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Causal relations between features and inferences: The case of object representations

Lucille Dompnier and Françoise Cordier

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- 1 In theory-based conceptions of categorization, representations of categories are embedded in the individual's background knowledge. Concepts "make sense" in the light of this knowledge and become "mini-theories" (Keil, 1989; Murphy & Allopenna, 1994). Characterizations of background knowledge foreground the role of the causal links between features and consider these causal links to be the glue that ensures categorical coherence. The aim of this article is to address the central question of the causal relations between features and their role in the induction processes.

The relations between features: from correlation to causality.

- 2 Since the 1970s (Malt & Smith, 1984; Rosch, 1975; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), the question of the correlations between features has held center stage within the theories of conceptual representations. Features are correlated if they tend to appear together within a concept (McRae & Cree, 2002; McRae, Cree, Westmacott, & De Sa, 1999). Correlations between features include various types of relations: causal, spatial, temporal or any other type of co-presence in the environment, such as "has feathers" and "has a beak" in the representation of a bird. The idea of dependence relations (Sloman, Love, & Ahn, 1998) thus refers to the set of potential relations between features.
- 3 Correlations cannot be processed independently of a background of knowledge about the categories which is acquired through experience with objects, by using them, talking or reading about them (Cree & McRae, 2003; McRae et al., 1999; Murphy &

Spalding, 1995). Murphy and Wisniewski (1989) postulated that a link is constructed if the correlation is explicitly observed and, at an even earlier stage, that knowledge of a field focuses individuals on series of statistical correlations (Keil, 1989; Murphy & Medin, 1985). For example, in the concept of a bird, "has wings" and "can fly" are more closely linked than "has feathers" and "chirps". The role of a feature in the determination of category membership results from the salience of the link between this feature and other features.

- 4 Ahn, Marsh, Luhmann and Lee (2002) have tested the role of knowledge. These authors tested the hypothesis that features which are explicitly recognized as being correlated with one another are those features which individuals have theories about. Their results suggest, firstly, that in the face of the vast number of possible correlations between features, individuals tend to encode only those combinations of features which they can explain in terms of a causal relation. They favor the interpretation that holds that, wherever possible, these representations of objects consist of causal relations and that conceptual coherence is highly dependent on explanatory coherence (see also Ahn, Kalish, Medin, & Gelman, 1995; Ahn, 1998; Keil, 1989; Medin & Ortony, 1989; Rehder & Hastie, 2001; Rips, 1989).
- 5 Given this conception of knowledge which is primarily set within a framework of causal explanations, the relations between features are characterized by a directional asymmetry: the cause - or absence of cause - produces the effect - or absence of effect - without the effect acting on the cause. This idea of an asymmetry which is inherent to causal knowledge contrasts with the formalizations of similarity-based models (Hintzman, 1986; Medin, & Schaffer, 1978; Nosofsky, 1986) which postulate that knowledge can be described in terms of symmetrical relations between features. The directional or non-directional character of the relations is all the more important when we seek to understand inferential processes. In a bidirectional model, the presence of a feature A makes it possible to infer the presence of a feature B and the presence of feature B makes it possible to infer the presence of feature A. However, even if knowing that an animal "flies" makes it possible to deduce that it "has wings", knowing that it "has wings" does not make it possible to conclude that it "flies". It would appear that a formalization based on a relational asymmetry is more appropriate in accounting for the structure of object representations. Some authors (Pearl, 2000; Rehder, 2003a) have further noted that knowledge which is causal in nature, compared to knowledge which is correlational in nature, is more likely to result in appropriate action in the world and reasoning about situations.

Causal Status Hypothesis

- 6 The Causal Status Hypothesis (Ahn, 1998) postulates that the features that are most important for category membership are those which possess a causal status. The functional features of manufactured objects in Ahn's study were judged to be more causal than the molecular and physical features. In the case of natural object categories, molecular features were judged to be more causal than the functional and physical features. It is therefore the causal status of a feature and not its nature that influences an object's categorization. In Ahn's categorization task, the results were similar to those obtained by Barton and Komatsu (1989). Ahn suggests that a feature's weight resides more in its causal role than in the nature of the object to which it

belongs, and that, all other things being equal, exemplars that preserve theory-based correlations are judged to be better category members than exemplars that do not preserve such explainable correlations.

- 7 There are different ways of modeling the causal relations between features depending on the ontological domain in question. The concept named "*psychological essentialism*" postulates that, for individuals, the members of the ontological category of living things share a set of features, or essence, which determines their identity and regulates their membership of the category (Braisby, Franks, & Hampton, 1996). The features which constitute the essence are deep and not available to perception, whereas the features which result from the essence are external and available to perception, with the shared essence explaining the surface resemblances (Medin & Ortony, 1989; Strevens, 2000). Links between essence and external aspects could be considered in terms of causal reasoning within the biological domain. According to Rehder (2007a), this type of reasoning consists of two steps: Individuals reason backwards from the identification of the perceptual features to arrive at the essence and then make a decision based on it. Children as young as 5 years of age seem to call upon their prior biological knowledge and beliefs (Coley, Hayes, Lawson, & Moloney, 2004; Meunier & Cordier, 2009). Essentialism presupposes a lack of sensitivity to context.
- 8 If the categories of living things are compatible with the belief that the individuals in these categories possess an essence, what is the case for other types of categories, for example manufactured objects? Unlike the reasoning applied to the categorization of natural objects, the categorization of manufactured objects would seem to be underpinned by a teleological mode of reasoning which considers that they have been intentionally created for a given purpose (Bloom, 1998; Kelemen, 1999). The possession of features and their importance depend on this.
- 9 Some authors (Lin & Murphy, 2001; Medin, Lynch, Coley, & Atran, 1997; Ross & Murphy, 1999) have further refined these proposals and postulate that context also has an influence on the reasoning performed by individuals: When a natural object has a functional role in a specific activity - for a fisherman, a fish is a "product" and has the functions "be sold" or "be eaten" - its categorization may be underpinned by a teleological mode of reasoning. Thus, for these authors, it is, beyond the nature of the object that is to be categorized, the functional role or utility of this object in the individual's activity that influences the type of reasoning that guides categorization, i.e. essentialist or teleological.
- 10 In a complex network of features, a feature is rarely either a cause or an effect, but can be both a cause of some features and an effect of other features. Within an essentialist framework, only the distal causes are important for categorization. The same is not the case for teleological reasoning. We may well imagine that it is important to gain a more precise understanding of the circumstances of all the causes (distal, intermediate, proximal) that are involved in a task. Taking account of the influence of the task context may lead us to attribute greater significance to the causes which impact directly on judgment: the proximal causes.

Causal centrality (or causal density) hypothesis

- 11 Rehder (2003b) and Rehder and Hastie (2001, 2004) have also studied the relations between feature importance and causality but have done so on the basis of causal

centrality. This places the "be the effect of" and "be the cause of" relations on the same level and the centrality of any given feature is thus linked to the number of relations which radiate from it.

- 12 As far as categorization is concerned, is the most important aspect of features their causality, their causality and centrality, or merely their centrality? We have seen how the causal status hypothesis deals with this question. In the study conducted by Rehder and Hastie (2001), the various modalities were manipulated through the reading of short texts in which the number and arrangement of the causal links were varied (compared to a control text in which the described events were described as independent). The results argue in favor of the role of causal centrality: the importance of a feature increases with the number of relations it maintains. This led Ahn and Kim (2000) to propose the idea of multi-determinism in which the importance of a feature is a function of both its causal status and its causal centrality. All other things being equal, causes are more salient than effects. However, when an effect feature is involved in a large number of causal relations, the causal status is in some way "submerged" by the causal centrality. Nevertheless, Rehder and Kim (2006) claim that past demonstrations of a causal status effect arose because features were presented in their causal order. Consequently, the result may be attributable to a "coherence effect" which confers sense on features in the light of their causal relationships.
- 13 Do the "be the effect of" and "be the cause of" relations really occupy the same level? Redher and Burnett (2005) tested two types of causal links: the Common Cause schema (one feature causes three other features) and the Common Effect schema (one feature is the effect of the other three features). If we ignore the direction of the causality, the Common Cause schema and Common Effect schema are analogous. However, if the relations are asymmetrical, and even though the two schemas imply that the causes will be correlated with the effects, then the Common Cause schema further implies that there will be a correlation between the different effects as a result of their common cause, whereas the Common Effect schema does not imply any such correlation between the causes. Rehder (2003a) has proposed an interpretation for this: in the case of a Common Effect schema, the cause features are not correlated, but instead participate in an "ordered interaction", that is to say that each of the causes is weighted with reference to the others¹. Whereas in the case of a Common Cause schema, the degree of category membership increases as a linear function of the number of effects present, in a Common Effect schema, some causes are more important than others: the level of membership undoubtedly increases with the number of causes present but in a non-linear fashion.
- 14 The patterns revealed by the experiment conducted by Rehder and Hastie (2001) testify not to a symmetry of causal relations but to their asymmetry since the relations between the causes in a Common Effect schema are of a different nature from the links between the effects in a Common Cause schema. Like Cheng's causal power theory (1997), the causal theory proposed by Rehder and Hastie is based on an asymmetrical and probabilistic representation of causality. This is a generative approach in that it predicts the presence of links - correlations or interactions - between features which are not directly linked by a causal relation.

Inference production

- 15 One important role played by concepts is to permit inductive inferences (Anderson, 1990; Chaigneau, Barsalou, & Sloman, 2004; Heit, 2000). Inference production can be addressed in two ways using two different types of task: feature- extension or category-based induction tasks(Yamauchi, 2005). In a category-based induction task, one proposition is supplied as a premise and another as a conclusion. The task is to specify whether the item given as the conclusion possesses the same feature as the item described as the premise and the individuals' responses depend on the similarity between the items in the premise, the representative nature of the items, the number of premises that instantiate the conclusion, the scope of the conclusion, and the number of accessed alternatives to the conclusion (Heit, 2000; Heit & Rubinstein, 1994; McDonald, Samuels, & Rispoli, 1996; Murphy & Ross, 2005; Nisbett, Krantz, Jepson, & Kunda, 1983; Osherson, Smith, Wilkie, Lopez, & Shafir, 1990; Rips, 1989; Yamauchi & Markman, 2000). Background knowledge would therefore play a role in determining whether or not a feature present in a member of a category is generalized to all the members of the category. In feature extension tasks, a proposition is supplied as a premise and the participants have to judge the relationship between the features associated with one and the same object. For example, "this car is very comfortable. Does it have leather seats?" This type of task makes it possible to identify the features which are correlated within one and the same concept. An unobserved feature can be inferred from an observed feature if these two features are correlated in the conceptual representation. Is this unobserved feature more easily inferred if it is a cause, an effect, or merely correlated? We are interested here only in feature-extension tasks.

Inference production and causal relations

- 16 Are features inferred more easily when their cause(s) or effect(s) are present? Rehder and Burnett (2005) investigated this question by comparing a Common Cause condition (CC) with a control condition (CT). In the CC condition, the participants memorized four causally related features associated with the category: one of these features was the cause of the other three. In the CT condition, the participants memorized the four features but no causal relation was proposed. The learning phase was followed by an inference production phase. The authors then proposed descriptions of exemplars some of whose features were not mentioned. The participants had to judge whether these were absent or present. In the CC condition, the inferences relating to the cause feature were strongly determined by the presence or absence of its effects. Similarly, in this condition, inferences relating to one of the effects were strongly influenced by the presence or absence of the cause. However, when the cause was present, the probability of inferring an effect increased with the number of effect features that were present. This suggests that the effects, although thought to be independent - because they were presented independently - were processed by the participants as being predictive of their mutual presence. Rehder and Burnett refer to this as a *non-independence effect*.
- 17 The Common Effect schema (CE), in which one feature is independently caused by each of the other three features, was also tested. The results indicate that the inference regarding the presence of a cause is influenced by the presence of the other causes even when the effect is absent. These results bear out one aspect of the theory of causal

power proposed by Novick and Cheng (2004)²: a single cause is often perceived as contributing to the production of an effect but is also thought to be insufficient to produce it alone. What might be rendered as "hard work" does not entail success but has to be combined with other factors such as "talent" and "opportunity". This research therefore shows, firstly, that it is easier to infer a feature when its causes and/or its effects are present; secondly, that the "effect features" in a "Common Cause" schema or the "cause features" in a "Common Effect" schema are not processed independently of one another; and, thirdly, that these results can be observed for various ontological domains (manufactured or natural objects). We can therefore hypothesize that this effect is due to the presence of general causal knowledge independently of the ontological domains in question (Ahn, Novick, & Kim, 2003).

- 18 However, this non-independence effect was not reproduced in the study conducted by Perales, Catena and Maldonado (2004). Their experiment called on two fictitious micro-organisms - Ladiarium and Espiridia - which were presented as the potential causes of the appearance of a chemical substance in the air which was the subject of biological research (diagnostic - or Common Effect - condition). In contrast, in a predictive - or Common Cause - condition, the proliferation of each micro-organism was described as a potential effect of the appearance of a chemical substance. The results suggest that most of the participants inferred the existence of a correlation between two elements which were defined as being the effects of a common potential cause and did not infer a correlation between two potential causes of the same effect. The authors consider that causal directionality has an effect on the inference of the presence of a correlation here.
- 19 We believe that this difference in the result patterns obtained by Rehder and Burnett (2005), on the one hand, and by Perales et al. (2004), on the other, can be explained. The studies conducted by Rehder and Burnett did not make use of any task requiring the inference of correlations. It was the increase in the probability of a cause being inferred as the number of other present cause features increased in a Common Effect schema that suggested the existence of a non-independence effect. In the experiment conducted by Perales et al. (2004), the task required the inference of explicit correlations between features with the same causal status. Consequently, only the effects of one and the same cause were explicitly linked. The indicator of correlation is either direct (Perales et al.) or indirect (Rehder & Burnett). In some way, the format of presentation forces the reasoner to operate on a different representational format.

The inferential potential of features and the ontological domain

- 20 In the framework of the Common Cause schema or Common Effect schema, inference production are observed for various ontological domains, and could be due to the presence of general causal knowledge, that can directly be the medium of causal reasoning. We can underline that, methodologically, in the majority of the studies cited here, the material is constituted of a fictitious object that was described in terms of features between which certain causal relations were or were not established. In other respects, research on intuitive theories which focuses on existing knowledge about real object underlines that the domains of categories (manufactured or natural objects) differ in the way in which they support generalization (Coley et al., 2004). According to

Keil (1989), living objects possess more correlated features than other objects. Thus the inductive potential of manufactured objects should be less than that of living objects (Gelman, 1988). It seems interesting to examine in too much detail these two incompatible points of view.

- 21 Chaigneau and Barsalou (*in press*) consider the difference in inductive potential not in terms of the domain to which the object belongs but in terms of complexity: given an equal level of complexity, living and manufactured objects would have equal inductive potentials. Thus, the more complex an object is, denser the network of features which underpins its conceptual organization. It seems that complexity is not the only critical factor. The individual's prior beliefs with regard to the domain seem equally important, as we will show it below.
- 22 Whatever the ontological domain in question, Sloman et al. (1998) suggest that certain features have a greater inferential potential than others. According to Hadjichristidis, Sloman, Stevenson, & Over (2004), individuals generalize a feature from a given concept to a target concept if they think that this candidate feature is central for the target concept (see also Rehder, 2006): the inferential potential of a feature would thus be a function of the number of links it has with other features in this network - i.e. its centrality. Rehder (2006, 2007b), and Kim and Rehder (2007) have proposed a theory of property generalization in which "one computes whether a novel feature is likely to appear in a target category not on the basis of any one characteristic of the feature (e.g., its centrality), but rather on the basis of one's beliefs about the causal laws which relate the feature to those of the target category" (Rehder, 2007b, p.87-88). This effect is referred to as a *coherence effect*: individuals generalize a novel feature from a given concept to a target concept if they think that this candidate feature is consistent with causal laws. Consequently, the generalization of a feature in a task would not be determined by the presence or absence of the causal feature in the items, but instead by the number of violations of the causal relations expected for each of these items. Finally, Rehder (2007b) proposes that the inductive potential of categories thought to arise from folk essentialism concerning biological types may in fact arise from a more general phenomenon, namely theoretical coherence, which potentially applies to types of categories in addition to biological types.
- 23 However, Meunier and Cordier (2009) have shown that the coherence effect, like the causal status effect, is unable on its own to explain some of the choices made by 5 year-old children. In the two studies conducted by these authors, the items which possessed an *internal causal* feature exhibited one violated causal relation (the link between the *internal causal* feature and the absent *surface effect*), whereas the items which did not possess this *internal causal* feature exhibited two violated causal relations (the links between the absent *internal causal* feature and each of the *surface effect* features). In our first study, the preference exhibited by the 5-year-old children to choose the item with the *internal causal* feature rather than the item with no such feature might be due to the fact that fewer causal links are violated in the former than in the latter case. In contrast, when, in our second study, a symmetrical situation was tested and the causal status was associated with a surface feature, no causal status effect of the feature was observed. The coherence effect is unable to explain these responses on its own and we must take the children's prior beliefs about essentialism into account.
- 24 In the case of manufactured objects, the situation is not exactly the same. Given that the function of an object plays a major role, does knowledge of an object's function

make it possible to produce inferences concerning its structure? In a network of causal relations, it would seem to be appropriate to consider this aspect to lie at the heart of a complex relational system which brings together the object's physical structure, the action, the situation in which it occurs, the produced events and the intention of the object's creator (Ahn, 1998; Chaigneau & Barsalou, *in press*). We can thus speak of the function's affordance as described in Gibson's theory (1977). This point of view contrasts with that referred to as the "creator's intention" which gives this intention a higher status than that of affordance (Bloom, 1998). For example, an object created to be a tea-pot continues to be a tea-pot even when it is used to water plants. Chaigneau et al. (2004) have attempted to reconcile these approaches in the HIPE model. When considering a category of objects, individuals can make use of their knowledge about: (a) the object's design history (H), (b) the object's physical structure and the physical settings in which it is found (P), and (c) the events that arise during the object's use, such as agent actions, object behaviors, and outcomes (E). On any given occasion, an agent has an intention (I) for conceptualizing one particular sense of the object's function and constructs it dynamically using a subset of the available knowledge. Function must be thought of as a composite element (Barsalou, 1993). This approach therefore proposes that a causal model lies at the root of inferences relating to actual or imagined functions (Pearl, 2000).

- 25 This causal model reflects the individual's dynamic capacity to construct functional interpretations in many different situations. It has been tested. The results emphasize that the agent's action and the physical structure directly determine the function and that this is not the case for intention or for the agent's purpose. They also indicate that the absence of immediate causes amplifies the effect of the intention of the object's creator. The authors go on to propose two principles, namely the "causal proximity principle" and the "causal updating principle". The causal proximity principle controls causal reasoning about the object's functionality. Specifying the physical structure and the agent's action appropriately is sufficient to determine functionality. The causal updating principle applies when the immediate causes are ambiguous or absent and individuals are required to make inferences on the basis of remote causes which then mediate the determination of functionality. The objects used in this study were unknown to the participants since the scenarios specified their intention, their purpose, their utilization and their structure. The scenarios made it possible to manipulate these four types of information independently of one another.
- 26 Let us illustrate some parts of this model on the basis of the causal relations which underlie the judgment of the quality of a car, and more precisely the judgment of its comfort (Dompnier, Cordier, Kirsche, & Lescop, 2006).

Figure 1 Network of causal links between the features revealed by Dompnier et al. (2006) in the conceptual representation of a car. All the features are related to the *comfort* feature

- 27 The causes which are spatially the closest to the *comfort* feature are the features for which this feature is the sole effect. These are the proximal causes of *comfort*. The more remote causes, such as *colors* and *seat upholstery* for example, are also undoubtedly directly linked to the *comfort* feature but also to another proximal cause: *brightness*. This is a first-order remote cause. The two most distal causes are *the seat trimmings* and *the accessibility of the levers of the steering-wheel*. The most distal causes are directly linked to the *comfort* feature through the inference of a proximal cause. This is referred to as the *causal updating principle* by Chaigneau et al. (2004): information concerning the *efficiency of the suspension* makes it possible to arrive at a two stage inference concerning *comfort* by passing via the feature *felt vibrations*.
- 28 After having modeled the network of causal relations between the features in the conceptual representation of an object, Cordier, Dompnier and Ros (submitted) tested the analysis of the position of the feature in the causal network in a judgment task (evaluation of the quality of described objects on a scale:). The analysis of the factor “position of the feature in the causal network” clearly indicates that the distal causes do not seem to have a major impact on judgments, unlike the proximal and intermediate causes. These results indicate that it is necessary to stress the importance of the task context for the theoretical modeling of a causal network.

To conclude

- 29 The ontological nature of the objects used in the experiments, within this complex system of causal representations, could have an impact on the semantic coherence of the system and the weight of its elements. This result does not confirm the idea that

the coherence effect (Rehder & Hastie, 2004; Rehder & Burnett, 2005) is generalized whatever the ontological domain. Other factors must be taken into account: type of reasoning (essentialist or teleological), the individual's prior beliefs, and the type of tasks used. However, a complete model of causal induction must be able to specify how novel causal relations can be acquired even when specific prior knowledge is lacking. In the absence of such prior knowledge, can people use more general structural information to form a causal model with reference to an ontological domain?

- 30 We do not perceive our world or external objects as a stream of unconnected elemental features. Here, too, central processes act on the data to yield an organized view. Causal induction is an example of such organizing processes. The interest of theory-based models lies in the way they focus on these causal links between features. Their value also lies in the fact that they can be applied to a variety of domains such as folk theory of society (Hirschfeld, 2001), the interpersonal context of rational activities (Bonnefon, 2007), marketing and advertising, medicine (Haslam & Ernst, 2002) and others.

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NOTES

1. The aim of some theories is to capture the probability with which the cause actually causes the effects, for example *causal power theory* by Novick & Cheng, 2004; or *causal model approach* by Waldmann & Hagmayer, 2001.
 2. Causal Power is defined as the probability with which a candidate cause would produce an effect in the absence of any background causes. It is proposed that causal power can be intuitively computed from the cause-effect covariation information (Cheng & Novick, 1992; Luhmann & Ahn, 2005; Perales & Shanks, 2008)
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ABSTRACTS

The theory-based conceptions of categorization postulate the existence of a network of causal relations between the features involved in object representations and consider that this network underpins both judgments of category membership and inference production. The aim of this article is to examine the proposed models (causal status, causal density) within the framework of theory-based conceptions and indicate how they account for inferential processes. Finally, we underline the importance of the task context, and of the role of the nature of the ontological domain for the theoretical modeling of a causal network based on an asymmetrical, probabilistic representation of causality.

Les theories de la categorization fondees sur les connaissances postulent l'existence d'un reseau de relations causales entre les traits impliqués dans les representations d'objets et que ce reseau sous-tend à la fois les jugements d'appartenance catégorielle et les inferences. Cet article se focalise sur les processus d'induction. Son but est d'examiner les modèles proposés pour rendre compte des processus inférentiels (modèle du statut causal, de la densité causale). Nous soulignons l'importance du contexte de la tâche et de la nature du domaine ontologique dans une modélisation théorique d'un reseau causal, basé sur une représentation multidéterminée et asymétrique de la causalité.

INDEX

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