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Capacities and Abstractions

1. The Primacy of Singular Causes

Recently I have been arguing that singular causes are primary and that general causal laws—such as 'Aspirins relieve headaches'—are best rendered as attributions of capacities for single case causation. I have been defending this position by painfully and methodically chipping away at the dominant opposition view, that causal laws are statements of some kind of regular association.[1] In its most sophisticated, and I think defensible, form, the association is taken to be probabilistic, something expressed in terms of partial conditional probabilities, or a probabilistic analogue of path coefficients.

On one front the attack has proceeded in two stages: First, to show that these probabilistic measures already require reference to singular causes if they are to work at all; second, to argue that even then they are not reliable, and the kind of unreliability is one that can't be removed by looking at the probabilities in a randomized experiment, as one might hope.

On the second front, I have argued that with the same kind of background causal information—both singular and general—that is necessary to establish causal laws via probabilities, it is perfectly possible, contrary to Hume, to establish singular causal claims without first establishing regularities, and to do so reliably. And, even more strikingly, in the so-called one-shot experiments of physics, there is generally no distinction made between establishing the singular claim and establishing the corresponding causal law. For example, in the Einstein-de Haas experiment described in "An Empiricist Defense of Singular Causes" (note 1) the move is automatic from the singular claim "orbitting electrons caused the magnetism in *this* iron bar" to the general law "orbitting electrons cause magnetism." This fits well with my reading of the causal law: the electrons in this iron bar show us what orbitting electrons are capable of.

Third, from (1) above, probabilistic measures, even sophisticated ones like the path coefficient, are not entirely reliable in their implications about causal laws. So it would be very wrong to take the probabilistic association to constitute the causal facts. Probabilities at best provide evidence about causes. But what exactly are they evidence for? On the third front I maintain that the simplest account aligns the probabilistic methods with those of the one-shot experiment: in both cases the methods are used to ensure that we have seen at least one good single case of the kind of causal connection in question, a case where a capacity was elicited to produce the appropriate effect. If we take it that this is what we want to find out, then all the pieces fall into place to see why various probabilistic measures provide the evidence that they do for our causal claims.

2. The Failure of the Defeasibility Account

The considerations described in the introduction point to the primacy of singular causal claims in thinking about causal laws. But exactly what is the relationship between a law statement and a singular claim? I propose that the causal law attributes a capacity to the featured characteristic—say, being an aspirin—a capacity to produce the appropriate effect in individual cases. How then are we to think about capacities? It is this question that I want to concentrate on here.

One promising account, at first appearance, is modeled on ideas about defeasibility: the cause will produce the effect; if it doesn't there is a reason. But it seems that when one tries to give a more precise statement of this idea, it always leads to formulations that are either trivial or false. In fact, given the conclusions sketched above, this should not be surprising. For attempts to explicate what capacity ascriptions are true in terms of what things regularly do, or even regularly do in the unlikely circumstances where they get into the right conditions—is still an attempt to explicate causal laws in terms of regularities. This is exactly what I have been arguing can't be done in the painstaking sequence described at the beginning. There is no probabilistic theory of causality. There is no deterministic theory either. Associations are at best evidence for causal laws, and which particular associations are evidence and under what conditions depends finely on the concrete ways in which the causal feature is realized.

Consider an example. To make it clear that the problems of causality are not confined to the fuzzy realm of the social sciences, the example is taken from a branch of applied physics, the study of lasers. Laser theorists teach that the fundamental principle by which a laser operates is this: an inversion in a population of atoms causes amplification in an applied signal. The amplification is narrow band and coherent.[2] Inversion means there are more atoms in the upper state than in the lower, contrary to the way atoms come naturally. This already suggests that accounts in terms of 'normal conditions' have the wrong starting idea, since the conditions must be very abnormal before the causal antecedent is ever instantiated.

The example serves a number of purposes. First, it concerns a capacity which we learned about at a particular time. It is new with quantum mechanics. In classical mechanics inversions could not produce signal amplifications. Second, the language appropriate to the manifestation of capacities—that of harnessing them—fits perfectly here. Quantum physicists have known since Einstein's paper on the A and B coefficients that inversions *could* amplify. But not until the microwave research of World War II did anyone have an idea how to produce an inversion and harness its capacity.

Third is a point that will turn out to be my central thesis—a point about abstraction and defeasibility. We do know ways to produce inversions now. So suppose you want to amplify some signal. It won't do just to ring up the shop and order an inverted population. Suppose it is delivered to you in a brown paper bag! Now you might be more cautious. You may know some general defeating conditions for amplification. For instance, the inverted atoms must not have a strong absorption line of the right sort from the lower state of the inversion. In fact, physicists take this term absorption, which has a particular concrete meaning here, and use it more abstractly, as a catch-all, to describe anything that might take up the energy that the inversion should be putting out—scattering, thermal agitations, or whatever. So imagine even that you use this catch-all phrase, and order an inverted population (at a given frequency) in a nonabsorptive medium (for that frequency). Won't you want to say more?

The point is yes, but what you will want to say depends intimately on what medium the inversion is in and how it was brought about, as well as on specific features of the signal you want to amplify. For example, depending on what the inverted medium is, the temperature of the amplifier may have to be very finely tuned to the temperature of the source.

One of the early reports by P. P. Kisliuk and W. S. Boyle[3] on successful amplification in a ruby laser provides a good illustration. Kisliuk and Boyle report a gain factor of 2, using a second ruby laser as a source for the signal. The use of a laser source gave them a signal strong enough not to get lost in the noise generated by the amplifier. To get significant amplification, the frequency of the signal should be matched to the transition frequency in the amplifying ruby. But the transition frequency in ruby depends on its temperature, so the temperature of the source and the amplifier must be about the same. Not exactly, however, for the ruby line width is also temperature dependent, and the gain is a function of the line width; so the optimum condition for a given temperature of the source is reached not when the amplifier is at exactly that temperature, but rather when it is somewhat colder. The authors report: "The expected difference is of the order of a few degrees near room temperature. . . . As the temperature is lowered, its control becomes more critical because of the narrowing of the line."[4]

There is nothing special about the laser case. Consider a second example. Donald Glaser built the first bubble chambers, using diethyl ether. He operated on the principle that a passing charged particle has the capacity to cause bubbling in a liquid in a superheated state. (The liquid is ready to boil and just needs a catalyst.) He also was successful with hydrogen and most of the heavy liquid hydrocarbons, like propane or freon. But surprisingly, the bubble chamber didn't work with xenon. The reason depends on the peculiar nature of the xenon—here the passing charged particles were exciting optical transitions and the energy was being sent off as light rather than producing the heat necessary to catalyze the boiling.[5]

The point again is that once general defeasibility conditions are laid out, there remains a very large number of enabling and stopping conditions that are dependent on the particular realization. The least that follows from this is that there is no hope to convert the abstract "I's have the capacity to A" into a specific law "if I and C_1 and . . . C_n and not-R_1 and . . . not-R_m then A" even where A itself might already be a causal verb. I do not deny that there are regularities of this form, in fact a vast array of them. Otherwise two lasers identically machined would behave in different ways. But, as with my original remarks, these regularities do not constitute the truth of the general causal claim. They are merely evidence for it; and evidence that is not entirely reliable, for just the kinds of reasons I mentioned at the start.

Equally important, one must notice that the kinds of regularities pointed to by the defeasibility account—even if we use causal language in their expression—are not all, or even the bulk of, the regularities associated with the capacity claim. We have been looking at the kind of behavior that best provides evidence for a capacity. But there is also all the behavior that the capacity explains—what happens when there are preventatives depends on the capacity, just as much as what happens when there are no preventatives. So there is a very large stock of concrete regularities associated with the capacity claim, both regularities explained by the capacity and regularities that are evidence for it.

3. Abstractions and Idealizations

I want to turn now to something that on the face of it looks like a very different topic—the relation of abstract models in physics to the more concrete laws that they are supposed to explain. Consider the two diagrams, Figures 1 and 2, and their labels.[6] The first is a schematic diagram of a laser constructed from specified materials in a specified way—it is a diagram of the first helium-neon gas laser. The diagram is schematic; it leaves out a large number of features, possibly even a large number that are relevant to its operation. The concrete object pictured here operates, I believe, under some law. I call the law a phenomenological law because, if we could write it down, it would literally describe the features of this concrete phenomenon and the nomological links among them. It would be a highly complex law and would include a specific description of the physical structure and surrounds of the concrete device. Possibly it could not be written down; perhaps the features that are relevant to its operation make an open-ended list that

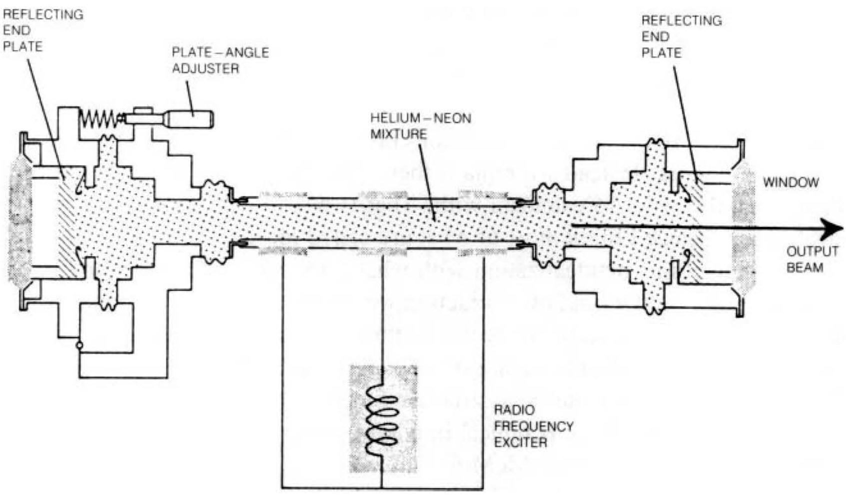
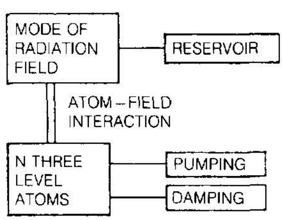


Figure 1. Sketch of He-Ne gas laser, Reprinted from William H. Louisell, Quantum Statistical Properties of Radiation. *New York: Wiley & Sons (Figure 8.1, p. 445).*



$$\frac{\partial S}{\partial t} = \frac{1}{i\hbar}[S, H_0 + W] + \left(\frac{\partial S}{\partial t}\right)_F + \left(\frac{\partial S}{\partial t}\right)_A$$

Figure 2. Block diagram of laser model. Reprinted from William H. Louisell, Quantum Statistical Properties of Radiation. *New York: Wiley & Sons (Figure 9.1, p. 470).*

cannot be completed. But because we are talking about a concrete object, there is some such law true of its operation.

Now look at the second drawing, and its accompanying equation. Here we do not have a schematic diagram for a particular laser, but rather a block diagram for *any* laser. In the block diagram we consider no particular medium, no specific way of pumping, no determinate arrangement of the parts. We abstract from the concrete details to focus, as we say, "on the underlying principles"; the equation we see here records one of these principles.

I want to distinguish this kind of abstraction from what I will call "idealization."[7] In (ur-) idealization, we start with a concrete object and we mentally discount some of its inconvenient features—some of its specific properties—before we try to write down a law for it. Our paradigm is the frictionless plane. We start with a particular plane. Since we are using it to study the inertial properties of matter, we ignore the small perturbations produced by friction. Often we do not just delete factors. Instead we replace them by others which are easier to think about, usually easier to calculate with. That is what I call idealization, or "ur-idealization," since I think most of what are called idealizations in physics are a combination of this ur-idealization with what I am calling "abstraction."

By contrast, in the kind of abstraction we see in the second example, we do not subtract or change some particular features of properties; rather mentally we take away any matter that it is made of, and all that follows from that. This means that the law we get by material abstraction functions very differently from idealized laws. For example, it is typical in talking about idealizations to say (here I quote specifically from Ernan McMullin): the "departure from truth" is often "imperceptibly small" or "if appreciably large" then often "its effect on the associated model can be estimated and allowed for."[8] But where it is the matter that has been mentally subtracted, it makes no sense to talk about the departure of the remaining law—a law like the one we see in Figure 2—from truth, about whether this departure is small or not, or about how to calculate it. After a material abstraction, we are left with a law that is meant not literally to describe the behavior of objects in its domain, but, rather, as I said, to reveal the underlying principles by which they operate—though saying this is just to label a problem.

What I want to focus on is the relationship between the abstract law and the vast network of laws that fall under it, which do literally describe the behavior of the concrete objects in its domain. For short, I call this network of complex laws, laws with highly detailed concrete antecedents, the "phenomenal content" of the abstract law. As with the causal example of inversions and amplifications with which we began, the phenomenal content of an abstract law is highly realization-dependent, and there is no recipe for going from the abstract law to its phenomenal content. The exact features which must be put back vary from one realization to another, and there is no further legitimate concept that covers them all. When I say legitimate I mean a concept that has independent criteria for its application, and does not just mean "whatever in the specific case is relevant."

I do not have a theory about what this relationship is or how it works. It seems to me that it is a crucial one; but there is no near-satisfactory philosophical account. In *Understanding Physics Today*, W. H. Watson gives a kind of Wittgensteinian account in terms of the unformalized and unformalizable training of physicists. I mention him because he points to the same problem that worries me: "In this way," he says, "we pass easily from one level of theory to another, usually a more abstract one. . . . Thus mathematical abstraction can be offered without its having to face the question, 'How is this relevant to the real world?' "[9]

Return now to capacities. Causal laws are best rendered, I claimed, as capacity ascriptions. Now what I want to say is that when capacity ascriptions play this role, they are functioning as material abstractions. Like our block diagram and its associated equation, they are abstract claims that cover and and explain a vast network of complex, detailed laws that do describe the behavior of the concrete objects in their domain; and like these other abstract claims, their phenomenal content is highly realization-dependent. The difference is that the realization-dependent laws that fall under a capacity ascription are laws about causings: "in such and such particular circumstances, x's cause y's," although, as with the non-causal case, these laws may not be finitely expressible.

4. Conclusion

I begin with an assumption that I do not defend here: contrary to Hume, we need some concept of singular causing already if we are to talk about causal laws. Then I present a structure with three tiers. At the bottom we have individual singular causings. At the top we have general causal claims, which I render as statements associating capacities with properties—"aspirins have the capacity to relieve headaches"; "inversions have the capacity to amplify." In between stands the phenomenal content of the capacity claim—a vast matrix of detailed complicated causal laws. Once the concept of singular causing has been let in, this middle level is unproblematic. These are just laws, universal or probabilistic, about what causings occur in what circumstances what percentage of the time.

The third level is more troubling. It sounds doubly non-Humean. First we have causal connections in the single case; then we add mysterious, or occult powers. But this is not what is happening. The capacity claim has two facets: first it is a material abstraction of a kind familiar in physics. It resembles the block diagram we looked at, and its accompanying equation; and it has the same peculiar and ill-understood relationship to the phenomenological laws that it covers. This relationship is indeed troubling, but it has nothing special to do with causation. Second, unlike the equation for the block diagram, the laws which make up the phenomenal content of the general capacity claim are laws about causings, and not about co-association. The use of capacity language marks this special feature of the phenomenal content. We see that the picture is not doubly non-Humean. Once we let in singular causation—as I think we must for other reasons—we have no more special problems with capacity ascriptions than with other abstract descriptions in physics. The laws of physics are indeed mysterious; but causal laws are not more mysterious than others.

Notes

1. Nancy Cartwright, "An Empiricist Defense of Singular Causes," forthcoming in a volume edited by Hide Ishiguro in honor of G. E. M. Anscombe. Also "Regular Associations and Singular

Causes," forthcoming in a volume edited by William Harper and Brian Skyrms. The fullest development of my views on these topics can be found in Nancy Cartwright, 1989. *Nature's Capacities and Their Measurement*. Oxford: the University Press.

2. Anthony E. Siegman, 1986. *Lasers*. Mill Valley, CA: University Science Books, section 1.1, "What is a Laser?"

3. P. P. Kisliuk and W. S. Boyle, 1968. "The Pulsed Ruby Maser as a Light Amplifier." In *Lasers*, ed. J. Weber. New York: Gordon and Breach, pp. 84–88.

4. Kisliuk and Boyle, note 3, pp. 84–85.

5. Peter Galison, 1985. "Bubble Chambers and the Experimental Workplace." In *Observation Experiment and Hypothesis in Modern Physical Science*, eds. P. Achinstein and Owen Hannaway. Cambridge, Mass.: MIT, Bradford, pp. 309–74.

6. From William H. Louisell, 1973. *Quantum Statistical Properties of Radiation*. New York: Wiley and Sons, p. 445; p. 470 respectively.

7. These views about abstraction versus idealization are heavily influenced by Henry Mendell. See Henry Mendell, 1985. *Aristotle and the Mathematicians*. Stanford University Ph.D. dissertation, especially 11.7, "The Abstract Objects."

8. Ernan McMullin, 1985. "Galilean Idealization," *Studies in the History and Philosophy of Science* 16:247–73.

9. W. H. Watson, 1963. *Understanding Physics Today*. Cambridge: the University Press.