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Causal Connectivity, Genidentity and the Ontology of Point-Eventism

Abstract. The concept of a causally connected set of point-events plays a crucial role in the point-eventistic definitions of a thing and a process formulated by Zdzisław Augustynek. Unfortunately, Augustynek's approach to causal connectivity is open to a serious objection that has so far gone unnoticed, stemming from the way causal interactions are viewed in contemporary physics. This finding can hardly be considered favorable for an advocate of the ontology of point-eventism. The aim of this paper is, therefore, firstly, to discuss this objection in detail and, secondly, to share some ideas on how to deal with the problem.

Keywords: philosophy of physics; philosophy of space-time; point-eventism; general theory of relativity; special theory of relativity; ontology; causation; events

1. Introduction

Zdzisław Augustynek, in the appendix to his book *Time: Past, Present, Future* (1991), presented an outline of the ontology of space-time that might be called *point-eventism* (henceforth: PE).[1] In general, the main thesis of the PE ontology states that every object is a physical point-event or a set founded in such events, i.e., a set of events or a family of some sets of events, and so on. Given the fact that point-events are fundamental objects assumed by the General (GTR) and the Special

[1] It should be mentioned, however, that the conviction about the fundamental importance of point-events in an ontology of space-time and physical world comes from (Reichenbach, 1958; Mehlberg, 1980). These inspirations were openly mentioned by (Augustynek, 1993a,b) on several occasions.

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Theory of Relativity (STR), some philosophers of physics believe that point-eventism accords better with Einsteinian mechanics than any other ontology of space-time.

Regardless of whether the framework of point-eventism is indeed best suited for a philosophical analysis of the relativistic space-time, it is well known that PE adopts several theses and definitions that may raise some doubts. In particular, the definition of a *thing* or, as some prefer, a *particle* proposed by Augustynek seems to pose the greatest problems. So far, however, objections have been raised primarily against granting things in the PE ontology the status of abstract entities or assigning them certain spatiotemporal features.[2] Relatively little attention has been paid to another essential property of sets identified with particles, namely their *causal connectivity*. We believe this is a serious oversight.

What makes us think this way? Broadly speaking, in point-eventism, being a causally connected set of events is defined as being a set founded in point-events that are all causes or effects of each other, unless they occur simultaneously. Things, but also *processes* such as world lines of particles, are expected to possess this feature. The overall significance of causal connectivity as a property of objects in the PE ontology is therefore considerable. Meanwhile, a deeper examination of Augustynek's theses shows that applying the original definition of causal connectivity misses the point, if other assumptions of PE are left intact. What is worse, the most obvious, as it might seem, attempts to adapt Augustynek's definition to the revealed circumstances fail. This turn of events forces a supporter of eventism to reconsider how causal connectivity, and consequently things and processes, should be defined.

The purpose of this article is, firstly, to present and discuss in detail our objection (Section 6) and, secondly, to share some ideas on how to deal with this kind of criticism (Section 7). Before doing so, however, we are going to recall the point-eventistic definition of a particle, both in its original (Section 2) and more sophisticated setting (Section 3). On this occasion, we will also get acquainted with the definition of a process introduced by the author of *Time: Past, Present, Future*. At last, we

[2] Arguments and strategies in question have been developed mainly by Grygianiec (2005, 2006, 2008, 2011) and Wolniewicz (2018). These objections, apart from Kuźniar's argument, which is later discussed in Section 3, concern, among others: the common use of a set-theoretical membership relation (∈) in Augustynek's definitions, the unobservability of events as non-extended objects, and the circularity of the point-eventistic definitions of temporal and spatial extension.

will devote some attention to the issues that are crucial to our critical examination, namely: the criteria of identity for point-events (Section 4) and the causal structure of the physical world (Section 5).

The last introductory comment concerns our use of formal methods. Since the objection we present, as well as all possible answers to it, have a physical rather than logical nature, our considerations will not be accompanied by any theorems, lemmas, or proofs, but only by definitions. The formalism used in this paper serves to express precisely what could be expressed, albeit less perfectly, in natural language. This approach, even if it does not fully correspond to Augustynek's views on logical philosophy, seems to us sufficient to achieve the aim of this paper.

2. Augustynek's definitions

The point of departure of our analysis must be the point-eventistic definition of a thing given by Augustynek (1991, 1993a,b). For an advocate of the PE ontology, a thing is a non-empty set of events which is both time-extended and space-extended, time-continuous, and causally connected. In the formal mode, if we denote the set of all things by **T** and its elements by a, b, c, and so on, this definition is as follows:

$$a \in \mathbf{T} \equiv [a \subset \mathbf{S} \wedge a \neq \emptyset \wedge a \in (Ec \cap Ep) \wedge a \in Cn \wedge a \in Cc]. \quad (\mathrm{D}\mathbf{T}1)$$

The right side of the above definition, as it is easy to notice, is a logical conjunction of six conditions. The first two of them, according to which each thing is a non-empty set of point-events, are in fact simple consequences of the thesis that all objects are events or sets founded in events, once we realize that no particle — not even the smallest and shortest-living one — is a point-event. In turn, the remaining four definitional requirements, if we denote the set of all point-events by **S**, its arbitrary subset by **X** and particular events by x, y, z, and so on, receive in the PE ontology following definitions.

First of all, a set of events is *time-extended* (Ec) iff at least two of its elements are absolutely temporally separated (time-different) $\bar{R}$ in the sense of STR, i.e., non-simultaneous in any inertial reference system:[3]

$$\mathbf{X} \in Ec \equiv \exists x, y \in \mathbf{X}\ [\bar{R}(x, y)]. \quad (\mathrm{D}Ec)$$

[3] In this paper, due to its subject, we do not refer to objects and relations that are relative (in the sense of STR), i.e., those dependent on an inertial reference system, but only to absolute ones.

Secondly, for **X**-sets to be *space-extended* (Ep), it means that at least two of their elements, which are absolutely simultaneous R in the sense of STR, i.e., simultaneous regardless of any inertial reference system, are absolutely spatially separated (space-different) $\bar{L}$, that is, occurring at different points of space or, in short, non-collocal:

$$\mathbf{X} \in Ep \equiv \exists x, y \in \mathbf{X}\ [R(x, y) \wedge \bar{L}(x, y)]. \tag{DEp}$$

Thirdly, a set of events **X** has the property of *time continuity* (Cn) iff **X** is totally ordered by the asymmetric relation of being earlier than W and no section in Dedekind's sense of **X** is a jump or a gap.[4] In the formal language being a time-continuous set is defined as follows:

$$\mathbf{X} \in Cn \equiv (\mathbf{X}, W) \in Ded. \tag{DCn}$$

Finally, a set of events **X** has the property of *causal connectivity* (Cc) iff every two absolutely time-different elements of it are linked by the so-called causal connection or, in other words, the unoriented (irreflexive, symmetrical and intransitive, i.e., neither transitive nor antitransitive) relation H in which there is no difference between cause and effect:

$$\mathbf{X} \in Cc \equiv \forall x, y \in \mathbf{X}\ [\bar{R}(x, y) \rightarrow H(x, y)]. \tag{D$Cc1$}$$

Let us note here that the definition of causal connectivity might be formulated alternatively. It is obvious, after all, that the temporal separation of any events x and y means that x is earlier than y or x is later than y. In a similar way, it can be said that the causal connection between x and y implies that x is either the cause or the effect of y. Hence, we may equally well call causally connected any **X**-set in which being by x earlier than y (we take x and y as arbitrary elements of **X**) entails that x caused or was caused by y, i.e., individuals x and y stand in some form of the asymmetrical causal relation D.

Of course, this does not mean that being by x an element of a causally connected set **X** and preceding in time some y, which is another member of **X**, necessarily implies that x is the cause of y. Unless we rule out the reversibility of causal processes, the occurrence of W separating

[4] At this point, let us note that while Augustynek, being a supporter of the relational theory of time not accompanied by any causal theory of time, accepts (DCn), for relationists who are less moderate, such as van Fraassen (1970) or Grünbaum (1973), temporal continuity is reducible to some causal properties of sets of events.

x from y does not allow us to determine whether x is the cause of y and it is true that $D(x, y)$, or perhaps x is the effect of y and in fact $D(y, x)$ holds. Nevertheless, as things stand, we are still able to define causal connectivity, or rather paraphrase its original definition, in terms of oriented (irreflexive, asymmetrical and transitive) relations W and D between events, if we use a logical disjunction for this purpose. So, at last, the definition (DCc1) can take any of the following forms:

$$\mathbf{X} \in Cc \equiv \forall x, y \in \mathbf{X}\ \{\bar{R}(x, y) \to [D(x, y) \vee D(y, x)]\},$$
$$\mathbf{X} \in Cc \equiv \forall x, y \in \mathbf{X}\ \{[W(x, y) \vee W(y, x)] \to H(x, y)\},$$

or a setting where $\bar{R}$ and H are completely replaced by W and D.

However, the condition of causal connectivity, as we have already mentioned, does not appear only in the point-eventistic definition of a thing. Meeting this requirement is also expected from any process, that is, a non-empty set of events which is time- but not space-extended, time-continuous, and causally connected. In the formal mode, if we denote the set of all processes by **Pr** and its elements by f, g, h, and so on, the definition of these objects can be formulated as follows:

$$f \in \mathbf{Pr} \equiv [f \subset \mathbf{S} \wedge f \neq \emptyset \wedge f \in (Ec \cap \bar{E}p) \wedge f \in Cn \wedge f \in Cc]. \quad (\mathrm{D}\mathbf{Pr}1)$$

As we can see, the basic difference between things and processes is the fact that things can be founded in events simultaneous to each other, but located in different regions of space. In the case of processes, this is completely excluded. Simultaneous elements of the same process simply need to be in the same place.

3. Kuźniar's argument and its implications

Nevertheless, a few years ago Adrian Kuźniar managed to demonstrate that the above definition of a thing is untenable.[5] Following Kuźniar's suggestions, presented by Grygianiec (2011), we realize that no set of events, and certainly no particle, can jointly satisfy the conditions of

[5] We omit the question of whether attributing the authorship of this argument to Kuźniar is justified, since the possibility of such criticism was explicitly anticipated by Augustynek (1991) when he wrote (on p. 123) that applying the temporal continuity condition to particles "requires that things are treated as processes".

temporal continuity and spatial extension. This is because the property of time continuity — the requirement that all sections of the order $(\mathbf{X}, W)$ are Dedekind cuts that are neither jumps nor gaps — forces us to recognize that the relation W in $\mathbf{X}$ is logically connected, and thus $W(x, y) \vee W(y, x)$, for all $x, y \in \mathbf{X}$. But the relation W on things cannot meet these expectations. Given a spatial extension of any $\mathbf{T}$-set, we may always deal with a pair of events that escapes the connectivity condition.

To simplify, there are events belonging to any $\mathbf{X} \in Ep$ that enter neither into the relation $W(x, y)$ nor $W(y, x)$, because at least two elements of $\mathbf{X}$ must be simultaneous. Otherwise we could not claim that these events constitute a spatially non-extended set. This leads to the conclusion that the set of all things — understood in accordance with Augustynek's guidelines — is empty ($\mathbf{T} = \emptyset$), since either $\mathbf{X} \in (Ep \cap \bar{Cn})$ or $\mathbf{X} \in (\bar{Ep} \cap Cn)$, but there is no $\mathbf{X}$ such that $\mathbf{X} \in (Ep \cap Cn)$.

Ultimately, the objection articulated above does not completely refute point-eventism, although it forces a philosopher who advocates the doctrine of PE to improve Augustynek's definition of a thing. There are several strategies to defend the eventistic standpoint, but the most natural seems to be to use the relation of identity of the thing through time and space, that is, the *genidentity of events* (G). This approach is supported by the fact that Augustynek briefly refererred to the genidentity in his main paper on the PE system, and in other articles he formulated three axiomatic definitions of the relation G. It can thus be assumed that reducing things to sets of genidentical events would find his approval.

Yet what is the proper definition of genidentity? As we already mentioned, Augustynek (1981, 1997) gave three different axiomatic definitions of genidentity. What they have in common is the involvement of the following relations between point-events:

(a) logical identity I and non-identity $\bar{I}$,
(b) absolute simultaneity R and temporal separation $\bar{R}$,
(c) absolute collocation L and spatial separation $\bar{L}$,
(d) causal connection H and its negation $\bar{H}$.

Individual definitions of genidentity differ in terms of the necessary conditions for G. The discrepancies between them also concern the existence of causally connected and absolutely simultaneous events. Our task, and we want to emphasize this, is not to analyze all these systems. This has already been satisfactorily done by Porwolik (2017a,b). At this point, we will limit ourselves to shedding some light on the last definition of genidentity, which, as a logical subsystem of two other axiomatic theories given by Augustynek, appears to be the easiest to accept.

In this connection, genidentity is a relation which, together with absolute simultaneity, on the one hand, results from the logical identity of events (AG1), and on the other hand, entails (in conjunction with simultaneity) the absolute collocation of any events (AG2):

$$\forall x, y \in \mathbf{S}\ \{I(x, y) \rightarrow [G(x, y) \wedge R(x, y)]\}, \tag{AG1}$$

$$\forall x, y \in \mathbf{S}\ \{[G(x, y) \wedge R(x, y)] \rightarrow L(x, y)\}. \tag{AG2}$$

In turn, the relations between genidentity, simultaneity and causal connection are such that genidentical and causally connected events are always temporally separated (AG3), while genidentical and temporally separated events are causally connected (AG4):[6]

$$\forall x, y \in \mathbf{S}\ \{[G(x, y) \wedge H(x, y)] \rightarrow \bar{R}(x, y)\}, \tag{AG3}$$

$$\forall x, y \in \mathbf{S}\ \{[G(x, y) \wedge \bar{R}(x, y)] \rightarrow H(x, y)\}. \tag{AG4}$$

As for the formal properties of genidentity defined in this way, Augustynek assumed that G is an equivalence relation in $\mathbf{S}$.[7] So, at first glance, an alternative definition of a thing might take the following form:

$$a \in \mathbf{T} \equiv \exists x \in \mathbf{S}\ (a = |x|_G). \tag{D$\mathbf{T}$2}$$

In the material mode, this would mean that things are abstraction classes of the genidentity relation over the set of all point-events.

The problem is that the above definition is also not without flaws. Although the condition of temporal continuity is not strictly expressed in (D**T**2), a particle understood in this way would not differ from a process in Augustynek's sense. Let us even suppose that Kuźniar's objection does not apply to the definition of a process, and the whole difficulty,

[6] The fourth axiom says that if events composing some particle stand in the cause-and-effect relation with each other, then they are temporally separated. Therefore, we can recognize (AG4) as the universal statement called the postulate of causality, pointed out, among others, by Eddington (1923), according to which the physical influence of any event x on another event y with the speed of light or smaller means that x is earlier than y in any system of reference.

[7] That genidentity, although not defined in the way we find in Augustynek's papers, is an equivalence relation was also assumed by Reichenbach, van Fraassen and Grünbaum. On the other hand, doubts about such a profile of the G relation, in particular its transitivity, were raised by Żabski (2008).

since every element of **Pr** is spatially non-extended, is removed.[8] Still, the belief that a thing is identical to its world line, resulting from the adoption of the definition (D**T**2), is hardly intuitive. After all, even the smallest particles appear to us as space-extended objects.

Perhaps this is why Grygianiec in his paper proposed to connect by the genidentity relation not point-events, but their temporally non-extended sets called *cross-sections*. It is worth recalling that the point-eventistic definition of such objects, commonly treated as time instant cuts of things, is as follows:

$$q \in \mathbf{Cr} \equiv [q \subset \mathbf{S} \wedge q \neq \emptyset \wedge q \in (\bar{E}c \cap Ep)], \tag{D\textbf{Cr}}$$

if the set of all sections is denoted by **Cr** and its elements by q, r, s, *etc.*

Now, if we take this idea seriously and define the *genidentity of cross-sections* (G^*) by substituting events for cross-sections in axioms (AG1)–(AG4) (a transition: $x \rightarrow q$ for all elements of **S** and **Cr** is necessary here), then we will be able to call a particle an abstraction class over the set of all cross-sections under a genidentity relation:

$$a \in \mathbf{T} \equiv \exists q \in \mathbf{Cr}\ (a = |q|_{G^*}). \tag{D\textbf{T}3}$$

This definition finally allows us to avoid objections discussed so far, since the condition of time continuity is transferred from the level of events (individuals) to the level of cross-sections (sets of individuals). The relation of being earlier in **Cr** is logically connected, because the simultaneity of genidentical cross-sections is equivalent to their logical identity. The absence of a time interval between any q and r, if they form the same particle, is sufficient to mark them as identical.

4. Criteria of identity in point-eventism

It is not difficult to realize that in the last paragraph we have actually formulated the *criterion* or *condition of logical identity* for cross-sections in the ontology of point-eventism. And let us clarify that by criterion of identity we mean a standard by which identity is to be judged, that is, certain metaphysical factor that justifies or establishes sameness.

[8] At least this is what Grygianiec (2011) claimed when reconstructing Kuźniar's efforts. Personally, we believe this is false, because different events that compose a process can coincide with each other, which is enough to conclude that W is not connected in such a set. However, we will not discuss this issue further in this paper.

But since point-eventism introduces the identity criterion for cross-sections, i.e., some sets of events, shouldn't it also specify what it means that events are the same? This would certainly be a reasonable supposition. Unfortunately, Augustynek did not give us an identity condition for point-events.[9] Of course, this does not mean that a logical identity of events can be arbitrarily determined. Although there is no specific answer to the question "What does it mean that events are the very same in the PE ontology?", we are sure that at least one and well known identity condition cannot be applied within the framework of point-eventism.

The condition at issue is the so-called *spatiotemporal criterion*, according to which two point-events are the same iff they are located at the same point of space-time, i.e., they occur "here" and "now". More precisely, when a philosopher who follows this criterion, such as Quine (1985), claims that two events are the same, he is assuming that:

$$\forall x, y \in \mathbf{S}\ [I(x, y) \equiv K(x, y)], \tag{CS}$$

where K stands as the space-time coincidence relation, that is, a logical conjunction of both absolute simultaneous and collocal point-events (in the formal mode: $K = R \cap L$).

This brings us to the question why (CS) cannot be applied in the PE ontology as an identity criterion for events. After all, a similar assumption is accepted by many philosophers of space-time physics.[10] The answer may become clear when we reveal that Augustynek — unquestionably influenced by Henry Mehlberg's results — distinguished, apart from particles, *physical fields*, which he defined as non-empty sets of events that are extended both in space and time, but do not share the features of time continuity and causal connectivity. As Mehlberg (1980) pointed out, physics proves the existence of many fields, among which we find also coincident ones, such as the gravitational field and the electromagnetic field. Obviously, these sets of events must occupy exactly the same regions of space-time. By adopting (CS), we would be forced to assume that referred fields are logically identical. However, a statement like

[9] One might, like Porwolik (2017b), say that such a criterion is included in axioms (AG1)–(AG4). Let us note, however, that Augustynek himself was probably not aware of the existence of such a criterion. Moreover, Porwolik's remark adds nothing when the use of G is avoided.

[10] For example, the spatiotemporal criterion was adopted by Reichenbach (1958), who wrote about a coincidence in the strict sense (on p. 124) that it is equivalent to the identity of events and, as a result, does not raise any conceptual problems.

this is absurd from the standpoint of modern physics. For this very reason, the ontology of point-eventism cannot be reconciled with the spatiotemporal criterion, as Augustynek (1993b) himself admitted.

As we have already mentioned, in exchange for the rejected spatiotemporal criterion, an advocate of point-eventism does not give us a specific answer to the question of what it means to be the same event. But since in both GTR and STR the causal activity of events, and in some cases even their observability, plays a large role, it appears a good idea to ground the identity of events on their causal features. Especially encouraging in this respect is the *causal criterion* formulated by Davidson (1980). According to the author of *Essays on Actions and Events*, any two events are the same iff they have exactly the same causes and effects. It seems to us that Augustynek's theses and definitions will not be violated, if we adopt Davidson's condition or its weaker version, in which the direction of interaction between events is not determined:[11]

$$\forall x, y \in \mathbf{S}\ \{I(x, y) \equiv \forall z \in \mathbf{S}\ [H(x, z) \equiv H(y, z)]\}. \qquad \text{(CH)}$$

We maintain our belief that the condition (CH) and similar criteria of identity accord best with the spirit of point-eventism, despite concerns about their circularity, raised by many authors, and their incompatibility with some models of space-time encountered in GTR, as pointed out by Earman (1972). Ultimately, all that matters is that for a philosopher committed to Augustynek's ontology, the most reasonable solution is to ground the identity of point-events in their causal profile.

5. The causal structure of the physical world

But this is where things get tricky. Be agreeing to reject (CS), we have permitted the existence of many different events that occupy the same point of space-time. Then we have discovered that it would be appropriate to identify these events with respect to their causal features. The problem is that modern physics distinguishes several types of causal interactions. Each of them differs in some respect, such as velocity, range, potential or relative strength, and their theoretical unification has not been fully achieved. Hence, denoting all gravitational, electromagnetic

[11] Note that a criterion similar to (CH) was used by van Fraassen (1970) in his definition of coincidence, since he claimed that x and y coincide just in case: for every z, z is causally connectible with x if and only if z is causally connectible with y.

and nuclear interactions simply by D and H, due to their nomological diversity, seems to be poorly justified.

As if that were not enough, within GTR itself there is a clear distinction between electromagnetic and gravitational objects, such as waves and fields. Moreover, as we remember, the distinctness of fields mediating these interactions was the main reason for rejecting (CS) as an identity condition for events. Would it then make the most sense to split the cause-and-effect relations — both oriented and unoriented — into several minor and more natural interactions? That sounds reasonable, especially when we take into account that the notion of causality evokes bad associations among philosophers of physics and scientists.[12] But how should such a division of the relations H and D be carried out?

The answer to this question is provided by contemporary physics. According to our best scientific theories, there are three *fundamental forces* or *interactions*, namely:

(i) electroweak H_e causal connection,
(ii) gravitational H_g causal connection,
(iii) strong H_s causal connection,

that is, relations which, from a formal point of view, we can still consider as unoriented connections in the sense that we do not distinguish between their causes and effects.[13]

Although an advocate of point-eventism touts his ontology as being primarily consistent with the results of Einsteinian mechanics, let us assume that the relata of all enumerated relations — including those described by the electroweak theory and quantum chromodynamics (the theory of strong interactions) — are point-events. This is necessary if we do not want the acceptance of PE to make sense only when we limit the scope of our analysis to macro-scale phenomena.

At this point, however, another question arises. Since all these interactions involve events, how can their mutual irreducibility be expressed

[12] These associations are particularly common among critics of causal theories of time, such as (Smart, 1969) and (Earman, 1972). Historically, also Russell (1903, 1912) attacked the notion of causality from similar positions, since, in his opinion, it does not fit the language of modern science and should be replaced.

[13] We are aware that weak interactions break the symmetry of some laws of physics and the nomological isotropy of time. This fact, however, does not prevent us from defining the electroweak connection, because H_e can be still derived from relations, among which there are also oriented ones, especially — weak interactions.

in the language of the PE system? Only one answer comes to our mind: the set of all events $\mathbf{S}$ should be logically divided into three subclasses, so that they become domains of various forces. In particular, $\mathbf{S}_e$, $\mathbf{S}_g$ and $\mathbf{S}_s$ should be defined in such a way that, firstly, their union is equal to $\mathbf{S}$ (in short: $\mathbf{S}_e \cup \mathbf{S}_g \cup \mathbf{S}_s = \mathbf{S}$) and, secondly, their intersections are empty ($\mathbf{S}_e \cap \mathbf{S}_g = \emptyset$, $\mathbf{S}_e \cap \mathbf{S}_s = \emptyset$ and $\mathbf{S}_g \cap \mathbf{S}_s = \emptyset$). Everything indicates that this is how the causal structure of the physical world looks like.

Of course, this approach to the matter may seem suspicious at first glance. After all, we do not perform a similar division of $\mathbf{S}$ in the case of temporal and spatial relations. Nevertheless, we must remember that the spatiotemporal properties of events — unlike fundamental interactions — are described by one theory, namely relativistic mechanics, which is a combination of GTR and STR. Until a similar unified theory of fundamental interactions is found, we are forced to admit that the physical world is divided into several (at least three) mutually irreducible subworlds. This leads us to the conclusion that at the level of point-events, i.e., objects without an internal structure, basic interactions can only occur between elements of the same *causal subworld* or *realm*.

To put it roughly, the cause of an event exemplifying a magnitude of the gravitational field must be another event from the same physical field. It is forbidden for an electroweak or strong event to be a direct cause or effect of an element of $\mathbf{S}_g$. Events from separate causal domains, as objects with different causal properties, are causally unrelated, because it would be difficult to indicate, at least in our current state of knowledge, what kind of particles transmit interactions between them. The so-called causal realms, as we see, are not completely open to each other.

6. Our objection and its implications

To be fair, however, we must admit that these causal realms are not entirely closed either. For instance, things can be analyzed not only as objects that bend space-time, but also as bodies that reflect light or as clusters of smaller particles like nucleons or electrons. The same remark applies to light rays and other signals — the objects that are described in PE as processes — since their deflection is explained by GTR as being caused by the structure of the gravitational field. We thus have proof that entities which are relata of various forces, not necessarily reducible to each other, exist and are by no means excluded by physics.

Now, it is easy to notice that such objects have a certain common feature. Namely, they are not only time-continuous and time-extended sets of events, but above all they are defined in the point-eventistic framework as causally connected. To put it briefly, they are Cc-sets. The problem is that, in the light of our findings from the previous section, being a set of events satisfying the definition (DCc1), which includes only a vague notion of causality, is not sufficient to call something a particle or a process, even if the remaining conditions from (D**T**1) or (D**Pr**1) are met. What is worse, this objection also applies to the definition (D**T**2), because any abstraction class of genidentity of point-events — due to the axiom (AG4), the content of which does not deviate from the meaning of (DCc1) — is by its nature causally connected. We therefore conclude that being a Cc-set, as long as we assume Augustynek's definition of causal connectivity, is a fact of little metaphysical significance.

But how is this possible? The key to understanding our objection is the observation that the causal isolation of events from domains $\mathbf{S}_e$, $\mathbf{S}_g$ and $\mathbf{S}_s$ somehow forces us to the following correction to Augustynek's definition. Taking into account the division of $\mathbf{S}$ into realms of various fundamental interactions, we can either (α) keep the original definition untouched, or (β) assume that it applies to only one causal subworld at a time. Because the choice of (α), as we have already tried to show, has no basis and insisting on it would lead to the conclusion that the class of all Cc-sets is empty ($Cc = \emptyset$), we are left with (β) as our only strategy. This means that we do not have a single property of causal connectivity, but three attributes relating to each of the fundamental forces.

How to deal with this? The most obvious solution, in our opinion, is to define the electroweak causal connectivity of **X**-sets as follows:

$$\mathbf{X} \in Cc_e \equiv \forall x, y \in (\mathbf{X} \cap \mathbf{S}_e)\ [\bar{R}(x, y) \to H_e(x, y)], \qquad (\mathrm{D}Cc_e)$$

then extend this practice to the gravitational and strong interactions:

$$\mathbf{X} \in Cc_g \equiv \forall x, y \in (\mathbf{X} \cap \mathbf{S}_g)\ [\bar{R}(x, y) \to H_g(x, y)], \qquad (\mathrm{D}Cc_g)$$

$$\mathbf{X} \in Cc_s \equiv \forall x, y \in (\mathbf{X} \cap \mathbf{S}_s)\ [\bar{R}(x, y) \to H_s(x, y)], \qquad (\mathrm{D}Cc_s)$$

and assume that things and processes, if we consider them as sets founded in events from both $\mathbf{S}_e$, $\mathbf{S}_g$ and $\mathbf{S}_s$, exemplify all these qualities jointly.

Equivalently, instead of having properties Cc_e, Cc_g and Cc_s together, one can speak of satisfying a single and more general condition:

$$\mathbf{X} \in Cc \equiv \mathbf{X} \in (Cc_e \cap Cc_g \cap Cc_s). \qquad (\mathrm{D}Cc2)$$

In the same way, as one might guess, both (AG3) and (AG4), that is, those parts of the assumed axiomatic definition of genidentity that involve the relation H, may be approached. On this basis, for example, (AG4) could be replaced by three axioms, each of which would state that genidentical and temporally separated events from a certain causal domain are always connected by an interaction of one specific type.

Unfortunately, the outlined proposal to solve the problem in the spirit of (β) also misses the point. Now the causal connectivity condition is possible to satisfy and we even have grounds to believe that all things and processes are actually Cc-sets in the above sense. However, meeting this requirement is not enough to capture the essence of what we call a thing or a process. Since we already agree with the thesis of PE that members of **T** and **Pr** are certain sets of events, we would expect their electroweak, gravitational and strong elements to stand in some relations that transcend the boundaries of a single causal world. To be clear, in this case we are not talking about reducing one causal attribute to another. This would require a confirmation of some unified field theory: something that has not yet been achieved. Nevertheless, we are able to associate events from various domains spatiotemporally, that is, to establish that certain causes and effects of interactions of different kinds together coincide or compose some part of a given thing or process.

Whether a set is founded in point-events that can be linked in the way just described appears to be an essential feature of both things and processes. Otherwise we could easily call a random bundle of successive events, each of which has only electroweak, gravitational or strong properties, and none of these bundles overlaps with the others in space and time, a particle or its world line. This seems unacceptable even to a radical supporter of point-eventism. But by setting the condition that each thing and process is a Cc-set in the sense of (DCc2), we do not rule out this scenario at all. One can also easily see that a similar objection would apply to the concept of causal connectivity emerging from those axioms which were intended to replace (AG4) in the manner mentioned earlier. So, in conclusion, the fact that such sets of events satisfy the outlined conditions makes the considered definitions too wide.

Taking all this into account, we are inclined to argue that the discussed definitions of causal connectivity do not reflect the true nature of this property. And since the condition in question plays a crucial role in Augustynek's definitions of things and processes, the plausibility of (D**T**1), (D**T**2) and (D**Pr**1) is at risk, regardless of Kuźniar's objection.

7. Three alternative approaches to causal connectivity

To sum up, the facts we have just presented make it doubtful whether meeting the condition of causal connectivity, as Augustynek defined it, guarantees that all elements of the set **T** are only and exclusively things. The same holds true for the elements of **Pr** and their status as processes. We clearly see that (DCc1) and (AG3) cannot be maintained when the causal view of point-event individuation is assumed. Moreover, jointly exemplifying Cc_e, Cc_g and Cc_s features — the answer we have adopted as the most natural way to avoid the argument — is not the solution we expected. These results do not give cause for optimism.

The question now arises whether the problem we have pointed out could be dismissed at all. The answer to this question seems to be affirmative. After all, the objection we have presented, similarly to Kuźniar's earlier argument, does not completely refute the ontology of point-eventism. In order to avoid it, one might opt for some other approach to causal connectivity and, consequently, to defining things and processes. At present, we see three such alternative strategies.

7.1. Causal connectivity of sets of cross-sections and coincidents

First of all, let us begin with the observation that among the point-eventistic definitions of a thing known to us, there is one that is not vulnerable to the objection we have raised. This definition is of course (D**T**3), according to which a particle is an abstraction class over the set of all cross-sections under a relation of genidentity. Yet accepting this definition, if we want to take it literally, entails a number of significant shifts in the point-eventistic standpoint. In particular, because once the decision to adopt (D**T**3) is made, each element of **T** becomes a family of sets of events, and not — as before — a set of events. As a result, (DCc1) and any attempts to improve it as a definition of causal connectivity shared by **X**-sets can be abandoned as needless.

At this point, however, it seems important to emphasize that the discussed strategy does not lead to the abandonment of causal connectivity from the PE ontology as a feature of things. Non-simultaneous elements of any particle are still expected to stand in some causal interactions. But this requirement, just like the condition of time continuity, is transferred to the level of sets of cross-sections, that is, sets of sets of individuals. From now on, the meaning of causal connectivity depends on the final form of an axiomatic definition of G^* and, especially, an axiom about the occurrence of a causal connection between cross-sections. The latter, if we stick to our decision to converse the field of axioms (AG1)–(AG4) from **S** to **Cr**, will turn out to be the following axiom:

$$\forall q, r \in \mathbf{Cr}\ \{[G^*(q,r) \wedge \bar{R}^*(q,r)] \rightarrow H^*(q,r)\}, \qquad (\mathrm{A}G^*4)$$

which states that if any two cross-sections compose the same particle at different instants of time, then these cross-sections are connected by an irreflexive, symmetrical and intransitive causal relation H^*.

One may ask whether this step, assuming that the complete translation of (AG1)–(AG4) from the language of point-events to the language of cross-sections does not encounter any problems, is justified, since it is impossible to talk about interactions between events without specifying their causal type. To put it bluntly, can a cross-section be the cause or the effect of another cross-section without any relativization?

The answer, at least in our opinion, seems positive. Cross-sections are, after all, natural spatiotemporal parts of particles.[14] Some of the properties we attribute to them, such as mass, velocity, or acceleration, are difficult to reduce to single events due to their nature. These features of cross-sections, and of things composed of them, appear to *emerge* from many simultaneous, but not necessarily collocal, events. We suspect that the causal powers of cross-sections also fit into this pattern, that is, they result from the causal powers of their elements. And because **Cr**-sets are space-extended and consist of many events, the differences between various kinds of forces lose their sharpness. The causal connection between cross-sections becomes something over and above the gravitational, electroweek and strong interactions of particular events.

The thesis that causal connectivity is a not a property of sets of individuals, but of families of sets of individuals, seems to have even stronger justification when, instead of things, we start talking about processes. The instantaneous cuts of a process, due to the spatiotemporal profile of the latter, are sets of events that are non-extended both temporally and spatially. Such sets in the PE ontology are called *coincidents*.[15] Their

[14] The fact that the features of cross-sections are more then the sum of the features of events that compose them is supported by authors such as Whitehead. As Palter (1955) wrote, Whitehead even claimed that we have a mode of perception that makes us aware of the bare existence of spatially distant elements of cross-sections.

[15] Note that the points of space-time in PE were classified by Augustynek (1991, 1993a,b) as coincidents, because they are abstraction classes of K in **S**.

formal point-eventistic definition, if we denote the set of all coincidents by **Ks** and its elements by x', y', z', and so on, is as follows:[16]

$$x' \in \mathbf{Ks} \equiv [x' \subset \mathbf{S} \wedge x' \neq \emptyset \wedge x' \in (\bar{E}c \cap \bar{E}p)]. \tag{D\textbf{Ks}}$$

The next steps may seem familiar. Going further, we define a process as an equivalence class of genidentity in **Ks**:

$$f \in \mathbf{Pr} \equiv \exists x' \in \mathbf{Ks}\ (f = |x'|_{G'}). \tag{D\textbf{Pr}2}$$

The *genidentity of coincidents* (G'), to which we refer to in (D**Pr**2), is an identity of the process through time and space. This equivalence relation, as it was the case so far, could be defined axiomatically. In particular, the sense of causal connectivity, as a feature somehow included in a relation of genidentity, can be expressed with the following axiom:

$$\forall x, y \in \mathbf{Ks}\ \{[G'(x,y) \wedge \bar{R}'(x,y)] \rightarrow H'(x,y)\}, \tag{AG'4}$$

according to which coincidents that compose the same process at different moments are causes or effects of each other, i.e., they enter into an unoriented causal relation H' that occurs in the set **Ks**.

Let us now explain how the new approach to causal connectivity, resulting from the adoption of (D**Pr**2) and (AG'4), may be justified. First, we can repeat after Sklar (1974) that coincidents, being sets of events occurring at the same point of space-time, are objects whose causal profile is immediately known to us. Such events, to put it in other words, are directly observable and no signal definitions, that is, the synchronization procedures used in STR and GTR, are required here. It is reasonable to assume that this epistemological feature of coincidents — the direct knowability of the properties of their elements — extends also to the properties of coincidents that emerge from the features of their parts.

The aforementioned epistemological profile of coincidents, we believe, provides grounds for treating them as objects that exemplify the instantaneous properties of processes. But above all, it reveals the role of coincidents standing in the relation G', and thus causally connected, as *material points*, since we identify at least some processes as world lines of things. In such a case, however, indexing causal connections between coincidents seems to lose its point. We usually think of material points as spatiotemporal idealizations of extended bodies, but which possess mass, velocity, momentum, and other properties that cannot be assigned to a

[16] A critique of (D**Ks**) can be found in our earlier work, i.e., (Raźniak, 2025).

single point-event. With even greater certainty we can therefore assume that the relation H' is something more than the sum of fundamental forces that obtain between the elements of different coincidents.

7.2. Causal connectivity of sets of events as a primitive property

Not all philosophers sympathetic to point-eventism and the relational theory of time would agree with the solution we have just presented. Recall that *relationism* in the philosophy of space-time, the first clear expression of which we owe to Leibniz, standardly states that all temporal, spatial and spatiotemporal objects are reducible to some relations between point-events or other physical objects. Yet the status of relations in which moments, points of space and points of space-time are founded is debatable. Augustynek, as we have seen, engages both causal and spatiotemporal relations to accomplish this task. This approach, however, does not find support from more radical relationists who advocate the *causal theory of time and space-time*, that is, a reduction of all spatiotemporal objects and properties to causal features of events.

The division between moderate and radical relationists is obvious and easily visible. Philosophers convinced to the secondary nature of time, space and space-time, such as Reichenbach (1958), van Fraassen (1970) and Mehlberg (1980), are reluctant to define things, processes, cross-sections and coincidents in terms of temporal and spatial extension (or non-extension).[17] Similarly, the authors we have already mentioned avoid axiomatic definitions of genidentity that would involve terms such as simultaneity, collocation and their negations. Genidentity, for them, is just a primitive relation, something irreducible to any other connections between point-events.[18] And the same is true for causal relations in the domain **S**, regardless of whether these relations are oriented, as Reichenbach argued, or whether Grünbaum, van Fraassen and Mehlberg were right in considering causal connections as unoriented.

One might now ask how a supporter of the causal theory of time would be willing to define the causal connectivity of things and pro-

[17] It is worth mentioning, however, that sometimes causal theories of time have much more modest goals. For example, Grünbaum (1973) in his theory merely tried to reduce topological temporal relations to causal and spatial ones. It would therefore be difficult to call his proposal a causal theory of space-time.

[18] As a side note, it can be mentioned that a number of interesting remarks on genidentity and its role in causal theories of time were made by Hoy (1975).

cesses. Assuming that things and processes are not sets of cross-sections or coincidents, but sets of events, the most likely answer would be that causal connectivity — as in the axiomatic definitions of genidentity we have discussed — has no explicit definition, but is entailed by the genidentity of events. And since, according to radical relationists, the concept of genidentity is primitive, the same should be said about connectivity.

But does the relativization of events to causal realms still allow us to recognize causal connectivity as an undefinable quality of **X**-sets? At first glance, it might seem that it is possible to preserve the primitive character of electroweak, gravitational and strong forces, as well as the associated properties of causal connectivity, i.e., Cc_e, Cc_g and Cc_s. The principles of the causal theory of time would then also be met by (DCc2). However, as we have already said, such an approach is wrong. It seems necessary then to provide a definition that would make the causal connectivity of any **X** dependent also on whether, within this **X**-set, interactions of one type coincide with interactions of other types. The only problem is that agreeing to such a solution would lead to the involvement of coincidence, i.e., a certain spatiotemporal relation, and thus to the collapse of the causal theory due to its circularity.

Contrary to appearances, the position of an extreme relationist is not as bad as it might seem. A supporter of the causal theory of time could claim that the argument from the previous section does not apply here because the division of interactions is secondary, and our objection only makes sense when spatiotemporal relations are defined. After all, many properties of fundamental forces, thanks to which we can recognize them, have a temporal or spatial character. For example, strong interactions differ from weak ones in the range of their impact. An advocate of the causal theory could therefore argue that the basic and primitive element of the physical world is a causal connection between events, which we are able to observe without resorting to more advanced measurement procedures.[19] Whether this connection has a gravitational, electroweak or strong profile becomes important and can be decided only when we determine the temporal order of events, i.e., the *topology of time*.

To be clear, we are not claiming that the answer we propose, or the causal theory of time itself, is immune to criticism. The papers we have cited by Lacey (1968), Smart (1969), Earman (1972) and Sklar (1974), in

[19] Here we ignore the controversy, raised among others by Lacey (1968), as to whether point-events are observable or theoretical, and thus unobservable, entities.

which many shortcomings of causal theories has been pointed out, prove the opposite. Radical spatiotemporal relationism remains a debatable view. Nevertheless, if one is convinced of the reducibility of temporal objects, relations and properties to their physical counterparts, and is determined to defend this thesis, recognizing causal connectivity as a primary feature of sets of events appears to be the best option. Nor is it, as we have tried to show, an option as naive and exposed to the objection from the previous section as it might initially seem.

7.3. Causal connectivity of sets of events as a secondary property

It is obvious, however, that neither the reduction of causal connectivity to a property of cross-sections or coincidents, nor the recognition of connectivity as a primitive feature of sets of point-events, exhaust all possibilities of rejecting the discussed argument. We believe that there is a solution that does not fall under our earlier objection and yet retains the original understanding of causal connectivity as a secondary, i.e., definable, quality of sets of events, so that the definitions (D**T**1) and (D**Pr**1) may be preserved. Let us then consider the most important assumptions and theses of such an approach.

The starting point of the present strategy is, of course, an adoption of moderate relationism and point-eventism in its framework provided by Augustynek. Temporal, spatial, spatiotemporal and causal relations between events are therefore equally important and are not subject to mutual reduction. Adopting such an approach allows us to notice that point-events, even if they do not belong to the same causal domain, because they cannot be connected by direct physical interactions, always enter into certain spatiotemporal relations. In particular, a connection that may occur between individual point-events from the sets $\mathbf{S}_e$, $\mathbf{S}_g$ and $\mathbf{S}_s$ is a relation of spatiotemporal identity, that is, a coincidence.

Clearly, the coincidence of any events x and y does not necessarily entail that x is the cause or effect of y, and thus it does not seem sufficient itself to speak of the set founded, among others, in x and y as causally connected. Yet it must be remembered that coincidence, being a spatiotemporal relation, also has some causal content, since from the fact that $K(x, y)$ one may infer that x and y are immediately observable. And although, given the division of $\mathbf{S}$ into causal realms, we cannot — contrary to van Fraassen — say that the coincidence of point-events is in fact a possibility of having the same cause or effect, it is hard to resist an impression that events related by different forces can be compared and correlated with each other by means of the relation K.

Based on the above remarks, it is possible to construct a new eventistic definition of causal connectivity that will replace (DCc1). From now on, we will call causally connected any **X**-set that jointly meets two conditions. The first one states that any two non-simultaneous elements of **X**, if they belong to the same causal subworld, must be connected by a direct fundamental interaction of a certain type. Its satisfaction by **X**, as it is easy to see, is indeed a fulfillment of the definition (DCc2). At the same time, however, for **X** to be a Cc-set, the second condition must be met. This is done when the membership of events x and y, which are additionally non-simultaneous and have different causal features, in a given set **X** entails the existence of such events $z, v \in \mathbf{X}$ that are connected by a direct causal interaction and each of them coincides with either x or y. In this context, the coincidence gains the role of a relation mediating in the connection between the elements of **X**.[20]

Since the new definition of causal connectivity should involve events from various causal domains, we assume that H_q is some form of generalization of fundamental forces. For brevity, let us further assume that H_q denotes not a binary but a quadruplet relation expressing the existence of a connection H_e, H_g or H_s between z and v that coincide (or are identical) with x and y. Then any Cc-set is defined as follows:

$$\mathbf{X} \in Cc \equiv \forall x, y \in \mathbf{X}\ \{\bar{R}(x,y) \to \exists z, v \in \mathbf{X}\ [H_q(x,z,y,v)]\}, \qquad (\mathrm{D}Cc3)$$

under the condition that **X** contains events from every causal domain.

To put it slightly less formally, the right-hand side of the equivalence (DCc3) means that any two non-simultaneous elements x and y of a given **X** are causally connected either indirectly or directly, that is, necessarily presupposing the existence of events $z, v \in \mathbf{X}$ or without such necessity. This is because the relation $H_q(x,z,y,v)$ can occur when x and y belong to different causal realms, for instance, $x \in (\mathbf{X} \cap \mathbf{S}_g)$ and $y \in (\mathbf{X} \cap \mathbf{S}_e)$, if there are events $z \in (\mathbf{X} \cap \mathbf{S}_e)$ and $v \in (\mathbf{X} \cap \mathbf{S}_g)$ such that $H_g(x,v)$, $H_e(z,y)$, $K(x,z)$ and $K(y,v)$. However, it may just as well be that x and y share their causal profile, and the realization of $H_q(x,z,y,v)$ is simply entailed by the fact that $H_g(x,y)$, $H_e(x,y)$ or $H_s(x,y)$.

[20] To some extent, we owe a similar solution, although with respect to completely different issues, to Reichenbach (1958). Namely, he claimed (e.g., on p. 138) that, for any events x and y, x is earlier than y iff it is physically possible that there is a causal chain whose ends coincide, and so are identical, with x and y.

In general, regardless of whether we are dealing with a direct or indirect connection of events, the very fact that $H_q(x, z, y, v)$ holds implies that $H_g(z, v)$, $H_e(z, v)$ or $H_s(z, v)$ is also true. Thus, the occurrence of a quadruplet causal relation always entails the existence of a binary fundamental interaction of some type. The only remaining question is whether events x, z and y, v merely coincide or are also identical to each other. Since, if all the relata of $H_q(x, z, y, v)$ are members of the same causal subworld, then we can say that, by the criterion (CH), not only $K(x, z)$ and $K(y, v)$, but additionally $I(x, z)$ and $I(y, v)$ hold. And if so, then the occurrence of $H_g(x, y)$, $H_e(x, y)$ or $H_s(x, y)$ is a fact.

In this connection, when (DCc3) replaces (DCc1) as the definition of causal connectivity, the objection we have raised no longer threatens (D**T**1) and (D**Pr**1). These latter definitions, if one is not a radical relationist and has no reason to believe that particles and processes are collections of cross-sections or coincidents, are entirely justified. If, on the other hand, one is closer to the view that particles are abstraction classes over the set **S** under a relation of genidentity and thus (D**T**2) should be preserved, one could defend this thesis by drawing inspiration from the definition (DCc3) and following our earlier comments.

How is it possible? To achieve this, only a minor correction of the axioms (AG3) and (AG4) is needed so that genidentity goes beyond the boundaries of a single domain. As a result, we get the following axioms:

$$\forall x, y \in \mathbf{S}\ \langle\{G(x, y) \wedge \exists z, v \in \mathbf{S}\ [H_q(x, z, y, v)]\} \rightarrow \bar{R}(x, y)\rangle, \qquad (\mathrm{A}G^\star 3)$$

$$\forall x, y \in \mathbf{S}\ \{[G(x, y) \wedge \bar{R}(x, y)] \rightarrow \exists z, v \in \mathbf{S}\ [H_q(x, z, y, v)]\}, \qquad (\mathrm{A}G^\star 4)$$

which, together with the axioms (AG1) and (AG2) determine the meaning of genidentity and, consequently, the meaning of causal connectivity.

Hence, when looking at the consequences of the third strategy, it is hard not to conclude that the overall costs of introducing the above definition and axioms into Augustynek's ontology are small, while the benefit of avoiding the objection under discussion is significant.

8. Conclusions

Finally, for the sake of clarity, let us summarize the above considerations:

1. As we have seen, Augustynek's approach to things as non-empty, extended both in time and space, time-continuous and causally connected sets of point-events is open to several objections, such as the

one raised by Kuźniar. This forces an advocate of point-eventism to reformulate the original definition of a particle.

2. Nevertheless, there is one more argument that threatens not only the original definition of a thing, but also the point-eventistic definition of a process, which has not been criticized so far. The basis of this objection is that point-events in the PE ontology must be individualized due to their causal features, and these in turn — in the light of our best scientific theories — are split into fundamental, i.e., electroweak, gravitational and strong, properties.

3. Given this division of the physical world into causal subworlds or realms, the condition of causal connectivity, as Augustynek's understood it, cannot be met, and the most obvious attempts to correct it prove insufficient to capture the essence of things and processes. From this perspective, therefore, the PE ontology might be accused of being inconsistent with the results of modern physics.

4. Despite this, point-eventism can be defended in, at least, three different ways. The first is to regard things and processes as special sets of cross-sections and coincidents, the second is to assume that causal connectivity is a primitive feature of sets of events, and the third is to reformulate the original definition so that causal connectivity is not limited to a single causal domain.

To sum up, we can safely say that the overall situation of point-eventism is not as dire as it might seem at first glance. There is no ontology, and especially no ontology aspiring to be physically adequate, that is completely immune to criticism. Evaluating metaphysical systems by their vulnerability to criticism will not lead us to any specific conclusions. Ultimately, what matters is whether the conceptual framework of such an ontology is sufficiently broad, sophisticated and advanced to allow the development and subsequent adoption of an alternative and faultless solution. Taking all this into account, we have no doubt that Augustynek's system meets this criterion.

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