on light, and therefore all derived quantities must account for the wavelength shift of Equation (5).

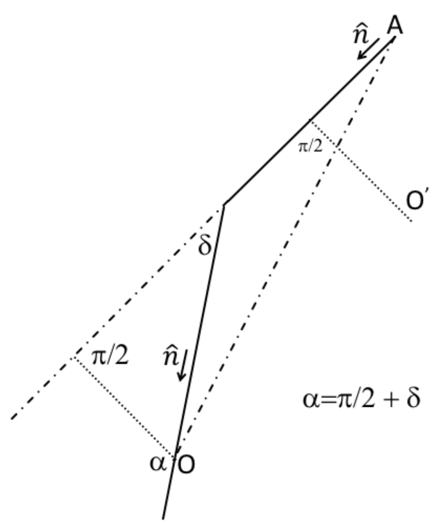

Figure 1: Geometry of light propagation.

In conclusion, we contend that our current formulation of relativity is a flawed, yet powerful, representation of nature that must be reexamined in order to develop a consistent quantum theory of gravity and also to understand the relationship between the gravitational and electromagnetic fields. The fundamental gaps that exist between classical and quantum physics are a direct result of Einstein's gaze down the road towards a theory based on backward null cone simultaneity and his decision to give standard simultaneity the better claim. Einstein's relativity employs standard simultaneity rather than backward null cone simultaneity for reasons of mathematical simplicity, but, in so doing it moves us further from reality by introducing the unmeasurable and hence unphysical one-way speed of light of traditional relativity. Therefore, one must return to the diverging roads and reascend the slope of nature by taking the first. Only by traveling Einstein's road not taken can our travels converge. *And that will make all the difference.*

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