

Clock boundary principle with respect to the role of time in laws of physics and its application to special relativity

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(dated November 8, 2008)

"Clocks slay time... time is dead as long as it is being clicked off by little wheels; only when the clock stops does time come to life." - William Faulkner

"Time discovers truth." - Seneca

"Time! the corrector when our judgments err. " - Lord Byron

Introduction

Time measurement plays a crucial role in special relativity (SR in further text). Time is measured with clocks and this paper will examine the role of clocks in general and as it pertains to SR. The examination will focus on physical reality of clocks and newly established principle of clock boundary.

The topic of this paper is not to dispute Einstein's SR - for the purposes of argument it is assumed to be correct as it has been accepted in its logic and verified in experiment. We will examine the role of time in relation to that of clocks. A term 'time' is often used interchangeably with that of a 'clock', at least when it comes to representation of physical reality of it that we experience. We will provide more rigorous distinction between the two and examine the effects to SR. The conclusions will not negate SR but will open new avenues for it and its application to reality. We will provide some new predictions that do not invalidate SR - however they do find SR to be a special case of a larger perspective.

SR states that physical laws should be the same in all inertial reference frames, i.e. the laws must look the same to one observer as they do to another. A notion of a clock is introduced in all deliberations of SR, as it is central to its logical composition and thought experiments.

Clock boundary principle

In order to formalize the principle that we will introduce here let us define the setting for principle's formulation.

Let observer R possess clock CR and observer D possess clock CD . R and D are objects isolated from each other and other objects and at the distance S and either at rest or moving relative to each other. Let both R and D conduct an experiment in which both use their respective clocks. Let the experiment be not fixed in duration. Let the experiment involve any number of observable phenomena. (0)

We can now formulate clock boundary principle based on premises of (0):

For any physical law that governs any experiment that relies on both clocks CR and CD (irrespective of any notion of simultaneity or synchronicity) to be true, such law can be true if and only if it holds for any possible duration of an experiment. (1)

We will call this principle a *clock boundary* because a clock *bounds* any physical law that we purport to be true to the point where such a law must be modified (if at all) to agree with above (1) principle. A short-duration experiment is something that we are accustomed to and it would not be a stretch to say that physical laws we have are proven to be true when tried in an amount of time we perform them. If a long-duration experiment that is constructed to verify consequences of a law cannot physically perform such verification (i.e. constricted by nature itself or by other laws that we hold true in respect of (1)), then that law is incorrect insofar as we can strive to adhere to clock boundary principle (1). The measure of incorrectness may not be apparent: a law that evidently is working may no longer do so under circumstances that we are not accustomed to or do not construct as a matter of course.

In a more mundane language it means that if for whatever reason the best possible clocks (for experiment we conduct for a period of time that is not limited) are not good enough to measure the consequences of any given physical law, then such law cannot be true.

If we're to put this in even more watered-down language (at the expense of not being entirely formal), it means that if in a given experiment best clock can't keep up with the phenomenon, then the physical law governing this phenomenon is only true for the part of such phenomenon we can possibly observe - regardless of how long we observe. In other words, a nature will bound the effect of its own laws to the extent that one can best verify them if one were to devote best effort and any duration of time to that verification.

One would be tempted to say that nature will expend only so much effort to enforce any laws (as they relate to time measurement) just enough to make sure that any best physical clock measuring such laws finds them in order up to the maximum ability of such physical clock to measure for any duration of time.

In a way, we could say that clock boundary principle is a principle of least action when it comes to time and observation of it via clocks.

Clock, or its manifestation (however we choose to interpret it), is not the same as time. However, time for any given observer is truly a mathematical idealization of a clock. Hence if for whatever reason concepts of time conflict with that of a physical manifestation of a clock, we must choose a clock to be the prevailing measure of underlying physical reality as it is the only true manifestation. This is the reason we can believe that nature indeed follows clock boundary principle.

In further considerations, we will use the terms *observation* and *observable* to the extent that physical laws apply to them. A quantification of observation and observability is given as the ability of a best clock to conduct any experiment for any duration of time. Hence a proportion of reality in such experiment may *not be observable*. In other words, in accordance with clock boundary principle, any mathematical formula that governs any law applies only to observable portion of phenomena that are governed by any such law. It doesn't mean that there is no physical reality in the un-observable portion of phenomena. What the principle of clock boundary says is that such portion is not governed by the law that applies to observable portion of it.

(2)

Finally, a philosophical argument may also be given: an innate 'least action' quality of nature is to enforce only those laws that in any measurement (relating to time) can be confirmed. The nature can only use resources available (i.e. that exist) to perform measurements in time. When resources no longer exist to perform such measurements (i.e. experiment cannot be carried out for some long period of time), it is the equivalent of nature itself not existing any more in time (should such measurements be made). If nature's existence were brought into question, any laws governing that existence would follow suit.

A consideration of clock boundary principle

At the core of this consideration is any experiment involving clocks (as stated above in (0)) that can last any duration of time. 'Any duration of time' is the physical manifestation of a principle. It means that if we conduct experiment for 1 second or 1 billion years, the physical laws should be proven equally as they relate to the clocks used in experiment.

The time element in duration of experiment (given our mortality and miniscule life spans compared to the time at large) is often neglected.

For the purpose of these considerations, an *object* of mass m and length l is a body with rest mass m and where length l is maximum rest length of an object in any direction. l will be defined as the 'length of the object' in further text. (3)

Suppose we have two objects at rest relative to each other. In order to perform any kind of measurements involving clocks, both objects must be equipped with physical clocks. We consider each object to be an observer of the other. So while one object is Observer and the other Observed, the opposite is apparently true as well.

We will consider the requirements for such physical clocks so that each observer can use its clock for any length of time. This means such clock must still perform its function and at the same time expend minimum amount of energy to be able to last any duration we chose. Whatever experiment is being conducted is unimportant other than involving clocks in both parties. Since interaction implies change in energy and momentum (which changes velocity), we will assume that whatever experiment they are conducting does not involve much of interaction and that change in their velocities is negligible due to observing each other.

Let us consider how we can build a clock to achieve the aforementioned objective. Any clock (however we build it) must be able to tell the two ends of a time interval apart. This means, it would notify when any given time interval starts, and when it ends (which signifies the beginning of the next interval).

Regardless of the method, in a physical sense, the end result is that such a clock would emit a photon when time interval starts and then emit another photon when it ends (which signifies commence of the next tick). We will call this photon a clock-photon (4).

Another important point is that the wavelength of a clock-photon cannot be longer than the length of the object (as defined above in (3)). If wavelength were longer, the clock workings may be unobservable by the object itself (meaning not absorbed). This reasoning is analogous to that of possible wavelengths in Plank's black body radiation. Note that the actual wavelength may have a multiplier of 2, however this does not affect our line of thought, as we will be only interested in a ratio of values derived from this length, hence any such constant multiplier will not weigh in. (5)

A photon emitted by the clock would be observed by the actual observer (watcher) in the same inertial frame. So we assume that there is neither change of energy nor momentum for the operation of the clock (not in a way that would affect further reasoning, see further (6)).

We do however assume that clock loses energy and the watcher gains it due to clock emitting clock-photons and watcher absorbing them. This means that both clock and watcher are changed by the operation of the clock. This is in fact required: the change of watcher is the very act of observing. Without such change, there is no time (no perception of it), and this whole discussion becomes meaningless. Such a process of emitting and absorbing photons may require emission of *recoil* photons to keep clock and watcher in the same spatial

disposition - however this process would only introduce a constant fractional multiplier which is not important for further considerations, so it is ignored (similarly as it is in (5)). (6)

We define a duration of a *clock tick* such that it is a minimum clock tick duration necessary (best in terms of capability of a clock to measure events) to prove a physical law correct for any duration of time (in line with clock boundary principle (1)). (6.1)

Generic experiment of measurements with physical clocks with respect to clock boundary factor

Let us assume that we have two objects at rest: R and D . (R and D stand for observe R and observe D . We know that this is interchangeable but for the sake of argument we will keep this notation for most of the argument for ease of following). Both R and D internally consist of a clock and of a watcher who watches the clock. Watcher is the intra-object observer. While R and D may or may not observe each other, they internally observe (watch) their own clocks for the purpose of experiment.

The two objects have rest mass of m_r and m_d . The length of each object is l_r and l_d .

Energy of a clock-photon (see (4)) in R would be (as defined above):

$$E_r = h \cdot \nu_r \quad (7)$$

where (per (5))

$$\nu_r = \frac{c}{l_r} \quad (8)$$

and h is Planck constant and c is speed of light.

Similarly we have for D :

$$E_d = h \cdot \nu_d \quad (9)$$

and

$$\nu_d = \frac{c}{l_d} \quad (10)$$

At some point the total amount of energy released so far by the either clock would be equal to the total energy contained in the object (per above discussion of change in clock and watcher ((5) and (6)), and assuming we build the clock to the best of our abilities in a physical sense):

$$m_r \cdot c^2 = N_r \cdot E_r \quad (11)$$

$$m_d \cdot c^2 = N_d \cdot E_d \quad (12)$$

N_r and N_d are the maximum number of clock ticks (per 6.1) that R and D are able to provide to the watchers (within R and D). Note that watcher cannot direct its energy (gained from clock-photons) back to the clock

because that would mean that information gained for the experiment would be lost.

Let us assume that the experiment is taking a very long time. Let us say that this time is T_u (12.1).

The minimum time interval for a clock tick that R is able to provide for this experiment is then obtained by dividing total elapsed time (T_u) with maximum number of clock ticks a clock is able to provide (so that experiment can take place for any given time according to clock boundary principle):

$$T_r = \frac{T_u}{N_r} \quad (13)$$

Same for D :

$$T_d = \frac{T_u}{N_d} \quad (14)$$

Let us assume that R is observing D and that distance between the two is S . Let us also assume that instead of one object D , there is a number of them ($D_1, D_2, D_3...$); so that surface area of a three dimensional sphere of radius S around R is filled with them.

In the experiment, clock of R would be used to measure events as they relate to D_i ($i=1, 2, 3..$). These events may not occur often, but may also occur all at once. In such a case a surface area of sphere filled with D_i would produce clocked events that are occurring more often than any single D_i could. We can write that effectively:

$$T_{def} = T_d \cdot \frac{1}{4\pi S^2} \quad (16)$$

as it pertains to the surface area of a three dimensional sphere.

Similarly T_{ref} is the effective time interval of a clock in R with respect to distance S :

$$T_{ref} = T_r \cdot \frac{1}{4\pi S^2} \quad (17)$$

By combining (7) and (8) and (11) and (13) and (17):

$$T_r = \frac{h}{c} \cdot \frac{T_u}{m_r \cdot l_r} \quad (18)$$

$$T_{ref} = \frac{1}{4\pi S^2} \cdot \frac{h}{c} \cdot \frac{T_u}{m_r \cdot l_r} \quad (19)$$

In the same fashion by combining (9) and (10) and (12) and (14) and (16):

$$T_d = \frac{h}{c} \cdot \frac{T_u}{m_d \cdot l_d} \quad (20)$$

$$T_{def} = \frac{1}{4\pi S^2} \cdot \frac{h}{c} \cdot \frac{T_u}{m_d \cdot l_d} \quad (21)$$

The meaning of 'effective time interval' pertains to a simple fact that if we double the number of on average evenly timed events we observe we will need to have a clock that can work twice as fast to be able to observe them and account for them.

Suppose that (for argument sake), T_d is 10 seconds and T_{ref} is 1 second. This means that R 's effective clock resolution is 10 times better than D 's. This additionally means that R can observe the workings of D very well. In another supposition, let us say that T_d is 1 second and T_{ref} is 10 seconds (the opposite). This means that R 's effective clock resolution is 10 times worse than D 's. This also means that R can observe D poorly.

If we look at above examples, we essentially will have 11 clock ticks in 10 seconds in a system made up of R and D . However, in the first one, 10 of those will be made by R , while in the second, only 1 will be made up by R .

If we look for a moment at R and D as a single system that is measuring results from an experiment, then total number of ticks provided by R and D clocks would be (in above example) 11. Measure of the ability of R to observe would be 10/11 in first example and 1/11 in the second.

In line with above reasoning and using time between ticks (which is inverse from number of ticks), then the true measure of observation (assuming R observes D) now becomes ratio of a percentage of time between effective clock ticks in D when compared to the sum of time between effective clock ticks of D and time between clock ticks of R (we use effective time at the place of calculation so result is consistent in any frame of reference):

$$P_{rd} = \frac{T_{def}}{T_{def} + T_r} \quad (22)$$

The (22) is a measure of observability of D when observed by R . We will call this value a *clock boundary factor*, or simply a *clock factor*.

Similarly:

$$P_{dr} = \frac{T_{ref}}{T_{ref} + T_d} \quad (23)$$

is measure of observability of R when observed by D .

This measure of observation (clock factor) stands for objects at rest (as we assumed that R and D are at rest to begin with). It would at first appear that above formulas (22) and (23) (and all derivatives) in case of moving objects should be made to adjust for SR effects (such as time dilation of T_u interval, which is the same if R and D are at rest relative to each other, or for mass increase or length contraction for one of the objects when observed relative to the other in formulas for effective time intervals). However we will show that would be

the same as putting the cart before the horse, and that clock factor remains the same as a consequence of clock boundary principle.

To do that, let us imagine that D accelerates relative to R and that this acceleration continues to some speed V . According to SR time intervals between clock ticks in D (as observed from R) would increase (we do not consider length contraction because we can assume it is much smaller than distance S). However number of clock ticks N_d would remain the same because from perspective of D its mass and length remained the same. Similarly, from perspective of R its own number of clock ticks N_r would remain the same as would time intervals between clocks. We imagine an experiment of any duration being carried out by D and R , specifically of duration that is now longer exactly by some factor γ_{rd} (this factor may or may not be the full relativistic factor and we do not make an assumption about what exactly its value is). In this case, from perspective of R a clock tick of D has increased to $\gamma_{rd}T_d$ and total duration of experiment (from perspective of R) now has to be longer by the factor of γ_{rd} . According to clock boundary principle, for a law to be correct, R must be able to complete this experiment, regardless of duration, lest such duration causes clock action that exceeds all the energy contained in R . Since R 's number of ticks remains constant, duration of its clock tick T_r has to increase to become $\gamma_{rd}T_r$ (see (6.1)). This means that ratio T_d/T_r must remain constant at any velocity and equal to that which is at rest.

Based on (16) and (22), we can write:

$$P_{rd} = \frac{1}{1 + 4\pi S^2 \frac{T_r}{T_d}} \quad (24)$$

and similarly (17) and (23):

$$P_{dr} = \frac{1}{1 + 4\pi S^2 \frac{T_d}{T_r}} \quad (25)$$

If ratio T_d/T_r remains constant (as well as its reciprocal), it means that clock factors P_{rd} and P_{dr} remain constant regardless of velocity for a given distance S .

Clock factors are invariant with respect to relative speed of clocks at any constant distance S .

Observation of velocities is directly correlated to P_{rd} and P_{dr} . If R is observing D during the movement of length l , only part of that movement will be observed for the purposes of aforementioned experiment (12.1). The part of movement for the same amount of time will be unobservable. Hence, when D is moving with constant velocity V , R will observe only part of its trajectory for the same interval of time. Velocity observed for any such experiment will be:

$$V_{rd_{obs}} = V \cdot P_{rd} \quad (26)$$

This means that a typical relativistic factor (which deals only with observable quantities) should be written as:

$$\gamma_{rd} = \frac{1}{\sqrt{1 - \frac{(V_{rd_{obs}})^2}{C^2}}} \quad (27)$$

From (19), (20) and (22):

$$P_{rd} = \frac{1}{1 + 4\pi S^2 \cdot \frac{m_d l_d}{m_r l_r}} \quad (28)$$

or from (27), (28) for relativistic effect:

$$\gamma_{rd} = \frac{1}{\sqrt{1 - \frac{V^2}{C^2} \cdot \frac{1}{\left(1 + 4\pi S^2 \cdot \frac{m_d l_d}{m_r l_r}\right)^2}}} \quad (29)$$

Similarly, the effect when observing D from R is:

$$\gamma_{dr} = \frac{1}{\sqrt{1 - \frac{V^2}{C^2} \cdot \frac{1}{\left(1 + 4\pi S^2 \cdot \frac{m_r l_r}{m_d l_d}\right)^2}}} \quad (30)$$

(29) means that when small body is observed near large body, relativistic effects to small body (when observed from large body) are practically in full force. When small body moves sufficiently far away from large body, the observed speed diminishes as a function of square of distance, and V^2/C^2 factor diminishes as a function of the fourth degree of distance.

(30) means that when large body is observed near small body, relativistic effects are very small to large body (when observed from small body) and diminish in the similar fashion as in (29) with distance

(26) means that even though observable velocity of light is same everywhere, velocity of light is governed by the clock factor (i.e. depends on mass and size of object from which it is observed and disposition of other large masses in the vicinity of the body). (31)

The observed velocity V_{obs} is the velocity that figures in any law of motion that depends on obtaining clock value from one referential system to another (and vice versa). For example, velocity used in momentum doesn't count as there is no need to know anything about internal processes. The term *velocity* should be used for the actual velocity we can measure, whereas *observable velocity* is that which applies to any physical law that purports to infer internal state of another object through use of clocks (meaning it depends on time in a physical sense).

The observability of D (and relativistic effects) depends on the object R from which it is observed. Relative to different observer objects (R_1, R_2, \dots) it would be different. If multiple objects are present near relatively moving object, the observable velocity is different for each one. According to principle of clock boundary, a physical law holds only up to the extent to which it can be verified (*if and only if* premise of the principle), and given our experiment works with sphere filled with observers (such as that they cannot overlap), it is only any one observer that is necessary for principle to hold. This means that relativistic effect on D in presence of a number of different observers (R_i) will be affected only inasmuch as it pertains to the object with largest P_{rd} . (29)

Therefore, the velocity may go down and up depending on the presence of large observer as defined through largest value of P_{rd} for any such observer R .

Some practical considerations

The (29) means that hypothetical traveling apparatus, after some distance from Earth (and other massive bodies in Solar system), can accelerate past the velocity of light without running into manifestations of infinite masses or impractical time dilation etc.

If we look at the Space Shuttle of mass 2×10^9 kg and length of 50 meters moving away from Earth (mass 6×10^{24} kg and size 1.2×10^7 m), and if we neglect other large bodies we get that a point where observable velocity is down to half is, per (26) where:

$$P_{rd} = 1/2$$

$$S = 7.5 \text{ million kilometers}$$

Per same condition (26), a distance where observable velocity goes down 100 times and where with shuttle observable velocity of $c/2$ the shuttle velocity would be 50 times velocity of light is:

$$P_{rd} = 1/100$$

$$S = 76 \text{ million kilometers}$$

At this distance, an apparatus could accelerate to near 50 times the velocity of light.

Of course, there are other massive bodies in the Solar system and it is the one that contributes the most that counts (27), so such apparatus may need to go outside Solar system before reaching velocities many times that of velocity of light.

Small objects (including elementary particles) will experience relativistic effects in much broader radius. For example, if observer on Earth observes an electron, the observable velocity of electron will diminish to $1/2$ only at a distance of approximately 10^{37} meters, which is larger than the known radius of the Universe. Hence, looking for observable proof of repercussions of clock boundary principle in the world of elementary particles (or very small objects) is not feasible.

For example in hydrogen atom, the relativistic effect in the same fashion is found to be practically 100%.

In conclusion, if boundary principle and its application here is correct, Special Relativity works, and Einstein

was right - for objects (including elementary particles) close to other objects of masses and sizes large compared to that of an object. Beyond that, the effect of SR diminishes rapidly.

Another important point to make is that SR with clock boundary principle is not symmetrical - clock factors are not equal for an observer and an observed. For example, in case of muon experiment, muon really does experience relativistic effects almost to the full (a 100% for practical intents and purposes), whereas Earth doesn't experience them almost at all (a 0% for practical intents and purposes). Hence, to make a simplistic generalization, in a close system of two where one is much larger than the other, relativistic effects are virtually entirely felt by the smaller one (as observed from the larger one). The actual ratio of relativistic effects is generally given with P_{dr} for R and P_{rd} for D (as observed from the other one).

Some thoughts and considerations of clock boundary principle

We will address some of the potential issues in contemplating classic SR (unaltered with clock boundary principle) as a special case of a larger perspective.

What happens when there is an object with velocity beyond velocity of light (far from us) which passes another object moving relative to us? Both of them have low apparent velocity from our perspective, so there is no issue that we can detect as far as SR. From the perspective of two objects, the velocity of light is the same as it ever was. Because just as their velocity is higher, so is the velocity of light ((31), which to us is observable velocity of light which is the same as the one we know), so relative velocity of light is still the same as it ever was (even if we can measure movements faster than velocity of light (per (26), all laws using observable speeds still use observable velocity of light). From their own perspective, they do not break any physical laws. Same goes for us.

The real consequence is this: all the laws are still the same for any given observer, and observable velocity of light is still constant everywhere. But when inertial frames (as above) get sufficiently far away, any conclusion we draw making an assumption of observability being ideal (where clock factor $P_{rd}=1$) fails and this means mass increase, time dilation, length contraction and velocity of light limit.

In rough words, two frames get disconnected enough through distance and lack of observation capability (per clock boundary principle insofar as it affects the laws of physics, not the full reality of it) that they behave as if they are almost separate 'universes' in some ways (very, very loosely speaking). As another thought, clock boundary principle may imply that there is no need for expanding space as velocity of distant objects is not limited (unlike observable velocity which is limited to velocity of light). Also, it could mean that observed homogeneity of the Universe can be maintained by carriers moving faster than light between clusters of matter separated by large distances, without breaking SR that accounts for clock boundary principle.

Finally we will put some practical perspective to all this. Which objects could travel much faster than velocity of light? First of all, the more distant the better, as relativistic effects fall with distance. Therefore it holds that the more massive and longer the object (such as a long massive cylinder for example), the better. For example, a hypothetical large apparatus far from Solar system will be able to accelerate many times beyond velocity of light. Another example is a galaxy that is far from other galaxies and massive. It can also reach and exceed velocity of light.

Finally, if the conclusions here hold, we can finish with an irony of its own: in a sense, even though space is big and accelerating larger objects is more difficult to achieve than smaller ones, it is ironic that largesse of space and high mass of a hypothetical space-faring apparatus are two things that could potentially make real time interstellar travel possible.