What becomes of a causal set

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Abstract

Contemporary physics is notoriously hostile to an A-theoretic metaphysics of time. A recent approach to quantum gravity promises to reverse that verdict: advocates of causal set theory have argued that their framework is at least consistent with a fundamental notion of ‘becoming’. In this paper, after presenting some new twists and challenges, we show that a novel and exotic notion of becoming is compatible with causal sets.

1 Introduction

Contemporary physics is notoriously hostile to an A-theoretic metaphysics of time. A recent approach to quantum gravity promises to reverse that verdict: advocates of causal set theory (CST) have argued that their framework is consistent with a fundamental notion of ‘becoming’. A causal set, or causet, is a discrete set of events partially ordered by a relation of causality. The idea is that these sets ‘grow’ as new events are added one by one to the future of already existing ones; furthermore, this ‘birthing’ process is said to unfold in a ‘generally covariant’ manner. Here is Sorkin (2006) advertising the philosophical pay-off:

One often hears that the principle of general covariance forces us to abandon ‘becoming’. To this claim, the CSG dynamics provides a counterexample. It refutes the claim because it offers us an active process of growth in which ‘things really happen’, but at the same time it honors general covariance. In doing so, it shows how the ‘Now’ might be restored to physics without paying the price of a return to the absolute simultaneity of pre-relativistic days.

The claim is that CST rescues temporal becoming and our intuitive notions of time from relativity. One might not believe that our intuitive notion of time needs or deserves rescuing, but there is no denying that if this claim is correct it would have significant consequences for philosophy of time.

After presenting the basics of CST in the next section, we investigate the possibilities for becoming in the theory’s kinematics in Section 3. We show that Stein’s becoming theorem in relativity is false in CST and try to use the resulting freedom to escape a dilemma imposed on becoming by relativity. Then in Section 4 we turn to the CST dynamics in search of a more robust becoming. Trying to square this sense of becoming with (discrete) general covariance has many costs. However, we show that if one is willing to pay them, a novel and exotic form of becoming is compatible with relativity.
2 The basics of CST

The guiding idea of CST is that the fundamental structure of the world consists of a discrete set of elementary events partially ordered by a relation that is essentially causal. The theory finds its inspiration in a theorem (Malament (1977)) that shows the precise sense in which the causal structure of a sufficiently well-behaved relativistic spacetime determines its geometry, up to a conformal factor. Paraphrased roughly, the causal structure of spacetime contains all the information we care about except for the scale or ‘size’ of spacetime. Motivated by this result, Sorkin and others formulated an approach to quantum gravity wherein discrete events supply the scale information and causal relations supply the rest. Quantum versions are being developed, but we’ll focus on the classical theory.

The basic structure of the theory is the causet $C$, i.e. an ordered pair $(C, \preceq)$ of a set $C$ of otherwise featureless events and a relation ‘$\preceq$’ defined on $C$ which satisfies the following conditions:

1. $\preceq$ induces a partial order on $C$, i.e., it is a reflexive, antisymmetric, and transitive relation;
2. local finitude, i.e., $\forall x, z \in C, \text{card}(\{ y \in C | x \preceq y \preceq z \}) < \infty$.

These simple conditions constitute the basic kinematic assumptions of CST. The local finitarity of causets means that they are discrete structures, and this discreteness leads to some relevant differences concerning the issue of becoming in relativity.

How do relativistic spacetimes emerge from causal sets? A classical spacetime $\langle M, g_{ab} \rangle$ is said to faithfully approximate a causal set $\langle C, \preceq \rangle$ just in case there is an injective function $\phi : C \rightarrow M$ such that

1. the causal relations are preserved, i.e. $\forall x, y \in C, x \preceq y$ iff $\phi(x) \in J^-(\phi(y))$;
2. and on average, $\phi$ maps one element of $C$ onto each Planck-sized volume of $\langle M, g_{ab} \rangle$. (?)

The first condition demands that the causet’s causal relations are preserved on the emergent level of the relativistic spacetime. The second condition captures the idea that a discrete structure should not give rise to an emerging spacetime with significant curvature at a scale finer than that of the fundamental structure. Such an injective function can easily be found if we simply identify the co-domain of $\phi$ to be determined by a random ‘Poisson sprinkling’ of events onto $M$. Given such a co-domain of $\phi$ in $M$, we obtain a causal set satisfying the kinematic axiom by lifting the set of events together with all the relations of causal precedence obtaining among these events. It is thus straightforward to find a causal set that is approximated by a given globally hyperbolic spacetime with bounded curvature.

Note that it is important that the selected events in $M$ are picked randomly and do not form some regular pattern such as a lattice. If the set of events exhibits too much regularity, then Lorentz symmetry would be broken because we would be able to distinguish, at an appropriately coarse-grained scale, such a lattice from its Lorentz boosted analogue.

3 Facing the same dilemma?

Is temporal becoming compatible with special relativity? Stein (1991) famously proves that there is a sense of becoming compatible with Minkowski spacetime. However, as we have stressed (deleted for review), just to identify some partition of events in Minkowski spacetime and call it becoming does not entirely remove the pressure on becoming from special relativity. What is required in addition is a philosophical justification for that choice of partition. Focusing on the present, the
worry is that any identification of a present in special relativity either answers to the presentist’s explanatory request or is compatible with the structure of Minkowski spacetime, but not both. For example, one might introduce a foliation of spacetime into spacelike hypersurfaces totally ordered by ‘time’. Presumably, that would complement a presentist notion of a (spatially extended) present and of becoming, but at the price of introducing structure not invariant under automorphisms of Minkowski spacetime. Conversely, the present can be identified with invariant structures such as a single event or the surface of an event’s past lightcone, but such structures will have radically different properties from those ordinarily attributed to the present by those seeking to save it (see: references deleted). Does the advocate of becoming face a similar dilemma in the context of CST?

In order to address that question, let us see whether we can construct a ‘present’ from the resources of CST. Beginning with the event of the ‘here-now’, one very natural definition of the events co-present with the ‘here-now’ are those events on a ‘spacelike slice’, technically a ‘maximal antichain’, i.e., a maximal set of events such that any two events are incomparable. But there are a number of problems with a present thus defined. First, maximal antichains do not, by definition, have any structure. If such a ‘spatially extended’ present were to have any spatial structure at all, then this structure must somehow be induced by, and thus be ontologically dependent upon, the larger—‘temporally extended’—structure of the causal set. Second, for any given event ‘here-now’, there are in general many maximal antichains of which it is an element. Thus, in a loose analogy to the many ways in which Minkowski spacetime can be foliated, the present in the sense of the set of events co-present with the here-now would thus not be uniquely defined. Third, and relatedly, a partition of a causal set into such maximal antichains would not be invariant under the automorphisms of its structure. Thus, it seems that a ‘spatially extended’ present in a causal set would very much run into difficulties of the sort encountered in special relativity.

Let’s probe deeper. In special relativity, Stein’s theorem tells us, essentially, that any binary relation ‘is definite as of’ adapted to the structure of temporally oriented Minkowski spacetime must coincide with ‘is in the causal past of’ lest it degenerate into the trivial or the universal relation, modulo a choice of temporal direction. One might now expect that a statement analogous to Stein’s theorem holds in CST as well. After all, there is an obvious sense in which the causal structure of causal sets is very much like that of Minkowski spacetime—indeed, CST is premised upon the idea that special relativity gets the causal structure of spacetimes as partial orderings among events basically right. Thus, it may appear as if a causal set is merely a discrete version of Minkowski spacetime. This expectation, as natural as it may be, is disappointed.

Stein’s notion of becoming is expressed as a binary relation $R$ between spacetime events. The relation $R$ can be interpreted as ‘is settled as of’ or ‘having become as of’ and similar notions. Imposing various conditions on becoming, Stein proves that a non-trivial relation that respects the basic structure of Minkowski spacetime exists. It turns out to be the relation that obtains between and only between an event and events in that event’s causal past. In particular, he assumes that $R$ is a reflexive, non-trivial, and non-universal relation on a Minkowski spacetime $(\mathbb{R}^n, \eta_{ab})$ of at least two dimensions ($n \geq 2$) invariant under automorphisms that preserve the time-orientation and generally is Lorentz covariant, and if $R_{ab}$ holds for some ordered pair of points $\langle a, b \rangle$, with $a, b \in \mathbb{R}^n$, such that $ab$ is a past-pointing (timelike or null) vector, then for any pair of points $\langle x, y \rangle$ in $\mathbb{R}^n$, $R_{xy}$ holds if and only if $xy$ is a past-pointing vector. The upshot is that for any event $p$ in Minkowski spacetime, all the events in $p$’s causal past have become for it.

The analogue of this theorem, however, is straightforwardly false in CST. To quickly see this, consider the simple causet in Figure ??—the ‘counterexample causet’. On this causet, a reflexive and transitive relation $R$ can be defined (set-theoretically, as is standard) as follows:

$$R = \{ \langle a, a \rangle, \langle b, b \rangle, \langle c, c \rangle, \langle d, d \rangle, \langle b, a \rangle, \langle c, a \rangle, \langle d, b \rangle, \langle d, c \rangle, \langle d, a \rangle, \langle b, c \rangle, \langle c, b \rangle \}.$$
In other words, this relation $R$—‘is definite as of’—holds of any event and itself, of any event and any other event in its causal past, and of any ‘spacelike related’ pairs of events such as $b$ and $c$ in Figure ??, and not otherwise. It is clear that this relation does not obtain only between events and events in their causal past, as it obtains between the spacelike related events $b$ and $c$! Nor is this $R$ the trivial reflexive relation nor the universal relation (e.g. $\langle b, d \rangle$ is not an element). But nonetheless $R$ is invariant under automorphisms of the structure, as it only relies on the causal relations themselves, except for the last two pairs, which are however symmetrically included and obtain between points with identical ‘relational profiles’ and hence are invariant under structure-preserving maps. In fact, we would expect to find relations violating the analogue of Stein’s theorem whenever we have ‘Hegelian pairs’ of events, i.e. pairs of events whose relational profile is identical. Automorphisms of a causal set map events to events in the causal set such that if a pair of events was standing in a relation of causal precedence prior to the mapping, their image will also do so.

Specifically for the counterexample causet, the pairs $\langle b, c \rangle$ and $\langle c, b \rangle$ can be included in $R$ without $R$ collapsing into the universal relation, as happens in Minkowski spacetime. There, whenever a spacelike vector is included in $R$, invariance under automorphisms demands that all spacelike vectors are in $R$; requiring transitivity then collapses $R$ to the universal relation. This does not happen in cases such as that represented in Figure ?? because events with identical causal profile can be mapped into each other without altering the causal structure at all. Thus, we see that in CST there can be non-trivial and non-universal relations of being definite as of that do not collapse to events in the causal past of the reference event. Is this enough to drive a wedge into the dilemma faced by advocates of relativistic becoming?

The first thing to note is that Hegelian subsets are rare. A Hegelian subset $H \subset C$ of events in a causal set $\langle C, \preceq \rangle$ is a set consisting of distinct events $x_1, \ldots, x_k$ in $C$ with the same relational profile, i.e., $\{x_1, \ldots, x_k\} \forall z \in C, z \preceq x_i \leftrightarrow z \preceq x_j, \text{ and } x_i \preceq z \leftrightarrow x_j \preceq z, \text{ where } i, j = 1, \ldots, k \}$

It is clear that any pair of distinct elements of a Hegelian subset cannot stand in the relation $\preceq$, i.e., they are by necessity ‘spacelike’ to another.

Now suppose we have a causal set with a Hegelian pair, i.e., a Hegelian subset of cardinality 2. The relation $R$ can thus symmetrically obtain between them in a way that leaves $R$ automorphically invariant, which is what led to the violation of Stein’s result transposed to CST. If we subtract from $R$ all pairs which stand in $\preceq$, then we will end up with the Hegelian subsets. Since its elements stand in $R$ symmetrically, these will be events which can be interpreted to be ‘determinate as of’ one another. In this sense $R \setminus \preceq$ gives us an automorphically invariant way to define co-presentness. And this in a theory which is supposed to ground relativity and whose only fundamental relation

\footnote{Singleton sets of events will satisfy this definition except that they do not contain distinct events. We insist on distinctness because we are only interested in Hegelian subsets of cardinality 2 or higher. Thus, $1 < k \leq n$ for a causal set of $n$ events.}
is relativistic causal precedence!

Does this give us the tools to thwart the original dilemma? For that to work, we would have to find large Hegelian subsets consisting of a nearly maximal antichain for the present to be at least almost global, and we would need many of them to have a decent sequence of subsequent presents.

However, this is not what we generically find in causal sets. Although we know of no pertinent analytical results or numerical estimates, we suspect that large and many Hegelian subsets are few and far between. The reason is that there are many more irregular structures that satisfy the kinematic axiom than there are structures which are sufficiently regular to sustain large and many Hegelian subsets. If this is right, then there are no grounds on which to expect that the few and small remaining Hegelian subsets can generically give rise to any macroscopic present.

What about those causal sets which do have large and many Hegelian subsets? They clearly satisfy the kinematic axiom, so are not ruled out unless we impose additional dynamical laws that they violate. Yet observe that in these rare circumstances where the necessary condition is satisfied, we have regular lattice structures. As explained above, such highly regular structures would lead to a detectable violation of Lorentz symmetry. This has the great virtue of making it empirically testable whether—if CST is true at all, of course—the fundamental causal set exhibits such regularities. We take the absence of any empirical tests pointing to a violation of Lorentz symmetry to be an indication that the actual fundamental causal set—again, if any—cannot be highly regular.

In sum, rather than escape the dilemma, it seems CST embraces it and even makes it rigorous. That is, generically there will not be Hegelian subsets sufficient to express the present, and when there are, they will violate Lorentz invariance.

Of course, an advocate of becoming happy with Stein’s relation can easily find a counterpart within causal sets. Given the structure of causets, it is straightforward to define relativistically kosher forms of becoming that essentially imitate the past lightcone becoming already compatible with the geometry of Minkowski spacetime. However, to those seeking a genuinely ‘tensed’ metaphysics of time, Stein’s result has always had limited appeal. At best it defines a notion of becoming compatible with Minkowski spacetime. But if one desires that Minkowski spacetime itself grows or changes, as many metaphysicists of time do, then Stein’s project is simply seen as irrelevant. As (ref deleted) and Skow (2012) point out, there is a difference between notions of becoming and flow that are observer or event dependent and those that are independent of observers or events. If one wants the world to become, as tensers do, then one wants a more substantial perspective independent sense of becoming. Can CST provide us with this?

4 Taking growth seriously

There is nothing in the kinematics of CST that suggests any kind of ontological growth. To find anything smacking of growth, one needs to turn to the dynamics. The dynamics for a causal set is a law of sequential growth. What grows are the number of elements, and it is assumed that the ‘birthing’ of new elements is stochastic. Suppose $\Omega(n)$ is the set of $n$-element causets. Then the dynamics specifies transition probabilities for moving from one $C \in \Omega(n)$ to another $C' \in \Omega(n+1)$.

Innumerable growth laws are possible. However, in a remarkable theorem Rideout and Sorkin (2000) show that if the classical dynamics obeys just a few natural conditions then the dynamics is sharply constrained. In particular, it must come from a class of dynamics known as generalized percolation. Since the differences within this class won’t matter for what follows, we can illustrate the idea with the simplest dynamics that satisfies the Rideout-Sorkin theorem, namely, transitive percolation, a dynamics familiar in random graph theory.
A simple way to understand this dynamics is to imagine an order of element births, labeling that order using integers 0, 1, 2... such that they are consistent with the causal order, i.e., if \( x \preceq y \rightarrow \text{label}(x) < \text{label}(y) \). (The reverse implication doesn’t hold because the dynamics at some label time may birth a spacelike event, not one for which \( x \preceq y \).) We begin with the causet’s ‘big bang’, the singleton set. Now when element 2 is birthed, there are two possibilities: either it is causally related to 1 or not, i.e., \( 1 \preceq 2 \) or \(-1 \preceq 2\). Transitive percolation assigns a probability \( p \) to the two elements being causally linked and \( 1 - p \) to the two elements not being causally linked. Ditto now for element 3, which has probability \( p \) of being causally linked to 1 (2) and \( 1 - p \) of not being causally linked to 1 (2). The dynamics enforces transitive closure, so if \( 1 \preceq 2 \) and \( 2 \preceq 3 \), then \( 1 \preceq 3 \). Another way to conceive of the dynamics is that when each new causet \( C' \) is born, it chooses a previously existing causet \( C \) to be its ancestor with a certain probability.

The heart of the idea that CST rescues becoming involves taking sequential growth seriously:

The phenomenological passage of time is taken to be a manifestation of this continuing growth of the causet. Thus, we do not think of the process as happening ‘in time’ but rather as ‘constituting time’... (Rideout and Sorkin 2000, 024002-2)

Becoming is embodied in the ‘birthing’ of new elements.

Although we’re interested in becoming, we should immediately remark that sequential growth is certainly compatible with a tenseless or block picture of time. In mathematics a stochastic process is defined as a triad of a sample space, a sigma algebra on that space, and a probability measure whose domain is the sigma algebra. Transition probabilities are viewed merely as the materials from which this triad is built. In the case at hand, the sample space is the set \( \Omega = \Omega(\infty) \) of labeled causal sets that have been run to infinity. The ‘dynamics’ is given by the probability measure constructed from the transition probabilities; for details, see Brightwell et al (2003). On this picture, the theory consists simply of a space of tenseless histories with a probability measure over them.

However, let’s take the growth seriously. Even before worrying about relativity, one might be concerned that an analogue of Smart’s ‘how fast does time fly?’ objection applies (Smart 1966). Smart famously argued that if time changes and change is the having of different properties at different times, then it seems that at least two times are needed for any metaphysics wherein the present moves. That seems to be the case here too. Remember that the elements being created are spatiotemporal. What does a dynamics over variables that are spatiotemporal even mean? We have an external time given by the dynamics—the time in which growth happens—and an internal time given by the spatiotemporal metric the causet inherits from its embedding in a relativistic spacetime. The causal set counterpart of Smart’s question beckons: how fast are elements born?

Is Smart’s objection fatal to the idea of cosmological ‘growth’? Here philosophical opinion divides. Anticipating Smart’s question, Broad (1938) argued that the kind of change that time undergoes is a \textit{sui generis} kind of process. It’s not to be analyzed as qualitative change, i.e. the change of properties with respect to time. It is its own thing. We get a hint of that answer in Rideout and Sorkin’s claim that birthing \textit{constitutes} time and is not \textit{in} time. The causet growth is time, in some sense, not something that happens in time. Like Broad, Skow 2009 believes that a second-order time isn’t required to make sense of a substantive sense of temporal passage. He regards this apparent second time dimension as a kind of metaphor to understand the action of primitive tense operators. For philosophers such as Broad and Skow, Smart’s objection has no purchase. Others, however, might complain that appeal to \textit{sui generis} processes and primitive logico-linguistic devices leaves a lot to be desired in terms of physical clarity. No matter our personal reactions to this issue, we will bracket this worry since stopping at this point would be needlessly controversial. After all, we’re trying to give CST becoming its best chance.
The problem with taking the primitive growth as vindicating becoming is that advocates of CST uniformly wish to treat the labeling time as ‘fictitious’. The reason is that the choice of label is tantamount to picking a time coordinate \( x_0 \) in a relativistic spacetime. Any dynamics distinguishing a particular label order will be non-relativistic. Not wanting the dynamics to distinguish a particular label (‘coordinatization’), the authors impose \textit{discrete general covariance} on the dynamics. This is a form of label invariance. The idea is that the probability of any particular causet arising should be independent of the path to get to that causet. In particular, if \( \alpha \) is one path from the singleton causet to an \( n \)-element causet, and \( \beta \) is another path, then the product of the transition probabilities along the links of \( \alpha \) is the same as that for \( \beta \) (and any other such path).

To get a feel for this, suppose that the singleton set births a timelike related element, Alice’s birthday, at label time \( l = 1 \), and then this 2-element causet births a third element, Bob’s birthday, spacelike related to the other two events at label time \( l = 2 \). That is path \( \alpha \). Path \( \beta \) instead births Bob’s birthday spacelike related to the singleton set, and then births Alice’s birthday timelike related only to the singleton set. Discrete general covariance implies that the product of the transition probabilities getting from the singleton to that 3-element causet is the same. Used as a condition to derive the dynamics, all sequential growth dynamics compatible with CST possess this symmetry. The further interpretation is that the probabilities respect this symmetry because the labels are pure gauge, that there is no fact of the matter about which path was taken.

\[
\begin{array}{c}
l = 2 \quad \text{\begin{tikzpicture}
\node (a) at (0,2) {a};
\node (b) at (2,2) {b};
\node (l) at (1,0) {$\bar{\text{\textit{l}}} = 0$};
\draw [->] (a) -- (l);
\draw [->] (b) -- (l);
\end{tikzpicture}}
\end{array}
\]

\[
\begin{array}{c}
l = 1 \quad \text{\begin{tikzpicture}
\node (a) at (0,2) {a};
\node (b) at (2,2) {b};
\node (l) at (1,0) {$\bar{\text{\textit{l}}} = 0$};
\draw [->] (a) -- (l);
\draw [->] (b) -- (l);
\end{tikzpicture}}
\end{array}
\]

\[
\begin{array}{c}
l = 0 \quad \text{\begin{tikzpicture}
\node (a) at (0,2) {a};
\node (b) at (2,2) {b};
\node (l) at (1,0) {$\bar{\text{\textit{l}}} = 0$};
\draw [->] (a) -- (l);
\draw [->] (b) -- (l);
\end{tikzpicture}}
\end{array}
\]

Figure 2: Alice’s and Bob’s birthday parties come into being.

With this simple example in mind, one can immediately see the trouble with regarding this growth as a real physical process (see Figure ??). Suppose the event \( a \) timelike related to the singleton set is Alice’s birthday party and suppose the event \( b \) spacelike related to both is Bob’s birthday party. To enforce consistency with relativity, there is no fact of the matter about which one happened after the singleton element event. To say which one happened ‘first’ is to invoke non-relativistic concepts. It’s therefore hard to understand how there can be growth happening in time. Seeing the difficulty here, Earman (2008) suggests a kind of philosophical addition to causal sets, one where we imagine that ‘actuality’ does take one path or another. With such a hidden variable moving up the causet, we do regain a notion of becoming. But as Arageorgis (2012) rightly points out, such a move really flies in the face of the normal interpretation of these labels as pure gauge. The natural suggestion is then that the above tenseless interpretation is best because it
doesn’t ask us to imagine one event came first.

Perhaps the sensible reaction to this problem is to abandon the hope that CST does produce a novel sense of becoming. Still, we are tempted to press on. The intuition motivating us is as follows. True, the dynamics is written in terms of a choice of label, but we know that a consistent gauge invariant dynamics exists ‘beneath’ this dynamics. In fact, rewriting the theory in terms of a probability measure space, as indicated above, one can quotient out under relabellings to arrive at a label-invariant measure space (for construction and details, see Brightwell et al 2003). And one thing that we know is gauge invariant is the number of elements in any causet. Focusing just on these and ignoring any labeling, we do have transitions from \( C \) to \( C' \) and so on. There is gauge-invariant growth.

The problem is that we are prohibited from saying exactly what elements exist at any stage of growth. Take the case of Alice and Bob above. The world grows from \( C_1 \) to \( C_2 \) to \( C_3 \). That’s gauge invariant. We just can’t say—not due to ignorance, but because there is no fact of the matter—whether \( C_2 \) consists of the singleton plus Alice’s party or the singleton plus Bob’s party. Causal set reality doesn’t contain this information. If it is coherent, therefore, to speak of a causet having a certain number of elements but without saying what those elements are, then CST does permit a new kind of—admittedly radical and bizarre—temporal becoming.

Whether this notion of becoming is coherent depends on the identity conditions one has for events. If to be an event, one has to be a particular type of event with a certain character, then perhaps the idea is not coherent. After all, what is the \( C_2 \) world like? It doesn’t have Alice and Bob in it (that’s \( C_3 \)), nor does it have neither Alice nor Bob in it (that’s \( C_1 \)). The world determinately has Alice or Bob in it, but it doesn’t have determinately Alice or determinately Bob. ‘Determinately’ cannot penetrate inside the disjunction. Notice that this feature is a hallmark of vagueness. The philosophical literature on vagueness is too huge to do justice to here, so we will simply note that there is a lively dispute over whether there can be ontological vagueness. The causal set program, interpreted as we have here, supplies a possible model of a world that is ontologically vague. Further discussion of this model seems to us worthwhile.

We close with a discussion of some of the strange features of this metaphysics. First, note that many philosophers, from Aristotle to today, have thought that the future is indeterminate (see, e.g., Øhrstrøm and Hasle 2011 and references therein). According to some versions of this view, it’s determinately true that tomorrow’s coin flip will result in either a head or a tail, but it is not determinate yet which result obtains. Vagueness infects the future. We note that the above causal set vagueness is quite similar, but with one big difference: on the causal set picture, the past too can be indeterminate! In our toy causal set, it’s not true at \( C_3 \) that \( C_2 \) determinately is one way rather than the other. Second, note that as a causet grows, events that were once spacelike to the causet might acquire timelike links to future events. If we regard the growth of a new timelike link to a spacelike event as making the spacelike event determinate, modulo the above type of vagueness, then this is a way future becoming can make events past. That is, there is a literal sense in which one can say that “the past isn’t what it used to be”. Finally, although we don’t have space to discuss it here, note that despite appearances transitive percolation is perfectly time reversal invariant. This allows the construction of an even more exotic temporal metaphysics. If we relax the assumption that events can only be born to the future of existing events, then it is possible to have percolation—and hence becoming—going both to the future and past. Choose a here-now as the original point. Then it’s possible to modify the theory so that the world becomes in both directions, future and past.
5 Conclusion

We have investigated the claim that CST rescues temporal becoming. At the kinematical level, CST does offer new twists in dealing with time and relativity, but the basic contours of the relativistic challenge remains. Serious constraints also threaten becoming if we take the time in CST’s dynamics seriously too. Here, however, if one is open to the costs and a sufficiently radical metaphysics, we maintain that there is a novel and exotic type of temporal becoming possible.

References


