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CONTRASTIVE CAUSATION IN GENETICS AND IN PHYSICS

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ABSTRACT

Jonathan Schaffer has argued that a contrastive causal ontology is beneficial in juridical contexts: lawyers and judges should treat the causal relation as a quaternary relation, not as binary one. In this paper we investigate to what extent a contrastive causal ontology is beneficial in genetics and in physics. We conclude that it is beneficial in these scientific domains. We also point out that the nature of the benefit differs in the three context (law, genetics, physics) that we discuss.

Key words: Contrastive causation, causation in genetics, causation in physics, Jonathan Schaffer.

1 Introduction

Jonathan Schaffer has recently presented and defended a contrastive account of causation in two papers: 'Contrastive Causation' (Schaffer 2005) and 'Contrastive Causation in the Law' (Schaffer 2010). In the first paper, the position is described as follows:

> I will argue that causation is a *quaternary*, *contrastive* relation: *c* rather than ***C**** causes *e* rather than ***E****, where ***C**** and ***E**** are nonempty sets of contrast events. (2005, p. 297)

The paper contains a philosophical defence of this position: Schaffer argues that treating causation as contrastive helps to solve five paradoxes with respect to causation: the paradox of absences, the paradox of fragility, the paradox of extensionality, the paradox of transitivity and the paradox of selection.

In the second paper Schaffer argues that causal claims made by lawyers, judges etc. implicitly rely on a contrastive conception of causation:

> I argue that specification of the causal contrast as lawful conduct is needed so that the right alternative gets assessed, and I argue that specification of the effectual contrast as the better outcome is needed so that the right damages get assigned. The view is not intended as a revisionary proposal but rather as a description of what is implicit in our practice[.] (2010, p. 260)

So Schaffer does not only argue that the general contrastive view is applicable to causation in the law, but also proposes a specific implementation of ***C**** and ***E**** in legal contexts: lawful conduct and better outcome.

The main thesis of the 2005 paper is of a general metaphysical nature: causation, as an objective relation in the world, is a quaternary relation. The theses in the 2010 paper are at a different level. On the one hand, he claims that lawyers and judges implicitly treat causation as a quaternary relation. In other words: in the ontology of lawyers and judges, causation is conceived as quaternary. This is not a metaphysical claim, but a descriptive claim about the ontology presupposed by a specific group of people. On the other hand, Schaffer also approves of this ontology: he thinks it is a good ontology that has the advantage of making lawyers and judges focus on what is really important causal knowledge. If lawyers and judges would see causation as a ternary or binary relation, they would be less focused. That is Schaffer's view on causation in the law, which we will present in more detail in Section 2. The crucial idea of focus on important causal knowledge will be clarified there.

Our investigation in this paper was prompted by the following remark of Schaffer:

> Arguably, causal and explanatory judgments in the sciences are always contrastive judgments. (2010, p. 263)

In the footnote attached to this remark, Schaffer refers to Goodwin 2008, which is a paper about explanation of regularities in chemistry. We will not use that paper because we want to focus on causation, more specifically causation between events. We think it is interesting to investigate to what extent and why a ternary or quaternary causal ontology is beneficial for specific groups of scientists.

In Section 3 we analyse causal claims in genetics, an important subdiscipline of biology. Section 4 deals with physics. We will try to answer the following questions:[1]

(1) Is the ontology of the causal relation in this field contrastive?

(2) If so, what kinds of contrasts are relevant in this field?

(3) If the ontology is contrastive, is it beneficial to make the contrasts explicit when making causal claims in this field? If there is an advantage, what does it consist in?

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[1] We thank an anonymous referee for proposing the three first questions as a way to disentangle the issues to be discussed and as a way of organizing our thoughts.

(4) Why is it useful to be aware of the fact that the causal ontology in this field is contrastive (assuming that it is is)?

(5) Because questions (3) and (4) look a bit similar, it is useful to clarify what we mean. Question (3) relates to the usefulness of an explicit contrastive causal ontology for people who are active in the given field. Question (4) is meant to be reflective: if you look at the field from an external perspective, what do we gain (in terms of better understanding of what is going on in the field) if we realize that that the causal ontology is contrastive?

2 Contrastive causation in the law

2.1 We already briefly explained the idea of contrastive causation in the introduction. Here is a more elaborate statement:

> The contrastive thesis is thus a thesis about *the number* and *the roles* of the causal relata. In particular it is the thesis that there are four causal relata in the roles of cause, causal contrast, effect, and effectual contrast, as follows:
> (*Contrast*) The causal relation has the form: *c* rather than *c*∗ causes *e* rather than *e*∗
> Causal judgment is judgment about the causal relation and so—given *Contrast*—makes reference not merely to cause and effect (as is usually thought) but also to their respective contrasts. (Schaffer 2010, p. 261)

With respect to causation in the law Schaffer argues that ...

> ... causation in the law requires specification of both the causal and the effectual contrast. Essentially, specification of the causal contrast as lawful conduct on part of the defendant is needed so that the right alternative gets assessed, and

> specification of the effectual contrast as the better outcome for the plaintiff is needed so that the right damages get assigned. (2010, p. 269-270)

In saying this, Schaffer actually makes two claims. On the one hand, he asserts that the contrastive thesis is true for causation in the law. On the other hand, he tells us how c^* and e^* are implemented in legal contexts: lawful conduct and better outcome.

To support his views Schaffer presents several examples. We discuss two of them: one that illustrates the necessity of a contrast on the cause side of the relation (2.2) and one for the effect side (2.3). In 2.4 we clarify how Schaffer sees the benefits of the contrastive ontology. In 2.5 we summarise Schaffer's view by means of the four questions above.

2.2 Consider a lifeguard who has been napping while on duty. While he was napping, a boy drowned. Consider the following binary statement:

(A) The fact that the lifeguard was napping caused the drowning of the boy.

According to Schaffer, people who make such binary statements always have an implicit contrast on the cause side in mind. If we make this contrast explicit, we get ternary causal claims. Examples of such claims in the lifeguard case are:

(B) The fact that the lifeguard was napping, as opposed to paying attention, caused the drowning of the boy.

(C) The fact that the lifeguard was napping, as opposed to going away to smoke a cigarette, caused the drowning of the boy.

There is a juridically very significant difference between these two ternary claims. In general it is the case that some contrasts lead to juridically *relevant* causal claims (e.g. (B)) while other contrasts lead to juridically *irrelevant* causal claims (e.g. (C)). It makes no sense to argue in a courtroom about whether (C) is correct or not, because both the putative cause and the contrast are non-lawful behaviour. Arguing about (B) makes sense because the contrast is lawful conduct.

2.3 The upshot of 2.2 is that it treating causation as (at least) a ternary relation allows us to distinguish between relevant and irrelevant causal claims. A similar argument can be given with respect to the effect side. If we consider the causal relation as ternary, without effectual contrast, it is again impossible to distinguish relevant from irrelevant claims. Let us look at Schaffer's example. An unlicensed practitioner of medicine (Jones) performs surgery on Smith, after which Smith dies. If we want to call Jones' act the cause of Smith's death, we need to know what would have happened if Jones had not operated on Smith, or if he operated properly. If Smith gained a day because of the operation (or if he would have died anyway on that day) the situation for Jones is different than if Smith would have gone on to live another 40 years if the operation were performed in a proper way. An important part of the information the causal claim should give us is whether the defendant "rendered the plaintiff worse off" (2010, p. 279), not whether there were damages in an absolute sense. This is something that cannot be expressed without a specification of the alternative scenarios on the effect side. We need a contrast that expresses a "comparatively better outcome" (ibid.) for the plaintiff than the actual outcome. The reason is clear: if the occurrence of *c* rather than *c** gives rise to an effect *e* that is equally good or better than the alternative effect *e**, why would the defendant be guilty of anything?

Together with the argument in 2.2 this implies that treating the causal relation as a quaternary one in the ways specified by Schaffer (i.e. with lawful conduct as causal contrast and better outcome as effectual contrast) allows lawyers and judges to distinguish relevant from irrelevant causal claims.[2]

2.4 Given the usefulness of the quaternary ontology, we need an adequate test to provide evidence for quaternary causal claims. Remember that we made reference to alternative scenarios to clarify the meaning of a causal claim in law, and to the need to restrict the considered alternative scenarios to *lawful behaviour* on the cause side and a *comparatively better outcome* on the effect side. Based on this, Schaffer proposes a new kind of counterfactual test procedure which allows us to provide the right type of evidence for our causal claims in juridical contexts. He describes the traditional test procedure as follows:

> Causal judgments made in the courtroom are often explicitly based on the sine qua non test. For instance, in a tort of negligence it will typically be asked: Would the actual damage to the plaintiff still have occurred had the defendant's actual breach of duty not occurred? (2010, p. 260)

The alternative he proposes is:

> I am arguing that the more useful test, which is implicitly at work behind the sine qua non test and so in fact is implicitly in use, is the following test: Would a better outcome for the plaintiff have occurred than the actual outcome had the defendant acted lawfully instead of breaching duty? Instead of "but for the defendant's breach, the plaintiff's damage would not have occurred," I suggest the more explicit "if the

[2] Each of the examples that Schaffer uses can be extended to show the usefulness of a quaternary ontology in one move. In the life-guard example, drowning of the boy can be contrasted with surviving on the effect side. In the surgery case, Jones' act can be contrasted with him doing nothing illegal.

> defendant had acted lawfully, the plaintiff would have met a better fate." (2010, p. 260)

This test proposal for juridical contexts is a specific implementation of the following general test procedure:

> (Test) c rather than c* causes e rather than e* if and only if (typically) if c* would have occurred, then e* would have occurred (2010, p. 262)

The underlying idea is that we should not consider all the possible situations in which *c* did not occur, since this could include situations that are irrelevant for the causal relation. We need to limit the number of alternatives to be considered in the counterfactual test. Schaffer does this by demanding that the counterfactual test does not simply consider the non-occurrence of *c* or *e*, but instead positively states the relevant alternatives that have to be considered, namely *c** and *e**.

It is in this alternative, superior test procedure that Schaffer locates the positive effect of a contrastive ontology. It allows better focus:

> First, instead of looking at scenarios in which the defendant's actual breach of duty did not occur (which might involve scenarios in which the defendant acts unlawfully in some other way), one is specifically instructed to consider the alternative supposition of lawful conduct for the defendant. Second, instead of then looking to see whether the actual harm to the plaintiff would still have occurred (when it might merely have been replaced by some equal or worse harm instead), one is specifically guided to look for the alternative of a comparatively better outcome for the plaintiff. An explicitly contrastive approach can thus potentially help the lawyer phrase her causal question in a more explicit way. (2010, p. 260)

In sum, a contrastive ontology with its associated, superior test procedure allows lawyers and judges to focus on what is really important causal knowledge for them. This is the advantage of a contrastive causal ontology in juridical contexts.

2.5 To facilitate comparison with causal claims in genetics and in physics, we briefly summarise Schaffer's views by means of the three questions presented at the end of the introduction:

(1-L) In the field of law, the ontology of the causal relation is quaternary. Binary or ternary causal claims are ambiguous and therefore do not have a fixed truth value.

(2-L) The causal contrast is always a form of lawful conduct. The effectual contrast always a better outcome.

(3-L) Making the causal contrast and effectual contrast explicit is helpful because it allows lawyers and judges to focus on causal claims that are juridically relevant. By introducing these contrasts, they can identify the one and only specific (quaternary) claim that is relevant, thus discarding all the others as irrelevant and unworthy of further investigation.

With respect to the fourth question, Schaffer's views imply that awareness of the contrastive nature of causal claims in the law helps us to understand what is going on in causal talk in juridical contexts. More specifically, the idea of contrastiveness is a tool that reveals that causal talk in the law has a surface structure and a (more complicated) deep structure. Let us use Schaffer's lifeguard example to illustrate this. Suppose we hear two lawyers argue which of the following possibilities is correct:

> The fact that the lifeguard fell asleep is a cause / not a cause of the drowning of the boy.

By means of a contrastive ontology, we can understand that what these lawyers are really arguing about is the following:

> The fact that the lifeguard fell asleep, as opposed to paying attention, is a cause / not a cause of the drowning of the boy.

The lawyers do not mention the causal contrast explicitly, because they assume that they share this contrast. Our answer to the fourth question for juridical contexts is:

(4-L) The general insight that the causal ontology in the law is contrastive is useful because it lays bare tacit, shared assumptions that allow the surface structure of the causal talk to be simpler than its deep structure.

3 Contrastive causation in genetics

3.1 Let us go back to the quote from Schaffer in the Introduction:

> Arguably, causal and explanatory judgments in the sciences are always contrastive judgments. (2010, p. 263)

This is a very strong claim, because it contains two universal quantifiers: *all* the sciences and *all* causal and explanatory judgments. Providing sufficient evidence for that claim is a huge task, and given its boldness the probability that it is false is extremely high. We assume that Schaffer is aware of that, and that his claim should rather be read as a description of a possible research route: like he has done for causation in the law, it is an interesting project to investigate contrastiveness of causal claims in several scientific disciplines. This is what we do in the remainder of this paper. We focus on the normative side: we will investigate to what extent non-binary (ternary, quaternary, ...) causal ontologies are beneficial for specific groups of scientists. We start with genetics (Section 3.2 – 3.4) and then discuss examples from physics (Section 4). This kind of investigation is similar to what Schaffer has done in his 2010 paper with respect to a quaternary causal ontology for lawyers and judges.

3.2 In genetics, an important class of causal claims relates specific genotypes to specific phenotypes.[3] Genotypes are said to cause certain phenotypes. A phenotype is "any measurable characteristic or distinctive trait possessed by an organism" (Elrod & Stansfield 2010, p. 23). Examples are: the colour of an organism's hair or the colour of an organism's eyes. Genotypes are the genetic basis – or cause – of these distinctive traits. They are the collection of alleles (alternative forms of a gene) possessed by the organism. Here is an example of the type of claim we consider:

> Normal leg size, characteristic of Kerry-type cattle, is produced by the homozygous genotype DD. Short-legged Dexter-type cattle possess the heterozygous genotype Dd. The homozygous genotype dd is lethal, producing grossly deformed stillbirths called 'bulldog calves'. (Elrod & Stansfield 2010, p. 49)

Homozygous genotypes are characterized by having identical alleles, for example *DD*, which is a combination of the allele *D* with itself. Heterozygous genotypes have different alleles, for example *Dd*. The claim above expresses that the structure of the genotype *causes* the nature of the phenotype (namely whether the cattle has normal size legs, short legs, or is grossly deformed). The genotype of the animal determines which of the three phenotypes it will exhibit. Consider another example:

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[3] Another important class of causal claims is those claims that relate the genotypes of the two parents in a cross to the genotype of the offspring. We do not use such claims here, though a similar argument could be developed by means of claims of this type.

> Ebony (black) body color in *Drosophila* (fruit fly) is governed by a recessive, mutant allele *e*, while wild-type body color is grey and is governed by a dominant allele e^+. Thus, a fly with both e^+ alleles (e^+/ e^+) or with a dominant e^+ and a recessive *e* allele (e^+/ *e*) will have a grey body. However, a fly with both recessive *e* alleles (*e* / *e*) will be black. (Elrod & Stansfield 2010, p. 25)

Again, the configuration of the genotype is said to determine the occurrence of the specific phenotype. The only difference is that, in the case of the cattle, there were three possible outcomes, while in this case the fruit fly has only two possible colours. We come back to this difference at the beginning of Section 3.4.

3.3 We will now argue for the use of a contrastive ontology when making claims of this type. As in our discussion of juridical cases, we start with contrasts on the cause side and then proceed to contrasts on the effect side.

Consider the colour of guinea pigs: they are either black or white. The colour is determined by a pair of genes (B and *b*). With respect to the phenotypic expression of these genes, we have three causal laws:

> All BB animals are black.
> All B*b* animals are black.
> All *bb* animals are white. (Elrod & Stanfield 2010, p. 28)

Take a black guinea pig *a*. In accordance with the laws above, the following claims hold:

(D) The fact that animal *a* has genotype BB, as opposed to *bb* is cause of *a* being black.

(E) The fact that animal *a* has genotype BB, as opposed to B*b* is not a cause of *a* being black.

If animal *a* would have had genotype *Bb* instead of *BB*, it would still have been black. But if animal *a* would have had genotype *bb*, instead of *BB*, it would have been white. Now consider a white guinea pig *c*. According to the laws above, the following claims hold:

(F) The fact that animal c has genotype bb, as opposed to Bb is a cause of c being white.

(G) The fact that animal c has genotype bb, as opposed to BB is a cause of a being white.

When we try to express these claims in a binary way, we run into some troubles. To show this, first consider a (non-problematic) binary claim about the white guinea pig:

(H) The fact that animal c has genotype bb is a cause of c being white.

This claim is not confusing, since any contrast in the set of relevant alternatives (B*b* and BB) will validate it. There is, in other words, no relevant contrast that makes this claim invalid. The contrast does not matter for the truth value of the causal claim and is thus irrelevant. So far so good. The situation is different for a binary claim expressing causation about the colour of the black guinea pig *a*.

(I) The fact that animal a has genotype BB is a cause of a being black.

This claim is confusing. As is clear from (E), there are cases when this claim is not valid, namely when the alternative genotype of the animal would have been B*b*. So, if we do not specify the considered alternative, we run the risk of making invalid causal claims. Given that there are situations when binary causal claims create confusion, geneticists may indeed benefit from a ternary causal ontology.

The case of the guinea pigs is no exception at all. Tomato plants with hairy stems result from the dominant gene H, while hairless stems are produced by the recessive gene *h*. This can be expressed by the following laws:

All HH plants are hairy.
All H*h* plants are hairy.
All *hh* plants are hairless. (Ibid, p. 48)

It is easily seen that this case fits the same pattern as our guinea pig example. When we want to make a causal claim about hairy plants, we need to specify the considered alternative to ensure that our claim is valid.

3.4 The two examples above, like the one about the fruit flies, all deal with cases where there are only two possibilities for the phenotype. In case of the fruit fly, its colour was black or grey; the tomato plant was hairy or hairless and the guinea pig was black or white. This ensures that there is no need to specify the contrast on the effect side: there is only one possible contrast. Suppose we reformulate (1) as follows:

(D') The fact that animal a has genotype BB, as opposed to bb is cause of a being black as opposed to white.

Stating that a guinea pig is black, instead of white, when those are the only two possible colours, is unnecessary.

However, there are many cases where we do have more than two possibilities for the resulting phenotype, for example the leg length of cattle as mentioned above. These cases may need something extra: a quaternary ontology instead of a ternary one. Let us investigate this.

Snapdragons are a type of flower that can have red, white or pink flowers. Their colour is linked to the genes R and *r* in the following way:

All RR flowers are red.
All R*r* flowers are pink.
All *rr* flowers are white. (Ibid, p. 29)

Consider the following quaternary causal claims about a pink flower *a*:

(J) The fact that flower a has genotype Rr, as opposed to RR, is a cause of a being pink as opposed to red.

(K) The fact that flower a has genotype Rr, as opposed to RR, is not a cause of a being pink as opposed to white.

When we try to express this in a ternary way, without specifying the contrast in the effect, we run into the same problems as before. The corresponding ternary claim is:

(L) The fact that flower a has genotype Rr, as opposed to RR, is a cause of a being pink.

Since this ternary claim can be specified into both a valid (J) and an invalid causal claim (K), it creates confusion. The ternary claim does not capture the entire meaning of the causal relation, and thus we need a quaternary one, specifying both the contrast on the cause and effect side.

Another example is the blood group system of humans. There are three possible alleles: I^A, I^B, *i* and four possible blood groups:

All I^AI^A humans have blood group A.
All I^Ai humans have blood group A.
All I^BI^B humans have blood group B.
All I^Bi humans have blood group B.
All I^AI^B humans have blood group AB.
All *ii* humans have blood group O. (Ibid, p. 46)

It is clear that geneticists again need a quaternary ontology to avoid confusion when making causal claims.

3.5 Let us take stock by going back to our four lead questions. Sections 3.2-3.4 support the following answers to the first three questions:

(1-G) In the field of genetics, the ontology of the causal relation is quaternary. Many binary or ternary causal claims are ambiguous and therefore do not have a fixed truth value.

(2-G) All alternative genotypes can be causal contrasts, all alternative phenotypes can be effectual contrasts.

(3-G) Making the causal and effectual contrast explicit is useful because it gives the geneticists an overview of all the different causal claims that can be made. These causal claims are equally interesting and have to be investigated and argued for separately.

Comparing (3-L) with (3-G) is interesting: in the context of genetics the contrasts widen our perspective, while in legal contexts they narrow down our perspective. So the benefits of the contrastive ontology are different.

In order to address the fourth question, we have to look at genetics from the outside. We propose the following answer:

(4-G) The general insight that the causal ontology is contrastive is a clue to understand why geneticists cannot make simpler, binary causal claims without confusing the issues they are investigating.

4 Contrastive causation in physics

4.1 In this section we will argue that causal claims in physics also presuppose a contrastive ontology. Like in the juridical and genetical cases, we start with contrasts on the cause side (4.2) and then proceed to contrasts on the effect side (4.3). In 4.4 we try to derive general insights from 4.2 and 4.3 by means of our four lead questions.

The physical examples we use below relate to the thermal expansion of aluminium rods. There is a functional relation between the rate of change in temperature and the rate of expansion of the rod. Take L_0 to be the initial length of the rod (in meters), dT to be the temperature difference (in C°) and dL the change in length, aka the expansion (in meters). Then the following law holds for aluminium rods:

$$dL = 0.0000222 \times L_0 \times dT$$

Analogous laws with a different parameter hold for other materials. Besides the (symmetrical) functional relationship, there is also an asymmetrical causal connection: one can change the length by changing the temperature, but not the other way around.

4.2 Before we look at physical examples, we want to present a medical toy example (which is inspired by an example developed in Hitchcock 1996). Consider the following ternary causal claim:

(M) The fact that John took a 100 mg dose of this drug, as opposed to no dose at all, is a cause of his recovery.

We assume that this is true (i.e. John would not have recovered without taking the drug, or his chance of recovery would be significantly lower). Let us assume that taking more than 100 mg is ineffective. Then the following ternary causal claim is false:

(N) The fact that John took a 100 mg dose of this drug, as opposed to 200 mg, is a cause of his recovery.

Given that the first ternary claim is true and the second one is false, we have to conclude that the corresponding binary claim is confusing:

(O) The fact that John took a 100 mg dose of this drug is a cause of his recovery.

This claim does not have a fixed truth value.

With respect to thermal expansion, a similar point can be made. First, consider a ternary causal claim that is true:

(P) Increasing the temperature of this aluminium rod from 50° to 250°C, as opposed to keeping it constant, caused an increase of its length.

Next, consider a ternary causal claim that is false:

(Q) Increasing the temperature of this aluminium rod from 50° to 250°C, as opposed to increasing in from 50° to 100°C, caused an increase of its length.

This causal claim would be true if there would be an expansion threshold (a minimal increase in temperature below which change in temperature does not cause expansion). Since there is no such threshold (cf. the law above, which excludes this) the ternary claim is false. Hence, we can conclude that the corresponding binary claim is confusing:

(R) Increasing the temperature of this aluminium rod from 50° to 250°C caused an increase of its length.

This claim does not have a fixed truth value.

4.3 Let us now look at contrasts of the effect side. All metals have a melting point, that of aluminium is 660,3°C.[4] Melting points constrain the range within which functional laws like the one given in 4.1 are valid. Consider the following ternary causal claim:

(S) Increasing the temperature of this aluminium rod from 50° to 250°C, as opposed to increasing it from 50° to 800°C, caused an increase of its length.

[4] We thank an anonymous referee for pointing at this convenient possibility for introducing contrasts on the effect side.

At first sight, this claim seems to be false, for the same reason as (Q) is false. However, there is a quaternary elaboration of this claim that is true:

(T) Increasing the temperature of this aluminium rod from 50° to 250°C, as opposed to increasing in from 50° to 800°C, caused an increase in length rather than melting.

The truth value of the ternary claim (S) is not fixed.

4.4 Let us now go back to our four lead questions. Our thermal expansion case supports the following answer to the first question:

(1-P) In the field of physics, the ontology of the causal relation is quaternary. Many binary or ternary causal claims are ambiguous and therefore do not have a fixed truth value.

We have only given examples about thermal expansion, but it is obvious that the relevant features (viz. threshold or not; and limited range of validity of a functional law) are present in many other subdisciplines of physics.

With respect to the content of the contrast, we can conclude:

(2-P) All alternative states of cause variables can be causal contrasts. Interesting effectual contrasts often can be found by considering radically different behaviour (such as melting as opposed to expanding/contracting).

As to the two remaining questions, it is convenient to reverse the order. Causal talk in physics seems to be constrained by (at least) two pieces of background knowledge. The first is that the claims are never universally valid, but only within contextually determined “normal” conditions. For instance, in the context of thermal expansion of solids, it is implicitly assumed that the validity of the causal claims is limited to temperatures below the melting point of the solids involved. If we talk about heating and expansion of gases, there is an implicit assumption that we confine ourselves to ranges where the container of the gas does not explode. The second piece of background knowledge is that the functional laws that govern the processes considered often exclude thresholds and imply a continuous "dose-response" relationship. Hence, our answer to the fourth question here resembles our answer for juridical contexts:

(4-P) The general insight that the causal ontology in physics is contrastive is useful because it lays bare tacit, shared background knowledge that allows the surface structure of the causal talk to be simpler than its deep structure.

With respect to the third question, it seems that the background knowledge we referred to above suffices to avoid confusion. Within the range of contexts demarcated by the background knowledge (viz. "normal" contexts that are governed by continuous functional laws without threshold conditions), the truth value of a causal claim is not influenced by the chosen contrasts. So our answer is:

(3-P) In physics, it is not necessary to make the causal or effectual contrast explicit.

5 Conclusion

We have argued that in each of three domains considered (law, genetics and physics) the ontology of causal claims is quaternary. In each domain, many binary or ternary causal claims are ambiguous and do not have a fixed truth value.

This similarity, expressed in the conjunction of (1-L), (1-G) and (1-P), is the only substantial conclusion we can draw that is valid across the domains considered here. A contrastive ontology can be beneficial for a number of reasons. In the three domains we have discussed there is a variety of such reasons, which are described in (3-L), (3-P), (3-G), (4-L), (4-P) and (4-G).

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