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Reducing Causality to Transmission

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Abstract.
The idea that causation can be reduced to transmission of an amount of some conserved quantity between events is spelled out and defended against important objections. Transmission is understood as a symmetrical relation of copresence in two distinct events. The actual asymmetry of causality has its origin in the asymmetrical character of certain irreversible physical processes and then spreads through the causal net. This conception is compatible with the possibility of backwards causation and with a causal theory of time. Genidentity, the persistence of concrete objects, can be given an explanation in causal terms. The transmission theory is shown to escape difficulties faced by two important alternative theories of causation: Salmon's (1984) Mark Transmission Theory and Dowe's (1992a) Conserved Quantities Theory.

1. *A reduction of the concept of a causal relation in terms of transmission*

The notion of causality is crucial to common sense, yet philosophers in the empiricist tradition have argued that it is impossible to provide a naturalistic account of that concept in such a way as to give it a scientifically respectable foundation. It would be a substantial achievement to show that causality is reducible, if only because that would justify the pervasive use of causal notions in scientific inquiry, from experimental physics to biology and psychology. A promising strategy to reduce causation is to explore the intuition that causes somehow transfer something to their effects. Among others, Aronson (1971a;b) and Fair (1979) have defended versions of such a "transference theory". However, they were unable to deal in a satisfactory way with some important difficulties, and consequently, many authors have remained skeptical of the possibility of a coherent and satisfying transference theory of causation. The aim of this paper is to show that the version of the transference theory built on the following reduction statement (T) can overcome those difficulties.

(T) Two events *a* and *b* are causally related in the sense that one is a cause of the other if and only if there exists a conserved quantity Q of which a particular amount P is transmitted between *a* and *b*.

The concepts of transmission, of conserved quantity, and of event figure prominently in (T). *Events* are what causality relates; for the present purpose, they are best conceived of as what fills some determinate space-time zone[1]. In this sense, events are concrete particulars with well defined boundaries in both space and time; they differ from ordinary objects like tables and chairs whose identity is determined by their spatial boundaries only[2]. The notion of a *conserved quantity* is taken from physics. It is in the spirit of a naturalization project that the proposed reduction cannot be achieved by a priori reasoning only. Both the justification of the existence of conservation laws to which quantities such as mass-energy, linear momentum or electrical charge are subject, and the eventual completion of an exhaustive list of such quantities are left to scientific, not philosophical, investigation.

If circularity is to be avoided, the concept of *transmission* must be given, in the context of this reduction, a non-causal meaning[3]. In this respect it differs from the ordinary meaning of the word "transmission" which has indeed a causal component. Furthermore, the fact that this word is currently applied to human actions gives it an anthropocentric connotation. If we were to include in the concept of transmission all the aspects of that ordinary meaning, the transference theory as based on (T) would therefore not only be circular, but also anthropocentric, in the sense that it would reduce all causality to the sort specific for human action. That consequence can be avoided by the following interpretation of what it means for an amount P of a conserved quantity Q to be transferred - or transmitted - between one event *a* and another event *b*: it must be understood as meaning that *the amount P is present in both events*[4]. Furthermore, it is crucial that one conceive of an amount P of, for example, energy present in a given space-time region as a particular capable of persisting through time. As a particular, P can be present in two different events where those events are conceived of as the total content of space-time zones. Thus, the transference theory requires an ontology recognizing particular properties P which have also been called "tropes" by Williams (1953) and "abstract particulars" by Campbell (1990). In this framework, one conceives of a concrete event as being constituted by the totality of the intrinsic tropes present in the space-time zone it occupies. A trope is said to be intrinsic to the zone where it occurs if it does not depend on anything outside that zone.

For *a* and *b* to be causally related, it is not sufficient that they possess amounts of some given conserved quantity which are *equal in magnitude*, but it is necessary that the amount present in *a* be *identical as a particular* with the amount present in *b*. Thus understood, "transmission" isn't a causal notion. But we now face the task of showing that it makes sense to say of a particular amount P of a conserved quantity Q that *it* is present in two different events. That will be the topic of section 3. Section 2 deals with the objection that a transference theory precludes a causal theory of time and excludes the possibility of backwards causation on purely conceptual grounds.

2. *The asymmetry of the causal relation*

It has been argued[5] that transference theories have no satisfying way of dealing with the asymmetry of causality. If transmission is understood non-causally the relation it establishes between two events becomes symmetrical, and then, so the argument goes, the asymmetry characteristic of causality can be brought in only from outside, i.e. from the ordering of the temporal localizations of the cause and the effect, relative to an independently determined direction of time. This has two undesirable consequences. First, it would then be, on pains of circularity, impossible to explain the direction of time by reference to the asymmetry of causation. Second, such a presupposition excludes both symmetrical and backwards causation as impossible on purely conceptual grounds; still it seems desirable to be able to consider the asymmetry of causality in this world as an empirical fact and symmetrical or backwards causation as an empirical possibility.

It is true that according to a transference theory causal relations are not necessarily asymmetrical[6]. But the asymmetry between cause and effect can be explained as a contingent feature of causation as it exists in the actual world. To do this, let us distinguish between two fundamental types of causal processes[7]. The first contains all processes which are completely determined by reversible laws of nature. The movement of planets or of billiard balls in ideal, i.e. frictionless, conditions belongs to this type of (intrinsically) symmetrical causal relations. The processes of the second group are irreversible in that their physical nature gives them an intrinsic asymmetry. Almost all processes taking place on earth belong to this second type, namely all dissipative processes or processes producing entropy[8]. Moreover, these processes are so pervasive that they constitute a sufficient basis for attributing asymmetry to *all* causal processes. Here is why. Putting aside events which are causally isolated, i.e. which are neither cause nor effect of anything[9], it is possible to represent the totality of all causal relations as a net, where the nodes represent the events and the lines linking the nodes represent the causal relations[10]. In so doing we have almost all the premises needed to conclude that there are objective grounds for justifying the idea that all causal relations existing in the actual world have a determinate direction.

P1. All events which are either causes or effects are located in a causal net.

P2. This net contains at least some causal relations which are intrinsically asymmetrical in virtue of their physical specificity (in our near neighborhood, namely on the surface of the earth, in fact countlessly many).

Let us add two further provisonal[11] assumptions.

P3. There is only one such net, i.e. all events participating in causation are linked by the same net.

P4. Among the intrinsically asymmetrical causal relations (cf. P2), there is a clear majority of processes having the same direction. This seems indeed to be the case on earth where all energetically isolated irreversible processes have the same direction.

With these assumptions in place, we can use the causal net to attribute a direction even to those causal relations in the net which are deprived of intrinsic asymmetry. This is because premiss P4 guarantees the existence of a unique direction D of the majority of the intrinsically asymmetrical processes in the net. It suffices to attribute this direction to the whole net, and indirectly to the intrinsically symmetrical causal relations it contains. The conception of the causal net makes the transference theory compatible with a causal theory of time insofar as the predominant direction D can ground both the asymmetry of causation and the direction of time[12].

We are now in a position to deflect two objections Michael Tooley has raised against reductionist theories of causation. His first argument is based on the following thought experiment. Tooley (1990, pp. 223f.) asks us to consider a very simple possible world consisting of only two particles, endlessly rotating around each other. Tooley challenges the reductionist to explain the asymmetry of causation in such a perfectly reversible world. Only by relying upon an independently defined direction of time could this be done. But in such a perfectly symmetrical possible world, this would be not so much an explanation of the asymmetry of causation, as an avowal that no such explanation is available. In Tooley's simple world there is neither ground for temporal nor for causal asymmetry. There are causally related events, but no objective difference between cause and effect. This situation clearly brings out the fact that for the transference theory, in the absence of intrinsically asymmetrical processes, all causal relations are symmetrical. Two events consisting of adjacent temporal parts (or "time-slices") of one of the particles in Tooley's simple world are causally related by the transmission of an amount of energy-mass, angular momentum or other conserved quantities, yet none of these causally related events is the cause, rather than the effect of the other. Neither is one objectively earlier than the other. Nevertheless, there is nothing contradictory or otherwise inacceptable in this result.

A variant of Tooley's thought experiment (not mentioned by him) has us consider the possibility that *our* world contains a region in which all processes are, from a physical point of view, perfectly symmetrical. As before, the theory implies that both causality and time are symmetrical in such a hypothetical region. Yet in order to exclude the possibility of an indirect ascription of asymmetry *via* the causal net, we would have to suppose in addition that such a region is causally isolated from ours[13].

Tooley (1990, pp. 224f.) proposes a second argument to show that a reductionist theory cannot explain the asymmetry of causality. We are asked to consider the conceptual possibility of there being two "inverted worlds" which are causally isolated from each other. It seems in fact more appropriate to speak of two "regions" within one possible world, for otherwise it would be impossible to analyse the relevant relations between these "worlds" existing in parallel. This time, both regions contain irreversible processes; actually, one of the regions resembles our own world to the smallest detail. The decisive assumption is that the two regions are almost completely similar to one another: they contain the same objects, down to the last elementary particle, the only difference between them being the direction of motion. The objects in the second region move in precisely the opposite direction with respect to their counterparts in the first region.

Now, according to Tooley, this thought experiment shows that the difference between cause and effect cannot be reduced to the asymmetry of physically irreversible processes, for in one of the two regions of that possible world the direction of causality is the direction of the irreversible processes, while in the other region these directions are opposite to one another.

In this form, the argument clearly begs the question against reductionist theories. When constructing his possible world, Tooley already presupposes that both time and causality have a unique direction common to both regions and independent of the type of physical processes going on in each region. Only this assumption allows him to conclude that in one of the regions the direction of the irreversible processes is *opposite* to the direction of time and causality. Without that question-begging assumption, nothing stands in the way of analyzing the situation in light of the transference theory: the two regions of Tooley's possible world are causally completely isolated from one another. Therefore, a reductionist theory determines the direction of both time and causation for each region independently of the other region. This is done by reducing these directions to the direction of the (majority of the) physically irreversible processes *in each region*. The situation only appears paradoxal in Tooley's presentation because he undertakes to *compare* the two regions with respect to the direction of their irreversible processes. But he can do this only by presupposing (and thus begging the question) that there is a global direction of time and causation providing the basis for such a comparison.

Another widespread argument against the transference theory is that it excludes the possibility of causation directed backwards in time[14]. Yet, the argument is only efficacious against those versions of a transference theory which ground the direction of each single causal relation directly on (the direction of) time. For them, it is true by definition that there cannot be causality backwards in time. The cause cannot be later than the effect if the fact that one event is the cause is determined by the fact that it precedes the other, with respect to an independently given time ordering. But the conception of the causal net allows us to acknowledge the possibility of processes evolving backwards in time. There might be intrinsically asymmetrical processes running in the direction opposite to the overall direction of the net, e.g. because their entropy spontaneously diminishes (where this diminuition of entropy is not compensated by a corresponding augmentation of the entropy of the environment of the system)[15]. This account of backwards causation shows that it does not, contrary to what Dowe claims, necessarily require a "violation of the conservation law for the quantity concerned" (Dowe 1992b, p. 194)[16].

It may help to explain the widespread rejection of the transference theory when one considers that Fair's (1979) version does indeed make backwards causation impossible for conceptual reasons. Fair tries to make his account compatible with a certain type of causal judgment in which the attribution of the roles of cause and effect does not coincide with the objective asymmetry of the process realizing the transference between those events. Take the common sense judgment that a floating ice cube cools the water surrounding it. According to the theory defended here, the direction of that causal relation is objectively determined by the direction of the flow of energy (which is an irreversible process). In this case the direction of the flow is only from the surrounding water to the ice cube. This means that the only causal judgment which correctly mirrors the objective asymmetry of that causal relation is: the water surrounding the ice cube warms it up. Our theory thus imposes a certain regimentation of the truth of common sense judgments regarding the direction of causal relations. Taken as a judgment of the objective direction of causation, the judgment that the ice cube cools the surrounding water, is wrong. Saying that the ice cube cools the water nevertheless remains a valid explanation, though one in which, contrary to what happens in causal explanations, the *explanans* doesn't designate the cause and the *explanandum* doesn't designate the effect[17].

Fair chooses to avoid such a regimentation and to justify the literal truth of the common sense judgment according to which the ice cube causes the cooling. He achieves this by making the hypothesis that the direction of the causal relation between *a* and *b* grounded on the transmission of energy from *a* to *b* is objectively undetermined (Cf. Fair 1979, pp. 242/3). Whether *a* or *b* is the cause, depends on the perspective one adopts with respect to that causal relation. As a result both causal judgments appear as compatible: the one which says that *a* is a cause of *b*, and the one which says *of the same particular causal relation* that *b* is a cause of *a*. However, Fair's thesis that the difference between cause and effect is in principle never objective is inacceptable within a realist theory of causation. Furthermore, Fair's account has the drawback of ruling out the possibility of symmetrical or backwards causation as objectively different from standard causation.

In a complex causal net, distant nodes may be causally related without one being a cause of the other. It may, for example, be the case that neither of two causes of a common effect or of two effects of a common cause is a cause of the other, still they may be said to be "indirectly causally connected". Our reduction (T) correctly predicts that neither of two such events is a cause of the other, for no particular amount of a conserved quantity is present in both of them. The distinction between two events which are causally connected in a general sense and two events where one is a cause of the other, can also be applied to more complex cases in which, for example, both forward and backward causal relations intervene between two distant events. I shall leave the thorough exploration of such possibilities for another occasion.

3. *Identity through time of an amount of a conserved quantity*

We still have to face the objection that an amount of a conserved quantity is not the sort of entity that can be transmitted. I shall distinguish an ontological and an epistemological version of this objection: according to the former, the identity of such an amount of a conserved quantity is ontologically indeterminate; according to the latter, that identity is epistemically inaccessible.

3.1. *The ontological objection*

The ontological objection goes as follows: in order for an entity to be said to have been transmitted between two events, that entity has to persist through time in the manner of a substance. But an amount P of a conserved quantity Q isn't a substance, and thus it makes no sense to say that it is transmitted.

It is indeed crucial for the applicability of the concept of transmission that what is being transmitted can be said to conserve its identity through time, in particular during the time interval of the transmission. This is why we must require of the transmitted amount P that it be an amount of a *conserved quantity*[18]. With respect to this concept, we can take advantage of its precise definition in physics. Conserved quantities are properties obeying a strict law of conservation. The necessity of this requirement is most obvious when it is contrasted with quantities which are *not* conserved through time. Particular forms of energy, like matter, potential energy or heat, are not conserved for they may be converted into another, provided the net change of the global quantity of energy is zero. The fact that there is, e.g., no conservation of potential energy makes it senseless to say of a given "amount" of potential energy that it is "transmitted" between one event and another (or between one place and another). Thus, if we grant that causality is grounded on transmission, we get a clear answer to the question: for *which quantities* is transmission necessary and sufficient for causation? It is precisely conserved quantities which can satisfy the requirement imposed by the very concept of transmission[19]. Energy-mass, momentum and electric charge are, according to our present state of knowledge, such quantities whereas potential energy, heat, force or information aren't[20].

Dieks (1986, pp. 88ff.) has argued that both classical and quantum physics provide reasons for denying that amounts of conserved quantities like energy and momentum can be considered as substances. Indeed, classical physics only postulates global, not local, conservation of energy and momentum. But in the quantum mechanical theory of interaction, these quantities are considered as locally conserved, albeit within a certain margin of imprecision which is, in the case of energy, determined by the well-known inequality $\Delta E \cdot \Delta t \geq h$. However, quantum theory also provides much deeper reasons to doubt the substantial character of mass-energy, momentum and the other conserved quantities. It is indeed a fundamental result of quantum mechanics that there are systems of "identical" particles whose components cannot even be individuated by their respective positions in space. Contrary to what is the case for macroscopic objects, if a collection of interacting bosons share all their intrinsic properties they must be considered identical to each other in the sense that they also share their localization. What is decisive for our argument is the fact that the lack of individual identity which characterizes interacting bosons of the same type and in the same state carries over to all of their properties. In particular, conserved quantities cannot be possessed by individual particles, but only by the collective formed by all interacting identical particles. Therefore, Dieks (1986) is right in saying that it makes no sense to suppose that some particular amount P is possessed by any one of those particles taken individually, rather than by the whole interacting system.

Nevertheless, this lack of individuality is not fatal to the idea of a transmission of P. The reason is that *before and after* an interaction, the particles participating in the interaction do have a sufficient degree of individuality to make it possible to consider them as individual bearers of the amounts of conserved quantities they possess. Let us consider the example of an interaction between two pairs of identical bosons, namely the pair a_1 - a_2 and the pair b_1 - b_2, where the members of each pair are held together by some interaction acting as a "glue". Now, when there is an elastic collision between the pair a_1 - a_2 and the pair b_1 - b_2, there will be an exchange of momentum between them. In this situation it makes no sense to ask whether it is b_1 rather than b_2 which has received a certain amount of momentum that has been lost by the pair a_1 - a_2. In virtue of their being glued together, b_1 and b_2 make up an interacting whole within which it is senseless to ascribe momentum to one rather than the other of its components. During the collision, this is even true for the ascription of momentum to one of all *four* involved particles: by hypothesis, all four particles are "identical" in the quantum mechanical sense which means that during the period of interaction they share their identity, which implies their sharing the identity of the amount of momentum they collectively bear. Nevertheless, far away from the region of its interaction with a_1 - a_2, the pair b_1 - b_2 has, *as a pair*, a form of diachronic identity which is admittedly weak, but sufficient to justify its distinctness from the pair a_1 - a_2.

What does it mean to call this diachronic form of identity "weak"? It is intended to express the acknowlegment of the fact that such particles - and the amounts of conserved quantities they bear - don't have the character of substances, even outside of their interactions with other particles identical with them. Quantum theory conceives of interactions as processes during which the interacting particles are annihilated and subsequently recreated. The newly created particles share all of their intrinsic properties with the formerly annihilated ones with the exception of the properties affected by the interaction. The Compton effect is, for example, conceived as the scattering of a photon by an electron during which at one moment the photon gets annihilated when the electron absorbs it, and at another moment a new photon gets created when the electron emits it. That physical conception of what an interaction between individual subatomic particles comes to prevents the application of the Aristotelian concept of a substance to such particles[21]. It is decisive for the assessment of the present argument against the transference theory that the restrictions imposed by quantum mechanics on the annihilation and creation of elementary particles justify the attribution of a weak form of diachronic identity to them. The existence of events of annihilation and subsequent creation doesn't contradict the causal continuity between different temporal parts of a given particle, as long as it is not involved in interactions with particles identical with it. In the case of the Compton scattering of a photon by an electron, the continuity bridging the gap between the annihilation and the recreation of the photon is being guaranteed by the "genidentity" - we shall return to this notion in a moment - of the electron during that brief interval of time. As to the conserved quantities themselves possessed by a particle, we can, for the purposes of the transference theory, substitute the concept of a "flow" (suggested by Dieks (1986)) for the inadequate concept of a substance. The transmitted amounts of conserved quantities have the identity of a flow, weaker than the identity of a substance, but strong enough to make their transmission possible.

It is crucial for our project to distinguish two kinds of identity through time. Genidentity characterizes the persistence of concrete[22] objects, whereas the individual amounts of conserved quantities possessed by those objects persist in the manner of a flow. The latter is the more fundamental type of persistence which can be considered as grounding the former. Indeed, our theory allows us to give a causal analysis of the relation of genidentity between the different temporal parts of a concrete object. Carnap, who adopted the notion from Russell (1914)[23] and Lewin (1923), explicates the concept of genidentity as the property of two world points belonging to the same world-line (cf. Carnap 1928, p. 170). Carnap explains that genidentity, i.e. "the belonging of two different states of an object to the same object" (*op.cit.*, p. 218) is one of a class of relations of "improper identity" (*ibid.*) which language groups together under the heading of identity but which fall short of logical identity proper : two temporal parts of the same object at different times aren't identical with each other in a logical sense for one satisfies predicates which the other doesn't.

The transference theory proposes to give genidentity a causal meaning[24]. It is grounded on the transmission of amounts of conserved quantities from each temporal part of an object to its adjacent temporal parts. The theory thereby relies on a more primitive kind of identity through time which characterizes amounts of conserved quantities themselves. It would be viciously circular if one tried to explain the persistence of such an amount P in turn as a causal process. But our theory doesn't do this. P stays identical with itself in virtue of the conservation law governing the conserved quantity of which it is an amount. The validity of the relevant conservation law is taken as a primitive fact. On this basis we can explain the persistence of an object possessing such amounts by conceiving of that object as a structured entity with respect to its existence in time, more precisely as a continuous series of events. The object persists because each of its "time-slices" transmits the amounts of conserved quantities it contains - mass being the most fundamental of these for material objects - to adjacent time-slices. Thus genidentity, the identity of an object through time, appears as derivative with respect to the more basic identity through time of the objects' ultimate constituents, which are the amounts of conserved quantities constituting it.

This distinction also enables us to explain how objects can persist in spite of complete substitution of all of their constitutive parts, as happens regularly with the cells in the human body. The genidentity of such an object in spite of its "regeneration" can be explained by the (primitive) identity of the majority of the amounts of conserved quantities it contains from one instant to the next. Mass being subject to a conservation law, the body's material parts persist through time. By contrast, if *all* material parts constitutive of an object were to be replaced simultaneously, there would be no transmission linking the object before and after that substitution event. In this case the theory correctly predicts that there is no *one* object persisting in spite of the substitution. Rather, the former object ceases to exist and a different, qualitatively similar object is brought into being.

Distinguishing between the primitive persistence of the transmitted particular quantities themselves and the genidentity based on it that characterizes the persistence of concrete objects, allows us to deflect the following objection. Dowe (1995b) argues that one is led into a dilemma if one tries to figure out how a *property* could be genidentical. Either a property is conceived of as a universal, in which case it can be possessed by different objects or by the same object at different times, but it makes no sense to say that the property it has later is genidentical to the property it had earlier. Indeed, the concept of genidentity applies exclusively to concrete objects, not to properties as universals, nor to property-particulars, like an individual amount of energy. Or "x possesses y" - as in "object x possesses the individual amount of energy y" - is a two-place predicate which, says Dowe, "suggests that energy is not a property at all, but a thing, a substance, separate from the object. (...) But energy cannot stand alone, possessed by nothing" (Dowe, 1995b, p. 369). The account presented here escapes the dilemma because it conceives of individual amounts of conserved quantities in a still different way. An individual amount of energy is an abstract particular, a trope. Tropes of conserved quantities have a primitive identity through time, different both from genidentity of concrete objects and from the identity of universals. The relation between an object and the tropes it contains can be understood as a third sense of the predicate "x possesses y". Yet it seems less misleading to state that relation by saying: "The concrete particular object x *contains* the trope y".

3.2. *The epistemological objection and the difference between causal processes and pseudo-processes*

Sometimes the argument throwing doubt upon the diachronic identity of particular amounts of conserved quantities has been stated in epistemological terms. It is impossible, it is said, to *recognize* that an amount P* is identical with some amount P when these are encountered in different events[25]. Dowe expresses this objection by saying that, if energy is the relevant conserved quantity, a transference theory lacks the conceptual equipment necessary "to distinguish energy transmission from a regular appearance of energy" (Dowe 1992a, p. 214). The background for this criticism is Reichenbach's (1928; 1956) and Salmon's (1978; 1984) theory of causal processes whose central idea is that a causal process can be characterized by its capacity for transmitting marks[26]. Put in terms of this theory, the objection is that transference theories don't provide any objective grounds for the distinction between pseudo-processes and causal processes. In a given situation, Dowe claims, it is in principle impossible to *decide* whether an amount P of a conserved quantity has been transmitted between *a* and *b* or whether the presence of an amount of equal magnitude of the same conserved quantity in both *a* and *b* is due to a coincidence or to some reason independent of the link between *a* and *b*. A reduction like (T), it is said, can't tell real from merely apparent causation, as in the following situation: event *a* bears a certain amount P of energy. Independently of this, a different although qualitatively indistinguishable amount P* is present in a spatio-temporally nearby event *b*. Moreover, the neighborhood of *a* and *b* makes it *look as if* P and P* were identical, in the sense of being one particular amount of energy.

This objection could only defeat the transference theory within a radically verificationist framework. Once we distinguish between an objective fact and our perhaps limited possibility to obtain knowledge of that fact, the problem pointed out by Dowe disappears[27]. We have made the hypothesis that amounts of conserved quantities have the diachronic identity of a flow which is strong enough to admit of transmission. This makes it possible to distinguish between, on the one hand, the transmission of P between *a* and *b* and, on the other hand, the accidental presence of two different amounts P and P* of the same conserved quantity and of equal magnitude in *a* and *b*, even if it is perhaps difficult to find out about this objective difference. Barring extreme verificationism, pointing out the epistemic difficulty of finding out about that difference does not constitute an ontological argument against its existence.

4. *The Mark Transmission Theory and the Conserved Quantity Theory*

I would now like to compare the explanatory power of the transference theory to that of two prominent competitors, namely Salmon's (1984) theory of causal processes[28], and Dowe's (1992a;1995a) "Conserved Quantity Theory". The former characterizes causal processes by their capacity of transmitting marks. There are two reasons for thinking that the transference theory provides a deeper explanation of causality than Salmon's theory. The first reason is that the transference theory can explain *why* causal processes are capable of transmitting marks whereas Salmon simply *defines* a causal process by its having this capacity. The second reason is that the process theory explains causality in the framework of a dichotomy - namely of causal and pseudo-processes - which is observer-relative and not ontologically exhaustive. The transference theory provides a more complete picture of the world for it can deal appropriately with world-lines which are neither causal nor pseudo-processes and so fall out of the picture drawn by the process theory.

Let us begin with the claim that a process theory doesn't have the conceptual resources to explain both the capacity of processes to transmit marks and the corresponding incapacity of pseudo-processes. A process theory takes processes to be the entities which are fundamental for the analysis of causation[29]. Salmon (1984, pp. 147-157) then defines causal processes as those capable of transmitting a mark. Taking processes as the point of departure excludes the possibility of giving an "analytical" explanation[30] of the property of being capable of transmitting a mark, by analysing processes (and pseudo-processes) into their constitutive components. The transference theory can provide such an analysis by taking a more fundamental kind of entity as its point of departure, namely events conceived of as what fills a space-time zone. This allows it to characterize (causal) processes as a subclass of all world-lines. A world-line is a continuous (with respect to both space and time) series of events. Those world-lines whose constitutive events are linked by a relation of transmission of some amount of conserved quantities, are causal processes.

Next, we can explain why these causal processes can transmit marks. A mark can be thought of as a property of an event. If the mark is determined by an amount of a conserved quantity possessed by the event, it can be transmitted to neighboring events in any world-line in which the event takes part. In this case, we can also speak in a more natural way of the mark as a property of the whole world-line all of whose constituent events possess it. We can illustrate this idea with the example of an acoustical signal. Such a signal typically consists of a packet of sound waves or of a local modification of a continuous sound wave. Both are forms of energy which are subject to a local conservation law. A signal exhibited by an event can be transmitted to neighboring events insofar as it is the appearance of an amount of a conserved quantity, namely of energy. Its propagation is just a special case of transmission of such an amount.

Our second argument against the process theory is that an ontology based on the categories of causal process and pseudo-process is not sufficiently fundamental for the aim of elaborating a theory of objective causality. First, these two categories do not exhaust the class of world-lines because some of them, of which I shall present an example shortly, are constitutive neither of a causal process nor of a pseudo-process[31]. Second, the concept of a pseudo-process shouldn't play any fundamental role in the ontology of causation for the following reason. Whether a given world-line is a pseudo-process or not depends not only on its not being causal, but also on the epistemological question of whether it appears as causal to observers in virtue of its structural continuity. This makes the category observer-relative and ill-suited for ontological purposes. Consider for example the fact that, as Kitcher (1989, p. 463) and Dowe (1992c, pp. 124/5) have noted, many causal processes do not possess structural uniformity over time because their evolution is subject to radical phenomenal change. Now, shadows of causal processes are paradigm cases of pseudo-processes. But if there are non-uniform causal processes, then they may cast non-uniform shadows. Are such shadows pseudo-processes or not? We leave this question to the advocate of the process ontology. It simply has no unique answer, independently of the epistemic attitude of a particular observer.

An example will show that shadows of non-uniform causal processes are only the tip of an iceberg of world-lines falling in neither of Salmon's fundamental categories. We can construct it as a variant of the example Salmon (1984, pp. 145/6) uses to illustrate the distinction between causal processes and pseudo-processes. In the centre of an astrodome, a rotating beacon illuminates a spot on the surrounding wall. The movement of the spot along the wall has become the paradigm of a pseudo-process while, e.g., the spread of light radiation from the central source to the wall provides a clear example of a causal process. Now, consider the world-line which is constituted by a series of spots on the wall which are located at some fixed distance from the illuminated spots but not themselves illuminated. Having the same temporal evolution as the world-line of the illuminated spot, it differs from the latter by a fixed spatial shift. The so defined series of events[32] is a world-line because it is spatio-temporally continuous, and it is not a (causal) process because nothing is transmitted between its constitutive events. Yet the question whether it is a pseudo-process or not has no unique answer, for it depends on the observer and his attitude: to qualify as a pseudo-process, a world-line must have the (deceptive) appearance of a process. Does the series of spots neighboring the illuminated ones share some phenomenally salient property which gives the impression of causality to an observer? It depends on whether the observer directs his attention to the relational property by which that world-line was defined. Moreover, our world-line also displays intrinsic uniformity: If the wall is uniformly painted, the continuous series of non-illuminated time-slices of wall patches display uniform surface structure, colour, and shape. The transference theory ignores the observer-relative category of pseudo-processes and focuses instead on what distinguishes causal relations in an ontological respect. It thereby provides an objective and exhaustive dichotomy based on an ontological criterion, namely that distinguishing between world-lines consisting of a series of events which are causally related by transmission and world-lines which are not.

As I noted earlier, Salmon has recently changed his mind and moved towards Dowe's proposal to define causal processes in terms of their "manifesting" (Dowe 1992a, p. 210) or "possessing" (Dowe 1995a, p. 326) a conserved quantity. But, as I shall now try to show, both manifestation and possession are too weak to make a reconstruction of the concept of causality possible. Nothing falling short of transmission will do. The most direct way to argue for this claim is by showing that a theory like Dowe's - and, for that matter, Salmon's (1994) - is bound to judge that certain clearly non-causal world-lines are causal processes.

Dowe (1992a;1995a;b) defines "a causal process" as "a world-line of an object that possesses a conserved quantity" (1995a, p. 323). Let us apply this criterion to the paradigmatic pseudo-process of the spot of light moving along the wall in the astrodome. On Dowe's criterion it turns out to be a causal process after all: Firstly, the series of spots clearly is a world-line, i.e. a temporally and spatially continuous series of events. Secondly, as Dowe recognizes, the continuous "series of different patches of the wall" on which the light spot appears manifests, or possesses, (an amount of) a conserved quantity, namely energy. Thirdly, within Dowe's own conception, we should not give the expression "object" its usual meaning. The reason is that he must deny that objects are identical through time in any sense which goes beyond their continuous manifestation or possession of certain properties. Whoever denies, as Dowe does, any form of diachronic identity to amounts of conserved quantities, is condemned also to deny diachronic identity to material objects - in a strong sense of identity. Matter, after all, is just one form of appearance of one of the conserved quantities, namely mass-energy. But if one conceives of anything as an object that merely manifests some kind of regularity, or even some fixed amount of a conserved quantity, then one cannot avoid counting the spot on the wall as an object.

One might try to escape the conclusion that denying the possibility of transmission implies identifying pseudo-processes with causal processes, by imposing stronger constraints on the notion of an object. Thus, Dowe has proposed to improve the notion of an object appearing in his definition of a causal process by requiring that

> "*an object must be wholly present at a time* in order to exist at that time. That is, when you have an object at a time, it is not that strictly speaking you just have a part of that object - a temporal part. If you have an object then you have the whole object at that time" (Dowe 1995a, p. 329; his emphasis).

This is meant to exclude "time-wise gerrymandered" aggregates from the class of objects. Such an aggregate can be constructed as the mereological sum of temporal parts of (what intuitively would count as) different objects, according to a relational definition such as, for example, "the closest ball to the black ball" (Dowe 1995a, p. 328) in a billiards game. The description "being the closest ball to the black ball" might be satisfied by the pink ball before the instant t_1 and by the red ball after t_1. The requirement that in order to count as an object, something must be wholly present at each time of its existence, is intended to ensure that it doesn't suffice to just give a relational definition, in order for the thus defined mereological sum to constitute a genuine object. The problem with this proposal is its circularity. For what does it mean to say that the gerrymandered object defined by that relational description is "not wholly present" at some instant $t_0 < t_1$[33]? Awaiting a more thorough explication of that notion, it simply seems to mean *that the red ball is not the same object as the pink ball*, and that therefore "when you have" - to use Dowe's expression - the pink ball at time t_0, you don't have the whole gerrymandered object at that time. If it means just that, Dowe's characterization of what it is to be a genuine object is circular.

The upshot is that the refusal to admit transmission seems to deprive an account of causation like Dowe's of any means to exclude the spot from the class of objects. But let us consider one last move in order to avoid that result. Dowe (1992c; 1995a) introduces a distinction between the spot and the patch of the wall on which the spot appears. This enables him to deny that the spot possesses conserved quantities, whereas the series of patches of the wall possesses them. Thus the spot would be ruled out as a causal process because it doesn't fulfil the second of the above listed requirements. But this defence only pushes the problem one step further rather than solving it. For if it is the series of wall spots which possesses conserved quantities, then *it* will serve as a counter-example to Dowe's account. What we said about the spot applies *mutatis mutandis* to the series of patches: it is a world-line, it possesses conserved quantities, and it is an object *on the weak standards which an account denying transmission has at its disposal*[34], given that it denies that the amounts of mass-energy constituting an object can be strictly identical to themselves through time. Dowe's account doesn't seem apt to avoid the disastrous consequence of judging the paradigmatic case of a pseudo-process, namely the world-line constituted by the illuminated series of (time-slices of) wall patches, as causal. This result refutes his account in its present form[35].

5. *Conclusion*

The aim of this paper has been to propose and defend a naturalistic account of causation based on the idea of reducing causation to a relation of transmission. Two major kinds of objections have been considered. Against the first kind of objection, it has been shown that the transference theory can account for both symmetrical and backwards causation, and that it is compatible with a causal theory of time. The concept of a causal net has played a crucial role in this endeavor. According to the transference theory, causation itself is a symmetrical concept whereas the asymmetry of the causal relations in our (region of the) actual world is a contingent feature which is due to the particular physical processes occurring there. Backwards causality is possible in a net like ours in which a majority of intrinsically asymmetrical causal relations determines a direction of forward causality. Symmetrical causality might exist either within our own causal net or in a different net which might be causally isolated from ours. In the former case the net bestows indirect asymmetry on all intrinsically symmetrical causal relations it contains. In the latter case, the whole net might be perfectly symmetrical with respect to both causality and time.

The persistence of a concrete object through time, i.e. genidentity, can be explained as resulting from transmission of amounts of conserved quantities - in the first place, energy-mass - from one time-slice of the object to its adjacent time-slices. But in order to avoid circularity, the diachronic identity of those amounts themselves must be taken to be primitive and directly grounded on the validity of the relevant conservation laws. If we conceive of those particular amounts as tropes whose diachronic identity is that of a flow, the theory seems able to cope with certain difficulties raised by quantum phenomena. Both the diachronic identity of particular amounts of conserved quantities and the genidentity of concrete objects fall short of the strong identity of an Aristotelian substance. What is crucial is that the former's diachronic identity is sufficiently strong to allow them to be transmitted from one event to another. The epistemic difficulty to tell genuine transmission of particular amounts of conserved quantities apart from the mere appearance of such transmission doesn't show that this difference is ontologically ill-grounded unless we accept radical verificationism.

Process theories, as Salmon's (1984) and Dowe's (1992a;b;c;1995a), are among the major rival realist theories of causation. But taking *processes* to be the most fundamental entities in the ontology of causation is a weakness for it makes it impossible to *explain why* causal processes can transmit marks or why objects persist through time. Instead of taking these as primitive facts, the transference theory explains them by taking *events* to be the most fundamental entities in the ontology of causation where events are contents of space-time zones. The process theory's central distinction between processes and pseudo-processes is firstly epistemic and observer-relative and secondly not exhaustive. By contrast, the transference theory's distinction between causal and non-causal relations is observer-independent and exhaustive of all world-lines.

Our defence of the idea that transmission is the crucial conceptual ingredient of objective causation has been completed by an argument intended to show that the weaker notions of regular appearance, manifestation or possession of a conserved quantity, are too weak indeed to be able to justify the judgment that paradigmatic cases of pseudo-processes are not causal. Dowe's (1992a;1995b) and Salmon's (1994) denial of the diachronic identity of particular amounts of a conserved quantity deprives them of a strong enough notion of an object which would allow them, on the grounds of their own definitions, to justify the judgment that the world-line constituted by the series of illuminated time-slices of wall-patches is not a causal process[36].

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[1]The fact that it takes events rather than objects as the fundamental relata of causation, distinguishes my version of the transference theory from those defended by Aronson (1971a;b) and Fair (1979). In virtue of this difference the theory defended here doesn't fall prey to Dowe's (1995b, pp. 366-8) objection that transference theories are incapable of conceiving the persistence of an object through time as a causal process. In section 3.1. below, I say more on how this can be done.

[2]Quine (1985) holds that *both* objects and events can be identified with the content of a space-time zone. For Quine, the difference between an object and an event is one of degree, depending on the length of the time interval defining the zone. Quine's conception has the counterintuitive consequence that short-lived objects and long-lasting events are inconceivable.

[3]Salmon (1994, p. 308) says of his own most recent definition of a causal process in terms of transmission: "This definition introduces the term 'transmits', which is clearly a causal notion."

[4]The conception of transmission as a symmetrical relation of presence of some particular amount of a conserved quantity in two different events entails restrictions on the maximal spatio-temporal distance by which two events can be separated so that a causal relation between them is still possible. It excludes pairs of events which are separated by a space-like (or as the limiting case, a light-like) distance, in the sense of the special theory of relativity, from the domain of potential cause-effect pairs.

[5]Cf. Ehring (1986), Dieks (1986), Dowe (1992a; 1995b) and Sosa and Tooley (1993).

[6]The concept of a symmetrical causal relation has been introduced by Grünbaum (1973, p. 188ff.).

[7]I use the terms "causal relation" and "causal process" interchangeably. This usage is justified by the thesis defended here that causal relations are grounded on a process of transmission.

[8]These processes can also be used to explain the origin of the asymmetry of time (cf. Reichenbach 1956, Grünbaum 1973). A relatively rare phenomenon which shows violation of time invariance (i.e. invariance with respect to reversal of the direction of the time axis in a spatio-temporal representation) and thus constitutes a further basis of the asymmetry of time and causation, is kaon decay (Cf. Dowe 1992b).

[9]Such events exist for a theory like ours which identifies events with the contents of space-time zones. Cf. note 32 below.

[10]The concept of a causal net has been introduced by Reichenbach (1956). Dowe (1992b) has recently put it to work within his "Conserved Quantity Theory" of causality. The fundamental difference between his theory and mine is that in Dowe's account, the basic notion is that of a process, where a process is defined by its manifesting (or possessing, as he now prefers to say - cf. Dowe 1995a) a conserved quantity, while I take events and a transmission relation between them to be fundamental. Other differences concern the issues of backwards causation and symmetrical causation. Cf. note 16 below.

[11]While examining Tooley's (1990) objections below I shall examine where abandoning these assumptions leads.

[12]According to this conception, one should rigorously speak only of the direction of the processes going on in time, and not of the direction of time itself. However, it seems unnecessary to try to eliminate the usual way of talking, as far as one is aware that it should not be taken literally. Cf. Horwich (1987).

[13]This condition puts heavy restrictions on the possibility of the existence of such a region (which would make premiss P3 false): nothing screens off gravitation, and the gravitational influence has spread from our part of the universe in all directions with the speed of light, since this part of the universe came into existence. A causally isolated part of the world would have to be outside the reach of the spreading gravitational field.

[14]An adequate theory of causation should be capable of accounting for cases of backwards causation if there are any (cf. Dowe 1996).

[15]This account of backwards causation is immune to Dowe's (1996, p. 16) objections against Reichenbach's (1956) explanation of the direction of causation. Reichenbach gives all processes in the net the same direction, namely that of the (majority of) entropy-increasing processes. My account differs from his in that the net imposes its global direction only on intrinsically *symmetrical* processes, thus leaving open the possibility of intrinsically asymmetrical processes pointing to the direction opposite to that of the majority. Dowe (1996, p. 17) arrives at a similar account in this respect, except that it is formulated in terms of "open forks", instead of "intrinsical asymmetry".

[16]Dowe (1992b; 1996) also explains the possibility of backwards causation with the help of the concept of a causal net. Yet, Dowe links backwards causation to a "conservation anomaly" - of the type allowed for by quantum physics as far as it confined to a small space-time region surrounding an annihilation/production event. Dowe (1992b) discusses neither the possibility of macroscopic backwards causation, nor the question of whether there are, or could be, intrinsically symmetrical causal relations, nor the possibility of the existence of regions with either symmetrical causation or causation directed in the opposite direction with respect to our region of the world. With respect to the latter issue, he only says that this could be possible in an "'uncoupled' portion of the universe" (Dowe 1992b, p.188). Yet, the argument against Tooley in the text shows that coupling to the same network is precisely required to be able to assess the direction of one (portion of the) net with respect to another. If two

regions were causally uncoupled, it would make no sense to ask whether their directions are the same or different.

[17]It is possible to reformulate the distinction between an explanation whose truth only depends on the *existence* of a causal link between the facts designated respectively by the explanans and the explanandum (or, for that matter, on the existence of a *nomic* link between them) and a genuine causal judgment whose truth requires in addition that the explanans designates the cause and the explanandum designates the effect, in terms of the distinction between (causal relations between) facts and (causal relations between) events. Cf. Davidson (1980), Vendler (1967), Zucchi (1993).

[18]Dowe (1992a) has insisted on the crucial role that conserved quantities play for causation although his own "Conserved Quantity Theory" doesn't allow amounts of these quantities to persist or to be transmitted.

[19]This account of causation has the following interesting consequence: If we assume that the validity of conservation laws is only a matter of natural law but not of *metaphysical* necessity, so that some possible worlds lack conserved quantities, then those worlds might also lack causality and in particular, their objects might neither all nor always persist through time. But that consequence seems plausible: if mass-energy weren't conserved, it would be possible that material objects appear from nothing or disappear into nothing. Similarly, if energy and momentum were allowed to get lost or created, objects could sometimes spontaneously start or stop moving without any cause.

[20]This is a reason to reject both Aronson's proposals that the transmission of *force* (Aronson 1971b, p. 145) or *heat* (Aronson 1985, p. 249) counts as a basis for causation and Krajewski's (1982, p. 225) and Salmon's (1984, p. 156; 1994, p. 303) suggestion that transmission of *information* does. Heat can't be said to be transmitted because, being just one particular form of energy, it isn't conserved but can be transformed in different forms of energy. Force and information are not transmitted in the physical sense required for causality because they are not conserved quantities. In particular, the sense in which information can be transmitted doesn't fit the requirements for causation. Firstly, the transmission of information is relative to a frame which previously fixes the set of all possible events, and their a priori chances of occurrence. Subjects with different epistemic backgrounds get different information by the same physical signals. Thus, the transmission of information is observer-relative and cannot ground an objective, absolute notion of causality. Secondly, the transmission of information only requires a reliable statistical dependence between two series of events. Nomic dependence between effects of a common cause which could not possibly be causally linked as cause and effect creates such a dependence, and so do purely accidental correlations.

[21]This doesn't preclude the application of the concept of a substance to macroscopic objects.

[22]An object is concrete if it fills some determinate position of space. No properties other than the object's own can be exemplified at that place without modifying the concrete object itself.

[23]Russell doesn't use the expression "genidentity". He has later (Russell 1948, pp. 333f.) introduced the notion of a "causal line" and used it to explain the identity of physical objects over time. However, Russell's notion radically differs from the one used here in being epistemic, rather than ontological. "A 'causal line', as I wish to define the term, is a temporal series of events so related that, given some of them, something can be inferred about the others whatever may be happening elsewhere" (Russell 1948, p. 477). Other passages of Russell's work (1948, pp. 476f., 500, 510) make it clear that a causal line is defined in terms of our ability to *recognize* the same object at different times, not in terms of its *being* the same object independently of any observers.

[24]No such attempt is made by Carnap in his analysis of the notion of genidentity. The idea that the identity of an object through time could be explained in causal terms, has been defended by Grünbaum (1973) and Armstrong (1980). Russell (1914, pp. 108ff.; 1948, pp. 333f., 476f.) has made clear that the concept of substance isn't adequate within a theory which considers the persistence of physical objects as a causal process.

[25]Cf. Quine (1973, p. 6); Ehring (1986, p. 256); Dowe (1992a, p. 203).

[26]Salmon (1994) has now abandoned this theory. Below, I shall give additional arguments against the mark transmission theory, beside Kitcher's (1989) and Dowe's (1992a;c) which Salmon recognizes as defeating his earlier theory.

[27]Cf. Aronson (1982; 1985) for a similar line of defense.

[28]The arguments I shall give presently have not been among the reasons for which Salmon (1994) himself has abandonded that theory. Given the importance and widespread echo Salmon's (1984) theory has encountered, it still deserves critical examination nonwithstanding the change of mind of its author.

[29]This choice is common to Fair (1979), Salmon (1984; 1994) and Dowe (1992a;c;1995a) who differ only in their answer to the question of which property of a process is decisive for its being causal.

[30]On this notion, cf. Cummins (1983).

[31]Compare Kitcher's remark that "we could succeed in Salmon's project without distinguishing the pseudoprocesses from the spatio-temporal junk. It will be enough if we can separate the genuine causal processes from the rest." (Kitcher 1989, p. 462).

[32]The conception of an event as the content of a space-time zone enables us to conceive of this world-line easily. Such theoretical fecundity is what ultimately justifies the chosen ontology of events. According to conceptions of events which are closer to common sense, there wouldn't be any events at all in this world-line for "nothing happens" in it whereas for common sense only changes count as events. Note that if we tried to follow common-sense in this respect, we couldn't hope to explain the persistence of objects through time in causal terms, for objects can persist without changing.

[33]The expression "to be wholly present" is mainly being used to characterize the relation between a universal and an individual object instantiating it. It is part of the definition of what it is to be a universal that it is "wholly present" in each of its instances, and therefore at each time at which some object exemplifies it. However, in order to apply meaningfully this locution to particulars instead of universals it is necessary to spell out which sense it has to be given in this quite different context.

[34]Dowe repeatedly says that "the precise characterization of 'object' is unimportant" (1992c, p. 126), or that "what counts as an object is unimportant; any old gerrymandered thing qualifies" (1995b, p. 371). These statements are contradicted by his own efforts (1995a, pp. 326-331) to exclude "time-wise gerrymanders" from the range of genuine objects (as I argue in the text, so far without success). Apart from the suggestion discussed in the text that an object must be "wholly present at a time", Dowe cites with approval Quine's (1976) conception according to which a physical object is "an intrinsically determinate portion of the space-time continuum" (Dowe 1992c, p. 126). Now, *this* is definitely too weak to exclude either the spot or the continuous series of time-slices of wall-patches (illuminated or not) from the domain of objects.

[35]Curiously, Dowe says about the spot on the wall that the reason why it doesn't qualify as a causal process is that "no energy is [...] carried off by the spot" and that "it cannot transmit a conserved quantity" (1992c, p. 127). I take this indeed to be the correct answer, but it is an answer that only a transference theory is capable of giving: As long as Dowe contests that energy can be transmitted at all, he cannot at the same time characterize the spot by its *not* carrying any energy. Carrying is, after all, a way of transmitting.

[36]I am grateful to Wolfgang Balzer, Bernd Buldt, Phil Dowe, Dan Hausman, Kevin Mulligan, Joëlle Proust, Elliott Sober and Wolfgang Spohn, and to my auditors in Leipzig and Konstanz where I presented parts of an earlier version of this paper, for helpful suggestions and critique, and to Marcel Lieberman and Joan Cullen for linguistic advice.