Relational-System Natural Kinds and the Function of Analogy

Theodore Bach

Abstract. Natural kinds are stable, mind-independent structures that support inductive practices. I claim that an important type of natural kind supports induction because kind-members exhibit a stable higher-order relational structure. For example, atoms and solar systems share certain likenesses because each exemplify the higher-order relational structure of a central force system – a type of relational-system natural kind of which atoms and solar systems are members. I argue that relational-system natural kinds are needed to explain the recent empirical finding that relational schema concepts have significant epistemic value. I further argue that analogical cognition – the cognitive process through which we can abstract relational commonalities – functions so as to develop relational concepts that describe relational-system natural kinds. These considerations bring together recent theoretical work in the philosophy of science and recent empirical work in the cognitive sciences. They also provide a new and naturalistically accommodating interpretation of the function of analogical cognition.

1. Introduction

Kornblith (1993) asks “What are we that we may know the world?” and “What is the world that we might know it?” Epistemological naturalism, at least in one of its forms, asserts that these questions are two sides of the same coin: identifying the knowable parts of the world will inform the nature of mechanisms whose function it is to know the world, and vice versa. Modularity theory presents one set of answers to these questions: many ontological domains are unobservable or often unavailable, but the mind consists of knowledge structures that have an innate basis and provide information about these domains. The goal of this paper is to describe a set of rival, domain-general answers to these questions. I will argue that there is an interesting ontological construct – “relational-system natural kinds” – as well as an epistemological construct – relational concepts learned through structural comparison – which together indicate how domain-general learning mechanisms can know the world.
In order for inductive practices to be successful there must be stable correlations of properties that repeat or co-occur throughout nature or a domain of nature. According to the explanatory approach to natural kinds, natural kinds are the mind-independent ontological structures that support successful inductive practice.\(^1\) In other words, a natural kind is a stable set of correlated properties that can be fruitfully studied. To use a stock example, instances of water reliably exhibit similar boiling point and potential to quench thirst. Scientists can observe these properties in a few samples of water and, on account of water’s status as a natural kind, accurately generalize these properties to unencountered samples. On the other hand, if a theoretical category fails to yield reliable predictions and explanations then this is evidence that it is not tracking a natural kind. The “superlunary” category of Aristotelian physics groups together all of the objects outside of the moon’s orbit. As Griffiths points out, “nothing follows from the fact that an object is superlunary other than the fact that it is superlunary and trivial transformations of this (e.g., it is not sublunary). There is no epistemic pay-off to be had by using this category” (1997, p.171). The objects outside of the moon’s orbit are an objective type (Armstrong 1989), but they are not a natural kind.

The explanatory approach frees the notion of kind-essence from its traditional and problematic implications. The essence of a natural kind on this view is the source that organizes, or accounts for, reliable property correlations (Boyd 1999; Kornblith 1993; Griffiths 1999;)

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\(^1\) The following philosophers adopt some version of the explanatory approach to natural kinds: Quine (1969), Kitcher (1984), Boyd (1999), Dupre (1993), Kornblith (1993), Griffiths (1999), Millikan (2000), and Laporte (2004). For specific formulations, see Boyd’s “accommodation thesis” (Boyd 1999) and Millikan’s theory of “substances” (Millikan 2000, chapter two). Two important issues for this theory of kinds are not discussed here. The first concerns how much of a contribution a theoretical category must make to inductive practices in order to reference a natural kind. On one view (Griffiths 1999) reference to kind members must at least result in above chance predictions. A related issue concerns whether the legitimacy of explanatory schemas can be extended outside of the academic sciences (see Dupre 1993; Boyd 1999; Millikan 2000; Laporte 2004). Boyd and Millikan suggest a continuum of epistemic legitimacy, with some folk inferential practices (e.g., folk psychology, folk physics) found at or just outside the limit of kind-tracking explanatory schemas.
Millikan 2000). It is the select property, or set of properties, that explains why one instance of the kind is non-accidentally like another instance of the kind. In the case of water, the source of property correlation is the microstructure H2O: the reason that two samples of water share a similar boiling point is their intrinsic microstructure. However, sources of property correlation are not always intrinsic features of kind-members. Any source of property correlation that supports induction functions as the essence of a theoretical category, or at least plays the theoretical role assigned to “essence” on Aristotelian and positivist models. It is now widely accepted that kinds often manifest property-regularity on the basis of relational properties. While generalizations that range over such kinds are more exception-prone, they nevertheless make important explanatory contributions. For example, the economic category money yields important generalizations (e.g., about inflation) that, while not exceptionless, are not available on explanatory schemes that restrict classifications on the basis of intrinsic properties.

2. Natural kinds with relational-structural essences

The explanatory essence of a relational-system natural kind is a stable structure of higher-order relationships. Formally, a relational system category such as robbery, democracy, chasing, and ecosystem is a relational system natural kind (RSNK) if it: (1) consists in a structure of higher-order relationships that is stable and explanatory of characteristic properties, thereby supporting inductive practices; and (2) is in principle multiply realizable. Token systems, e.g., individual members of RSNKs, consist in a set of individuals, objects, and/or events that realize the induction-supporting relational structure. The essence of a RSNK is not the realizers of the relational roles but the higher-order relational roles themselves. Put slightly differently, the

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essence of a RSNK is the set of individuals under the aspect of their relations to one another. Relational-role kinds are then identified with specific roles in relational systems.

Consider the kind money again. Money is not a RSNK though it is a relational role kind defined by its role in a RSNK that consists of various other relational roles such as buyers, sellers, resources, and so forth. This particular relational complex – variously called the “market” or the “economy” – is stable and repeats throughout nature. Because of this relational stability we can study a few instances of the market and make some reliable generalizations to other spatio-temporal instances (of that token system, but also to other token systems that are members of the RSNK). For example, the structural relationship between price level, currency, capital, and consumers (and not green bills and the buildings on Wall Street) explains why economists can predict that sharply rising inflation rates will lead to discouraged investment. Note that the membership conditions for RSNKs are more general than the conditions for functional kinds (ontological units that are implicit but rarely defined on many accounts). A central force system, for example, is a RSNK. The reason that the solar system, the satellite system of Earth and the moon, and the atom (Rutherford and Rydberg) share certain similarities is because of a naturally stable relational structure, e.g., the relations between mass, attractive force, and the distance between central and peripheral objects. Yet central force systems are not plausibly functional categories. Other examples of RSNKs include ecosystems and calculators. More controversially, symmetry and modus tollens are RSNKs.

Water, on the other hand, is not a RSNK. Following Putnam’s intuition, XYZ watery stuff lacks the essential water property H2O. Water is not multiply realizable. Assuming there is

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3Because the relationships that define RSNKs are more general than functional relationships, the proposed ontology is distinct from a functional ontology. But when the defining relations are causal-functional, RSNKs should be thought of as analogous to higher-level “role” kinds as opposed to, say, “realizer” kinds. I will leave open what types of relations can define a RSNK.
such a thing as XYZ water, would “surface water” name a RSNK? The answer will depend on some further details about surface water. If the components X, Y, and Z have causal profiles radically different from the causal profiles of H, H, and O, then there is no common and stable higher-order relational system that is grounding inductions across H2O water and XYZ water, in which case the likenesses are truly accidental. On the other hand, imagine that the chemical designations X and Y co-refer such that X and Y have the same causal profile. Imagine further that X and Y, while exhibiting intrinsic differences with H, bear a causal relationship to Z that is similar to or the same as the causal relation that H bears to O, and also that Z, while exhibiting intrinsic differences with O, bears a causal relationship to X and Y that is similar to or the same as the one that O bears to H. In this case we witness a stability of higher-order causal relationships that repeats in nature and which is multiply realized; in this case surface water is a RSNK.

Relational kinds contrast primarily with intrinsic kinds and historical kinds (e.g., species). But these divisions are not sharp. For example, relational kinds and intrinsic kinds occupy locations on an inductive spectrum, with relational properties accounting for inductive success at one end, and intrinsic properties accounting for inductive success at the other end. For example, relational properties play a more central role in explaining the likenesses between carnivores then they do in explaining the likenesses between tigers. Of course, the distinction between relational and intrinsic properties is also not exclusive. As Lewis remarks “…properties may be more or less extrinsic; being a bother has more of an admixture of intrinsic structure than being a sibling does, yet both are extrinsic” (Lewis 1983, pg. 197). Putting this together, the likenesses between members of an RSNK are mostly explained by properties that do not have a significant admixture of intrinsic structure.
3. The epistemic value of conceptualizing relational system natural kinds

Conceptualizing relational systems requires having a mental predicate that relates arguments. What does this require? The relational category chasing is exemplified by a dog chasing a cat in one spatio-temporal location, and a cat chasing a yarn in another spatio-temporal location. In order to understand both as instances of chasing, a child must have a representational symbol – the mental predicate CHASING – which can be matched across representations of the situations. This means that the predicate must be untethered from any particular argument values. If a child’s use of the mental predicate CHASING is restricted to the argument values DOG and CAT, then the child will not grasp that the cat is also chasing the yarn. Such a child does not possess the relational system concept CHASING. Relational role concepts (e.g., PERSUANT) are defined in reference to their superordinate relational systems (e.g., CHASING). Concepts for relational-role categories therefore describe the roles that comprise relational systems.

Researchers in the cognitive sciences have recently converged on the importance of relational concepts in higher-order cognition. In particular, researchers agree that relational concepts are central to causal-explanatory (Gentner & Medina, 1998; Ahn et al., 2000), analogical (Gick & Holyoak, 1983; Gentner & Kurtz, 2006), mathematical (Dixon & Bangert 2004), perceptual (Kotovsky & Gentner, 1996; Green & Hummel, 2004), and creative (Gentner et al., 1997; Nersessian & Chandrasekhar, 2009) aspects of cognition. If relational concepts track relational categories, this should not be surprising. The behavior of an object/event is often explained by its participation in a relational category. For example, we explain how a particular ecosystem functions in terms of relational roles such as predator and carrying capacity: predict
the motion of planets in terms of a central force system; and explain the validity of an argument in terms of the relationship between premises and conclusion. More pedestrian, we explain how a person can have a conversation with another person who is thousands of miles away in reference to the relational system of telecommunication but not in reference to the particular shape, color, or weight of a telephone (non-relational categories).

3.1 The relational shift

Research indicates a learning bias during development against relational categories and in favor of object categories. According to the Mac-Arthur Communicative Developmental Inventory, of the 296 nouns that 8- to 16-month olds understand, 93 percent are entity nouns and 7 percent are mixed entity-relational nouns (Gentner, 2005, p. 251). When children do learn relational terms, they are initially treated as entity terms (ibid. p. 251). An important difference between object and relational categories explains this bias. Object categories have rich overlap of superficial features that are readily detectable by children. In contrast, the axes of similarity that bind relational category members are less obvious and detecting them requires conceptual sophistication. As Gentner puts it, object categories are “out there” – they are perceptually obvious partitions in the world. Members of relational categories, on the other hand, are diffuse and varied.

Gentner & Ratterman (1991) describe this developmental curve in terms of the “career of similarity” thesis:

This account posits that within any given domain (a) overall similarity is the earliest and most naturally responded to…and (b) the order in which partial matches come to be noticed is, first, matching objects, then matching relations, and finally matching higher-order relations. Our assumption is that this sequence is epistemological, not maturational: Children come to perceive similarity between objects (e.g., the likeness between a red apple and a red ball) before they
perceive similarity among *relations* (e.g., the similarity between an apple *falling from* a tree and a *spoon falling from* a table); and appreciation of such lower-order relational similarity in turn precedes appreciation of higher-order relational similarity (similarity in relations between relations: e.g., the similarity between a squirrel swishing its tail and *causing* an apple to fall from a tree, and a toddler waving her arm and *causing* a cup to fall off the table). (Kotovsky and Gentner, 1996, p. 2798)

It is useful to frame the challenge of this epistemic ascent in terms of the multiple realizability of relational categories. It is difficult to abstract the concept BARRIER because barriers are realized by concrete walls, cell membranes, and poverty. It is similarly difficult to conceptualize the category *gift* because gifts are realized by diamonds, flash-frozen steaks, and the act of naming a star after someone. In fact, a common conceptual mistake is to identify a relational category with one of its realizers, as when a child identifies *uncle* with “a nice man with a pipe” (Gentner and Kurtz, 2006). Going in the other explanatory direction, the framework of relational categories places Fodor’s and Putnam’s criticism of mind-brain identity theory in developmental context: according to Fodor and Putnam, identity-theorists commit a sophisticated version of the child’s error when they identify the relational category *mental state* with one of its object-level realizers, namely, brain states.

4. Implications for a naturalized analogical cognition

I assume that a central purpose of cognition is to discover and gather information about explanatory kinds. It would be advantageous if cognizers possessed a mechanism that aided the discovery of the essential properties of RSNKs, a type of natural kind. Because RSNKs are found in many domains, an ideal mechanism would possess the flexibility to discover RSNKs in
various domains. Contrast this to modular mechanisms, which are domain-devoted and, as a result, considerably less flexible.

Recent empirical work on analogical cognition strongly suggests that structural comparison – the fundamental feature of analogical cognition – is a domain-general learning mechanism which facilitates the development of relational concepts that describe explanatorily valuable RSNKs. Empirical and computational theories of analogical cognition, and in particular Gentner’s widely accepted *structure-mapping theory* (SMT), claim that when cognizers compare two domain representations (e.g., the representations of an atom and a solar system) they are psychologically constrained to map and focus on relational predicates while discarding non-relational attribute features. But, as Goodman has pointed out, there are always many relations. It is true of almost any object pair (e.g., a solar system and an atom) that they share the relation “larger than a grain of sand”. What is to prevent *this* relational predicate from being mapped and focused on during structural alignment? If analogy involves a highlighting of relational predicates, there must be a constraint that guides the mind towards specific relational commonalities.

To solve this problem, SMT puts forth a central claim in a processing constraint called *the systematicity principle*. This principle asserts that when aligning two representations, people prefer “a predicate that belongs to a mappable system of mutually interconnecting relationships” (Gentner, 1983, p. 163). Thus the representational alignments that drive similarity cognition create a focus only on those relational commonalities that are similarly embedded in interconnected systems of relations. In other words, the mind will seek out a relation if it is a component of some larger *system* of relations. Consider the Rutherford analogy, “the atom is like our solar system”. The systematicity principle predicts that alignment of the atom representation
and solar-system representation will highlight the common relation: *The planets/electrons REVOLVE AROUND the sun/nucleus*. This relation is preserved because it is constrained by the higher-order relation: *The fact that X attracts Y CAUSES Y to revolve around X*. This deep relational system can also be extended to include the mass of the sun/nucleus and its causal connection to the above higher-order relation. Because *hotter than* does not participate in an interconnected system of relations, it is (fortuitously) an ignored relation in the mapping process.  

But perhaps the most important finding for this research program is that structural comparison facilitates the abstraction of relational predicates which can then be used as the basis to form relational concepts that describe RSNKs. When two structured representations are aligned and mapped, cognitive constraints act to promote the salience of relational information. Metaphorically, when we align two representations a common relational structure will “pop-out”. Gentner et al. (1997) call this “the comparison as X-ray phenomena”. For example, the act of comparing the atom to the solar system can highlight the higher-order relation “the fact that a central object attracts peripheral objects causes peripheral objects to revolve around the central object”. In addition to learning about the atom, learners can develop a more abstract and explanatorily useful understanding of a central force system.

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4 The studies from Clement and Gentner (1991) provide direct evidence for the systematicity principle. Participants in the study had to select which of two relations to match with a third relation. The only difference between the two relations was that one of them was part of a causal system and the other was an isolated relation. Participants strongly preferred the systematic relation over the non-systematic relation. More generally, the processing principles of SMT have been computationally simulated by the Structure-Mapping-Engine (SME) with considerable success (see Falkenhainer et al., 1989). Besides providing computational meaning to the spatial metaphor of structural “alignment”, SME demonstrates that a real-time learning mechanism can arrive at a deep, structural mapping without any prior programming for the target structure. SME is intended to model an actual executive-function mechanism that we can call the “analogies processor” (see Gentner 1989, pg. 215). By means of parallel or dialogical processing, the analogy processor can scan two domain representations and determine which predicates are semantically similar. It then deselects object-matches and constructs candidate structural mappings according to the parallel connectivity constraint. Finally, it selects a structural mapping based on the systematicity constraint.
Now consider that structure-mapping abilities arise very early in development. There is evidence that children can transfer relational knowledge at 10 and 13 months (Chen et al., 1997), and even at 7 months (Kuehne et al., 2000). If structure-mapping ability is innate, then this raises questions about its adaptive purpose. A reasonable, and I think compelling, possibility is that the function of structure-mapping abilities is to facilitate the abstraction of relational knowledge structures that correspond to the essential properties of RSNKs. Indeed, the systematicity constraint privileges relations that are embedded in higher-order relations, thereby targeting interconnected systems of relations – the relational clusters found in nature – rather than gerrymandered, Goodmanian similarity classes. Also, because structure-mapping processes are domain-general, they have the flexibility to discover RSNKs across a range of domains. Surely this domain-general mechanism would often be a more economical solution to the epistemology of RSNKs than a confederacy of domain-devoted (e.g., modular) mechanisms.

5. Conclusion

Natural kinds are objective stability structures that permit minds like ours to gather information about kind members and then project this information to unencountered members. I argued that there is an interesting type of natural kind for which kind-members are like one another because they exemplify the same higher-order relational structure. This type of natural kind has not received sufficient theoretical attention, yet recent empirical research in the cognitive sciences has shown that relational concepts that encode such kinds have considerable epistemic value. The current essay endeavored to bridge work in naturalized metaphysics with empirical work in the cognitive sciences. A compelling finding was that analogical cognition
may have the function of extracting relational predicates that are central to our conceptual abilities to track an explanatorily important type of natural kind.

References


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