Are causal laws a relic of bygone age?

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Abstract:

Bertrand Russell once pointed out that modern science doesn't deal with causal laws and that assuming otherwise is not only wrong but such thinking is erroneously thought to do no harm. However, looking into the scientific practice of simulation or experimentation reveals a general causal comprehension of physical processes. In this paper I trace causal experiences to the existence of innate causal capacity by which we organize sensory information. This capacity, I argue, is something we have got in virtue of natural selection as can be seen from experiments with intelligent animals like crows and chimpanzees. So understanding the empirical world is impossible without the use of causal categories. The reason why Russell believed that modern science does not refer to causal laws is, I think, because he argued that the laws of mathematical physics give us a non-causal description of reality. In contrast to such a claim I hold that theoretical laws are prescriptive rules of description rather than descriptions themselves.

Keywords: Causality; experience; biological evolution; laws of nature; scientific theories, and Bertrand Russell

The use of causal simulation on computers has become more and more common in order to picture what might have happened in the past and what may happen in the future. For instance, the current scenario about the origin of the Moon takes its creation to be the result of an impact between the very young Earth and the Mars-sized object called Theisa around 4.5 billons years ago. However, a recent computer simulation shows that rather than a big impact between the Earth and another very large object, another explanation just as plausible would be one in which a series of much smaller impacts each created a disk of debris surrounding the Earth that accreted into smaller moonlets eventually merging into one big moon. Such an alternative scenario seems possible given what planetary scientists know about the formation of the early solar system and the causal behaviour of gravitating and spinning bodies. Furthermore, because of the earthly composition of the Moon's minerals the latter scenario may be more probable than the leading scenario. Regardless of which one of these scenarios that is true they both provide us with a possible causal picture of what might have happened when our Moon was formed.

In modern science we see such computer simulations of the interaction and development of either physical, chemical, or biological systems being used in almost all disciplines. Programming a high-speed supercomputer with a causal model enables scientists to calculate the evolution of many dynamic parameters at once, thereby allowing them to depict what would happen with a system under the influence of internal or external causes. To be successful such a simulation requires that the scientists have sufficient knowledge of the particular causal processes involved in the hypothetical scenario to create a reliable numerical representation. But it also requires that they have a general understanding of what it takes for something to be causally related if such a simulation is correctly regarded as mimicking a causal process. Both conditions seem to be in place in most scientists because causal modelling and making computer simulation seem to be abundant among today's scientists. Yet, if we take a look at fundamental physics there is no indication that causation plays any crucial roles in physicists' way of understanding physical laws. Already more than one hundred years ago Bertrand Russell made this observation by claiming that the law of causality is a relic of a bygone age.

The question I want to raise in this paper is therefore how we got there and whether we still need the concept of causation to comprehend what goes on in modern physics. Why is it so that the concept of causation is fundamental for our survival and understanding of nature, but that the theories of physics, which are often regarded as the basic science for all other sciences, do not contain any references to such a concept? It seems evident that we have to know the concept of causality before we can discuss its legitimacy in today's physical thinking. I shall argue that it is only if one holds a representational view on scientific theories that there really is a conundrum. So my response to the Russellian statement is that scientific theories do not represent nature but establish the linguistic rules by which we may talk about nature. As long as one considers experimental practice to be fundamental for any theoretical insight into nature, our notion of causation is second to none. The concept of causality is fundamental for human understanding because it is given to us as part of our biological heritage.

1. Innate causal schemata

Not so long ago it was part of common sense that animals do not have the capacity to think and therefore could not reason about cause and effect. But all this has changed due to the study of some of the higher animals like dolphins, chimpanzees, ravens, and crows. These animals are intelligent and show signs of mental capacities involving causal reasoning. The indication does not only come from field observations. Ingenious behavioural problem-solving tests yield evidence for their non-verbal thinking. Thirsty crows presented with a half-full tube containing water drop pebbles into it, thereby raising the water to a level that permits them to drink. They are also able to choose heavy solid stones from hollow and light objects that would stay on the surface. So crows seem to have a clear causal understanding of what to do in order to increase the water level and what kinds of aids that can help bring about the wanted effect. This is not surprising given that a causal understanding of one's action with respect to the environment must be one of the most important factors for survival and will benefit any organism that has gained such a capacity.

Many animals have what it takes to have causal understanding without knowing that they have such an understanding. It is reasonable to assume that only humans have the capacity to know that they have causal beliefs. The Swedish philosopher and cognitive scientist, Peter Gärdenfors, suggests that causal understanding should be divided into four different phylogenetic levels of thought processes: (1) foreseeing the physical effects of one's own action; (2) foreseeing the physical effects of others' actions; (3) realizing the cause of others' action; and (4) realizing the cause of physical events (Gärdenfors, 2003, p 41). As he argues, many animals can manage the level expressed in (1), because there would be no point in having an inner world of experiences if one could not anticipate the probable consequences of one's own action. Further, some animals are able to predict the physical effects of others' action. Chasing prey may be possible only if the predator can foresee what would happen if the prey were allowed to move in this or that direction. Ravens seem to have the capacity to cooperate in order to narrow down the behavioural possibilities of their prey, just like lions and chimpanzee exhibit a similar capacity when stalking game or hunting smaller monkeys (Marzluff and Angell (2012), pp. 75-76). Gärdenfors mentions that one way of managing level 3 is to identify the intentions that drive the others. Crows may thus to a certain extent grasp what other crows think and attempt to think ahead of them. For instance, they distract attention and deceive their fellow species the moment they wish to hide food.

I assume that the capacity of these thought processes is innate. It is natural selection that provided higher organisms with the cognitive capacity to experience things and events as causally connected. Such a capacity I call a schema of causal understanding. There can be little doubt that the first three forms of causal understanding are part of some non-human animals' cognitive interaction with their environment. Gärdenfors takes a softer line as he discusses level 4. He sees it as "the typical case of causal reasoning", which "turns out to be surprisingly difficult for animals other than humans. However, the available data on how other animals handle the different kinds of causality is scant and much more research is needed in this area." Since Gärdenfors wrote his book more and more evidence has accumulated that animals as gifted as crows may have some comprehension of the causal laws of nature.

A very recent study on the performance of the New Caledonian crow is just one of several water displacement experiments that show that crows, rooks, and Eurasian jays to a certain extent understand what may cause a physical event. If a crow understands that dropping heavy stones into a water-filled tube causes the surface to rise, and that light objects will not have the same effect, it understands simple causal laws. The New Caledonian crows seem also able to estimate the size of a volume by paying attention to the narrow tube instead of the wide tube, and they can pass a modified test that only 7-10 years old children have been able to solve successfully (see Logan, Jelbert, Breen, Gray, and Taylor, 2014). But, as one would have guessed, the authors also concluded "our results do not provide support for the hypothesis that these crows can infer the presence of a hidden causal mechanism". Indeed, being able to understand cause-and-effect relationships is one thing, whereas understanding hidden causal mechanisms is quite another. The latter requires abstract thinking that may go well beyond other animals than humans.[1]

From an evolutionary point of view it is interesting that some birds, like *corvis* and parrots, have developed some form of causal thinking. Birds and mammals do not share any recent common ancestors and their brains are structured quite differently. It is assumed that their common predecessors split into different evolutionary branches sometime between 286-246 million years ago. Nevertheless, the pressure of the environment to adapt has resulted in a similar cognitive development in birds as in mammals. To see

[1] Some observations may be interpreted such that the New Caledonian crow is able to reason about hidden causal agents. This has been suggested by Taylor et al. (2012); whereas Boogert et al. (2013) in a response emphasize that there might be other interpretations.

how causal reasoning may have developed in mammals scientists turn to the investigation of our closest relatives such as the Great Apes and other non-human primates.

The evidence for a similar understanding of physical causes in non-human primates is not as impressive as with *Corvis*. A common problem-solving experiment to test chimpanzees' causal understanding is the trap-tube task. A transparent horizontal tube is designed with a trap along its length such that the chimpanzee must use a tool to extract a food reward, and at the same time it must avoid the trap in which food will drop if pulled or pushed over it. Several experiments in the past show that chimpanzees have difficulty learning to solve this task, and this lack of unambiguous evidence is the reason why Gärdenfors hesitates in ascribing a clear notion of physical causes to chimpanzees. One obstacle has been to decide whether unsuccessful results might be explained as a failure of the chimpanzees to abstract functional information from the stimuli by viewing the trap as an arbitrary cue or as an inability on their part to perceive the causal relationship between the trap and the loss of food. Another obstacle is that the use of tools may divide the attention of the chimpanzees between managing a long stick and avoiding the trap which would result in a poorer performance.

In a more recent study, however, the researchers tested eight chimpanzees on a non-tool-version of the experiment believing that the inclusion of a tool in previous experiments may have masked the chimpanzees' ability to avoid the trap. Their conclusion is in favour of the existence of a physical cause-and-effect understanding in the chimpanzees.

> The results of this study support the notion that the inclusion of a tool in the trap problem confounds the examination of both its solution and the cognition underpinning its solution. By testing chimpanzees without a tool, we have found that they are capable of solving trap problems with far greater ease than has been previously thought. Furthermore, we have provided evidence to support our hypothesis that the successful subjects did not treat the predictive stimuli as arbitrary cues but instead formed mental representations of their functional properties (Seed, Call, Emery and Clayton, 2009, p. 33).

With regard to functional properties the authors proposed about one subject, called Annette, that she "had encoded functional information, concerning features such as the solid and continuous shelf and the inability of objects to pass through barriers such as the blockers."

In another study, conducted with chimpanzees, orangutans, and children, the experimental set-up was quite different (Albiach-Serrano, Sebastián-Enesco , Seed, Colmenares, and Call, 2015). In this case one section of the experiment was designed such that the subjects had access to pulling two bands of paper, on one of which the reward was placed, whereas the other was broken and the reward was placed on the unconnected part of the strip. Earlier versions of this experiment had shown that non-human primates were able to focus on the functionally relevant cues and abstract from the irrelevant ones such as the colour of the bands. However, these versions were not sufficient to establish that chimpanzees have a causal reasoning competence because they might have learned to associate a broken band with only the visual cues that were presented to them. Therefore another section of the experiment was designed to test whether or not the subjects reasoned differently if they could not move the strips upon which the rewards were placed. Instead of paper bands, strips were painted very similar to the real paper bands.

> The ''real'' condition, made with paper strips, could be solved based on either perceptual knowledge or causal knowledge. The ''painted'' condition, which looked very similar to the real condition, could be solved only by learning from perceptual cues. Therefore, if subjects learned to solve the task based just on perceptual cues (e.g., avoiding the image of the gap), they should perform similarly in both conditions and should be able to transfer the solution from one condition to the next. If, alternatively, they had causal knowledge of the task, they should perform better in the real condition than in the painted condition and should not transfer knowledge from the former to the latter. (p.177)

During the trials under the real conditions the subjects should pull the continuous strip to gain their reward, but tested under the "painted" condition they only had to touch the continuous strip to get their treat. So the aim of both the trap experiment and the broken band experiment was to test the perceptual knowledge hypothesis against the causal knowledge hypothesis. The perceptual knowledge hypothesis is the assumption that the subjects do not learn how to solve the task in any other ways than by focusing on perceptual cues such as the connectedness of the band.

Evidently, neither apes nor humans can gain causal understanding of a particular problem without experiencing how things are and turn out to be. Induction works on past perceptual and behavioural experience. So learning from perceptual cues must mean that the subjects are able to distinguish between irrelevant or relevant signs. Colours, shapes, and sizes of the objects involved in the experiments will in most cases be considered contingent properties, and reliable experiments must be designed to exclude that these features play any permanent role in the subject's solution of the task. But what about visual phenomena like spatial contact or temporal succession? We know too well that it is improper to say that spatial contact and temporal succession are by themselves signs of causal powers. Our notion of causality is an abstract concept that does not only apply to what meet the eye. We need more information about the world before we can decide that visual cues like spatial contact or temporal succession may count as evidence for a causal relationship.

In contrast, the causal knowledge hypothesis holds that grown-up humans grasp the problem of causal relevance because they see various states of affairs to be causally connected and not just juxtaposed based on insight into the causal laws. However, earlier on-off experiments, where the food was either placed in close contact with the ribbon (but not connected with it) or indirectly placed on the ribbon, seem to indicate that chimpanzees were not able to distinguish between causally relevant and causally irrelevant contact. Whenever humans directly experience spatial contact between two things to be an example of a causally relevant contact it is because we already possess an appropriate causal understanding and we use the visual information to judge that the present situation belongs to a similar type of arrangements of which contact has proven to be causally relevant. This kind of knowledge might consist in grasping the situation by associating persisting objects or individual substances with causal powers. In other words, the assumption to be tested was that both children and chimpanzees have a real understanding of physical effects of a broken band and that chimpanzees, just like children, do not learn to solve the causal task merely by associative learning based on repeated experience of the same perceptual cues of the exact same situation over and over again. [2] The question was whether or not non-human apes could use analogical reasoning on information of past experiences that did not involve perceptual cues only.

The experiment tested a group of chimpanzees and a group of orangutans, and groups of 2, 3, 4-years old children under similar conditions. Each species was divided into two subgroups, one of which began their trials under the "real" condition and the other under the "painted" condition and after a number of trials the subgroups were swopped and tested under the other condition. The apes perform significantly better under the real condition than under the painted condition, and where they were above chance level under the real condition they were at the chance levels in the painted condition. The authors summarize their result by the following statements:

> Overall, subjects performed better in the real condition than in the painted condition despite the fact that both conditions looked almost identical and that similar contingencies were applied in both cases (i.e., picking the continuous strip provided the reward resting on top). When the second condition was removed from the analyses (to avoid order effects), all groups solved the real condition and no group (except for the 4-year-olds) solved the painted condition. In fact, whereas most of our subjects solved the former, no chimpanzee or orangutan, and only one 2-year-old and four 3-year-olds (4-year-olds aside), solved the latter, suggesting that the perceptual cues provided were not sufficient for them to learn in the amount of trials given. This is further supported by the fact that although all groups improved their performance throughout trials in the real condition (for the chimpanzees this was nonsignificant, possibly due to the need for more trials), none did so in the painted condition. (p. 185)

These results seem to prove that all the tested species solved the broken strip problem by relying on some innate causal understanding of the task. If the ability of the chimpanzees and the orangutans to solve the task had been learned only involved visual cues, one would have assumed that they could have performed just as well under the painted condition as under the real condition. But none of these species could transfer visual information from the real condition to the painted condition and use it to improve their chances to gain a treat. I think it is fair to conclude based on this test that human and non-human apes possess innate causal schemata but that this particular experiment, in contrast to the trap-tube experiment

[2] I consider understanding to be the organization of acquired beliefs and the causal schemata to be the innate cognitive disposition of an organism to structure visual stimuli into causally connected events. Hence understanding is different from knowledge. See Faye (2014), Ch. 2.

mentioned above, does not give us solid evidence that the apes understand some events to have physical causes.

2. Causal understanding and the world in itself

The common legacy of Hume and Kant is that the full notion of causation stems from our cognitive capacity of the mind. From the senses we receive the impressions of contact and succession to which the mind adds its idea of power or necessary connection among those sense impressions. Hume thought that it was our habits that forced us to see regular adjacent things as causally connected, whereas Kant took Hume's proposal further and argued that the notion of causation was an a priori category of understanding by which the rational mind grasps the sensations as they appear in sensory intuition. For both, the concept was part of our mental set-up. Little did they know that today's cognitive science and evolutionary biology would confirm that we process sensory input in a manner that provides us with a causal understanding of the world and that this capacity of the human mind is something that has evolved as part of our cognitive adaptation.

The Darwinian theory of evolution reminds us that selection and adaption take place whenever some genetic changes in the organism are beneficial for its survival and reproduction. This holds for physical as well as cognitive features. So the evolution of a causal understanding of the happenings in the world must have undergone a similar process of selection and adaption. But this says nothing about whether or not causal understanding is beneficial for animals, because this is how nature operates independently of any cognitive representation, and it just happens that a causal grasp of the world corresponds to the basic structure of the world. Another possibility would be that there is no further reason for the success of causal thinking than that it has proven to be successful in relation to the biological evolution. A claim of the opposite is mere guess work. To us it appears that the world is causally structured but this is exactly how it should be if causal thinking is beneficial for survival. We cannot go beyond experience and show that our concept of causation really corresponds to reality as it is in itself.[3]

It is well-known that Bertrand Russell argued that the concept of causation was of no use in science. He famously compared laws of causality to the monarchy: “The law of causality, I believe, like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm.“ (Russell, 1912, p. 1) If Russell was correct, does this indicate that the real world is not causally structured and that the notion of causality is suitable only for describing biological organisms and their cognition? Looking into the basi~~s~~ laws of physics we find no causal features, which seem to prove that Russell was correct in his mistrust in causal thinking. Based on this observation we may even conclude that it is possible for humans to go beyond human experience and characterize the real world, and not the world as humans experience it, as it is in itself. In other words, if the fundamental laws of nature represent the reality as it is in itself, and if the fundamental laws are not causal laws, then it seems as if we can conclude that causality is a category by which we and other animals comprehend our experience but nothing like it corresponds in the real world. However, such a conclusion is premature, I believe. Russell may be right about the structure of the fundamental physical laws and yet the explanation of the lack of causal features inherent in the laws of physics need not be that no such features belong to nature. This is what I want to argue in the remaining part of this paper.

3. Laws without causality

First of all it is safe to assume that the way we perceive the world depends on the cognitive faculties that the biological evolution has given us. These faculties have been selected to help optimize the organisms' interaction with their environment. How could it be that we might have certain cognitive faculties that

[3] From a Darwinian perspective it does not make much sense to claim that we can transcend our experience and establish by metaphysical reasoning the structure of the world-in-itself. All metaphysical questions can only be answered with respect to our experience. See Faye (2016) for a Darwinian approach to science and metaphysics.

were not selected by the environment unless we invoke God's intervention or the happenstance of a cosmic event? Such possibilities are not open for a naturalist. Also it is reasonable to assume that we cannot have knowledge of the world, which does not rely on these faculties and even supersedes the capacity of these faculties. If we accept that humans' cognitive abilities have evolved according to natural selection, it is plausible to assume that we do not have the capacity to grasp the world as it is in itself independently of human experience because human cognitive faculties are adapted to serve this experience only. Therefore, the conclusion is that seeing the world in causal terms is fundamental to human experience, and that physics as an empirical science has to make room for causal considerations in order to obey sense experience.

The practise of the experimental sciences reveals that behaviour and observation rely heavily on our causal understanding of the world. We use experiments to acquire knowledge of physical phenomena which would be inaccessible to us by mere perception, and experimentation makes sense to us only because the effect of our own and other animals' actions are understood in causal terms. Our actions are not blind but motivated by the effects they cause. Likewise experimentation presupposes a correct assumption that we can bring about physical effects that cause other physical effects. The comprehension of science and its practise requires the capacity of being involved in all four phylogenetic levels of the causal thinking: (1) foreseeing the physical effects of one's own action; (2) foreseeing the physical effects of others' actions; (3) realising the cause of others' action; and (4) realising the cause of physical events.

Nevertheless, it might still be true that physics as a theoretical discipline does not formulate causal representations and does not appeal to causal explanations in its understanding of physical phenomena. Such a claim is possible but it takes for granted that 1) the notion of causality in modern physical science does not refer to something different from mechanical forces and 2) fundamental physical theories, if successful, yield an objective description of the structure of the world. I shall challenge both assumptions.

We are disposed to see the world as causally structured, but this fact does not imply that the causal schemata are imposed on only one type of things, events, or processes. It can be imposed on all sorts of things that are experienced to accomplish certain functional or structural features, and when humans eventually formed a more reflective notion of causal relations including modal properties, this notion was applied to particular relations of things, event, and processes within very different scientific domains. I suggest that depending on the research context we should distinguish between different applications of the notion of causality. We may intend to talk about a *cause* and thereby to refer to the action of a thing or an individual substance, or we may wish to talk about *causal processes* and for that reason focus on the features that characterise the process.

A cause is something that brings about a change. For instance, my remarks made her laugh, the lion caused the death of a zebra, an avalanche caused a tree to break, etc. These examples all illustrate our basic schematized notion of causation in operation as we experience the connection between everyday things and events. In virtue of induction we have acquired knowledge about the circumstance under which individual things may be successful as causes. In other words, human and non-human animals have to learn to apply the innate causal schemata to what they actually sense, and it may take a while before they are able to realise that unfamiliar things are causally connected. Causal knowledge can be expressed as an empirical generalisation from previous experiences, and it enables us and other animals to foresee what will happen if the proper circumstances are met. Whenever we or other animals experience the right circumstance, we or they are, based on previous experiences, able to anticipate the result of bodily interactions with the environment. The ability to bring about something in the proper circumstances came to be regarded as the power of the subject to do so. Later the same ability was broadened out to include physical, non-bodily events.

In physics such powers are by analogical reasoning attributed to all physical things in the form of powers to move something by direct contact. Still, even though gravitation in classical mechanics does not work by direct contact between one body and another, the Earth's mass is often regarded as the cause of the unsupported stone falling to the ground or the cause of the Moon's deviation from moving in a straight line and orbiting around the Earth. The Earth and other bodies with a mass are able to exercise a gravitational force. Also in classical electrostatics is the term 'force' used to express the effect an electric charge has on other charges. Likewise we observe the presence of electromagnetic fields by their action on charged particles. Electric fields act on charged particles by pushing (or accelerating) them along the direction of the electric field. Magnetic fields only act on moving charges. In the presence of a magnetic field a moving charge senses a force that acts perpendicularly to the direction of its velocity. So the word 'force' in classical physics refers to the manifestation of the capacity of a certain entity to cause a particular change in another system. And in so far as physical theories include a term like 'force' it is reasonable to claim, or so it is argued, that these particular theories deal with causal laws.

In contrast to causes we have causal processes. We can think of radiation, current, corrosion, heat flow, solidification, melting, maturing, ageing, etc. as causal processes. A process is characterized by some more permanent entity that changes its properties while it develops in space and time. The reason why a process is named "causal" is that it is taken to obey the same criteria by which we get to know the presence of causes. If we know the cause of a particular effect and it is within our power to bring this cause about, we can produce the effect. But we can also intervene and prevent the cause from occurring with the result that the expected effect does not occur. These criteria can also be used to establish causal processes since a process is caused by an event prior to the process itself. But how causal processes are characterized depends on the discipline within which they are described, and how they are described does not fit into any causal law statement. For instance, radiation in physics may be described as transportation of energy from one point in space to another point in space. In basic physics processes might also be characterized in terms of other conserved quantities. Such descriptions tell us how we can talk meaningfully about physical processes. What they do not tell us anything about is how the world is causally connected.

This brings me to the most crucial point. People working with physics rarely distinguish between ontology and semantics. Physical theories are both considered to represent laws of nature and to provide the syntactic and semantic rules for describing those laws. But how can they functions in both ways? Considering the natural language Ferdinand de Saussure made a distinction between *langue* and *parole*. The first refers to the language system that includes a vocabulary and the syntactic and semantic rules for using the vocabulary. The latter signifies the spoken language in which sentences are stated or uttered according to the rules provides by the system. Because statements or utterances in their declarative form are about concrete state of affairs they may be true or false, whereas the linguistic system as such cannot be attributed any truth value. It is a natural phenomenon. I hold that a similar distinction must be made with respect to the mathematical language of science.

Scientific theories, as I see them, consist of a vocabulary and a set of syntactic and semantic rules for using this vocabulary. Newton's so-called laws of motion are in fact meaning-constituting principles which define certain quantitative terms in relation to one another. Moreover, the syntactic rules of a theory connect variables that stand for attributes and not substances, but the ascription of attributes to representation of individual substances takes place in models.[4] A physicist draws on a particular theory to describe an individual model in the same manner as an ordinary human being draws on a natural language to speak about everyday life. The difference is that the natural language contains words for both properties and entities that possess those properties, while a scientific theory only contains mathematical terms for properties, i.e. quantities. The terms for objects do not figure in the theory but come from an abstract representation of a concrete system that fits the vocabulary of a theory. Such abstract representations act as models for the theory. The model constructs concrete objects in an idealized way such that they are stripped from all properties that are considered irrelevant. For instance, Newton's theory does not contain terms for physical objects like the Sun, the planets, the tide, pendulums, billiard balls, etc. but if we think of these objects as abstract point masses we can make a model of a central force system or a model of a

[4] Arguments for a non-representational view on scientific theories can be found in Faye (2014).

pendulum, etc. on which we can apply Newton's theory in order to predict the motion of a particular system.

The linguistic rules are often taken to be the expressions of natural laws, but if they are rules for relating quantitative terms and thereby creating a linguistic structure, they cannot at the same time represent laws of nature. Examples are the basic equations of Newton's mechanics, Maxwell's electrodynamics, Schrödinger's wave equations, and the field equation of general theory of relativity. The mathematical formula provides us with explicit syntactic rules, whereas the semantic rules come from implicit conventions of interpretation by which the community ascribed physical meaning to the mathematical sign. For instance, the basic linguistic rules of wave theory are $\lambda = vT$, $f = 1/T$, $\omega = 2\pi f = 2\pi/T$, $k = 2\pi/\lambda$, where λ designates the wavelength, v the phase velocity, T the period of oscillation, f the frequency, ω the angular frequency, and k the wave number. Using these definitions it is possible to formulate more complex expressions like the wave equation of motion. In physics, however, such an equation is used in a context of a model where a concrete system is represented by a structure of abstracted entities. Not until a scientific theory is used to describe a model are scientists able to produce statements in the form of explanations or predictions that can be said to be true or false.

The above account brings us back to Russell. The theoretical laws of physics do not contain causal expressions because they are not about nature but provide us with instructions on how we can talk intelligibly about nature. The theoretical laws are definitions of the involved quantities. Apart from the theoretical laws a theory may contain other fundamental laws like conservation principles and other structural principles of description such as the constancy of the speed of light in vacuum and the quantisation of energy exchange.[5] The latter may be called boundary principles, not to be confused with

[5] Johansson (2005) makes a similar point. I subscribe to his argument that both mass as well as force are theoretical quantities and in Newton theory we therefore need the force law as well as the law of gravitation to define both. The main difference between him and me is that he holds that the theoretical laws can be true or false, while I believe that definitions are prescriptive and therefore cannot be true or false because there is something that makes

boundary conditions. The conservation principles and the boundary principles are all empirically well-established but within a scientific framework they have the status of constitutive principles for describing a physical system. Michael Friedman, being inspired by Hans Reichenbach, talks about relativized a priori principles that are constitutive for a scientific framework but, nevertheless, revisable during a scientific revolution (See Friedman, 2001). These principles have empirical content, but they cannot be empirically confirmed or disconfirmed within the same framework in which they play a constitutive role. This is similar to what I have in mind.

The theoretical laws of physics neither explicitly nor implicitly contain causal expressions since all of them say something about quantities and nothing about objects and events. Not until the fundamental laws are applied to some model that yields an abstract representation of an object or a physical system is it possible to formulate descriptions in virtue of which we can provide causal explanation. The fundamental laws provide us with instruction for the description of how a system behaves. But we need information about the forces acting on the system before we can say anything about its causal behaviour. This information is something that comes from the scientific practice of observation and experimentation. So based on observation and experimentation it becomes possible to formulate causal ceteris paribus laws, i.e. causal statements that are true in case some riders are satisfied. Because no causal relationship holds universally, but only if some factual circumstances are right, it is merely by empirical investigation that we can settle under which circumstances a certain type of event acts as a cause and under which it does not. Therefore the cognitive status of causal laws is remarkable different from that of theoretical laws.

4. Conclusion

them so. But theoretical definitions are revisable if we discover that they do not do their job properly in virtue of serving as vehicle for conceptual understanding.

Looking back on Russell's famous remarks about causality I have pursued two goals. The first was to show that even if he was right about the lack of causal laws in physical theories, the notion of causality is not an old-fashioned and obsolete concept. The concept belongs to the most fundamental ways of understanding the world or rather to the most fundamental way of characterizing our grasp of the word. It exists as an innate scheme by which not only humans – but other animals as well – organize and structure the perceptual content of their experience. Seeing one's action as causally connected with the world depends on cognitively more and more developed schemata by which various organisms organize their visual stimuli. As we have seen, experimental studies indicate that some higher animals, like crows and chimpanzees, may be able to understand the cause of physical events. In all animals it is part of a learning process to achieve competence in the application of causal schemata on regularities they have not perceived before. Some of the above experiments show that the capacity of causal thinking is part of the phylogenetic cognitive structure of the species, whereas the application of the causal schemata on a concrete set-up goes with the ontogenetic development of the individual organism.

The second goal was to show that Russell's claim about causal laws was both correct and incorrect at the same time. First I made a distinction between theoretical laws and empirical laws. A scientific theory is nothing but its theoretical laws. Theoretical laws are the linguistic rules recommended for describing aspects of a physical system given certain background assumptions, whereas empirical laws are not part of a theory and may or may not be causal. It is true that scientific theories do not contain causal laws. The reason, I suggest, is that scientific theories are not representations of physical affairs but provide us with meaning-constituting principles and other descriptive constraints which physicists then can apply on models that are intended to represent concrete physical systems. Causal laws, on the other hand, are empirical generalizations made in the light of observation and experimentation. They depend on ceteris paribus conditions.

As physicists set up a model their intention is to produce an abstract representation which helps them to explain a certain phenomenon. Such an explanation may be a causal or structural account depending on the type of question they want answered. The explanation may appeal to causal laws but it need not, and may just describe how something happens rather why it happens. Causal laws are not important as long as we want to understand particular events or processes. But causal laws are important for understanding the practise of science regardless of whether or not causal laws are mere regularities. The knowledge of such regularities is fundamental for our ability to conduct experiments and for our ability to understand the world around us. So causal laws may not be part of modern physical theories but they are indispensable for a successful experimental practise.

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