A Computational Model of Space, Time, and Light

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Abstract

We present a simple, computational model of space, time, and the photon. Our model of space assumes that space is actually performing computations to change the properties and positions of systems. However, we do not assume that space is processing classical bits, or otherwise make assumptions about the mechanisms carrying out these computations. Instead, we treat the total energy of a system as the physical measurement of the amount of information that space must process to generate the next state of that system. Therefore, in our model, as the total energy of a system increases, the amount of information processed by space also increases, causing the amount of time it takes for space to process the current state of that system to increase as well. We show that this relationship between energy, information, and time implies that time-dilation will occur without space-time. Further, we show that the difference between the analog of the Lorentz factor for our model and the relativistic Lorentz factor is less than .0297 for velocities less than $\frac{1}{2}c$, where c is the speed of light in a vacuum. However, unlike relativistic time-dilation, our model has objective time, and therefore, all events occur in a definite, objective order, meaning causality is always intact. As such, in our model, the Joule is nature's bit, and therefore, the more energy a system contains, the more time it takes for space to generate the next state of that system.

We then build a model of the photon using concepts from our model of space and time. Our model implies that a photon will have some mass, albeit a very small amount, and we provide a formula for the mass of a photon, as well as its volume, each expressed as a function of its wavelength. Additionally, our model of the photon is capable of sublimating into smaller, self-similar parts, which we argue would produce interference patterns when single photons are fired through a double slit. Finally, because photons have mass in our model, they would be subject to gravitational forces, and therefore, the path of a photon would be altered by gravitational acceleration, without space-time.

1 Introduction

We typically think of mathematics as describing nature, as opposed to nature performing mathematics. That is, if a mathematical model generates outputs that are within some tolerable range of error when compared to the behavior of some measurable process of nature, then we view that model as describing that process of nature. But by turning this on its head, we could also say that if we'd like to know the output of a mathematical model that describes some measurable process of nature, then we could query that measurable process of nature. That is, if a mathematical model describes the behavior of some measurable process of nature, then by definition, that measurable process of nature can be used to approximate the outputs of that mathematical model.

For example, imagine that we have a model that generates the positions of the particles of a gas in a volume over time given some set of initial conditions for the particles. Now assume arguendo that we have some means of actually setting the physical initial conditions of the particles in the gas. We could then view the behavior of the gas over time given a particular set of physical initial conditions as the answer to the question, "how would our model behave given this set of initial conditions?" In reality, we probably have no means of setting the initial conditions of every particle in a gas, but the point remains: whether or not we can fully exploit it, nature can still be viewed as performing computations.

What follows is an exploration of the physical consequences of assuming that nature is in fact performing computations with a locally finite amount of information processed per unit of time. Remarkably, we arrive at conclusions that are consistent with relativistic time-dilation due to velocity, and offer sensible explanations for the properties of light.

1.1 Energy, Information, and Time

Assume arguendo that nature is in fact performing some form of computations to generate the phenomena we experience, and that as such, the path of each object is processed and then updated in discrete increments.[1]

Now imagine that one person in a park throws a football, while at the same time, another person 200 meters away throws another identical football at the same velocity, from the same height. Is there an order in which the individual paths of the footballs are processed? Our everyday experiences suggest that so long as the two footballs don't interact, each path should be processed and updated in parallel, independently of the other. Therefore, if nature is performing computations, we assume it is processing in parallel.

Assumption 1.1. *All independent systems are processed independently, in parallel.*

[1] We will use the words "system" and "object" interchangeably, with usage determined by their intuitive connotations. For example, we will call a football an object, but an abstract collection of particles a system. We view each as a collection of particles that change their properties and positions over time.

Assumption 1.1 comports with everyday experiences, where independent phenomena (i.e., those that don't interact with each other over the time period in question) all appear to happen in parallel, independently of each other. Assumption 1.1 then leads to the following corollary:

Corollary 1.2. *If independent systems are processed in parallel, and simultaneous behavior among systems is possible, then it follows that something is coordinating the processing between systems.*

Corollary 1.2 says that if independent systems are processed independently, in parallel, but are still capable of producing simultaneous behavior, then there must be something coordinating their processing.[2] Returning to the previous example, because both footballs are traveling with identical velocities from the same initial height, they will land at the same time. Since their paths are processed in parallel, something must be coordinating the processing of the actions that cause them to land at the same time. Assuming otherwise would imply that one of the footballs could be in an area of space where processing happens more often, which implies that the footballs could land at different times, despite being thrown under the same initial conditions. Though we will allow for local time-dilation, this is not the mechanism for it, and so we assume that all computations occur simultaneously everywhere, and that therefore, the number of times an object is processed over a given interval of time is constant everywhere.

Assumption 1.3. *Computation occurs only upon the occurrence of a* ***click****, which happens once per Planck time for all systems, simultaneously.*

Assumption 1.3 implies that if k clicks have occurred, then the amount of time that has elapsed is simply $k\hbar_t$, where $\hbar_t$ is the Planck time. Conversely, if Δ_t is some interval of time, then $k = \frac{\Delta_t}{\hbar_t}$ is the number of clicks that have occurred over that interval of time.[3]

Figure 1: Time and the number of clicks

Assumption 1.4. *The current state of a system is updated only upon the occurrence of a* ***bang****, which occurs on the last click required to fully process the current state of that system.*

[2] Our model makes use of objective time, despite allowing for time-dilation, meaning truly simultaneous action is possible. The mathematics for facilitating this is straightforward, and is set out in Section 2.3 below.

[3] For simplicity, we assume Δ_t is a multiple of $\hbar_t$.

Assumption 1.4 says that objects update their properties and positions independently, but only upon the occurrence a click. Therefore, while the number of clicks that have occurred over a given interval of time is a global constant, the occurrence of a bang is object specific. That is, a given click could cause one object to change position, whereas another object would remain stationary for that click if it hasn't been fully processed yet.[4]

Returning again to the previous example, assume it takes two clicks to process the current state of each football. Assumption 1.4 tells us that every other click will constitute a bang. On the first click, the current state of each football would be processed in parallel, but neither football would change position. On the second click, the current state of each football would be fully processed, and therefore, their positions would be updated simultaneously. This process would repeat upon each click, so that after an extremely large number of clicks, we would see the path of each football emerge over macroscopic intervals of time.

Assumption 1.5. *The maximum amount of information that can be processed per click in a space of volume V is given by Ve_v, where e_v is constant across all volumes of space.*

Assumption 1.5 says that the maximum amount of information processed per volume of space per click is constant everywhere.

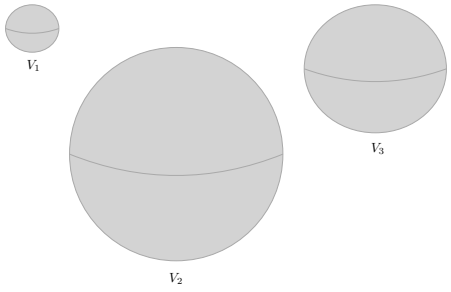

Figure 2: The computational power of each volume is proportional to its size, meaning V_1 would process the least amount of information per click.

Though it may seem odd to assume that there is some limit to the amount of information that nature can process per unit of time, consider the contrary position in the context of a computational model of nature: if nature had a truly unlimited amount of computational power, why would time exist at all? All processes would simply unfold immediately. As such, we impose a limit on the amount of information processed per click, but instead of an overall limit, Assumption 1.5 places a local limit on the amount of information that can be processed per click, saying it is proportional to the volume of the space where the computation is taking place.

[4]It is reasonable to be suspicious of the idea that a macroscopic object would remain stationary for some period of time while it is "processed". It is therefore important to note the incredibly small intervals of time we are considering, which are on the order of 10^{-44} seconds.

Assumption 1.6. *Each click has two phases, an* ***open phase*** *and a* ***close phase****, with the open phase occurring before the close phase. Computation occurs upon the open phase of a click, and bangs occur upon the close phase of a click. The number of clicks that have occurred is measured relative to the close phase of each click.*

The open phase and close phase of a click can be viewed as two timelines, each broken into segments of the Planck time, but offset by some fixed amount of time. Note that we haven't changed the relationship between the number of clicks that occur and the amount of time that has elapsed, since we count the number of clicks using the close phase of a click. As such, we measure time using the close phase of a click, which is consistent with physical reality, where we measure time using measurable changes in properties and positions, which in our model, occur only upon the close phase of a click.

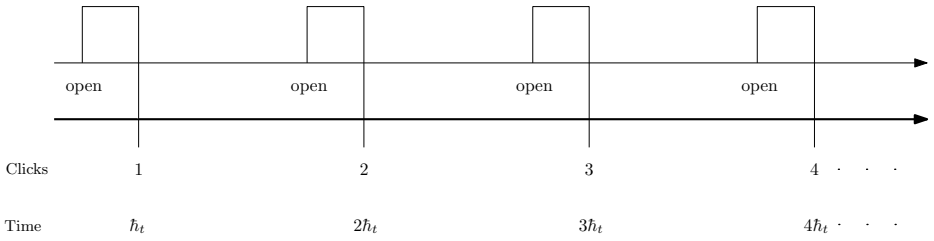

Figure 3: The open phase of a click happens just before the close phase.

Assumption 1.5 assumes that computation takes place in a particular volume of space, and Assumption 1.6 assumes that computation occurs at a particular time, just before the close phase of each click. For example, consider a system at time t that is one click away from a bang, so that at $t + \hbar_t$ we will reach the close phase of the next click, causing that system to update. That is, there is some incremental amount of information that needs to be processed to update the system, and once that happens, the system will update to a new state. Let's assume that new state requires the system to change its position. If at t the system is at a location in volume V_1, then the processing upon the open phase of the next click, just before $t+\hbar_t$, takes place in V_1. Then upon the close phase of that click, at $t + \hbar_t$, the system will be updated to its next state, and its position will be updated to its new location in V_2. As such, the position of the system at t is in V_1, and its position at $t + \hbar_t$ is in V_2.

Returning to the previous example, the footballs will each draw on the computational resources of the volumes of space they occupy over time. Since they are moving, they will have different positions over time, and therefore occupy different volumes of space over time, but they will at all times occupy the same amount of volume.[5] Therefore, Assumption 1.5 implies that they will at all times have access to the same computational resources. Additionally, because

[5] We assume they are perfectly rigid for purposes of illustration.

we have assumed the footballs are identical in all respects, the amount of information processed to generate the path of each football from the time it is thrown till the time it lands should be the same for each football. Therefore, because each football has access to the same computational resources, and requires the same amount of information to be processed to generate its path, the number of clicks required to generate the path of each football should be the same. But how do we think about the amount of information that is being processed to generate their paths?

We typically think of information in bits, so it might seem natural to first identify the physical properties of the ball (e.g., its shape, color, mass, etc.), and the arc of its path, and then develop a schema that would allow us to represent these properties as a series of binary strings. We could then ask how many bits it would take to encode that representation. Assuming we use an objective measure for the length of the encodings, this approach would yield the same answer for both footballs. But even if we choose an objective measure for the length of the encodings, like the Kolmogorov Complexity,[6] we would still be forced to make an arbitrary choice with respect to how detailed our representations are. That is, like most macroscopic objects, a football has a simple macroscopic structure, but a very complicated structure at the levels of granularity we are considering. We can then either choose some arbitrary level of detail for our representations, or instead be faced with considering objects so complex that they probably couldn't be processed in any meaningful way on any computer.

The problem underlying this approach is an assumption that nature has represented and encoded these objects in a manner analogous to how human beings represent and encode objects, as opposed to acting on the objects directly. While we generally represent objects and then perform operations on their representations, there is no reason to assume that nature performs computation using representations, as opposed to manipulating the objects themselves.[7] If that is the case, then then there would be no representations to consider, and therefore no encodings to measure. In short, the ordinary concept of information, measured in bits, would be inapplicable.

With that in mind, we note that since the footballs are identical, they have identical masses, and therefore identical potential energies. Because they have the same initial velocities, and mass, they have the same kinetic energies. As such, at all times, they have the same total energies, from launch till landing. We also note that if we know the kinetic and potential energy of an object, we know its mass, and its velocity, and can therefore plot its path as a function of time. So it seems that the more we know about the energy of an object, the

[6] In this case, it would be the length, in bits, of the shortest program that generates the representation on a Turing Machine.

[7] For example, while we can perform physical operations on DNA to achieve particular physical results, we must first represent the physical sequences we intend to operate on in a symbolic, human language, in order to understand the physical objects we are attempting to manipulate. In contrast, nature appears to operate directly, without any symbolic processing. That is, the presence, absence, and quantity of physical material automatically drives the behavior of nature, as opposed to a conscious reflection on the material encountered.

more we know about how that object will behave. Therefore, the total energy of an object seems a good candidate for a measure of the amount of information that must be processed to generate the next state of that object.

Assumption 1.7. *The number of clicks required to process the current state of a system with total energy E_T and volume V is given by,*

$$k = \left\lceil \frac{E_T}{V e_v} \right\rceil. \tag{1}$$

2 Computational Time-Dilation

2.1 The Computational Volume

Consider a stationary object S, composed of identical particles that are small enough to give the object an apparent macroscopic volume of V.

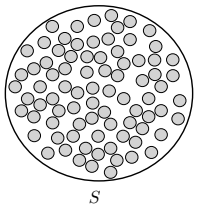

Figure 4: An object S composed of identical particles.

If we assume there is some empty space between the particles within S, then there must be some difference between V, and the actual volume occupied by its component particles. If we let V_p be the actual volume of each of the particles in S, and let n be the number of particles in S, then the actual volume of S is nV_p. Because equation (1) has units of clicks, it follows that e_v has units of Joules per meters cubed per click ($\frac{J}{m^3 \text{ click}}$). Because the individual particles within S are identical, and they each have a volume of V_p, it follows from Assumption 1.5 that they each occupy a volume of space capable of processing a total energy of $V_p e_v$ Joules per click. Therefore, we say that the **computational volume** of S is $\mathbb{C}_S = nV_p e_v$, which has units of Joules per click. As such, the computational volume that processes the current state of an object is proportional to the actual volume of that object.

Now imagine that we pack the particles within S as tightly as possible so as to minimize the amount of empty space, but without changing the volumes of the individual particles, and call this changed system $\bar{S}$. It follows that the apparent volume of $\bar{S}$ will be some smaller apparent volume $\bar{V}$. However, because the actual volume of $\bar{S}$ is still given by nV_p, the computational volume is still given by $\mathbb{C}_{\bar{S}} = \mathbb{C}_S = nV_p e_v$. As such, the computational volume of an object is proportional to the actual volume of that object, not its apparent volume.

2.2 Computational Groups

In the previous section, we said that the computational volume of S was given by $nV_p e_v$. That is, we allowed all of the particles within S to pool their computational resources to process their paths as part of a collective whole, S. However, we also need to allow for systems to be processed independently. We will revisit this subject in greater detail below, but for now, we say that whenever two particles **interact**, they form a **computational group**.

For example, if two particles p_1 and p_2 interact, and they have actual volumes of V_1 and V_2 respectively, then they form a computational group, and their computational volume is given by $(V_1 + V_2)e_v$. Assume they have total energies of E_1 and E_2 respectively. It follows from equation (1) that the number of clicks required to process their current state is given by,

$$k = \left\lceil \frac{E_1 + E_2}{(V_1 + V_2)e_v} \right\rceil.$$

As such, assuming k is constant over time, every k-th click will constitute a bang for both p_1 and p_2. If they are not part of a computational group, then they do not pool resources, and their paths are computed in parallel, which implies that the number of clicks required to process the current state of p_1 and p_2 is given by $\left\lceil \frac{E_1}{V_1 e_v} \right\rceil$ and $\left\lceil \frac{E_2}{V_2 e_v} \right\rceil$, respectively.

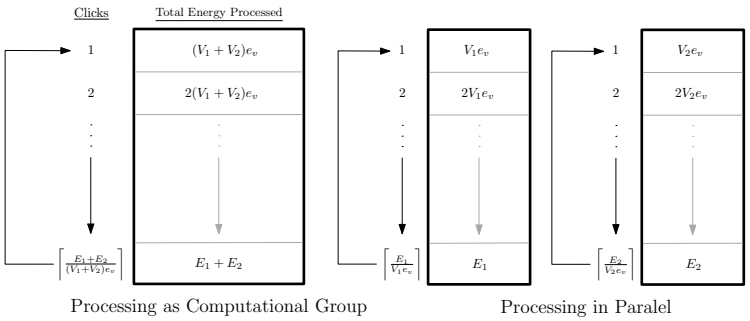

Figure 5: Processing as a computational group versus processing in parallel.

If a series of particles form a chain of interactions, where p_1 interacts with p_2, and p_2 interacts with p_3, and so on, then all such particles form a single computational group.

The intuition for computational groups stems from the following example: consider an object that has a velocity of v that is composed of equal amounts of two types of particles that are identical in all respects, except one type of particle has a higher total energy than the other. If we do not allow for the pooling of computational resources, then the lower energy particles will be updated more often, since according to equation (1), they require fewer clicks to process. Over time this would result in the lower energy particles maturing through their paths faster than the higher energy particles, which could create the appearance of

two independent objects emerging at the macroscopic level over time. As a result, we need a way to allow a group of heterogenous particles to update their properties and positions as part of a whole, and that is the purpose of the notion of a computational group.

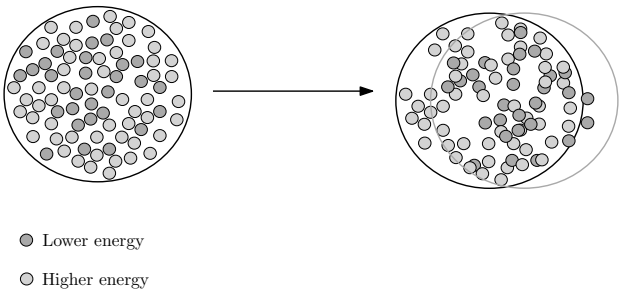

Figure 6: Different rates of processing produce different rates of ageing.

Consider the following as an example: imagine an idealized baseball consisting of particles small enough to give the baseball a smooth apparent volume. Even when the ball is in an apparent state of rest, the particles will still have thermodynamic velocity, causing them to interact with each other, and thereby causing them to pool resources as a computational group. Nonetheless, assume arguendo that at first the particles in the ball are not part of a computational group. Now imagine that a bat hits one side of the ball. When the bat hits the ball, the particles within the ball will begin to collide, and therefore a network will emerge, beginning at the point where the bat hits the ball, and eventually spreading out through the entire ball, until all particles within the ball are part of a single, computational group, causing all of their positions to be updated simultaneously, which would cause the ball to behave like a single object, despite consisting of a large number of individual particles.

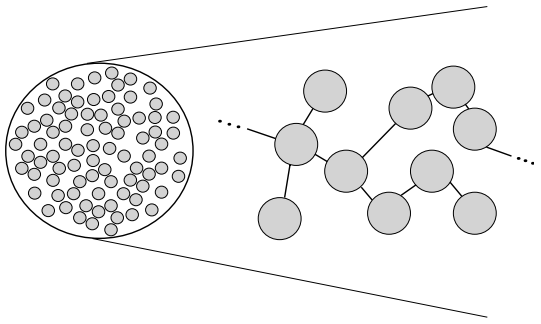

Figure 7: Particles forming computational groups.

However, this does not imply that all of the particles will have the same velocities or directions at all times. Instead, it implies that whatever their

velocities may be, their positions are updated simultaneously, as all particles share equally in the combined computational resources of their respective volumes. Nor does it imply that the particles are bonded together in any way: the notion of a computational group does not define the interactions between the particles, it only dictates how often the properties and positions of the particles within the computational group are updated.

From here on, unless we specify otherwise, all particles in a given system will be assumed to be part of a single computational group.

2.3 Computational Time-Dilation

Now consider two systems of particles, S and $\bar{S}$, which are identical in all respects, except that the particles in S are stationary while the particles in $\bar{S}$ are all traveling with a velocity of $v > 0$ in the same direction. If E and $\bar{E}$ are the total energies of S and $\bar{S}$, respectively, then it follows that $E < \bar{E}$. Because S and $\bar{S}$ are identical in all respects except save for their total energies, it follows that they have the same computational volume, $\mathbb{C}_{\bar{S}} = \mathbb{C}_S = Ve_v$. Therefore, if we let k and $\bar{k}$ be the number of clicks required to process the current state of S and $\bar{S}$, respectively, we have,

$$\frac{\bar{k}}{k} = \frac{\left\lceil \frac{\bar{E}}{Ve_v} \right\rceil}{\left\lceil \frac{E}{Ve_v} \right\rceil} \approx \frac{\frac{\bar{E}}{Ve_v}}{\frac{E}{Ve_v}} = \frac{\bar{E}}{E} > 1.$$

Now let $\Delta t = k\hbar_t$ and $\Delta \bar{t} = \bar{k}\hbar_t$. It follows that,

$$\frac{\Delta \bar{t}}{\Delta t} = \frac{\bar{k}}{k} \approx \frac{\bar{E}}{E},$$

which implies that,

$$\Delta \bar{t} \approx \frac{\bar{E}}{E} \Delta t. \tag{2}$$

Equation (2) says that the amount of time that elapses processing the current state of the higher energy system, $\bar{S}$, is greater than the amount of time that elapses processing the current state of the lower energy system, S. Because the processing of both systems is done simultaneously, in parallel, it follows that the higher energy system will be updated less often than the lower energy system over any given interval of time. The net effect is that if we increase the total energy of a given system, keeping all other properties of that system constant, we increase the amount of objective time it will take for that system to progress through its states. Thus, a higher energy system will objectively "age" slower than its lower energy equivalent.

This result is consistent with relativistic time-dilation, which states that time-dilation is a function of velocity, and that faster moving systems experience less time relative to slower moving systems, therefore causing time to appear

as if it were going slower inside a faster moving system from the perspective of a slower moving system. In the context of computational time-dilation, it would mean that the properties and positions of the faster moving system would be updated less often than the properties and positions of the slower moving system, meaning that from the perspective of the slower moving system, time would appear to be going slower inside the faster moving system. However, unlike relativistic time-dilation, there is an objective amount of time that has elapsed. That is, S and $\bar{S}$ always experience the same amount of time in the computational model, which is simply the number of clicks multiplied by the Planck time. Therefore, in the computational model, it is not the difference in the amounts of time experienced by two systems that causes time-dilation, but instead the difference in the amounts of time required to process the current states of those systems that causes time-dilation.

Now assume that S and $\bar{S}$ have the same mass m. We assume that the total energies of S and $\bar{S}$ are given by,

$$E = E_K + E_P = mc^2,$$

and,

$$\bar{E} = \bar{E}_K + \bar{E}_P = \frac{1}{2}mv^2 + mc^2,$$

respectively. This implies that,

$$\Delta\bar{t} \approx \left(1 + \frac{v^2}{2c^2}\right)\Delta t. \tag{3}$$

2.3.1 Comparison to Relativistic Time-Dilation

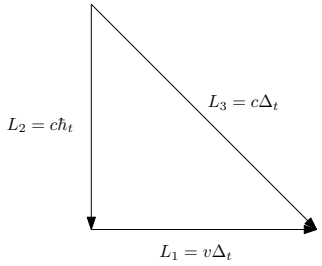

Figure 8: S and $\bar{S}$ experience different amounts of time under relativistic time-dilation.

Now let us compare equation (3) to the result obtained by assuming that S and $\bar{S}$ are subject to relativistic time-dilation. Let Δ_t be the amount of time that has elapsed from the perspective of S as $\bar{S}$ travels a distance of $L_1 = v\Delta_t$. Assume that there is a photon gun also traveling at a velocity of v in the same direction as $\bar{S}$, and that it takes $\hbar_t$ for the photon to travel from the gun to the

detector when the gun is stationary. Now assume that from the perspective of S, when the gun is traveling with a velocity of v, the photon travels from the gun to the detector over the same period of time that $\bar{S}$ travels a distance of L_1.

By the pythagorean theorem, $L_1^2 + L_2^2 = L_3^2$, and therefore,

$$\Delta_t = \frac{\hbar_t}{\sqrt{1 - \frac{v^2}{c^2}}}.$$

From the perspective of $\bar{S}$, the photon has traveled a distance of $\hbar_\ell$, and as such, $\bar{S}$ experiences an amount of time equal to $\hbar_t$, while S experiences an amount of time equal to Δ_t. This implies that, in general, if $\bar{S}$ experiences an amount of time $t_{\bar{S}}$, then the amount of time experienced by S is given by,

$$t_S = \frac{t_{\bar{S}}}{\sqrt{1 - \frac{v^2}{c^2}}}. \tag{4}$$

Because the amount time experienced by both S and $\bar{S}$ under computational time-dilation is simply the number of clicks that occur multiplied by $\hbar_t$, we cannot directly compare equations (3) and (4). However, we can compare the number of states S and $\bar{S}$ progress through under the relativistic model versus the number of states that they progress through under the computational model over a given interval of time. We assume that under the relativistic model, the number of states that S and $\bar{S}$ progress through is proportional to the amount of time experienced by S and $\bar{S}$, respectively, with the same constant of proportionality, n, for both S and $\bar{S}$.

It follows that, under the relativistic model, when S experiences an amount of time equal to t_S, it progresses through nt_S states, while $\bar{S}$ progresses through $nt_{\bar{S}} = nt_s(1 - \frac{v^2}{c^2})^{\frac{1}{2}}$ states. We cannot know the actual number of states that S and $\bar{S}$ will progress through without making additional assumptions, but we can consider the ratio of the number of states that S will progress through divided by the number of states that $\bar{S}$ will progress through, which is simply the Lorentz factor,

$$\gamma_r = \frac{1}{\sqrt{(1 - \frac{v^2}{c^2})}}.$$

Now let us consider the computational model. The number of states that S and $\bar{S}$ will progress through under the computational model over any interval of time t is $\frac{t}{k\hbar_t}$ and $\frac{t}{k\bar{\hbar}_t}$, respectively, the ratio of which is,

$$\gamma_c \approx (1 + \frac{v^2}{2c^2}).$$

We note that for velocities less than $\frac{1}{2}c$, $\gamma_r - \gamma_c$ is less than .0297, which means that for velocities less than $\frac{1}{2}c$, a given pair of systems would progress through their states at similar relative rates in both models. Finally, we note

the obvious: equation (3) clearly allows for velocities in excess of the speed of light. But, because our model has objective time, all events occur at a specific, objective time, and therefore, there is an objective frame of reference from which we determine the order of all events. Therefore, causality is always intact. As such, the speed of light can still be viewed as constant in a vacuum, while leaving the door open to the possibility of velocities in excess of that speed.

In sum, the concept of the computational volume implies time-dilation will occur. If we also assume that total energy is given by $E_T = E_K + E_P = \frac{1}{2}mv^2 + mc^2$, then for velocities less than $\frac{1}{2}c$, systems would progress through their states at similar relative rates in both the computational model and the relativistic model.

2.3.2 Stationary Time-Dilation

Equation (2) suggests that time-dilation might be a general phenomenon that occurs whenever we change the total energy of a system. As such, if it were possible to change the total energy of a system without affecting the velocity of that system, then equation (2) suggests that we could induce time-dilation in stationary systems. If so, then we could use the different rates at which systems progress through their states to store information. For example, assume that S_1 and S_2 are identical, stationary systems that progress through their states at the same rate, and that we can measure this rate. If we can change the total energy of S_1 without affecting the velocity of S_1, or otherwise disturbing its progression through its states, then we could induce time-dilation in only S_1, and use the difference in the rates at which S_1 and S_2 progress through their states to represent a number, or simply the presence of a difference, i.e., a binary 1.

3 The Mass and Volume of a Photon

In this section, we will use the concept of the computational volume to derive a formula for the mass and volume of a photon.

3.1 The Computational Volume of a Photon

Let h be Planck's constant and let λ be the wavelength of a photon. We assume that the total energy of a photon is given by Planck's equation:

$$E_T = \frac{hc}{\lambda}. \tag{5}$$

Let P_1 and P_2 be photons with wavelengths $\lambda_1 \neq \lambda_2$, respectively. Let k_1 and k_2 be the number of clicks required to process the current state of P_1 and P_2, respectively. Because clicks happen once per Planck time, photons should travel a distance equal to one Planck length per click. We could however allow for the path of a photon to be updated less often than once per click, and still produce a velocity of one Planck length per click. For example, we could

assume it requires two clicks to process the current state of a particular photon, in which case the photon would travel a distance of two Planck length's after two clicks, but remain stationary every other click. This is however an awkward result that undermines the concept of the Planck length, which is the distance actually traveled by a photon per Planck time. As such, we assume that only one click is required to process the current state of a photon. Let $E_1 = \frac{hc}{\lambda_1}$ and $E_2 = \frac{hc}{\lambda_2}$. It follows that for all λ_1, λ_2,

$$\left\lceil \frac{E_1}{V_1 e_v} \right\rceil = \left\lceil \frac{E_2}{V_2 e_v} \right\rceil = 1.$$

We now make the following additional assumption that,

$$\frac{E_1}{V_1 e_v} = \frac{E_2}{V_2 e_v} = 1.$$

That is, we assume that for all photons, regardless of wavelength, the ratio of total energy to computational volume is exactly 1.[8] This means that, regardless of wavelength, photons always have the minimum computational volume necessary to process their motion in one click. It follows from this assumption that,

$$\frac{\frac{hc}{\lambda_1}}{V_1} = \frac{\frac{hc}{\lambda_2}}{V_2},$$

which implies that,

$$\frac{V_2}{V_1} = \frac{\lambda_1}{\lambda_2}.$$

Therefore, the computational volume of a photon is inversely proportional to its wavelength, which for some $\alpha > 0$ is given by,

$$\mathbb{C}_\lambda = \frac{\alpha}{\lambda} e_v. \tag{6}$$

3.2 The Components of a Photon

Because the computational volume equals the actual volume multiplied by e_v, the volume given by $\frac{\alpha}{\lambda}$ must be filled with something. Though we admittedly do not know what fills this volume, we will assume arguendo that it is filled with identical particles, and then examine the consequences. If these particles are identical, then each such particle should contribute equally to the total energy of the photon. We also know that the number of these particles must increase as the wavelength of the photon decreases, since as the wavelength decreases, the volume of the photon increases, and therefore, more particles must fill that larger volume.

[8] As is evident, our model is centered around light, in that light travels the minimum distance, in the minimum time, using the minimum computational volume necessary to do so.

We call these particles **J-bits**. Let $\hbar_e = \frac{h}{1\text{second}}$. That is, we divide h by one second to obtain the scalar portion of h with units of Joules. We assume that each J-bit has a total energy of $\hbar_e$. Let n be the number of J-bits in a given photon. Because each J-bit contributes equally to the total energy of a photon, it follows that,

$$n\hbar_e = \frac{hc}{\lambda} \Rightarrow n = \frac{c}{\lambda}.$$

Because $\hbar_e$ has units of Joules, it follows that n is dimensionless. This implies that,

$$\frac{\hbar_e c}{\lambda} = \frac{hc}{\lambda},$$

where c has units of meters on the left-hand side of the equation. As such, if $n = 1$, then $\lambda = c$ meters, and so a single J-bit is equivalent to a photon with a wavelength of c. As such, we assume that, like a photon, the current state of a J-bit is processed in one click, and that therefore, the computational volume of a J-bit is $\frac{\alpha}{c} e_v$. Interestingly, the equation above suggests that photons have a maximum wavelength of c meters, and that wavelengths should jump in discrete intervals as a function of n.

3.3 The Mass of a Photon

We will first solve for the mass of a J-bit. We assume that for a J-bit,

$$E_T = E_K + E_P = \hbar_e;$$

$$E_K = \frac{1}{2} m v^2;$$

and,

$$E_P = mc^2.$$

It follows that,

$$v = \sqrt{\frac{2E_K}{m}},$$

and that,

$$m = \frac{E_P}{c^2},$$

which implies that,

$$v = c\sqrt{\frac{2E_K}{E_P}}. \tag{7}$$

Because photons travel with a velocity of c in a vacuum, and J-bits can be viewed as photons with a wavelength of c meters, we assume that J-bits also have a velocity of c in a vacuum. It follows from equation (7) that,

$$E_P = 2E_K.$$

That is, the potential energy of each J-bit in a photon is twice its kinetic energy. Since the total energy of a J-bit is $\hbar_e$, it follows that $E_K = \frac{1}{3}\hbar_e$ and $E_P = \frac{2}{3}\hbar_e$. This implies that the mass of a J-bit is given by,

$$m = \frac{E_P}{c^2} = \frac{2\hbar_e}{3c^2} = \frac{2}{3c^2}E_T. \tag{8}$$

Therefore, if n is the number of J-bits in a photon, then the mass of a photon is given by,

$$m = n\frac{2\hbar_e}{3c^2} = \frac{c}{\lambda}\frac{2\hbar_e}{3c^2} = \frac{\hbar_e c}{\lambda}\frac{2}{3c^2} = \frac{2}{3c^2}E_T.$$

This is the same equation given in (8) for the mass of a J-pair. Finally, we have the total energy of a photon given by,

$$E_T = E_K + E_P = \frac{1}{2}mv^2 + mc^2 = \frac{1}{2}(\frac{2}{3c^2}E_T)c^2 + (\frac{2}{3c^2}E_T)c^2 = \frac{hc}{\lambda}.$$

3.4 The Volume of a Photon

In Section 3.2, we assumed that the computational volume of a J-bit is $\frac{\alpha}{c}e_v$. We arrived at this conclusion by assuming that photons, and the J-bits found inside photons, always have the minimum computational volume necessary to process their current state in one click. We now consider a macroscopic hypothetical which we will use to create a definition of physical volume that we will apply to the J-bit. From that, we derive a formula for the actual physical volume of a photon.

Imagine an object that has some holes in its structure, but assume that the object is nonetheless strong enough to maintain its shape in a vacuum. Now imagine that we have a probe that can scan not only the surface of the object, but also its internal structure, in three dimensions, and can therefore determine its volume by distinguishing the object from the vacuum it exists in. How does the probe distinguish between the object and the vacuum? It must be the case that the object and the probe interact in some way.

By analogy, we define the volume of a J-bit as the volume of space contained in the boundary at which it will interact with other particles. We assume that this is a sphere with a radius of $\hbar_\ell$, and call $\hbar_\ell$ the **radius of interaction** for the J-bit. The position of a J-bit is given by the center of this sphere. We are not assuming that a J-bit will interact with all particles that are at its boundary. But rather, whatever rules govern the interactions of a J-bit, it will only become "aware" of other particles when those particles are at its boundary. In general,

we define a **particle** as any object that has a single radius of interaction. So, for example, a group of J-bits traveling in the same direction would not constitute a particle, since they each have their own radius of interaction, whereas each individual J-bit would constitute a particle.

Further, we assume that it is not possible for one particle to enter the volume of another particle. That is, interactions happen at a distance equal to the radius of interaction. As such, we assume that if upon the close phase of a given click, a group of particles updates their positions in way that would cause their volumes to overlap, then one of those particles maintains its original position, and the other particles have their positions adjusted by the minimum distance necessary in their respective directions of motion to eliminate any overlap. This adjustment happens instantaneously upon the close phase of the click where the overlap would have occurred. Upon the open phase of the click after their positions are adjusted, the particles can interact with each other if the boundaries of their volumes are adjacent.

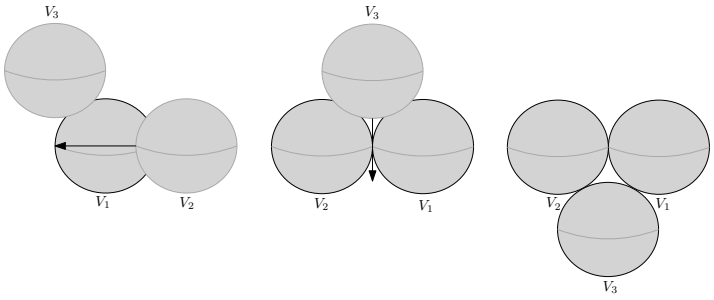

Figure 9: Adjusting particle positions to eliminate overlaps in volumes.

Because each J-bit has a radius of interaction of $\hbar_\ell$, we say that the actual volume of a J-bit is given by,

$$V_L = \frac{4}{3}\pi\hbar_\ell^3, \tag{9}$$

and that therefore, the computational volume of a J-bit is given by,

$$\mathbb{C}_L = \frac{4}{3}\pi\hbar_\ell^3 e_v. \tag{10}$$

Because $\frac{E}{\mathbb{C}_L} = 1$, it follows that,

$$\frac{E}{\mathbb{C}_L} = \frac{\hbar_e}{\frac{4}{3}\pi\hbar_\ell^3 e_v} = 1,$$

which implies that,

$$e_v = \frac{\hbar_e}{\frac{4}{3}\pi\hbar_\ell^3}. \tag{11}$$

As such, e_v has units of Joules per meters cubed per click, which is to be expected, since it is the constant of proportionality between actual volume and computational volume, which has units of Joules per click. Its value can be interpreted as saying that a spherical volume with a radius of $\hbar_\ell$ can process the current state of a system with an energy of $\hbar_e$ in one click. Because clicks happen once per Planck time, we can also express the constant of proportionality between actual volume and computational volume as having units of Joules per meters cubed per Planck time. Let ε_v denote this modified version of the constant of proportionality. In the case of a J-bit, $\frac{E}{V\varepsilon_v} = \hbar_t$, and so it follows that,

$$\varepsilon_v = \frac{\hbar_e}{\frac{4}{3}\pi\hbar_\ell^3\hbar_t} = \frac{e_v}{\hbar_t}. \tag{12}$$

Note that we also assumed that $\mathbb{C}_L = \frac{\alpha}{c}e_v = \frac{\alpha}{\lambda}e_v$. Because $\mathbb{C}_L$ has units of Joules per click, it follows that α has units of m^4, where m denotes meters. We note that for any λ,

$$\frac{E}{Ve_v} = \frac{\frac{hc}{\lambda}}{\frac{\alpha}{\lambda}e_v} = 1.$$

Solving for the value of α, we find,

$$\alpha = \frac{hc\frac{4}{3}\pi\hbar_\ell^3}{\hbar_e} = \frac{4}{3}\pi\hbar_\ell^3 c.$$

Because $\hbar_e$ has units of Joules, it follows that α has units of m^4, and therefore c above has units of meters. As such, the physical volume of a photon with wavelength λ is given by,

$$V_\lambda = \frac{\frac{4}{3}\pi\hbar_\ell^3 c}{\lambda}, \tag{13}$$

where c has units of meters. Finally, it follows that the number of clicks required to process the current state of a photon is given by,

$$k = \frac{E}{\mathbb{C}_\lambda} = \frac{\frac{hc}{\lambda}}{\frac{\alpha}{\lambda}e_v} = 1.$$

4 Photon Sublimation and Reassembling

In this section, we will develop additional concepts that will allow us to describe how our model of the photon sublimates and reassembles.

4.1 Position, Velocity, and Acceleration

We describe change in position in terms of an **initial position** $p_0 \in \mathbb{R}^3$ and a **velocity** $v \in \mathbb{R}^3$. For example, let Z be an object with initial position

$p_0 = (x, y, z)$ and velocity $v = (v_x, v_y, v_z)$. Assume that the current state of Z can be processed in one click. The position of Z after one click is then given by,

$$p_0 + v\hbar_t.$$

In general, after k clicks, it is given by,

$$p_0 + vk\hbar_t = p_0 + v\Delta_t. \tag{14}$$

Now assume that it takes n clicks to process the current state of Z. It follows that the position of Z will be updated every n-th click, and will be given by,

$$p_0 + v\left\lfloor \frac{k}{n} \right\rfloor n\hbar_t. \tag{15}$$

That is, Z will travel a distance of $vn\hbar_t$ every n-th click, which will give Z a velocity of v.

For example, assume that Z has a computational volume of c Joules per click, a mass of $m = 1$ kg, an initial velocity of $v_0 = \sqrt{c}$ meters per second, and that after acceleration, $v_f = \sqrt{4c}$ meters per second. First, we solve for n prior to acceleration using equation (1), which gives $n = c + 1$ clicks. Turning to equation (15), the position of Z prior to acceleration is given by,

$$p_0 + \sqrt{c}\left\lfloor \frac{k}{c+1} \right\rfloor (c+1)\hbar_t.$$

As such, every $c+1$ clicks, Z will travel a distance equal to $\sqrt{c}(c+1)\hbar_t$. Now we solve for the value of n after acceleration, again using equation (1), which gives $n = c + 2$ clicks. Thus, after acceleration, the position of Z is given by,

$$p_0 + \sqrt{4c}\left\lfloor \frac{k}{c+2} \right\rfloor (c+2)\hbar_t.$$

4.2 Velocity Groups and Directional Groups

In Section 2.2, we introduced the notion of a computational group, where a group of particles all pool their computational volumes and update their positions simultaneously. In this section, we introduce two specific types of computational groups: a **velocity group** and a **directional group**. The particles in a velocity group travel with the same velocity, but can have independent directions of motion. The particles in a directional group travel with the same velocity and in the same direction. In each case, the particles pool computational volumes as a computational group. In the case of a velocity group, each particle maintains its own radius of interaction and occupies its own volume, but nonetheless pools the computational resources of that volume with all other particles in the velocity group as a computational group. In the case of a directional group, all particles in the directional group exist within a single spherical volume, with a single radius of interaction, with the size of that volume equal to the sum of the volumes of the particles in the directional group. As such, the particles

in a velocity group are still independent particles, whereas the particles in a directional form a single particle.

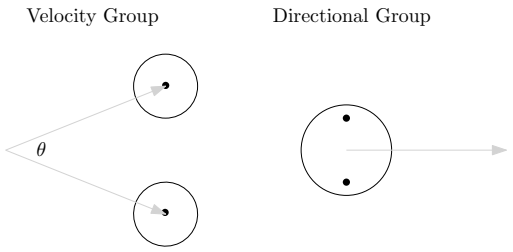

Figure 10: Particles in a velocity are independent particles, whereas particles in a directional group form a single particle.

For example, consider two J-bits, J_1 and J_2, with velocity vectors v_1 and v_2, respectively. If J_1 and J_2 form a directional group, then they form a computational group and $v_1 = v_2$. Since they form a single particle with a combined volume of $\frac{8}{3}\pi\hbar_\ell^3$, they will have a single radius of interaction of $^3\sqrt{2}\hbar_\ell$. If they form a velocity group, then they form a computational group and $\|v_1\| = \|v_2\|$. Since they are still individual particles, they will each have a volume of $\frac{4}{3}\pi\hbar_\ell^3$ and a radius of interaction of $\hbar_\ell$.

4.3 The J-Pair

In Section 3.2, we defined the photon as consisting of J-bits, and assumed that each J-bit has a total energy of $\hbar_e$. We now allow for each J-bit to split into a pair of identical particles that can exist individually for only one click at a time, and otherwise must be part of a velocity group or a directional group. We call a pair of these identical particles a **J-pair**. We call each of the particles in a J-pair a **dot** and assume that they each have a total energy of $\frac{\hbar_e}{2}$. As a velocity group, the two dots in a J-pair will have velocity vectors v_1 and v_2, respectively, such that $\|v_1\| = \|v_2\| = c$. However, we assume that $v_1 \neq v_2$, and that therefore, v_1 and v_2 will form an angle θ. We assume that θ is the same for all J-pairs generated by J-bits found inside photons.

We assume that as a directional group, a J-pair is indistinguishable from a single J-bit. As such, a J-bit is actually a J-pair of two dots with velocity vectors v_1 and v_2 operating as a directional group. Because the two dots in a J-bit operate as a directional group, they both travel in the same direction, and we assume the velocity vector for that directional group is given by,

$$v = \frac{v_1 + v_2}{\|v_1 + v_2\|}c.$$

Because the two dots in a J-pair form a directional group or velocity group, they form a computational group, and therefore pool computational volumes. Since a J-bit can be viewed as a J-pair operating as a directional group, it follows

that the computational volume of each dot is $\frac{4}{6}\pi\hbar_\ell^3 e_v$. As such, when two dots operate as a directional group, they form a single particle, i.e., the J-bit, but when they operate as a velocity group, they form two distinct particles, each with a computational volume of $\frac{4}{6}\pi\hbar_\ell^3 e_v$, and a radius of interaction of $\frac{1}{\sqrt[3]{2}}\hbar_\ell$.

4.4 Photon Sublimation

Assume that we have a single J-bit traveling along the x-axis in $\mathbb{R}^2$, so that the x-axis bisects the angle θ formed by its underlying J-pair. If the underlying J-pair switches from a directional group to a velocity group, then each dot will begin to travel in the direction of its respective velocity vector, at a velocity of c, and therefore, the dots will be separated by a distance of $2\sin(\frac{\theta}{2})k\hbar_\ell$, where k is the number of clicks for which the J-pair has operated as a velocity group. As such, the distance between the dots will grow linearly as a function of time.

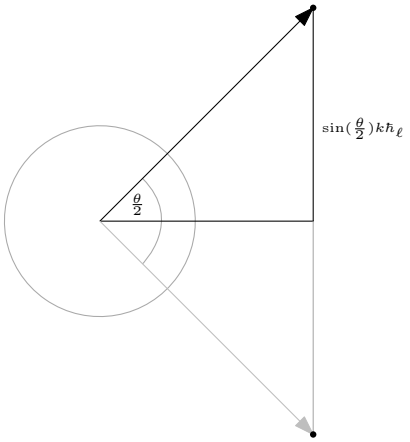

Figure 11: Each dot travels in the direction of its velocity vector as a velocity group.

Now imagine that we have a single J-bit traveling along the x-axis in $\mathbb{R}^3$, again so that the x-axis bisects the angle θ formed by its underlying J-pairs. Although we have assumed that θ is the same for all J-pairs found inside photons, we note that we can rotate the velocity vectors of a J-pair around the x-axis, and still obtain the same resultant velocity vector for the J-pair as a directional group, which in this case will always be $(c, 0, 0)$. It follows that even if we know the direction of motion for a J-bit, we cannot be sure what directions in which the underlying dots will travel as a velocity group - we only know that the angle formed by the two dots in any given J-pair will be θ.

We assume that the J-bits in a photon are all part of a single directional group, and thereby form a single particle, the photon. It follows that the radius of interaction of a photon of wavelength λ is given by $\sqrt[3]{\frac{c}{\lambda}}\hbar_\ell$. Further, we assume that each J-bit in a photon has the same direction of motion. That

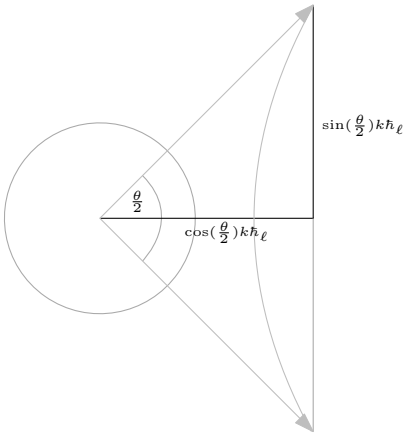

Figure 12: We assume the dots within a cloud will occupy a cross section of a cone.

is, even if the J-bits in a photon switch from a directional group to a velocity group, they will continue to travel in the same direction.

However, that is not true of the underlying J-pairs. That is, if all of the underlying J-pairs within a photon switch from a directional group to a velocity group, then the dots will begin to travel off in the directions of their respective velocity vectors. Because we cannot know in which directions the underlying dots will travel, for simplicity, we assume that when the J-pairs within a photon switch from a directional group to a velocity group, the dots occupy a cross section of a cone projected from the center of the photon of height $\cos(\frac{\theta}{2})\hbar_\ell k$ and radius $\sin(\frac{\theta}{2})\hbar_\ell k$, which we call a **cloud**, where k is the number of clicks for which the J-pairs within the photon have operated as a velocity group. When the underlying J-pairs in a photon switch from a directional group to a velocity group, we assume that the directional group among the J-bits switches to a simple computational group, meaning all of the dots in the cloud pool their computational volumes and update their positions simultaneously.

Further, we assume that all of the J-pairs within a photon are either operating as a velocity group or a directional group at any given time. That is, it is not possible for one J-pair to operate as a directional group while another J-pair operates as a velocity group within the same photon. We call the process of all J-pairs within a photon switching from a directional group to a velocity group **photon sublimation**. The switch from a directional group to a velocity group occurs upon the open phase of a click, and then the position of each dot is updated accordingly upon the close phase of that click.

4.5 Photon Reassembling

We assume that once a J-pair switches from a directional group to a velocity group, it will remain in a velocity group until another particle is at the boundary

of one of the dots, at which time both dots reassemble using the location of the interacting dot as the new initial position for the J-pair going forward. We assume that dots ignore each other for this purpose, and that as such, the presence of one dot at the boundary of another dot's volume will not cause a J-pair to reassemble.

For example, assume a J-pair with dots d_1 and d_2 is operating as a velocity group, and that at the close phase of a click at time t, a particle is on the boundary of d_1.

Assume that d_1 is located at p_0 at time t. We assume that at $t + \hbar_t$ (one click after d_1 encounters the particle), the J-pair will reassemble at the location,

$$p_0 + \frac{v_1 + v_2}{\|v_1 + v_2\|} c\hbar_t.$$

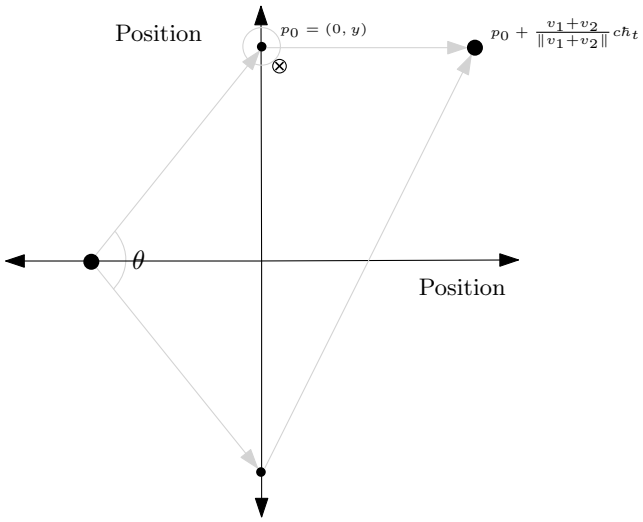

Figure 13: A J-pair reassembling after an interaction.

That is, the J-pair reassembles one click after the interaction, using the location of the interacting dot as its new initial position, and operates as a directional group thereafter using the same velocity vector it used prior to sublimating.[9]

Now imagine that after a photon sublimates, a large number of J-pairs that together comprise that photon are traveling as a velocity group, and assume that at time t, a particle is on the boundary of one of the dots in the cloud, and that this dot is located at p_0 at time t. We call this dot the **anchor**.[10] As described above, the J-pair associated with the anchor will reassemble at time $t + \hbar_t$ at the location $p_0 + \frac{v_1+v_2}{\|v_1+v_2\|} c\hbar_t$. However, we also assume that all of the

[9] If each dot has a particle on its boundary, then we assume that the selection between the two possible locations for reassembling is random.

[10] If multiple dots in the cloud interact with other particles at the same time, then we assume that one of those dots is randomly selected as the anchor.

J-pairs that together comprise the photon will reassemble as a directional group (i.e., a photon) at time $t+\hbar_t$, around the anchor, so that their relative positions after reassembling will be the same as they were prior to sublimation. We call this process **photon reassembling**.

We assume there is some number $0 < \rho < 1$, such that the probability that photon sublimation will occur occur on any click is given by $1-(1-\rho)^{m-1}$, where m is the number of clicks since the photon encountered another particle. That is, even if all of the underlying J-pairs in a photon are operating as a directional group, if another particle is on the boundary of the photon, then m will reset to one at the open phase of the first click after the interaction.

4.5.1 The Velocity of the Photon

Because the distance between any two dots traveling as a velocity group could be greater than $\hbar_\ell$, it follows that photon reassembling could cause individual dots to travel a distance greater than $\hbar_\ell$ in one click, i.e., at a velocity in excess of c. However, the path of the anchor will always have a length of $k\hbar_\ell$, where k is the number of clicks the dots have been traveling as a velocity group. It follows that the photon itself will always travel a distance of $k\hbar_\ell$ over the interval of time $k\hbar_t$, which means the photon will always have a velocity of c.

As noted above, the anchor always travels at a velocity of c. However, its pair might have to travel at a velocity greater than c to reassemble with the anchor. It follows that the anchor and its pair do not operate as a directional group or velocity group for the one click that causes the photon to reassemble. That is, at the open phase of the click immediately after the anchor encounters another particle, the path of the anchor and its pair will be computed individually, resulting in different velocities, though they both end up at the same location at the close phase of that click. Similarly, we assume that all dots in the cloud operate individually for that one click.

Since it is possible for a dot to travel a distance greater than $\hbar_\ell$ in one click, we will need to address the fact that any such dot would accelerate without the application of force. We accomplish this in the next section by constructing a more generalized class of J-pair, and from that, constructing a model of how dots can accelerate without the application of force, while still conserving total energy.

4.6 The Generalized J-Pair

In Section 4.3, we assumed that θ, the angle formed by the velocity vectors of the dots in a J-pair, is the same for all J-pairs found inside photons. We still make that assumption, but in this section, we will assume arguendo that other types of J-pairs exist, outside of photons, for which θ can vary. Further, we assume that as θ changes, the allocation of kinetic energy and potential energy of the J-pair changes as a function of $\theta \in [0, \pi]$. Specifically, if the velocity vectors of the dots in a J-pair form an angle θ, then we say the kinetic energy and potential energy of the J-pair are given by the following:

$$E_P = \frac{\theta}{\pi}\hbar_e \text{ and } E_K = \Big(1 - \frac{\theta}{\pi}\Big)\hbar_e. \tag{16}$$

As such, the total energy of each such J-pair is still $\hbar_e$. For the J-pairs found inside a photon, we noted that $E_P = 2E_K$, which implies that,

$$\frac{\theta}{\pi}\hbar_e = 2\Big(1 - \frac{\theta}{\pi}\Big)\hbar_e,$$

and therefore, $\theta = \frac{2}{3}\pi$. Since,

$$v = c\sqrt{\frac{2E_K}{E_P}},$$

it follows that,

$$v = c\sqrt{2\frac{(\pi - \theta)}{\theta}}. \tag{17}$$

Similarly, we can express the mass of a J-pair as a function θ:

$$m = \frac{E_P}{c^2} = \theta\frac{\hbar_e}{\pi c^2}. \tag{18}$$

As such, we can view θ as characterizing a unique J-pair with a constant velocity in a vacuum given by equation (17), and a mass given by equation (18). For $\theta = \frac{2}{3}\pi$, that velocity just happens to be c.

We note that if $\theta = 0$, then $E_P = 0$ and $E_K = \hbar_e$, which implies that the velocity of the J-pair will be undefined, while its mass will be well-defined as zero. If we interpret the equation $F = ma$ literally, then the amount of force required to accelerate a truly massless particle should be zero. As such, if a J-pair is characterized by $\theta = 0$, then it should be able to change velocity without the application of force. Therefore, we assume that if $\theta = 0$, then that J-pair can travel any finite distance per click, in any direction. That is, it will always have some finite velocity, but that velocity can change to any other velocity without the application of force. Because any such change in velocity will occur without the application of force, the total energy of any such J-pair would remain constant before and after any such change in velocity. As such, any such J-pair would conserve total energy.

By analogy, we assume that, individually, the dots have no potential energy, and a kinetic energy of $\frac{\hbar_e}{2}$. They are therefore massless particles with undefined velocities. As a result, dots can change velocity and direction without the application of force, which would allow for photon reassembling.

Under this view, the J-bit is the product of two massless particles, each with a total energy of $\frac{\hbar_e}{2}$, operating as a directional group. We can view the directional group as fixing the velocity vectors of these massless particles, thereby creating well defined velocities for both particles. If purely kinetic, truly massless particles have free velocity vectors, then when a purely kinetic particle fixes its velocity vector, it is no longer purely kinetic, and therefore potential energy

must be created, if total energy is to be conserved. There is still the question of how much potential energy is created, and we view θ as determining how much potential energy is created by the directional group. Thus, the formation of a directional group between two purely kinetic particles creates potential energy, and therefore mass.

5 The Path of a Photon

In this section, we will apply the concepts developed in this paper to describe the behavior and path of a photon in the double-slit experiment, and in the presence of gravitational acceleration.

5.1 The Double-Slit Experiment

Consider an idealized double-slit experiment as set forth in Figure 14 below. We call the barrier containing the slits the "slit wall", the wall on the right with the photon detectors the "detector wall", and the top and bottom walls the "top wall" and "bottom wall", respectively. Note that we have labeled the slits as "1" and "2". We begin by considering the two paths from the photon gun to the detector wall through the midpoints of slit 1 and slit 2, and call these "sublimating path 1" and "sublimating path 2", respectively.

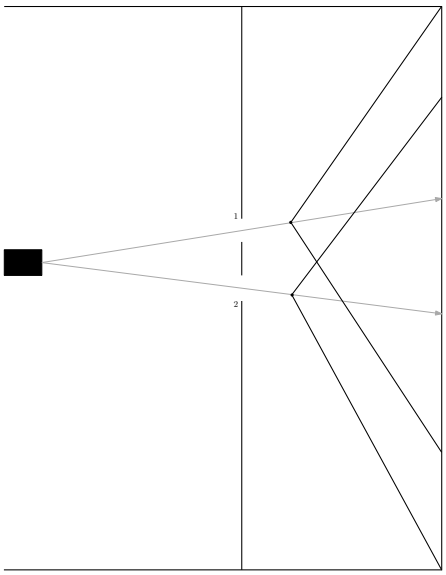

Figure 14: Photons fired at a detector wall through a double slit.

Now we ask, beginning with sublimating path 1, where is the first point along this path that the photon can sublimate? If it sublimates prior to passing through slit 1, then one of the dots in the cloud will probably interact with the

slit wall, causing the photon to reassemble at that location, meaning the photon would hit the slit wall, and therefore not make it to the detector wall. However, the photon could sublimate very close to slit 1 itself, in which case it could pass through slit one without any of the dots interacting with the slit wall. So let's assume that the photon sublimates somewhere near slit 1, and therefore all the dots make it through slit 1 without interacting with the slit wall. Because the radius of the cloud increases as a function of time, even if none of the dots interact with the slit wall, one of the dots in the cloud could interact with the top wall, causing the photon to reassemble at that location, meaning the photon would hit the top wall and not make it to the detector wall. Nonetheless, there is some first point along sublimating path 1 where the photon can sublimate and still be certain to reassemble at a location on the detector wall.[11]

Because sublimation can occur at any point after this first point and still allow the photon to reach the detector wall, the path of the dots sublimating from this first point will define a region of possible locations on the detector wall for photons that travel along sublimating path 1. We call this "sublimating region 1". Similarly, there will be a first point where sublimation can occur along sublimating path 2, and we call the region of possible photon locations along the detector wall associated with sublimating path 2, "sublimating region 2". Depending on the locations of slit 1 and slit 2, there could be overlap between sublimating region 1 and sublimating region 2, in which case, the probability of a photon arriving at the intersection of sublimating region 1 and sublimating region 2 would be higher than the probability of a photon arriving in the non-intersecting portions of sublimating region 1 and sublimating region 2.

We now consider the range of paths that a photon could travel from the photon gun to the detector wall without sublimating, and call these "direct paths 1" and "direct paths 2". Direct paths 1 and direct paths 2 will each define a region of possible locations along the detector wall for photons that travel along paths within their ranges without sublimating. We call these regions direct region 1, and direct region 2, respectively. If there is any overlap between direct region 1 and sublimating region 1, then the probability that a photon arrives in that intersection is higher than the probability that it arrives in the non-intersecting portions of direct region 1 and sublimating region 1. Similarly, if there is any overlap between direct region 2 and sublimating region 2, then the probability that a photon arrives in that intersection is higher than the probability that it arrives in the non-intersecting portions of direct region 2 and sublimating region 2. The end result would be an "interference" pattern, in that the overlapping regions would have a higher density of photons than the non-overlapping regions over time, exhibiting positive interference with a single photon.

[11] We assume the "ceiling" of the experiment is high enough to ignore.

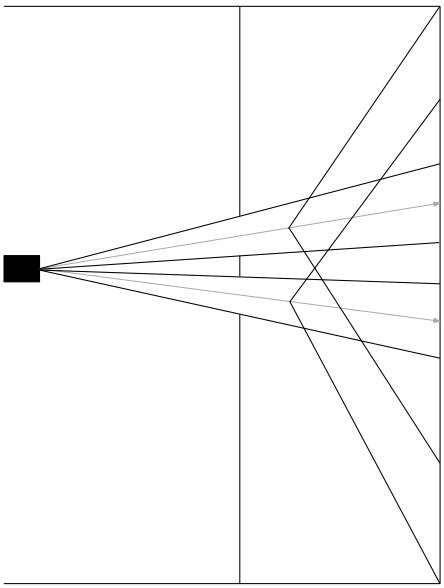

Figure 15: The direct paths and the sublimating paths could overlap as well.

5.2 Photon Acceleration due to Gravity

If photons are subject to the gravitational force, which experimental evidence suggests is the case, then in our model, they would behave like any other object with mass, and would therefore accelerate in the presence of gravitational acceleration. Because gravity is an accelerating force, its impact on the path of an object is a function of time. Because photons have an extremely high velocity, they are generally observed for only extremely short periods of time, meaning the impact of acceleration due to gravity on the path of a photon would generally be negligible. However, if a photon travels a long distance around a massive object, then if the period of time were long enough, and the object it passes were massive enough, the impact of gravitational acceleration on the path of the photon should be observable. Assuming the velocity of a photon is c prior to gravitational acceleration, it follows that the velocity of that photon will be greater than c after gravitational acceleration. However, we can still view the speed of a photon as constant in a vacuum, and allow for that speed to be changed in the presence of forces and other objects. Moreover, as mentioned above, in our model, there is an objective order to the occurrence of all events, and therefore causality is always intact.

6 Changes in Velocity Due to Time-Dilation

Imagine a toy soldier that marches one centimeter per second. In the relativistic model, if we place this toy soldier on a system with some velocity v, it follows

from equation (4) that the toy will experience less time than its stationary equivalent. Therefore, its individual velocity along its march (i.e., if we ignore its forward velocity of v) will be slower than that of its stationary equivalent, since equation (4) implies that it will experience fewer seconds and therefore take fewer steps than its stationary equivalent. Similarly, in the computational model, equation (3) implies that the toy's position will be updated less often than its stationary equivalent, thereby causing it to take fewer steps than its stationary equivalent. As such, in both models, time-dilation could change the apparent velocity of a system.

Assume that the individual velocity of the stationary toy (i.e., the velocity of its march) is v_0. As noted above, the toy soldier traveling on the system with velocity v will have some slower apparent velocity for its march in both models due to time-dilation. We argue that in both models the actual velocity of the march of the toy is still v_0, whether it is stationary or part of a moving system, and that the slower apparent velocity is not due to acceleration, and therefore merely an apparent velocity. That is, while we must have accelerated the toy in order for it to be traveling as part of a system with a velocity of v, we did not apply any acceleration that should impact its own, independent velocity along its march. Moreover, we accelerated the toy to give it a velocity of v, yet its own individual apparent velocity has slowed down as a result. As such, we argue that this change in the apparent velocity of the toy along its march is not due to acceleration, but is instead a distinct phenomenon due to time-dilation.

Consider a system S in the computational model that has a velocity of $v > 0$, and a total energy of the form $E_T = E_P + E_K + E_M$, where we do not know the properties of E_M or how it causes the object to behave. Nonetheless, we assume arguendo that we can change E_M without affecting E_P and E_K. It follows from equation (1) that $k = \left\lceil \frac{E_T}{Ve_v} \right\rceil$. If we decrease E_M, then we will decrease k, meaning that the system will be updated more often, implying that its position will be updated more often, increasing its apparent velocity. That is, we could decrease the total energy of a system, yet cause an increase in its apparent velocity. Similarly, we increased the total energy of the traveling toy soldier relative to its stationary equivalent by giving it a velocity of v, yet somehow decreased its apparent individual velocity along its march.

This more general type of change in apparent velocity due to time-dilation suggested by equation (1) is therefore physically distinguishable from ordinary acceleration. For example, if we decrease the total energy of a system, we cause all of its properties to be updated more often, including its position, thereby increasing its apparent velocity. In contrast, if we accelerate a system, we increase its total energy, causing all of its properties to be updated less often, meaning the system would update its position less often, but "jump" a greater distance on each update. Thus, we would be able to physically distinguish this type of change in velocity due to time-dilation from ordinary acceleration by considering the change in total energy in the system. If a decrease in total energy gives rise to a decrease in velocity, or an increase in total energy gives rise to an increase velocity, then this is acceleration. As such, cooling a system would constitute ordinary acceleration, since it decreases the thermal velocity

of a system, while decreasing its total energy. In contrast, when we decrease the total energy of S by reducing E_M, we are not accelerating S. We are instead changing the rate at which it progresses through its states. Therefore, we conclude that this type of change in apparent velocity does not constitute an actual change in velocity, which we argue would require an increase in total energy due to the application of an accelerating force.

Moreover, we argue that because this change in velocity due to time-dilation is physically distinguishable from acceleration, apparent velocity and actual velocity are also physically distinguishable from each other. Specifically, we argue that the kinetic energy of a system that experiences a change in apparent velocity due to time-dilation will remain constant. Assuming otherwise implies that an accelerating force was applied to that system, which is clearly not the case. Returning to the traveling toy soldier, we are not saying that the total kinetic energy of the traveling toy soldier is the same as its stationary equivalent. We are however saying that the kinetic energy of the motion of its march is the same as its stationary equivalent, despite the difference in their apparent velocities.

In sum, both the relativistic and computational model imply that time-dilation can change the apparent velocity of a system. However, equation (1) of the computational model suggests that it might be possible to induce this type of change in apparent velocity without accelerating the system at all. That is, if we change the total energy of a system with a non-zero velocity, we could change its apparent velocity by changing the rate at which its position is updated, without the application of an accelerating force.