Temporal and Atemporal Asymmetries in Causation

Abstract: This article proposes a new account of causal asymmetry and of how it relates to temporal asymmetry. The key concept on which the account is based is that of inclusion, i.e. of an object being "in" another. Thus, part I develops the notion of what is "possible with respect to" a given object, and what is not, based on what is included in it. This leads to a counterfactual dependence asymmetry which is independent of the direction of time. Part II provides a crash course in local time, describing how to derive temporal precedence ("before") and time's characteristic asymmetry in terms only of states of physical objects called "recorders", a derivation which yields a relativistically correct model of time's arrow. Putting the counterfactual and temporal asymmetries together allows, in part III, to propose an explanation of why causes are observed to precede their effects in time. The upshot is that, even though many of our intuitions about causal asymmetry are profoundly connected to our temporal perspective, there remains a robust counterfactual asymmetry whereby a change in an object requires something distinct from it.

Keywords: causal asymmetry, counterfactual dependence, local time, change, perspectivity, inclusion, possibility, aition.

1. Introduction

What is causal asymmetry, and what does it mean for effects to depend upon their causes? That they do so depend is a presupposition we routinely make in everyday life, but it also plays a crucial role in scientific enquiry (see e.g. Illari and Russo, 2014). Yet close scrutiny shows the dependence relation between two causal relata to be elusive, whichever way the relation is construed to go: On the one hand, there is a long philosophical tradition which views causes as implying, and therefore as sufficient, for their effects. John McTaggart (1915), for example, holds that cause-propositions imply effect-propositions, a fact itself accounted for by the laws of nature. Similarly, in David Lewis' counterfactual theory of causation (1973), the cause strictly implies—Lewis uses the symbol "□→"—the effect, where the implication relation itself is explicated, famously, in terms of possible worlds and their relation of closeness to our own world. And in J. L. Mackie's well-known "INUS" account of causation (1965, 1974), conditions consisting of an aggregate of constituents are sufficient, but unnecessary, to bring about the effect. This tradition, of which examples could be multiplied further, has roots in older thinkers such as Galileo, Hobbes, and also Hume (despite his "Humean" scepticism about causation).[1] Viewing causes only as necessary for their effects, on the other hand, seems to be less prominent in the literature, but necessity appears together with sufficiency in thinkers such as Lewis (1973, pp. 562-3), Galileo,[2] and Hume.[3] And in Mackie's account (1965), causes appear as necessary—though later corrected to "non-redundant" (1974, p. 62)—parts of the above-mentioned sufficient conditions.

A detailed critique of either way of viewing the dependence relation is beyond the scope of this article (see e.g. Anscombe, 1971; Ingthorsson, 2019). Suffice it to remark that both ways are beset with problems which are both easy to spot and difficult to solve: Sufficiency accounts need to deal with the objection that a cause—and even an entire aggregate condition,

[1] See Ingthorsson (2019, pp. 4-6); Anscombe (1971). For sufficient causation in Hume's thought, see also Millican (2010).
[2] as quoted in Ingthorsson (2019, p. 4).
[3] "... if the first object [i.e. the cause] had not been, the second [the effect] never had existed." (2000, section 7, part 2, 29).

as envisaged by Mackie and Hobbes[4]—can in principle always be prevented from reaching its effect, even though this may not be possible in practice. But preventability is, I think, merely the symptom of a deeper, logical gap: A proposition about an object cannot strictly imply one about a distinct object (though of course it may do so materially). But cause and effect are supposed to be distinct. Given this, the existence of the cause cannot strictly imply that of the effect, a point made along similar lines already by Wittgenstein (1995, 5.135–5.1361). Illustrative of this is that, even in the case of beheading as a cause of death—a seemingly indisputable instance of sufficient causation and a standard example cited in much of the literature (e.g. McTaggart, 1915, *passim*; cf. also Hume, 2000, section 8, part 1, 19)—the cause does not imply the effect, a point argued in detail by the neurologist D. Alan Shewmon (2007). Necessity accounts, on the other hand, face the equally simple difficulty that any object cited as a cause necessary for an effect—as in statements of the form "if *c* had not occurred, *e* wouldn't have occurred"—can be replaced by something else.[5] At any rate, this applies when *c* is meant to be a particular token, rather than type, of object. In addition to these difficulties, a strong case can be made that causal asymmetry is fundamentally a perspectival notion, something deeply engrained in the worldview of us agents in spacetime with our inextricably temporal perspective, not a mind-independent feature of the world, a point argued in detail in much of Huw Price's work (e.g. 1996, 2007).

In short, causal asymmetry seems to melt away before our eyes the better we try to understand it, a situation which places the enquiring mind before a curious dilemma: Should we regard causal asymmetry as just another one of those deep-seated intuitions which turned out to be anthropocentric illusions—such as anisotropic space and global simultaneity—and sacrifice it with them on the same heap? If so, why should we bother continuing to look for causes at all and to carry on with the scientific enterprise? Or should we, to avoid such a radical self-undermining of thought, cling to causal asymmetry aprioristically, as a metaphysical truth not in need of justification?[6] Or, as a third option, should we accept a double standard, going on with life and scientific enquiry assuming causal asymmetry *ac si daretur* (to adapt a well-known phrase from Hugo Grotius), while accepting that, fundamentally, there is no such thing?

The aim of this article is to put forward a new account of causal asymmetry, and of how it is related to temporal asymmetry. The key concept on which the present account is based, and in whose light these two asymmetries will be analyzed, is the notion of inclusion, i.e. of an object being "in" another.[7] I therefore depart from the dominant tradition of starting with events as relata. Events, after all, are about what happens to objects: their changes, their coming into being, and their destructions. This is apparent from the grammatical form of statements describing events, such as "a firecracker goes off", "I decided to head north", and such like. The present account therefore puts objects and what is included in them centre

[4] as cited in Anscombe (1971, p. 134).
[5] Cf. Anscombe (1971, p. 145), and Lewis' (2000) retraction of his own counterfactual account on the basis of cases of redundant causation.
[6] Cf. Weaver (2019, ch. 3). A critique of causal apriorism can be found already in Geyser (1933, ch. 3). The polarization between these two options in contemporary thought is well illustrated in R. Kuhn's video "What is causation?"
[7] A detailed exploration of this notion is given by Strumia (2012).

stage, rather than using global conditions—such as laws of nature or the existence of other worlds—as the main explanatory basis for asymmetries in causation. This makes it, to use Michael Tooley's diction (1990), a "singularist" account. In addition to this, it limits itself to dealing with causation in the relatively macroscopic world insofar as it assumes "classical", rather than quantum mechanical, identity conditions of objects—the possibility of extension to quantum mechanics will be briefly discussed at the end of the article. As to the relation of causal to temporal asymmetry, it will likewise be spelt out before the background of a local, rather than global, concept of time, something I have set out in more detail elsewhere.[8]

It will be useful to distinguish three asymmetries,[9] all of which have to do with the notion of a one-sided dependence of an effect on its cause. It will be investigated whether these asymmetries are ontologically robust or merely apparent:

- The counterfactual asymmetry whereby, if the cause doesn't exist, nor does the effect—but not vice-versa.
- The "from-to" asymmetry, whereby the cause is viewed as the "source" of a change, and the effect as its end point or "receiver". Such a view is found, for example, already in the thought of Francisco Suárez, according to whom *causa est principium per se influens esse in aliud* (1965, disputation XII, section II, art. 4), and causation itself is a type of *influxus* (*ibid.,* art. 13). We find a similar view in contemporary transference theories of causation.[10]
- The modal asymmetry, whereby, given the cause as a state of affairs which is fixed, i.e. has a probability equal to unity, the effect has a probability somewhere within the open interval (0, 1) and is influenced—in particular, raised (cf. Mellor, 1995, ch. 6)—by the cause.

I will assess the ontological status of these asymmetries through the following steps: in part I of this article, a detailed investigation of changes of objects will be undertaken in order to see whether any counterfactual dependence is involved in them. The analysis will start with very simple instances of change of an object's constituents, qualities, mass, and momentum, which will lead up to an account of the counterfactual asymmetry in general and in more complex causal processes, in section I.6. Then, in part II, I will provide a brief crash course in local time, in particular on deriving the notion of "before" and of time's local arrow in terms of a particular type of objects, which will be called "recorders". These results will allow, in part III, to give an explanation of why causes are observed to precede their effects in time. Based on all this, it will finally be possible to give an answer concerning the status of the three asymmetries.

In all of this, it will be a key heuristic help to keep present the etymological roots of the concept of "cause": Ancient Greek knows αιτία, or το αἴτιον as words for "cause". The latter is the substantival form of the adjective αἴτιος, meaning "guilty, responsible" (also of something positive), literally "having a part in" or "part-y". Both words come from αἶσα

[8] [title and journal omitted for review]. Cf. also Harrington (2008), and Rovelli (2019).
[9] For an overview and in-depth treatment of different types of causal asymmetries see Hausman (1998).
[10] For a discussion and critique, see Dowe (2000, ch. 3).

(from **aitja*), "part", itself derived from αἴνυμαι, "to take".[11] This etymology suggests that causes are entities which "have a part" in the effects which they are meant to explain. In what follows, I will however use "aition" (pronounced [ɑˈitɪɒn]) as a technical term in its etymological sense: an aition of *p* is simply an entity which has, or includes, *p*—where *p* may for example be a constituent, a quality, or a particular momentum—whether or not the object is also a "cause" of anything. Thus, any entity is an aition of anything it "has" in itself: a football, for example, is an aition of any constituent in it, of its colour, and its momentum. This is true whether we consider an object *qua* such or any particular state of it.

I. The counterfactual asymmetry in causation

I.1 Assumptions

I will start with the assumption that well-defined, separate logical objects called "entities" exist. Assuming this entails no commitment to taking entities as ontologically fundamental—they may or may not be derivable in terms of something yet more fundamental. In the following, entities will be symbolized by the final letters of the Latin alphabet, sometimes in their uppercase and sometimes in their lowercase forms, depending on context. Furthermore, any two or more entities *x, y, ...* can be grouped into collections written as *[x, y, ...]*. I will assume that such collections are themselves entities in their own right. Here, the purpose of the square brackets is precisely to group two or more entities into a new entity. Given this, the expression *[x]*, denoting a singleton collection, will be taken to mean the same as simply *x*, in contrast to the use of curly brackets in set theory, where *{x}* is taken to have a different meaning from *x*.

Correspondingly, any entities within the square brackets denoting another entity are viewed as having a relation of "being included in" the latter. Thus, for example, both *x* and *[x, y]* are included in the entity *[[x, y], z]*. Again, contrast this with the set-theoretical relation of "being an element of", where *{x, y}* is an element of *{{x, y}, z}*, whereas *x* is not. However, analogously to sets, collections too are defined only by that which they include, independently of the order. To illustrate these rules, *[[x, y], z]* is identical to *[z, [y, x]]*, but not to *[x, y, z]*, since the latter does not include the entity *[x, y]*. Entities included in another entity will be called its "constituents", "parts", or sometimes "sub-entities". Also, note that, since *x* and *[x]* are identical, and the former is included in the latter, any entity includes itself.

Furthermore, for any entity, there is a collection of its conceivable states. These states may differ, for example, in virtue of the entities included in them, of quality or quantity, or of being included or not included in another entity. "Conceivable" here means "compatible with the definition of its entity". For example, for a given cat—call it Ginger—hungry Ginger, Ginger coloured purple, or Ginger in a basket are conceivable states of Ginger, whereas Ginger run over by a car is not a living being, hence not truly a cat (except by analogy), and hence not Ginger. Thus, it is not included in the collection of Ginger's conceivable states, although it is of course included in the collection of Ginger's *body*'s states (cf. Runggaldier

[11] See any good Greek dictionary, e.g. Gemoll and Vretska (2006).

and Kanzian, 1998, pp. 154-167; Mellor, 1998, pp. 115-117). Any state of an entity is itself an entity.

Suppose now that there is an entity X which is constituted by grouping together atomic entities $x_1, \ldots, x_n$ in some way using *[...]*. Consider the collection of possible recombinations of these atomic entities under the grouping operation *[...]* and call the collection so obtained $C(X)$. For example, if $X = [x_1, x_2, [x_3, x_4]]$, then $C(X)$ will include members such as $[x_1, x_2, x_3, x_4]$, $[[x_2, x_3], [x_1, x_4]]$, $[x_2, [x_1, [x_3, x_4]]]$, and so on. It will also include X itself. These examples illustrate that the grouping operation can be applied iteratively, i.e. in such a way as to group the atomic members included within the sub-entities of an entity together into new entities. This process can be repeated as long as at least two atomic entities remain which can be grouped together. It is clear that the number of these combinations, i.e. the cardinality of $C(X)$, depends only on the number of atomic entities included in X, not on the way in which X is built up from them. Also, for a single atomic entity x, $C(x)$ is just $[x]$, which is equal to x.

Next, an entity x will be called "possible with respect to" an entity y exactly if x can be obtained from that, and only that, which is included in y. When precisely this holds will be explored in the following sections up to I.6. For the moment, I will limit myself to proposing a necessary condition: For any entities x and y, x is possible with respect to y only if it is included in $C(y)$, or in other words, only if it can be constructed from the atomic entities included in y using the grouping operation.

Finally, an entity will be called simply "possible" only if some entity exists with respect to which it is possible. Again, this is a necessary condition, but not also a sufficient one since, even if an entity x is possible with respect to some existing entity y, it cannot be excluded that there are other reasons which rule out the existence of x. For example, the laws of nature might do so.

In what follows, the entities under consideration will typically be macroscopical physical objects—anything from rocks to cats to galaxies—which will be termed simply "objects". However, where generality permits, I will argue in terms of entities in general, and any results of the investigation will also apply to objects in particular. Where, on the other hand, uniquely physical properties (such as mass or momentum) are discussed, I will use the term "object" rather than the more general "entity". Similarly, the term "included in" or simply "in" will in general have the abstract, technical meaning given above, whereas for objects in particular, it will mean the familiar spatial relation, as in "the cat is in the house".

I.2 Proto-change and the simple counterfactual asymmetry

Suppose now that, for an entity X, two states such as $[x_1, \ldots, x_n]$ and $[x_1, \ldots, x_n, y]$ exist, where no assumptions are being made about the temporal order of these two states. The state written last includes a constituent which is not included in the state written first, and which is not a combination of that state's atomic constituents. Hence, $[x_1, \ldots, x_n, y]$ is not in $C([x_1, \ldots, x_n])$, and is therefore not possible with respect to $[x_1, \ldots, x_n]$. But since $[x_1, \ldots, x_n, y]$ by assumption exists, it is possible. Given this, it is necessary that an entity Y distinct from X exists which includes y, whether it does so improperly—in which case $Y = [y] = y$—or properly. For only together with such a *Y* does $[x_1, ..., x_n]$ form a collection $[[x_1, ..., x_n], Y]$, with respect to which the state $[x_1, ..., x_n, y]$ is possible. *Y* in turn, from the definition given in the introduction, can be termed an aition of *y*.

If any two or more states of an entity exist—in other words, if these two or more states are actual existents, as opposed to mere unrealized possibilities—this will be called "proto-change". The everyday notion of "change" adds to this a time order: an entity always changes from an earlier state to a later one, thereby allowing a distinction between a *terminus a quo* and a *terminus ad quem*. Proto-change is thus a more basic, though less familiar notion, than change.[12] In any change, there are two states of an entity, so that any change is a proto-change. Also, for reasons which will be given in section II, whenever there are two states of an entity and, in addition, these two states are observed, a temporal order between them must be observed, so that any proto-change, insofar as it is experienced, is a change.

By the argument above, whenever two states of an entity are differentiated in virtue of a constituent which is not simply a combination of atomic constituents in that entity, there is counterfactual dependence of such proto-change upon an aition of the constituent, a dependence relation which is independent of the direction of time. Conversely, however, the existence of the aition does not depend upon the proto-change. This is an extremely simple—indeed almost trivial—asymmetric dependence relation but, as I will argue in the following sections, it can be used to analyze such relations also in other types of proto-change, and in this way to shed light on the elusive problem of what it means for an effect to depend on its cause.

I.3 Qualitative proto-change

The next case to examine is qualitative proto-change where, for some entity *x* and some quality *q*, *x* has two states, one with *q* and one without. Does such proto-change counterfactually depend upon anything? At least two cases need to be distinguished:

Qualitative case I: In many cases, qualitative proto-change consists simply in one state of an entity including constituents which are not in the other state, and which themselves have the quality in question. Examples of this type of proto-change are familiar from everyday life: a food has a spicy state in virtue of including spicy constituents which are not in its bland state, a building painted red includes red constituents which are not in its non-painted state, and so on. Thus, if *X* is the subject of such proto-change with respect to some quality *q*, there is a *y* which is in one state of *X* and not in the other, and which in addition has quality *q*. Therefore, this type of proto-change falls under the simple case of proto-change considered in the previous section. As above, we can then conclude that there is a *Y* distinct from *X* which includes such a *y*, whether properly or improperly. The proto-change of *X* depends counterfactually on there being such a *Y* and, for the same reason as above, this counterfactual dependence relation is asymmetric. However, any *Y* including a suitable *y*—i.e. one which has *q*—will do. Therefore, the *q*-proto-change of *X* in general depends counterfactually on the existence of a particular type of entity, not a particular token, an issue which will be discussed

[12] Cf. Aristotle's distinction between what is "prior and more knowable ... in nature, and to us" (Posterior Analytics, 71b, 33-35).

in more detail in section I.6. Since such qualitative proto-change is accounted for in virtue of the parts of an entity, we may call it "aitic". Note, however, that whereas one state of X has q aitically, no assumptions were made as to whether y, or indeed Y, has q aitically or in some other way.

Qualitative case II: But not all instances of qualitative proto-change are of the aitic type. States of an entity having different qualities may also exist in virtue of rearrangement of the constituents of an entity, rather than in virtue of different constituents. Such qualities can therefore be called "holistic". Examples include the denseness or looseness of a material, mechanical or optical qualities which derive therefrom, the roughness of a surface, or the electrical conductivity resulting from a reaction of chemical substances included in an object. In such cases, for any two states of the entity in question, each state is included in the C-collection of the other. Thus, the proto-change of an entity with respect to such a quality now does not depend counterfactually on there being a different entity having constituents with this quality, as it did in qualitative case I. The question whether there is any counterfactual dependence at all in such cases will be readdressed after a discussion of quantitative proto-change and proto-change in momentum.

The distinction between these two cases does not claim to cover all qualitative proto-change in any type of entity—for example, proto-change in ferromagnetism, a phenomenon due to electron spin (see e.g. Griffiths, 2013, section 6.4.2), falls under neither case—but it arguably does cover the vast majority of qualitative proto-changes in macroscopic objects, as in the examples just given.

I.4 Quantitative proto-change

Observable properties of entities are described quantitatively through real numbers, on the set of which there is a familiar antisymmetric relation $\leq$, and a corresponding asymmetric relation $<$, allowing any two elements of this set to be compared. I propose interpreting these relations as ones of inclusion, so that for any two real numbers r and s, $r \leq s$ means that r is "included in" s, and correspondingly, $r < s$ mean that r is "properly included in" s.[13] This interpretation allows extending the notion of being "possible with respect to", also to quantitative proto-change of objects and to understand counterfactual asymmetry in such proto-change. In doing so, I will assume—in line with the "macroscopic" scope of this paper—that the quantities considered are sharp, i.e. have no or negligible uncertainty. To illustrate how such extension can be carried out, consider the case of the "naïve" mass of physical objects. The term "naïve" here is shorthand for the everyday assumptions that all physical objects have positive mass, that any constituents of which they are built up do so too, and that mass is not a function of the relative position or velocity of these constituents, so that we can ignore relativistic effects.

[13] This is consonant with the use of standard set-theoretical relations of inclusion in the construction of number systems in mathematics. For example, in Kuratowski's construction of the naturals through nested sets, for any two natural numbers m and n such that $m < n$, the set defining m is an element of that defining n. Similarly, in the Bertrand-Dedekind construction of the reals, for two real numbers p and q such that $p \leq q$, p is a subset of q. See e.g. Holmes (2012, pp. 25-26 and pp. 94-96).

Given these conditions, for any object *X*, and any two different real—and by assumption positive—numbers *q'* and *q** describing the mass of *X*, if *X* has two states *X-q'* and *X-q**, there is a constituent which is in one of the two states, but not in the other. Not conversely, of course, since if *q'* and *q** are equal, we cannot conclude that they have the same constituents. But since the forward implication holds, such quantitative proto-change is an instance of the simple case of proto-change discussed in section I.2. Thus, one of the two quantitative states *X-q'* and *X-q** is not possible with respect to the other. We may conclude that one or more aitia distinct from *X* exist including the mass which distinguishes *X-q'* from *X-q**. The mass-proto-change of *X* depends counterfactually upon the existence of such aitia, and since it matters only that these include constituents having this mass, the counterfactual dependence is again upon a type of object, not a particular token. The general case, where relativistic effects come into play, will be considered below.

Similar considerations can be applied to the total energy of an object—that is, the sum of the kinetic and potential energy of the centre of mass of the whole object as well as of any energies internal to it, whether kinetic, potential (in particular also binding energies), or those energies contained in the mass of the constituents of the object themselves. On the basis of the interpretation of "≤" as a relation of inclusion, we can postulate that for two total energy values *e** and *e'*, and two corresponding states *X-e** and *X-e'* of an object *X*, one of the two is possible with respect to the other only if its total energy is less than or equal to that of the other. Then, if *e** and *e'* are unequal, there is always an aition of energy external to *X,* in consonance with what we know from physics.

What about other quantifiable properties of an entity? Do their quantitative proto-changes depend counterfactually on something distinct from the entity, as they did in the cases of naïve mass and total energy? They clearly do when the proto-change is of the type described as qualitative case I, since such proto-change consists in an entity having different constituents. But they do not where the proto-change consists in the rearrangement of the constituents of an entity. This can occur, for example, in the proto-change of the spatial dimensions, geometry, or volume of an object, and as a consequence, also in the proto-change of quantitative measures describing holistic qualities of an object, such as when the opacity of an interstellar dust cloud changes as its constituents rearrange.

I.5 Momentum proto-change

The momentum of an object (linear or angular) is a quantity of particular importance for the philosophy of causation. Proto-change in it clearly consists neither in an object's having different constituents, nor in rearrangement of its parts. Given this, does proto-change in the momentum of an object depend counterfactually on something distinct from it? Recall that all proto-change, insofar as it is observed, is change. But all observed change in momentum obeys the canonical equation

$$\frac{dp_i}{dt} = -\frac{\partial H}{\partial q_i},$$

where q_i is a generalized position coordinate, p_i its conjugate momentum, and *H* the Hamiltonian. This tells us that a necessary condition for momentum to change is that the object under consideration not be a free one, i.e. that the Hamiltonian contain terms other than the object's own kinetic energy, such as ones representing potentials or friction,[14] since otherwise the right hand side is zero identically. The above question can therefore be answered in the affirmative. That which is required for proto-change of momentum can, by analogy to what has been argued in the previous sections, be viewed as aition of momentum, an interpretation justified by the fact that not only particles moving in space have momentum, but fields do so too.[15] Also, we once again have an asymmetric dependence on a type of object, not a token. In these respects, the case is similar to those of naïve mass and energy. But there is also an important difference, which can be seen by considering a coordinate transformation in which the generalized position q_i is multiplied by –1. Then, the momentum $p_i = \partial L / \partial \dot{q}_i$ conjugate to this position (where L is the Lagrangian) changes sign too, so that, for any two unequal i-th momentum components, the inequality between them is reversed. In other words, if p_i' and p_i^* are two such components, each of the two can legitimately be viewed as "greater" than the other. The spatial coordinates and their orientation reflect, after all, an arbitrary choice. Given this, if x is an object to which the two momenta belong, *neither* x-p_i' nor x-p_i^* is possible with respect to the other—in contrast to the other two cases just mentioned, where only one of two states was impossible with respect to the other.

That objects cannot change their momenta of themselves, but require something else to do so, is one of the most general assumptions we make about causal asymmetry in everyday life, and given the above, this assumption is justified. But this point also allows us to revisit the issue of whether any notion of counterfactual dependence can be upheld also in holistic proto-change: When parts of an object rearrange, in most cases there is momentum proto-change of some of them, in particular—but of course not only—when they collide with each other. The exception to this is the case of a purely inertial rearrangement of the parts under which an object's geometry or volume changes. In the non-inertial case, the holistic proto-change of an object, while it does not depend counterfactually on something external to it, does so depend on the exchange of momentum between its parts. In particular, this is the typical situation for most cases of holistic qualitative proto-change, for example of the optical properties or electrical conductivity of an object.

These considerations on momentum can be used, by way of a corollary, to understand counterfactual asymmetry in an important class of causal interactions, namely those where an object is destroyed, or a living being killed. We get two cases: In the first, the momenta of the parts of the object lead to their rearrangement in such a way as to destroy it. Such destruction is therefore a holistic change which is possible with respect to what is included in the object. In the second case, momentum is imparted which does not belong to the parts of the object, so that such destruction depends counterfactually on an aition of momentum distinct from the object. Examples of holistic destruction include slow decay, but also violent explosions resulting from the release of internal energies, whereas killing an animal or shattering a glass are typical aitic destruction events.

Finally, it is interesting to compare the role which time plays in momentum proto-change as opposed to the other instances of proto-change considered: Whether we define momentum

[14] On Lagrangians and Hamiltonians with friction, see Riewe (1996).
[15] For the electromagnetic field, see e.g. Griffiths (2013, section 8.2).

simply as mass times velocity (crossed from the left with a position vector in the case of angular momentum), or more generally as the partial derivative of the Lagrangian with respect to velocity, time enters constitutively into the definition of momentum. As is well known, the sign of momentum is reversed under time reversal, as succinctly expressed in the equation $p(-t) = -p(t)$.[16] None of this applies to the other qualities and quantities discussed. However, momentum has in common with them that its proto-change, and not only its change, depends counterfactually on the existence of a corresponding aition, so that here too there is counterfactual asymmetry independently of the direction of time.

I.6 The $\mathcal{P}$-collection and counterfactual dependence in general

According to the discussion so far, three conditions are necessary for an entity *x* to be possible with respect to an entity *y*: 1. that *x* is included in $\mathcal{C}(y)$; 2. that *x*'s total energy is included in that of *y*; 3. that, if *x* and *y* have the same constituents, their momenta are equal. The first condition is a simplification which applies to low-energy, non-relativistic regimes, and can therefore be used in the analysis of counterfactual asymmetries in familiar, everyday situations, as was done above. In the general situation, we need however to allow, in addition, for the fact that particles can be produced given the energies (kinetic or potential) of the parts of an object (see e.g. Taylor and Wheeler, 1992, ch. 8). Thus, some entities are possible with respect to another which contain additional constituents, and are therefore not in that entity‘s collection of recombinations of its constituents, i.e. in its $\mathcal{C}$-collection. The second and third conditions can be unproblematically extended to relativistic environments simply by reading them as referring to the relativistic, rather than the "naïve" momenta and energies, of an object and its parts.

We can now generalize our account: for any *x*, there is a collection $\mathcal{P}(x)$ which includes all and only that which is possible with respect to *x*, or in other words, all entities which can be constructed or produced given that, and only that, which is included in *x* and given its total momentum. Thus, for any two entities *x* and *y, y* is possible with respect to *x* exactly if it is included in $\mathcal{P}(x)$. The $\mathcal{P}$-collection of an entity is never empty, since it always includes the entity itself. In particular, in the case of an atomic entity, it will include nothing else. However, the cardinality of the $\mathcal{P}$-collection of an entity tends to grow quickly with the number of its constituents, which after all are allowed to recombine in a wide variety of ways compatible with conditions (2) and (3). It is in general not a straightforward matter to state fully the content of the $\mathcal{P}$-collection of an entity, since this collection is not only arrived at combinatorically—as was the case with the $\mathcal{C}$-collection—but considerations concerning, for example, particle production, chemical reactions, and in general a whole plethora of possible holistic proto-changes need to be taken into account as well. Despite this, the $\mathcal{P}$-collection is well-defined for any entity, being both spanned and delimited by that which is included in it—you can in general obtain several entities from a given one, but not anything whatsoever. For any *x,* any entity in $\mathcal{P}(x)$ other than *x* itself can be thought of as "virtually included" in *x.* Also, extending what has been said in section I.1, we can now state that for an entity to be

[16] Cf. the discussion in Weizsäcker (2002, section 4.1).

possible at all, it is necessary that it is included in the $\mathcal{P}$-collection of an existing entity. Finally, note that the relation of "being possible with respect to" allows any two entities x and y to be compared: x may be possible with respect to y, or vice-versa, or both, or neither. Said relation therefore generates a partial order on the collection of all entities.

To illustrate all this let, for example, s be our solar system in 1800 according to Earth's frame of reference, g the collection of electronic gadgets of the 21st century, and k a block of kryptonite: g is possible with respect to s, not vice-versa, and k is not possible with respect to either s or g.

It is now possible to analyze counterfactual asymmetry in proto-change along the most general lines covering the cases discussed so far. If an entity x has two states, we get two cases:

1. Either, at least one of the states of x is not possible with respect to the other. Then, there is an aition distinct from x having the property which distinguishes the two states, and the proto-change depends counterfactually on the existence of such an aition. Examples of this case are proto-changes of qualitative type I, of naïve mass, total energy, or momentum.

2. Or, each state of x is possible with respect to the other, as occurs in holistic proto-changes. Then, there are again two alternatives: a. Either, there is a sub-entity of x having two states such that at least one of the two is not possible with respect to the other. Then, case (1.) applies to any such sub-entity, and the proto-change of x as a whole depends counterfactually on the proto-change in such sub-entities. b. Or, there is no sub-entity of x to which case (1.) applies. Only two examples of this emerge from the above inventory of macroscopic proto-changes (though there may be more): purely inertial proto-change, and spontaneous magnetization in magnetic materials below the Curie temperature (Chikazumi, 1997, pp. 118-124). Of course, the claim is not that such proto-changes are simply brute facts in need of no further explanation,[17] but rather that, for the entity itself as well as its sub-entities, no aitia distinct from them are required for such proto-changes.

Now, while it is not possible in this article to attempt a full inventory of all proto-changes in any type of entity, as for macroscopic physical objects, the vast majority of their proto-changes fall into the above typology, and most of them in turn belong to category (1) or (2.a). All such proto-changes depend counterfactually upon suitable aitia, i.e. ones with the relevant property. But any proto-change, insofar as it is observed, is a change. Hence, the vast majority of changes in objects depends on such aitia. This includes cases of destruction which, though they are changes of an entity only in an analogous sense, are changes of the substrate of an entity in a univocal sense. It also includes the coming into being of a new entity within a system of entities, since this system can be regarded as an entity in its own right which has a new constituent. Thus, by the considerations in section I.2, it requires an aition of that

[17] For the inertial case, cf. the discussion in Weizsäcker (2002, section 6.3).

constituent.[18] If now we recall that events are what happens to entities, then most events—at any rate in the world of macroscopic physical objects—depend counterfactually on suitable aitia. What all this means for the notion of dependence upon a "cause" will be explored in section III.

This counterfactual dependence relation has three properties: First, it is asymmetric, since said proto-changes depend on the existence of suitable aitia, but not vice-versa. Second, it is time-symmetric, since it hinges on proto-change rather than change. Third, the dependence is in general on the existence of a type of object, namely an aition having the relevant property, not a particular token. However, token-dependence occurs in a particular case too: that where the token is the only existent aition, or the only available one, required for a given proto-change. This is familiar from everyday causal judgments of the form "If it hadn't been for entity *c*, event *e* couldn't have occurred" (or such like). Such judgments are justified in the case just mentioned, but not otherwise. This is why the statement "*c* is the cause of *e*" cannot in general be reduced to a counterfactual statement such as "had *c* not occurred, *e* would not have occurred" (cf. again Lewis, 2000).

Observe, finally, that complex causal processes familiar from everyday life typically combine aitic, holistic, and inertial changes. As examples, consider cases such as sweetening tea by putting sugar into it, or developing illness as the result of infection with a virus. In each case, objects are put into others, momentum is imparted, new properties are acquired as constituents recombine, and parts move inertially within their wholes. Insofar as these processes have aitic and holistic changes as their components, they involve counterfactual dependence. Thus, the present account of counterfactual asymmetry in causal processes is not limited to simple ones—such as a planet acquiring more mass—but can also be used to understand complex ones as are typical of the biological world.

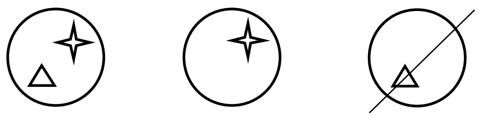
II. Local time

It remains to be explained how the counterfactual causal asymmetry relates to temporal order. Before doing so, I will give a brief sketch of how to derive the relation "before" between events or states of affairs in atemporal terms, and from there on, the local arrow of time. Readers interested in the full derivation should consult [title and journal of publication omitted for review].

We are familiar with the fact that objects bear traces of causal interactions in which they have been involved, so that one can derive, from traces in a given object, information about events in its causal history. In this sense, objects, whether simple ones such as a rock, or complex ones such as the human brain, can be viewed as "recorders". But I will again take a timeless view and consider the collection *S* of all of states of a particular recorder, that is, of its actually realized states as opposed to its merely possible ones, independently of any assumed temporal order. Very often, we find on this collection a typical asymmetry, illustrated in the

[18] I am not concerned here with the case of an entity's coming into being before the backdrop of utter nothingness, nor with complete annihilation, problems beyond the scope of this article.

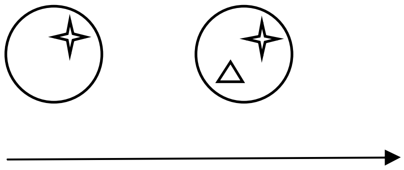
following picture, in which the circle symbolizes a recorder, and the triangle and the star each symbolize a record in it:



In words, the two states drawn first are included in *S*, whereas the stroke out one is not. Can we say anything about the before-order of the recorder's states from this atemporal fact? In many cases, we can: for example, if the moon has a state with the crater γ and another with the craters c and γ, we may tentatively conclude that γ is before c, and the impact event causing γ before that causing c. Similarly, if there is a state of a person with knowledge of computer programming and Japanese, and another state with knowledge of computer programming, but no Japanese, we may again tentatively conclude that this latter state is the earlier of the two. However, the atemporal criterion just outlined is not perfectly reliable, because records can also be deleted, thereby also destroying the asymmetry on the *S*-collection of a recorder. I therefore introduce the notion of an "amended recorder": a recorder such that records in it are not interfered with. Note that this criterion does not make reference to "earlier" or "later" states of the recorder, and therefore escapes the charge of circularity. For an amended recorder, then, quantification over its *S*-collection yields the before-order between records matching that known from everyday experience, as well as the events to which these records correspond. Letting *A* be such a recorder, and r_x a record of event *x* in *A,* we may then define:

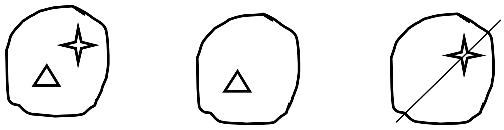
D.1 An event *y* is before an event *x* for *A* iff there is a state of *A* with r_y and without r_x, and a state with r_y and r_x, but no state with r_x and without r_y.

Applying this definition to the above illustration, we can then draw



where the arrow indicates the order from earlier to later for *A*. In this way, the familiar phenomenon of temporal precedence can be reduced to atemporal notions.

But is the concept of an amended recorder, which after all is an idealization, useful for establishing before-orderings given that physical recorders can only approximate it—and can even do so very well—but can never fully satisfy its definition? Suppose we replace the amended recorder by a non-amended one (*NA*), symbolized below by the squiggly shape, locating it at the same coordinates in spacetime so that it is able to record the same events as above. Their before-order is already known by quantifying over states of an amended recorder. Given this, does quantification over all of *NA*'s states and applying (D.1) to it ever give the reverse order? If so, this order would correspond to the atemporal configuration of states



It turns out that this cannot occur. For either *NA* records the star, in which case there is a state of *NA* with the star and without the triangle, contradicting the condition symbolized by the third item in the above illustration; or, *NA* fails to record the star, in which case the first item does not exist. Thus, quantification over the states of a non-amended recorder may fail to give the complete before-ordering established by an amended one, but this order cannot be violated. The local before-order can therefore be reliably established using physical recorders, as is done in the historical and paleontological sciences.

Returning now to the amended recorder, notice that the before-order of its states as defined by (D.1) corresponds to an order of inclusion: a later state has all the properties of an earlier one, plus additional ones, so that a complete description of the later state includes that of an earlier state. Any two states of an amended recorder are therefore such that, in this sense, one is included in the other. This allows accounting for the claim from section I.2 whereby all proto-change, if observed, has a before-order: For suppose that A is an amended recorder and B an object having two distinct states B^* and $B^\sim$. If A records these states, it has two states itself, which we can call, correspondingly, A^* and $A^\sim$. From above, either A^* is included in $A^\sim$, or vice-versa. But since the order of inclusion is that of the before-order as recorded by A, either B^* is before $B^\sim$, or vice-versa. On the other hand, suppose we replace A by a non-amended recorder *NA*: Then, it may occur that one state, call it NA^*, has only a record of B^*, whereas $NA^\sim$ has only a record of $B^\sim$. But then, neither state of *NA* allows the two states of B to be compared with one another. They remain two isolated impressions in *NA* and cannot be identified as two states of a single, changing object. The situation is analogous to a living being without memory, which cannot experience change, but only a series of unrelated impressions. Thus, if it is observed that one and the same object has two states, a before-order between these states must also be observed.

In this context, it is important to realize that the before-order is not "merely subjective", let alone illusory, on the account that it is defined in terms of a recorder. Rather, it is an observable, which like other observables—such as length or mass—is defined operationally in terms of a measuring instrument, in this case the recorder. Measuring this observable yields unique results which are not a figment of our mind (as, say, a dream is), nor are they susceptible to arbitrary, subjective interpretation.[19] What is more, the before-order of the states of a physical object is a relativistic invariant, since all these states are timelike-related. Thus, in the above example, the before-order of B's states as recorded by A is the same as the before-order recorded by any observer, independently of their frame of reference.

Note also that the above derivation of temporal precedence relied entirely on the notion of the collection of states of an object and the asymmetry described above which appears on this collection, making no reference to the character of physical law. Hence, it does not matter for

[19] Cf. the similar epistemological considerations in Harrington (2009, pp. 260-261).

the above derivation that the laws of nature are, by and large, time-symmetrical. Nor can it be claimed that the time-symmetry of the laws of nature rules out that said asymmetry exists: for example, it is possible for the moon to have a state with crater *A* and crater *B,* and another with just crater *B*, but none with just crater *A.* The situation would be symmetric if this last state existed too. But of course, the laws of nature, time-symmetrical though they are, do not prescribe that it exists. Said type of asymmetry on the collection of states of objects therefore can and does occur, also in non-amended recorders.

Next, it is possible to equip the amended recorder with a counting mechanism, in order not only to ascertain a before-order, but also to quantify the duration between events. Roughly, this is done by using several instances of a particular record of type r^* (e.g. "sunset" or "pendulum swing"), and using nested sets including these instances, ordered by successive inclusion in a way analogous to Kazimierz Kuratowski's construction of the natural numbers.[20] The type of object needed to do this is called an "ideal recorder". The local natural parameter can then be fine-grained further, using some other type of record, in order to construct fractions, and in thought—though not physically—the full set of rationals, and from there on, the reals, on any given interval. In this way, states of a recorder *A* are provided with real indices t, so that they can be written as A_t. In other words, the temporal parameter so constructed is attached to a recording object, yielding a local total ordering of events which, in contrast to a global such ordering, is relativistically correct.

The irreversibility of the local arrow of time can also be derived using recorders.[21] This is done by associating records in a recorder with propositional content, just as, for example, we associate a footprint in the ground with the proposition that somebody has walked past. Specifically, given a state A_t of a recorder *A*, any record produced in it is written as r_t—that is, *A*'s temporal index is transferred to such a record. Records r_t are then associated with time-indexed propositions p_t. Thus, given a temporally indexed state A_t of a recorder, only local times less than or equal or to t have propositional content, and all others do not. From this, it is easy to show that the notion of changing the past generates a contradiction, whereas this does not apply to that of changing the future. We therefore obtain a local fixed past and open future, and in this way, an irreversible arrow of time.

In sum, the essential features of the passage of time known from experience—namely precedence ("before"), quantitative duration, and irreversibility—can be accounted for locally from atemporal notions. Note also that, since more records correspond to more interactions, entropy increases the higher we are up the local before-order, as it should—but this increase is only a symptom of the passage of time, not the reason for it (cf. Dainton, 2010, pp. 47-50).

III. Why do causes precede their effects?

At this point, we have:

- A counterfactual asymmetry whereby most macroscopic events require, and would not come about without, suitable aitia. This asymmetry was derived on the basis of the

[20] See the footnote in section I.4.
[21] For details, see section [omitted for review] of [omitted for review].

notion of the $\mathcal{P}$-collection of an entity, and is thus independent of the direction of time.

- An asymmetric relation "before" between events and states of affairs, which is invariant in the special case of the change of one particular physical object. This relation was derived from the notion of the collection of states of a recording object, with no reference to any notion of causal priority or dependence between the relata. For an event to be before another, it is therefore not essential that the two are in any way related causally, nor is temporal order a consequence of causal order,[22] a conclusion consonant with the fact that some events between which a before-order is recorded, namely in particular spacelike-related ones, are not causally related.

- Both asymmetries are derived from the notion of inclusion, but in different ways and yielding independent concepts. Metaphorically speaking, two "arrows", the asymmetry of counterfactual dependence and that of time, are fired from the same bow,[23] inclusion, but fly off it orthogonally.

However, temporal asymmetry and counterfactual dependence seem to be more closely connected, since it appears obvious that an event does not depend on just any suitable aition independent of its place in the temporal order, but rather on one which should be present *before* the event itself, and which we can think of as its *cause*. Can this systematic connection between the two asymmetries be accounted for using what has been developed so far?

For the case where the entity which is the subject of change is a macroscopic physical object—from a rock to an embodied person—this can be done along general lines as follows: Let X be such an object, and suppose that the change it undergoes is of the type which depends counterfactually upon an aition, i.e. one belonging to case (1) or (2.a) in the classification from section I.6. Then, there is an object x included properly or improperly in X such that x has two distinct states, x and xp, where p may be either a particular momentum, or a property which x has in virtue of some constituent. Suppose, moreover, that for some observer, x is before xp. From the existence of x's two states, we can conclude, as was done in part I, that there is an entity Y distinct from x such that p is included in Y (it does not matter for the argument whether or not Y is included in X). But we can say more: a state Y_s of Y must exist such that p is not also included in x, i.e. this state must include p separately from x. Otherwise, the state of x without p could not exist. Next, let W be a collection including the states of x and Y under consideration. Because the before-order between states of physical objects is invariant, we can safely conclude that in W, x is before xp as well. W is thus partitioned into two states: an earlier state W_1 including x, and a later state W_2 including xp. Can W_2 include Y_s? No, because W_2 includes xp, which contradicts its including Y_s. But Y_s must exist. Therefore, it exists in W_1. It can be concluded that, if a macroscopic physical object is observed to acquire a property, an entity must preexist which is either an aition of that property, or of the momentum needed for the object to acquire it. This applies to simple

[22] in contrast to what is affirmed e.g. in Lewis (1987, p. 38).
[23] to use an image from Loewenstein (2003).

cases, such as a rock acquiring more mass, as well as to complex ones, such as a human being changing their neural pattern in the course of a learning process. But the argument also works for a macroscopic physical object losing, as opposed to acquiring, a property, provided that this be once again a change of type (1) or (2.a). The reason is that, if the object loses a particular property, there is always a sub-object of it which acquires a particular momentum, or a constituent, so that we get *x* before *xp*, as above.

For this argument to work, it is not required that *p* goes away from *Y,* so that *Y* would be left in a state without *p*. We can remain agnostic whether such a state exists. This is desirable because, even though there are many cases where, on the basis of conservation principles, it makes sense to demand that it does—take for example the transfer of mass or momentum from a body to another at a particular point in spacetime[24]—there are others where it does not. An example is the transfer of knowledge from one person to another, in which the knowledge does not leave the teacher when it is transmitted to the learner. The same is true of the magnetization of a material when a magnet is applied to it. Thus, we can use the above argument also for such cases. Also, we need not assume that any property being transferred in the interaction is necessarily a conserved quantity.

Note, in the above example, the "from-to" asymmetry: *Y* appears as the "source", *x* as the "receiver" of *p*. Along these lines, we would also, in everyday language, call *Y* the "cause" and *xp* the "effect" of the interaction, not vice-versa. Given this identification together with the above argument, we can conclude that, if an object acquires a property, and this change is a proto-change of type (1) or (2.a), it requires a preexisting cause. The commonsensical assumption that causes must precede their effects is then justified. But observe also that, if we reverse the time direction in such interactions, "sources" typically become "receivers", and hence also "effects" become "causes". This, at any rate, is true in those cases where *p* goes away from one object and is transferred to the other. Thus, if we assume that the above change where *x* becomes *xp* is such a case, and we time-invert it so that *xp* now loses *p*, *xp* becomes the "cause" of *Y*'s having *p.* The cause-effect distinction is then inverted wholly and without remainder by inverting the direction of time. Observing this illustrates that this distinction is indeed profoundly linked to our temporal perspective, corroborating Huw Price's case. However, this should not mislead us into thinking that there is no asymmetric dependence relation at all in causal processes, since it remains true that proto-changes of the types under consideration depend counterfactually upon the existence of suitable aitia, as has been shown.

The above argument whereby, if *x* acquires *p*, an aition of *p* must preexist, can be challenged as follows: Suppose that *p* is a property which *x* has as a constituent—e.g. a piece of mass, a colouring substance, or similar—and we imagine this constituent to jump back and forth between *x* and *Y* in such a way that *x* has *n* states, where $n > 2$. Then, *W* is likewise partitioned by *p* into *n* states. But then, for a given x_k which has *p*—where *k* indicates *x*'s place in the before-order—the above way of arguing allows us to conclude only that the state Y_s is in some W_j such that $j \neq k$, but not that $j < k$. Thus, Y_s need not preexist *xp*.

[24] As Erik Curiel (2000) has pointed out, conservation accounts run into problems when the transfer is assumed to occur over a finite *volume* of spacetime.

To answer this, consider *W*'s *n*-th state: since one of the two entities x and Y acquires p in such a way that it has p in W_n, the other—for the reason already given—must have p in some W_k such that $k \neq n$, and therefore in some earlier state. But we can replace n by any n' such that $1<n'\leq n$ and argue in the same way. Letting $n' = k$, we see that, for any W_k such that $1<k\leq n$, if one of the two entities acquires p such that it has p in W_k, then the other must have p in a state with an index less than—and not merely other than—k.

IV. Comparison to Aristotle's philosophy of change, time, and causal asymmetry

The present account of causal and temporal asymmetry can be characterized as broadly Aristotelian, although it is also based on insights which were not available to Aristotle, in particular from contemporary theoretical physics. Thus, there are continuities as well as differences to Aristotle's thought on the subject:

First and most fundamentally, like Aristotle, I distinguish between the possible and the actual, where an entity's being actual implies its being possible, but not vice-versa.

Second, I agree with Aristotle, along general lines, that possibilities are entity-relative: not anything whatsoever is possible for a given entity; rather, an entity's possibilities are both spanned and constrained by its characteristics. But this is spelt out in different ways in Aristotle's account and the present one: Aristotle uses the notion of the "potential" (δύναμις) of a thing, which can mean, in the words of S. Marc Cohen and C. D. C. Reeve (2020, section 12), either "the *power* that a thing has to produce a change" or "its capacity to be in a different and more completed state". On the other hand, I have distinguished between: 1. which states are conceivable for a given entity, i.e. compatible with its definition, and 2. which entities are possible with respect to which others, and in particular which *states* of a given entity—which after all are themselves entities—are possible with respect to which others, where the precise sense of "possible with respect to" was explicated in sections I.1 to I.6.

This distinction gives rise to a variety of combinations between (1.) and (2.). To illustrate these, consider the example of an astronaut called Liz in a state s in which she carries a rucksack containing only tools and a bland cheese sandwich.

Liz, *qua* herself, has a collection of conceivable states. Some of these are:

a. possible with respect to state s; for example, one where she is separated from her rucksack in such a way that the total momentum of herself and the rucksack is the same as that of state s.

b. not possible with respect to s alone, but possible with respect to s in combination with another entity; for example, a state where Liz has curry on her spacesuit, or one where she with her rucksack on her back has a momentum not equal to that in state s. In these cases, there is counterfactual dependence on an aition of the curry or the momentum, respectively, distinct from what is in s.

c. not possible with respect to anything in the universe, and hence impossible, e.g. Liz having a non-existing substance on her spacesuit, or her traveling at 3/2 of the speed of light relative to her speed in *s*. Since such states are ones of Liz *qua* herself, they too are in the collection of her conceivable states.

These cases illustrate that the collection of conceivable states of an object is in general very large, but it is constrained by the identity conditions of the object.

On the other hand, considering the entities possible with respect to *s*, we need to distinguish between those which are in the collection of Liz's conceivable states (as already given under (a.) above), and those which are not. An example of the latter is a lifeless human body, which after all can result from the rearrangement of the constituents of *s* without the need for anything else. Since being alive is essential to Liz, this is not one of her states, even though it is a state of this particular physical body.

Consider, finally, a state *s'* where the matter in *s* is rearranged in such a way that it contains Liz's lifeless body, but the total momentum of *s'* is not equal to that of *s*. Again, *s'* is not a conceivable state of Liz, but it is a conceivable state of the matter in *s*. Due to the difference in momentum, *s'* is not possible with respect to *s*, so that the existence of *s'* depends counterfactually on an aition of momentum which is not in *s*. An example of this is what we could call an "external", or aitic, destruction event, e.g. one brought about by a meteorite. However, once again the temporal order does not matter, but only the proto-change involving *s* and *s'*: the relationship between the two states would be the same if we considered the situation in reverse—a construction rather than a destruction.

There are thus various senses of what we could call, in Aristotelian fashion, the "potential" of Liz given her state *s*, in some of which there is counterfactual dependence on an external aition, in others not. Note that in this analysis, as far as counterfactual asymmetry is concerned, it matters only whether two entities are possible with respect to each other according to the criteria given in section I.6. In particular, it does not matter what the order of the two entitities is in local time, nor which locally measured time interval separates them, nor whether they are observed to immediately succeed one another or rather are separated by intermediate steps.

Third, the distinction between changes, or proto-changes, accounted for "externally" and "internally" is itself a similarity to Aristotle's account. But again, the details differ: Aristotle (e.g. in Metaphysics, 1046a, 10) distinguishes between changes whose origin is "in another thing" and those where it is, somewhat cryptically put, "in the thing itself qua other" (ᾗ ἄλλο). The first type corresponds to those proto-changes which, in my classification, depend counterfactually on an aition external to the entity in question (type 1 in section I.6). The second type corresponds to what I have called "holistic proto-changes" of an entity. Most of these, I have argued, consist in a proto-change of a sub-entity which depends counterfactually on an aition external to it, rather than to the entity itself (case 2.a). Thus, there is in these cases no fundamental difference between "external" and "internal" proto-changes, the difference being merely one of where the boundaries are drawn.

Fourth, it is important to note that the present account is not one of "passing properties around": the claim is not that, for a given entity *x* and any property *p* whatsoever*,* if *x-without-p* and *x-with-p* exist, an aition of *p* distinct from *x* must exist. While this way of viewing causal asymmetry works well in some cases—e.g. in the proto-change involving a bland and a spicy state of a dish, or in the induced magnetization of a piece of iron—it does not work in general: a substance which proto-changes its conductivity holistically does not need an aition of conductivity (as noted in section I.3 above), nor does the proto-change of a window with an intact state and a broken one require an aition of "intactness" or "brokenness". Rather, aitia of momentum, whether internal or external, are required in these cases—hence the importance of momentum and of the canonical equation cited in section I.5 for the present account. How all this relates to Aristotle's thought is not quite clear: On the one hand, Aristotle does often talk as though a thing's acquiring a particular form always required a source of that form. But on the other, he also views locomotion itself as a kind of transfer of form (on these points, see e.g. Metaphysics, 1049b, 17-29; Physics 202a, 3-12) making his view more amenable to one which recognizes the central role of spatial recombination, rather than a simplistic "passing properties around" view, for the changes in the properties of things.

Fifth, Aristotle's view of causation makes use, quite naturally, of an intuitive "from–to" distinction, insofar as changes of things are accounted for through "sources" or "origins" (ἀρχαί) inside or outside them (see e.g. Metaphysics, 1046a) something also true of Suárez' view cited in the introduction. We have seen, however, that this leads to the danger, pointed out by perspectivalism, of confusing a distinction which arises from our temporal perspective with one of asymmetric, counterfactual dependence. The present account therefore disentangled the temporal from the counterfactual asymmetry, arguing that there is a counterfactual dependence of proto-changes on suitable aitia independent of the direction of time. This, in combination with a local account of time, then made it possible to derive the result that, in a change of an entity from an earlier state to a later one, a suitable aition must preexist in local time. We thus ended up with a view similar to Aristotle's (see again Metaphysics, 1049b) but with the extra benefit of being able to give an account of why it is that the aition must preexist, and why it is that what we call "causes" precede "effects".

V. Conclusion

We can now revisit the three types of causal asymmetry given at the beginning of this article:

1. The counterfactual asymmetry in most causal interactions involving macroscopic objects is robust: from an atemporal perspective, most proto-changes depend upon suitable aitia; viewed in time, this dependence is one of effects upon causes. On general lines, this asymmetry consists in the fact that an object can realize states which are not possible with respect to what is in a given state of it alone, but which are possible with respect to that state and an entity other than the object. Therefore, such states would not come about without such another entity. Notice that this counterfactual asymmetry was not postulated first in order to then to define the notion of "cause" in terms of it, as is done in counterfactual theories of causation,[25] but rather

[25] Cf. Ingthorsson's critique of proceeding in this way (2019, esp. section 3).

was derived, through the steps given in section I. Since, then, most proto-changes of macroscopic objects require a suitable aition, they obey the principle of sufficient reason, that is, they are not free lunches which come gratuitously out of nowhere. But at the same time, the existence of an aition of a particular property does not imply a corresponding proto-change in another object. In this sense, aitia behave indeterministically. This analysis, if correct, may allow us, somewhat surprisingly, to wed indeterminism with the principle of sufficient reason, at least for many types of macroscopic proto-changes. I say "may" because the present article has limited itself to giving an account of causal *asymmetries*, without attempting to explain what *causation* consists in: it has been established that very many changes depend counterfactually upon aitia, but how entities exchange their properties, and why they do so at all, is a further issue.

2. The "from-to" asymmetry in many causal interactions between two physical, macroscopic objects is inverted by switching the time-direction, an observation which corroborates the case for the perspectival nature of this asymmetry. This however, for reasons pointed out, does not make the asymmetry "merely subjective".[26] Moreover, the asymmetry's direction is a relativistic invariant.

3. The modal asymmetry arises from the fact that, for a given recorder and two causally related states of affairs, there is a state having a record of one of them (the "cause"), but not of the other (the "effect"). With respect to this state, the cause is certain or "fixed", and thus modally independent of the effect, whereas the effect is uncertain. Said asymmetry is therefore perspectival. However, it remains true that the cause, insofar as it is an aition, can make an event possible which would otherwise be impossible, as has been shown. Therefore, it can, and typically does, raise the probability of its effect. Thus, it is not an illusion that we can manipulate things in order to influence the probabilities of what will happen in our local future, whereas the local past is unchangeable in virtue of its propositional content, as sketched briefly in section II.

In other words, perspectivalists and Humeans rightly draw attention to the fact that many of our causal intuitions are deeply connected to our temporal perspective, as described in points (2) and (3). But they forget the atemporal counterfactual dependence asymmetry described in (1). This, I think, is due to their rooting causation in global conditions, such as regularities or laws of nature, disregarding what is in concrete objects, and what possibilities are virtually included in them.

Of course, the present account of causal asymmetry is set in an essentially macroscopic landscape. Can it be extended to the complex-number dominated world of quantum mechanics? On the one hand, we no longer have, at the quantum level, a well-defined notion of an entity as self-identical in different states (cf. Lowe, 2003, p. 78). But we do retain the notion of a collection of possibilities, since the state vector, as a superposition of eigenstates

[26] Cf. Price (2007, *passim*) on this distinction.

multiplied by probability amplitudes, can arguably be interpreted as such a collection (cf. Weizsäcker, 2002, section 8.2). But whether such extension can be carried out would need to be explored separately. The same goes for causal asymmetry in cases such as mental causation or the causation of existence from non-existence, and for questions such as whether information or teleological principles are likewise aitia on which some states of affairs depend.

In any case, as concerns the realm of macroscopic objects and their changes, the existence of causal asymmetry is not a brute fact, nor an underivable presupposition of thought, nor a deep-seated but antiquated intuition to be given up like the monarchy, as Bertrand Russell famously proposed for the notion of causation (1913, p. 1). Rather, causal asymmetry is a complex phenomenon having both temporal and atemporal components, both of which can be accounted for from the still more basic notions of entity, inclusion, and possibility.

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