The Origin of Time In Conscious Agents

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Abstract

Studies of the evolution of perception using evolutionary games and genetic algorithms reveal that natural selection routinely drives veridical perceptions (i.e., perceptions that resemble the truth) to quick extinction when they compete against perceptions that are non-veridical and tuned to fitness. This motivates an interface theory of perception, which proposes that our perceptions are not windows on truth, but are more like the windows interface of a PC. The icons on the desktop of a PC allow us to use the computer without being distracted by irrelevant details about its internal structure and operation. Similarly, our perceptions allow us to act adaptively in the world while being ignorant of its true structure. Space-time is our species-specific desktop and physical objects are icons on that desktop. Space-time and physical objects are not insights into objective reality, but species-specific adaptations that allow us to survive and reproduce. This requires a radical reformulation of our notion of the nature of objective reality, and of our notion of time. In light of the evolutionary results, I propose that consciousness, rather than space-time and physical objects, is fundamental. I propose a formal model of consciousness based on a mathematical structure called conscious agents. I then propose how time and space emerge from the interactions of conscious agents.

1. Introduction

Time is an enigma. On the one hand, nothing is more familiar to us than time. We feel its passing, we measure it precisely with clocks, and we know one day we shall run out of it. On the other hand, if we are pressed to say what time *is*, to try to define it, we find it surprisingly difficult. And that goes not just for the proverbial man in the street, but also for the brightest philosophers and scientists.

St. Augustine, in his *Confessions, book XI*, wrote, "What, then, is time? I know well enough what it is, provided no one asks me. But if I am asked what it is and try to explain, I do not know."

Centuries later, William James in his *Principles of Psychology* could do little better with time, admitting "Its meaning we know so long as no one asks us to define it, but to give an accurate account of it is the most difficult of philosophic tasks."

Time is deeply puzzling, and that puzzlement is reflected in the diversity of theories that have been proposed (see, e.g., Bardon 2013; Maudlin 2012a). Parmenides and Zeno, Greek philosophers from the town of Elea roughly 500 years BCE, held that time is an illusion of the human mind, and that reality itself is timeless. Heraclitus, their contemporary from the town of Ephesus, disagreed, claiming that time and change are fundamental realities and, as his view was famously described by Plato, that "No man ever steps in the same river twice." Plato himself, talking via his character Timaeus, proposed that time arises from the motion of the sun, moon and planets, and that if these ceased to move then time itself would stop. Aristotle disagreed, proposing that even if these heavenly bodies stopped moving other objects would continue to change, and time is simply our accounting device to keep track of such changes. St. Augustine returned to

a view similar to that of Parmenides and Zeno, arguing that time exists only in the human mind.

Newton (1687/1934) proposed that time and space are aspects of objective reality, independent of the human mind, and claimed "Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year."

Locke (1690) in *An Essay Concerning Human Understanding* agreed with Newton about the reality of time, and tried to bootstrap our conception of time from pure experience: "Tis evident to anyone who will but observe what passes in his own mind, that there is a train of ideas, which constantly succeed one another in his understanding, as long as he is awake. Reflection on these appearances of several ideas one after another in our minds, is that which furnishes us with the idea of succession; and the distance between any parts of that succession, or between the appearance of any two ideas in our mind, is that we call duration."

Kant (1787) in his *Critique of Pure Reason* disagreed with Locke's claim that our conception of time can be bootstrapped from experience, and claimed to the contrary that time is not an aspect of objective reality but is an innate *a priori* concept that we impose upon our experiences.

Einstein (1921) in *The Meaning of Relativity* disagreed strongly with Kant, arguing: "The only justification for our concepts and system of concepts is that they serve

to represent the complex of our experiences; beyond that they have no legitimacy. I am convinced that the philosophers have had a harmful effect upon the progress of scientific thinking in removing certain fundamental concepts from the domain of empiricism, where they are under our control, to the intangible heights of the *a priori*. For even if it should appear that the universe of ideas cannot be deduced from experience by logical means, but is, in a sense, a creation of the human mind, without which no science is possible, nevertheless this universe of ideas is just as little independent of the nature of our experiences as clothes are of the form of the human body. This is particularly true of our concepts of time and space..."

2. Time in Physics

Einstein did indeed bring time and space back from the intangible heights of the *a priori* in his theories of special and general relativity, and the conception of time that follows from his theories is still a key point of departure for modern scientific and philosophical theories of time.

Whereas Newton proposed an absolute space having three dimensions and a separate absolute time having just one, Einstein's theory of special relativity requires instead a four-dimensional space-time with the structure of a Minkowski space. This requires a new conception of the relationship between time and space, as noted by Minkowski (1909): "The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."

In the new union of space-time, an event p has four coordinates, t_p, x_p, y_p, and z_p and the interval between two events p and q is

$$I = (t_p - t_q)^2 - (x_p - x_q)^2 - (y_p - y_q)^2 - (z_p - z_q)^2.$$

This interval is proportional to the time that an accurate clock would measure between the two events; clocks measure intervals. Null intervals, i.e., intervals with $I = 0$, describe the behavior of light and are called light-like; positive intervals are called time-like and describe the behavior of massive objects; negative intervals are called space-like and connect events that are not causally related.

Special relativity makes predictions about time and the behavior of clocks that differ from the predictions of Newton. For Newton, time proceeds at the same pace everywhere in the universe, so that one can unambiguously speak about events across the universe being simultaneous for all observers. In special relativity, different observers in different inertial frames of reference, i.e., who move at different constant velocities, will disagree about which events are simultaneous. However, for events with time-like separation all observers agree about the *order* of events.

Moreover, because clocks in special relativity measure intervals, two observers who traverse from an initial event to a final event via different intervening intervals will find that their clocks, in general, disagree when they compare them at the final event. This leads to the "twins paradox" in which one twin can leave earth on a rocket and upon his return find that he has aged at a slower rate than the twin who remained. This is often explained, incorrectly, as due to the acceleration of the twin in the rocket, but in fact is simply due to the difference in intervals that the twins traversed (e.g., Maudlin 2012a).

The representation in special relativity of all space-time events by a Minkowski space puts all events on an equal footing, in the sense that no events are picked as the "now" while other events are past or future. This has led many physicists to conclude that the human perception of time in terms of past, present and future is illusory. As Brian Greene (2007) puts it: "... there is convincing evidence that the spacetime loaf—the totality of spacetime, not slice by single slice—is real. A less than widely appreciated implication of Einstein's work is that special relativistic reality treats all times equally. Although the notion of now plays a central role in our worldview, relativity subverts our intuition once again and declares ours an egalitarian universe in which every moment is as real as any other."

Einstein himself held this view. At the funeral of his friend Besso, Einstein said, "Now Besso has departed from this strange world a little ahead of me. That means nothing. People like us, who believe in physics, know that the distinction between past, present, and future is only a stubbornly persistent illusion." Bardon (2013).

However, Maudlin (2007) disagrees, noting that there is no contradiction between accepting the Minkowski "block" or "loaf" representation of space-time and also accepting that time does indeed pass: "I believe that it is a fundamental, irreducible fact about the spatio-temporal structure of the world that time passes ... The passage of time is an intrinsic asymmetry in the temporal structure of the world, an asymmetry that has no spatial counterpart ... Insofar as belief in the reality of the past and the future constitutes a belief in a 'block universe', I believe in a block universe. But I also believe that time passes, and see no contradiction or tension between these views."

Maudlin (2012b) makes a strong case for his view, by developing the mathematics of "directed linear structures" and using it to reanalyze the geometry of Minkowski space. He finds that "in Relativity, but not in classical space-time, time order of events alone determines the fundamental geometry of space-time ... Spatial structure only emerges as a consequence of being embedded in a surrounding temporal structure."

Smolin (2013) agrees that time is real, but denies the reality of the past and the future: "Whatever is real in our universe is real in a moment of time, which is one of a succession of moments. The past was real but is no longer real. We can, however, interpret and analyze the past, because we find evidence of past processes in the present. The future does not yet exist and is therefore open."

However Aharonov and his collaborators (2009; 2010) have reformulated quantum theory in a way that allows the flow of time to be real, but in which time flows forward from the past toward the future *and* flows backward from the future to the past. They claim to have empirical evidence that weak measurements in the future can amplify the quantum Hall effect for light in weak measurements of the present. They admit, however, that "all the effects discussed here can certainly be computed using the standard view of time flowing from past to future".

Most physicists who believe in the reality of time do take the standard view that time flows from past to future. The widely recognized conundrum faced by this view is that the basic equations of classical and quantum physics are invariant under time reversal—although this statement requires certain caveats (Albert 2000). The question is how an arrow of time arises when the basic equations of physics don't have such an arrow. The second law of thermodynamics, which says that entropy increases with time,

is sometimes invoked to provide the arrow. The simplest version of this idea won't work, since the second law of thermodynamics also predicts that entropy should increase if we run the time-reversed version of the equations of physics. Put another way, if there is a half melted ice cube in a glass of water, not only does the second law say that, *ceteris paribus*, it is statistically quite likely that the cube will be more melted ten minutes from now, it also says that it is statistically quite likely that the cube was more melted ten minutes ago. Thus, to get an arrow of time from the second law, one must assume that the universe itself began in a state of exceedingly low entropy (Albert 2000; Carroll 2010; Greene 2007).

Attempts to combine general relativity and quantum theory lead to deep questions about time. General relativity itself entails that space-time can curve and that the flow of time is slower where gravity is greater (Wald 1984). The effects of gravity on time affect the clocks on GPS satellites and must be corrected in order for GPS systems to work properly. Combining general relativity and quantum theory seems to require that space-time itself, near the Planck scale, has a discrete structure—that there are atoms of space-time, and that time itself is discrete (Dowker 2013). Theoretical and experimental research on "space-time crystals" might provide evidence for this discrete structure and for a breaking of time symmetry in the ground state of such crystals (Bruno 2012; Li et al. 2012; Shapere and Wilczek; Wilczek 2012).

3. The Complex of our Experiences

The point of departure for the new ideas developed here is Einstein's (1921) remark, quoted above: "The only justification for our concepts and system of concepts is that they serve to represent the complex of our experiences..." Our complex of experiences comes to us through our senses, and our sense organs are the products of evolution. This raises the obvious question: What relation between our experiences and objective reality is likely to be shaped by evolution?

The assumption widely held today is that this question has a straightforward answer: Evolution by natural selection has shaped our perceptions to give, in the normal case, true reports about the true state of the objective world. Of course our senses don't report all of the truth, and on occasion they are fooled and we perceive illusions. But, granting these provisos, we can be confident that our perceptions are true guides to objective reality. Thus physics, and the sciences more generally, can confidently use the predicates in which our perceptions are couched, predicates such as space and time and objects and force, to construct theories of objective reality.

The evolutionary argument for true perceptions goes roughly as follows. Those of our predecessors whose perceptions were more accurate *ipso facto* had a competitive advantage vis-à-vis their compatriots whose perceptions were less accurate, and they were thus more likely to pass on their genes to the next generation, genes that *inter alia* coded for their more accurate sensory systems. Thousands of generations of this process effectively winnowed out false perceptions so that today we, who are the offspring of those who saw more truly, can be confident that our perceptions are also true or, in the standard jargon, "veridical".

This argument is accepted by most vision scientists, and appears in a standard textbook: "Evolutionarily speaking, visual perception is useful only if it is reasonably accurate … Indeed, vision is useful precisely because it is so accurate. By and large, *what you see is what you get.* When this is true, we have what is called **veridical perception** … perception that is consistent with the actual state of affairs in the environment. This is almost always the case with vision…" (Palmer 1999, emphasis his).

The vision scientist Pizlo and his collaborators (2014, p. 227) agree: "We close by re-stating the essence of our argument, namely, veridicality is an essential characteristic of perception and cognition. It is absolutely essential. *Perception and cognition without veridicality would be like physics without the conservation laws.*" (Emphasis theirs.)

The evolutionary theorist Trivers (2011) agrees: "...our sense organs have evolved to give us a marvelously detailed and accurate view of the outside world—we see the world in color and 3-D, in motion, texture, nonrandomness, embedded patterns, and a great variety of other features. Likewise for hearing and smell. Together our sensory systems are organized to give us a detailed and accurate view of reality, exactly as we would expect if truth about the outside world helps us to navigate it more effectively."

These intuitions and informal arguments are *prima facie* plausible. But we are not restricted to these, since there are powerful tools at our disposal to study evolution by natural selection, tools such as evolutionary games and genetic algorithms (Allen and Clarke 1984; Hofbauer and Sigmund 1998; Mitchell 1998; Nowak 2006; Poli et al 2008; Samuelson 1997; Sandholm 2007). In the case of evolutionary games, for instance, we can create a variety of different worlds with a variety of different fitness functions in each world and allow artificial organisms with a variety of different perceptual strategies to compete in these worlds.

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This has been done for hundreds of thousands of randomly chosen worlds, and the results are clear: Natural selection routinely drives veridical perceptions to extinction when they compete with nonveridical perceptions that are tuned to fitness (Marion 2013; Mark et al. 2010; Mark 2013). The reason for this result is also clear: Fitness and truth are distinct. Fitness depends not just on the true state of the world, but also on the organism, the state of the organism and the action to be taken. So, for instance, one cannot specify the fitness conferred by a pile of dung without specifying a target organism, its state, and the action. The pile can convey substantial fitness to an African ball-rolling dung beetle looking for a quick snack or looking to grab provisions and, guided by the Milky Way, to transport them for safe storage (Dacke et al., 2012). For a college freshman looking for a quick snack, or planning to grab food for a frat party, the same pile is worthless.

Moreover, fitness does not, in general, vary monotonically with structures in objective reality. Too little salt or too much salt, for instance, can be fatal, but a quantity somewhere in between conveys the greatest fitness. The same is true of water, oxygen, sunlight and countless other resources. For organisms that need to maintain homeostasis, fitness is a nonmonotonic function of the objective state of the world. A perceptual system that is tuned to truth will not, in general, be tuned to fitness (Mark et al. 2010).

The same conclusions result when we turn from evolutionary games to genetic algorithms. Here we find that veridical perceptions are, in general, so unfit that they never even get a chance to compete and go extinct (Mark 2013).

So our intuitions and informal arguments for the claim that natural selection favors veridical perceptions are just false.

4. The Interface Theory of Perception

If natural selection does not favor veridical perceptions, then what kind of perceptions does it favor? And what good are perceptions that don't tell us the truth?

A useful metaphor to answer both questions is provided by the windows interface of a computer (Hoffman 1998; 2009; 2011; 2012; 2013; Hoffman and Prakash 2014; Hoffman and Singh 2012; Hoffman et al. 2013; Koenderink 2011; 2013; Mark et al. 2009; Mausfeld 2002). If the icon for a text file that you're editing is green, square, and centered on the desktop, that doesn't mean that the text file itself is green, square, and centered in the computer. The perceptual features of the icon are not intended to resemble the truth of the computer—its transistors and voltages and software—but are instead intended to help the user interact with a text file. Indeed, the interface is useful, in part, precisely because it hides the truth of the computer. If you had to deal directly with the transistors and voltages, you would never finish editing your file.

So our perceptions are not a window on truth, but instead are like a windows interface. Space-time is our species-specific desktop, and physical objects are the icons on our desktop. Our perceptions of space-time and physical objects are not an insight into the true nature and causal structure of objective reality. Instead, they are a species-specific adaptation that has been shaped by natural selection to allow us to survive and reproduce. Perception is not about truth, its about having kids.
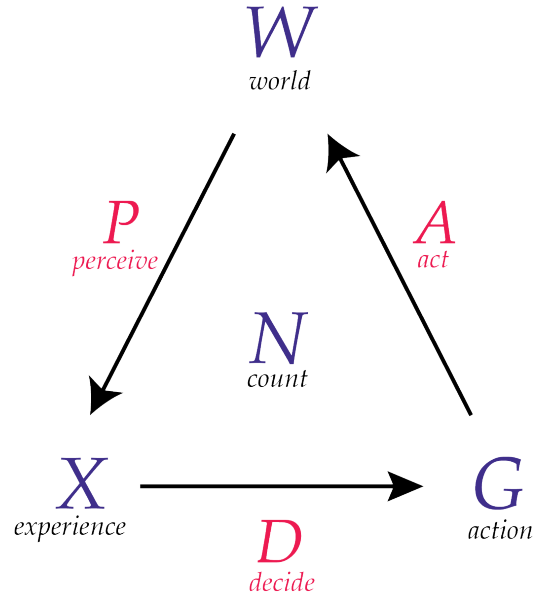
5. Conscious Agents

In light of what evolution tells us about our perceptions, let's return to Einstein's comment quoted earlier: "The only justification for our concepts and system of concepts is that they serve to represent the complex of our experiences ... this universe of ideas is just as little independent of the nature of our experiences as clothes are of the form of the human body. This is particularly true of our concepts of time and space..." Einstein has a good point. Our concepts of time and space are not independent of our experiences, but are shaped by those experiences just as clothes are fitted to the body. Einstein, however, took our experiences to be reliable reports about the objective world, and so concluded that our concepts of time and space are not just *a priori* constructions out of touch with reality, but rather are genuine insights that are reliable points of departure for more sophisticated scientific theories that can truly describe the objective world.

A better understanding of the evolution of perception by natural selection dictates a radically different conclusion. Our experiences are not reliable reports about objective reality, they are merely a species-specific adaptation, shaped for survival and reproduction. The same goes for our concepts of time and space that, as Einstein rightly points out, are heavily shaped by our experiences. So we cannot assume that space-time, or the physical objects within space-time, is an insight into objective reality. And therefore we cannot assume that the appearance of causality within space-time is an insight into objective reality. What looks to us like cause and effect in space-time is just a species-specific adaptation, and therefore just a useful fiction. Physicalist theories of objective reality are therefore almost surely false.

And this means that physicalist theories of the mind-body problem, which propose that our conscious experiences are caused by, or arise from, or are identical to, activity in the brain, are almost surely false (Hoffman 2008; Hoffman and Prakash 2014). Einstein declared "The only justification for our concepts and system of concepts is that they serve to represent the complex of our experiences..." Yes. But it's now clear that our experiences are not caused by physical objects in space-time, objects such as neurons and the brain.

If we can't solve the mind-body problem by starting with the physical and explaining how consciousness arises, then perhaps we can try solving it the other way: start with a mathematical theory of consciousness and explain how physics and space-time arise. That is the goal of a new theory of "conscious agents" (Hoffman 2008; Hoffman and Prakash 2014).

Informally, a conscious agent has six components, as illustrated in Figure 1. A conscious agent has a space X of possible conscious experiences and a space G of possible actions it can take. It perceives the world W via a perceptual map P, decides how to act via a decision map D, and acts via an action map A. The maps $P, D,$ and A can be thought of as discrete communication channels. An integer N keeps track of the number of discrete messages transmitted over P.

$$W$$
world

$$P$$
perceive

$$A$$
act

$$N$$
count

$$X$$
experience

$$G$$
action

$$D$$
decide

Figure 1. A conscious agent. The world is represented by a measurable space W. A conscious agent comprises the remaining six components of the diagram. The maps P, D, and A can be thought of as communication channels. X is the measurable space of conscious experiences of the agent, and G is the measurable space of its possible actions. An integer N counts the successive experiences of the agent.

More formally, a conscious agent is defined as follows.

**Definition 1**. A *conscious agent, C,* is a six-tuple

$$C = ((X, \mathbf{X}), (G, \mathbf{G}), P, D, A, N)), \qquad (1)$$

where:

(1) $(X, \mathbf{X})$ and $(G, \mathbf{G})$ are measurable spaces;

(2) $P : W \times \mathbf{X} \rightarrow [0,1]$, $D : X \times \mathbf{G} \rightarrow [0,1]$, $A : G \times \mathbf{W} \rightarrow [0,1]$ are Markovian kernels; and

(3) N is an integer. □

Any number of conscious agents can be joined into networks (more specifically pseudographs) of interacting agents. For instance, two agents can be joined as illustrated

in Figure 2. This shows an undirected join, in which information flows from each agent to the other. Directed joins are also possible, in which information flows from one agent to another, but not vice versa.

$$G_2 \xleftarrow{\ D_2\ } X_2$$

$$P_1 = A_2 \qquad N_1 = N_2 \qquad A_1 = P_2$$

$$X_1 \xrightarrow{\ D_1\ } G_1$$
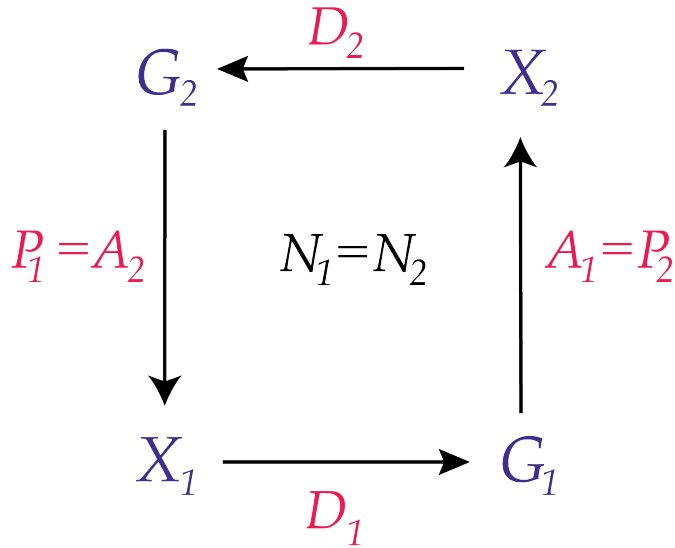
Figure 2. Two conscious agents, C_1 and C_2. Each agent is part of the world W for the other agent. The lower part of the diagram represents C_1 and the upper part C_2.

Three agents can be joined as in Figure 3.
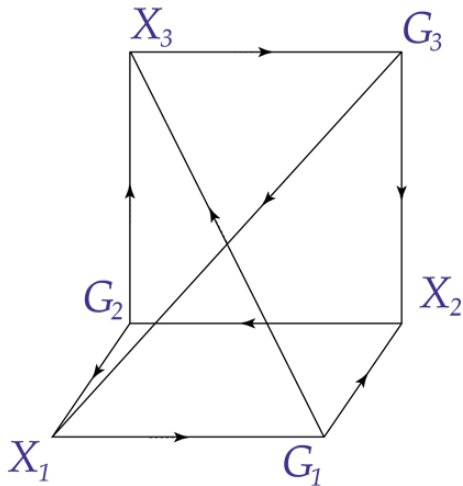
Figure 3. Three conscious agents joined into a network.

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It happens that there are networks of conscious agents that have the computing power of universal Turing machines, and that any subset of a pseudograph of conscious agents is itself a single conscious agent (Hoffman and Prakash 2014). Thus the formalism of conscious agents provides a complete framework for computationally rigorous models of perception and cognition, and a rigorous solution to the so-called *combination problem* of consciousness, i.e., the problem of combining conscious experiences and conscious subjects (Blaumer 2011; Coleman 2013; Goff 2009; Seager 1995).

6. Time From Consciousness

The theory of conscious agents proposed by Hoffman and Prakash (2014) takes conscious agents, rather than physical objects and space-time, as fundamental. Thus the perceptions and actions of a conscious agent are not localized in space-time, and conscious agents cannot be reduced to microphysical particles or fields. Instead, the theory of conscious agents has the burden of showing how space-time and physical objects, and indeed all of physics, arises from the dynamics of networks of conscious agents.

Now although each conscious agent is not localized in space-time, its conscious experiences result from *sequences* of communications it receives via its perception channel P. Thus there is a total order, T, on its sequence of perceptual experiences, S, and the cardinality of this sequence S is given by its counter N. Now T is not physical time, but it is a subjective "time" for the conscious agent. Moreover the sequence S of conscious experiences grows with each new conscious experience. The conscious experience $S(N)$ is the "now" of the conscious agent and the conscious experiences

$S(1)\ldots S(N-1)$ are its "past". Anticipating a new conscious experience $S(N+1)$ is anticipating something in the "future".

This notion of subjective "time" that falls naturally out of the theory of conscious agents comports well with Einstein's (1921) comments on the fundamental nature of time: "The experiences of an individual appear to us arranged in a series of events; in this series the single events which we remember appear to be ordered according to the criterion of "earlier" and "later," which cannot be analyzed further. There exists, therefore, for the individual, an I-time, or subjective time. This in itself is not measurable. I can indeed, associate numbers with the events, in such a way that a greater number is associated with the later event than with an earlier one; but the nature of this association may be quite arbitrary."

If a conscious agent C_i receive a message over its perception channel P_i it increments its experience counter N_i and adds a new experience to its sequence S_i. If, in consequence, agent C_i sends a message to agent C_j, then C_j increments its experience counter N_j and adds a new experience to its sequence S_j. Thus, although there is no absolute ambient time around, nevertheless we can say that there is a "simultaneity" correspondence between the conscious experiences $S_i(N_i)$ and $S_j(N_j)$, even though in general $N_i \neq N_j$. In this fashion, we can propagate out "simultaneity" correspondences between conscious agents across entire pseudographs, and thus connect the individual "times" T. It is an interesting and open technical question to ask for what pseudographs and agent dynamics it is possible to use the "simultaneity" correspondences between all

pairs of conscious agents to create a *global* total order of conscious experiences for the *entire* collection of conscious agents, and thus to create an "absolute time".

7. Space-time From Consciousness

The dynamics of a pair of conscious agents, interacting as shown in Figure 2, can be described as a Markov chain whose transition probability is simply the tensor product of the Markovian kernels P_1, D_1, P_2, D_2 acting on a state space (X_1, G_1, X_2, G_2) (Hoffman and Prakash 2014). Using the experience counters, N_1 and N_2, of the two agents (which we now take to be identical, or nearly so), we can create, using standard methods in the theory of Markov chains, a new Markov chain called the "space-time chain" (Revuz 1984; Hoffman and Prakash 2014). Intuitively this space-time chain is the original chain together with an extra component added to its state vector that counts the number of steps in the chain up to each point.

One can show that the eigenfunctions of the space-time chain associated to the dynamics of a pair of conscious agents is *identical* in form to the wavefunction of the nonrelativistic quantum free particle (Hoffman and Prakash 2014). From this one can read off a correspondence between properties of the dynamics of conscious agents, and physical properties, such as time and energy, of quantum free particles. The proposal that emerges, then, is that physical particles are simply shorthand representations for the much richer dynamics of conscious agents; particles only capture a small part of that dynamics, namely its *asymptotic* (i.e., long term) behavior. The physical properties of time and space emerge as a convenient interface for representing the dynamics of conscious agents.

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A connection between the dynamics of pairs of conscious agents and relativistic physics can be made using the tools of geometric algebra (Doran and Lasenby 2003). We note that states of the dynamics of a pair of agents are described by the six quantities X_1, G_1, N_1, X_2, G_2, N_2. These six quantities give rise to a local patch of relativistic space-time as follows. The six quantities can be represented by a geometric algebra $\mathcal{G}(2,4)$, where the counters N_1 and N_2 have negative signature and the remaining components have positive signature. The geometric algebra $\mathcal{G}(2,4)$ is the conformal geometric algebra for Minkowski spacetime, and the foundation for supersymmetric theories of massless relativistic particles. The "rotor group" of $\mathcal{G}(2,4)$ is isomorphic to the Lie group SU(2,2), providing a connection to the twistor theory of quantum gravity proposed by Penrose (2003).

Given any pseudograph of conscious agents, we can take *each* interacting pair and create a new local patch of relativistic space-time for that pair by means of a geometric algebra $\mathcal{G}(2,4)$ that describes their dynamics. We can then take the combination of each pair to create a new *single* conscious agent out of that pair, and then create new patches of relativistic space-time by means of geometric algebras that describe the interactions of these new combination agents with other combination agents. In this fashion we can proceed to create a nested hierarchy of geometric algebras, a hierarchy of patches of relativistic space-time from the Planck scale to macroscopic scales. It will be interesting to look for connections between this approach to space-time and the approach of causal set theory (Dowker 2013); where causal set theory has space-time atoms as primitives, we here have conscious agents as primitives and space-time atoms emerge as linear representations of their dynamics.

8. Conclusion

We have proposed that consciousness, not space-time and physics, is fundamental and that consciousness can be formally modeled by dynamical systems of conscious agents. The sequence of conscious experiences of a conscious agent is a totally ordered set, with properties much like the "I-time" or "subjective time" that Einstein (1921) describes. The subjective times of distinct conscious agents need not match, and indeed might not be embeddable into a single total order. But by looking at causal connections between conscious agents, in which an action by one agent triggers a perception in another, one can connect various elements within their separate subjective times. By associating conformal geometric algebras $\mathcal{G}(2,4)$ with these causal connections, we might be able to grow a hierarchical patchwork of discrete space-time atoms that, when approximated by a smooth surface, gives back the curving space-time of general relativity.

In this view space-time is a construction of the observer, not an *a priori* objective reality. Perhaps the metric of space-time is created to represent, and be proportional to, the potential knowledge (or, conversely, ignorance) of the observer. If so, the second law of thermodynamics (that the entropy of an isolated system cannot decrease) might simply emerge as a consequence of this construction of space-time in which larger volumes code for greater ignorance, and smaller volumes code for greater knowledge. A classic example, for instance, of the second law is a box with a partition dividing its volume in half, and with a gas confined to one of the halves. If the partition is removed rapidly, the gas expands to fill the entire volume without changing temperature, and in the process the

entropy of the gas increases. Entropy, and our ignorance, grows with the volume of space.

This connection between volumes of space and subjective knowledge or ignorance comports well with Bekenstein's (1981) discovery that the entropy of a black hole is proportional to the area of its event horizon, and the elaboration of this discovery into the holographic principle (e.g., Susskind 1995); it also comports well with a subjectivist view of the probabilities underlying entropy, taking those probabilities to reflect our ignorance rather than being measures of objective indeterminism. Space-time might really be an *invention* of certain conscious agents to keep track of what they know. In this regard, it is straightforward to prove an *Invention of Space Theorem* which states that space-time symmetries in the perceptions and actions of any observer (e.g., Euclidean, Galilean, Lorentz, Poincare, conformal spacetime) do not entail that objective reality itself has those symmetries, even though the perceptions and actions operate through that objective reality (Hoffman et al. under review). Just because we see the world as Euclidean (or Lorentzian) does not at all entail that the world is in fact Euclidean (or Lorentzian). These symmetries in our perceptions and actions, rather than reflecting the true structure of the world, might instead be compact and convenient representations of aspects of the fitness functions critical to our evolution.

What then is the origin of time? The theory of conscious agents suggests that the origin of I-times or subjective times might be the *finiteness* of observers. A finite conscious agent has finite capacity in its perception channel P and obtains only limited information from a single use of that channel. In consequence, it must use this channel more than once, leading to a *sequence* of subjective experiences, i.e., to subjective time.

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If the conscious agent were infinite and its perception channel P had infinite capacity, then one "look" would be enough, and there would be no need for a sequence of subjective experiences, no need for a subjective time. Time (and space-time) as it appears in physics then emerges as simply a way to organize the subjective times of countless conscious agents into a coherent framework.

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