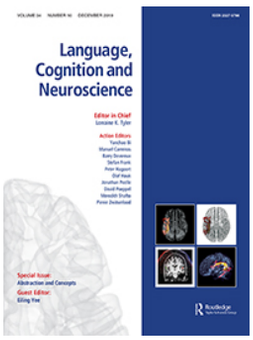

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Metaphoric extension, relational categories, and abstraction

Dedre Gentner[a] and Jennifer Asmuth[b]

[a]Department of Psychology, Northwestern University, Evanston, IL, USA; [b]Department of Psychology, Susquehanna University, Selinsgrove, PA, USA

ABSTRACT

We propose that concepts exist along a continuum of abstraction, from highly concrete to highly abstract, and we explore a critical kind of abstract category: relational abstractions. We argue that these relational categories emerge gradually from concrete concepts through a process of progressive analogical abstraction that renders their common structure more salient. This account is supported by recent findings in historical linguistics, language acquisition and neuroscience. We suggest that analogical abstraction provides a major route for the development of abstractions in language and cognition.

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Analogical abstraction; progressive alignment; career of metaphor; concept development; relational categories

Theories of embodied cognition have emphasised the role of sensorimotor systems in conceptual representation (Barsalou, 2008; Gibbs, 2006; Glenberg & Kaschak, 2003). A core assumption of this view is that conceptual processing recruits the same neural systems that are engaged during perception and action. Evidence that semantic processing can be influenced by a person's concurrent actions and perceptions (Kaschak et al., 2005; Kaschak, Loney, & Borreggine, 2006; Meteyard, Zokaei, Bahrami, & Vigliocco, 2008; see Vigliocco, Meteyard, Andrews, & Kousta, 2009, for a review) has led some theorists to propose that all representations are modality-specific (e.g. Barsalou, Breazeal, & Smith, 2007). This raises the question of how – and even whether – abstract concepts could come about.

We contend that people possess abstract concepts as well as concrete, sensorimotor concepts. We propose further that there are rich connections between concrete, embodied concepts and abstract concepts (Goldstone & Barsalou, 1998). Specifically, we propose that abstract concepts often arise from concrete concepts, as suggested by the fact that metaphoric systems drawn from concrete experience are often used to express abstract ideas (Boroditsky, 2000; Lakoff & Johnson, 1980). We further propose that there is a continuum of abstraction from highly concrete to highly abstract, such that many relatively abstract concepts still retain aspects of their concrete meaning. We present psychological, historical, and neural findings to support the claim that there is a continuum of abstraction, focusing on a particularly important class of abstract concepts – *relational abstractions*.

Because the idea of abstraction is used in multiple ways in cognitive science (Burgoon, Henderson, & Markman, 2013), we begin by clarifying our usage. By *abstract*, we mean having few properties that are available to the senses. For example, a concrete concept like *cat* has multiple sensory properties – it can be seen and touched; it has characteristic patterns of movement and characteristic sounds, and so on. In contrast, the concept *justice* cannot be tasted, seen, or heard. *Justice* cannot be recognised by any perceptual characteristics. We take the process of abstraction to be one of decreasing the specificity (and thereby increasing the scope) of a concept.[1]

To preview, our thesis is that

- Relational concepts are critical to human reasoning
- Relational concepts often evolve from concrete, embodied concepts via a process of structural alignment and abstraction
- Language use influences the emergence of relational concepts, both in children's learning and in language evolution
- The gradual abstraction of concrete concepts into relational concepts is one main route by which abstractions arise in language and cognition

The importance of relational concepts

The ability to represent and reason about relations between entities or situations, and to perceive common relations across disparate situations, is a key

CONTACT Dedre Gentner gentner@northwestern.edu
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feature of higher-order cognition and one in which we greatly exceed other species (Christie, Gentner, Call, & Haun, 2016; Gentner, 2003, 2010; Penn, Holyoak, & Povinelli, 2008). Gentner, Loewenstein, and Thompson (2003), Gentner (2010) and Christie and Gentner, (2010, 2014) have argued that relational thinking is essential for higher-order cognition, and that the acquisition of relational concepts is critical in cognitive development (See also Chatterjee, 2010). Relational thinking is also critical for acquiring expertise within mathematical and scientific domains (e.g. Goldwater & Schalk, 2016; Richland & Simms, 2015). More broadly, relational concepts are integral to our intellectual and social life; consider relations like *causation*, *contradiction, agreement,* and *dispute,* for example. Thus it is important to understand how relational abstractions are acquired and how they evolve within a language.

One way to trace the cognitive benefits of learning relational concepts is to observe the effects of learning relational language. For example, Pruden, Levine, and Huttenlocher (2011) coded children's production of spatial language (including spatial relations such as *edge* and *side* as well as dimensional terms such as *tall*) during natural family interactions. Children's spatial language between 14 and 46 months predicted their performance on nonlinguistic tests of spatial ability at 54 months. More direct evidence that learning and using relational language can support relational cognition comes from studies by Loewenstein and Gentner (2005). They gave 3–5-year-old children a simple spatial mapping task, in which children saw an object hidden in a three-tiered box and had to search for a "winner" object in the corresponding place in an identical box. The children were more successful if they had heard spatial relations for the three tiers (e.g. *top, middle, bottom*). The relational language advantage persisted over a two-day delay, even when no spatial terms were used at test (Loewenstein & Gentner, 2005) – evidence that spatial relational language influenced children's representations of the scene (rather than being some sort of immediate priming effect). Loewenstein and Gentner concluded that applying this relational framework helped children delineate the two spaces and see the correspondences.

If spatial relational language is instrumental in forming relational representations, then children who lack terms for spatial relationships may be seriously disadvantaged in spatial tasks. Gentner, Özyürek, Gurcanli, and Goldin-Meadow (2013) gave the same spatial mapping task to 6-year-old deaf children in Istanbul, whose hearing loss had prevented learning a spoken language, but who not been exposed to a sign language. Although they had developed their own gesture systems (*homesigns* (Goldin-Meadow, 2003)) to communicate with others, these homesigns did not include stable gestures for spatial relations. Compared to hearing Turkish children (matched by responses on a different spatial task), the deaf children performed significantly worse on the spatial mapping tasks – at or only marginally above chance. Gentner et al. concluded that the deaf children were less successful in the spatial mapping task because, without a consistent set of spatial relational terms, they were less likely to represent the arrangements of the boxes in a uniform way and therefore less able to align the two arrays. These findings suggest that having explicit language for spatial relations gives children the tools to create corresponding relational representations.

Gentner (2010, 2016; Gentner & Christie, 2010) has proposed that relational language supports the acquisition and use of relational concepts in several ways (see also Pyers, Shusterman, Senghas, Spelke, and Emmorey (2010) and Shusterman, Ah Lee, and Spelke (2011) for examples of the importance of consistent spatial terms in Nicaraguan Sign Language and in navigation through a search task). One key role of relational language in acquisition is that common language invites comparison (Gentner & Medina, 1998; Gentner & Namy, 1999). Learning relational concepts from experience is challenging, because (as we discuss) relations are not obvious in the world. Specifically, hearing the same relational label applied to two different things invites the child to compare them and extract their commonalities.

Of course, spatial relations are only one example of the relational concepts that are central to the human experience. For example, even young children acquire kinship relations (X is the sister of someone), functional relations (you can drink X), and causal relations (X can move things). We next outline some key characteristics of relational concepts.

Relational concepts

Theories of categorisation have often treated all concepts as fundamentally alike. But concepts are not uniform in character, and the variations support a range of different functions (Gentner & Kurtz, 2005; Kloos & Sloutsky, 2004; Medin, Lynch, & Coley, 1997). One important difference is that between entities and relations. In discourse terms, entity concepts are often used to refer to things in the world, and relational concepts are used to assert connections between these referents. Broadly speaking, relational concepts can be thought of as those denoted by verbs and prepositions, and entity concepts, as those denoted by concrete nouns (However, as we will discuss, some nouns express relational concepts, and not all verbs express

relations.). Therefore, we begin by comparing verbs and prepositions with nouns. We then turn to a more subtle contrast within the class of nouns – that between nominal relational concepts and nominal entity concepts.

Verbs and other relational form classes

Relational classes like verbs and prepositions differ from concrete noun categories not only in their grammatical privileges, but in their semantics (Croft, 1991, 2001; Gentner, 1981, 1982; Gentner & Boroditsky, 2001; Graesser & Hopkinson, 1987; Kersten, 1998; Kersten & Earles, 2004; Langacker, 1987, 2008; Pavlicic & Markman, 1997; Vigliocco, Vinson, Druks, Barber, & Cappa, 2011). Gentner (1981, 1982, 2005; Gentner & Kurtz, 2005) laid out a set of phenomena that differentiate verbs from concrete nouns. These include differences in memory, mutability and polysemy.

(1) Verbs are less well remembered then nouns (e.g. Kersten & Earles, 2004). If people hear a list of sentences, and later are given a recognition task with new sentences, they show poorer recognition memory for verbs than for nouns, especially if the verbs are combined with new nouns.
(2) Verb meanings are more mutable than those of nouns (Gentner & France, 1988). The term *mutability* refers to a word's propensity to assume different meanings across varying contexts. Evidence that verbs are more mutable than nouns comes from studies by Gentner and France (1988) in which people were asked to paraphrase semantically strained sentences such as "The car worshipped." The dominant response was to use a synonym for the noun (roughly preserving the noun's usual referent) and to alter the meaning of the verb to fit that referent: e.g. "The vehicle only responded to him," or "Someone's vehicle was given a rest on a Sunday."
(3) Verbs are more polysemous than nouns; that is, dictionary entries for verbs tend to have more meaning senses than those for nouns (controlling for word frequency) (Gentner, 1982).

These three phenomena are interrelated. Verb mutability contributes to their poor memory performance, because it leads to verbs being encoded in context-specific ways (Gentner, 1981; Kersten & Earles, 2004). For example, if a person initially encodes the verb *worship* in the context of "worshipping a deity" they might fail to recognise the same verb in a sentence like "Fred worships his girlfriend." Mutability also contributes to the greater polysemy of verbs, in that some contextually driven uses of a given verb can become sufficiently entrenched as to become alternate word senses. Why are verbs so mutable? Gentner and France (1988) suggested that this arises in part from their discourse function of conveying relations among the things referred to in a sentence. Given a sentence like "The carpet argued with the curtains," people typically assume that the two nouns refer to things in the world – namely, a carpet and some curtains – and they adapt the meaning of the verb *argued* to convey something that would be possible for these referents, such as "clashed with each other."

Similar patterns hold for prepositions: they convey relational meanings, they are contextually mutable, and they are highly polysemous. (Boers, 1996; Brugman, 1988). But verbs and prepositions are not the only relational terms. Relational categories may also be named by nouns. We now turn to nominal relational categories, contrasting them with nominal entity categories.

Nominal relational categories

Research on concepts in cognitive psychology has largely focused on concepts with common intrinsic properties, such as *cat* and *trombone*. But recent work has investigated a different kind of nominal concept – relational categories[2] (Asmuth & Gentner, 2017; Gentner, 2005; Gentner & Kurtz, 2005; Goldwater & Markman, 2011; Markman & Stilwell, 2001; Rehder & Ross, 2001). By *relational category* we mean a category whose membership is determined by common relational structure, rather than by common intrinsic properties. For instance, for X to be a *bridge*, X must connect two other entities or points; for X to be a *carnivore*, X must eat animals. Relational categories contrast with *entity categories* like *cat* and *trombone*, whose members share many intrinsic properties. This distinction can be seen even for more abstract categories. For example, all the members of the abstract entity category *mammal* have warm blood, an internal skeleton, a circulatory system, and so on. In contrast, the abstract relational category *carnivore*[3] includes cats, spiders, sharks, falcons, frogs, and even a few plants. They share only the relation that they eat animals. Importantly, we are not saying that concrete entity concepts lack relational structure. Our representations of entity concepts like *cat* typically include relational structure as well as sensorimotor properties. For example, our representation of *cat* includes relations such as that cats eat meat, that they chase mice, and that they are chased by dogs, as well as intrinsic sensory properties such as whiskers, soft fur, and large eyes. The difference between entity concepts and relational concepts is not that entity concepts lack relational

Table 1. Examples of shift from literal, concrete meaning to abstract, figurative meaning over time.

Sanctuary 1340: A holy place • *Þi sanctuary lord þe whilk þi hend festynd; lord sall regne wiþouten end and ouyre. In þat sanctuary oure lord sall be kynge, þat is in all sauyd men, wiþouten end.*	1374: church or other sacred place (in which, by the law of the medieval church, a fugitive from justice, or a debtor, was entitled to immunity from arrest) • *To whiche lugement they nolden nat obeye but defendedyn hem by the sikernesse of holy howses, þat is to seyn fledden in to sentuarye.*	1400: A similar place of refuge in a non-Christian country; an asylum. • *That Cytee [Ebron] was also Sacerdotalle, that is to seyne, seyntuarie, of the Tribe of Juda: And it was so fre, that Men receyved there alle manere of Fugityfes of other places, for here evyl Dedis*	1445: Metaphorical extension to heart as place for faith • *Fides thyn herte enbracyth As hir propir sanctuary, and medelith with al thi deedys …*	1568: figurative usage: a place of refuge • *Vsing alwaise soch discrete moderation, as the scholehouse should be counted a sanctuarie against feare*
Anchor 880: An appliance for holding a ship, etc., fixed in a particular place • *Ðin ancor is git on eorþan fæst*	1225: To secure (the ship) with an anchor; to place at, or bring to, anchor • *For þi is ancre … vnder chirche iancred*	1382: first figurative: That which gives the feeling of stability or security. • *The which as an ankir we han sikir to the soule*	1578: To cast anchor, to come to anchor • *Cortez … anckred at the rivers mouth.*	1586: Figurative: To fix oneself, one's attention, thought; take up a position. • *[She] wild me those Tempests of vaine loue to flee: And Anchor fast my selfe on vertues shore.*

information; on the contrary, they are often rich in *both* relational and featural information. Rather, the difference is that relational concepts are low in intrinsic perceptual features.[4]

The paucity of psychological research on relational categories might suggest that such categories are rare. But in fact they are quite common. Informal ratings of the 100 highest frequency nouns in the British National Corpus revealed that about half of them refer to relational categories (Asmuth & Gentner, 2005). This suggests that they play a significant role in adult discourse. Nouns naming relational concepts – such as *proportion, goal,* and *obstacle* – are commonly found in adult conversation and facilitate concise and effective communication. We would go further, and assert that such terms also allow effective *internal* processing as well – that relational concepts – including nominal relational concepts – form a cognitive toolkit that supports higher-order thinking (Gentner, 2010, 2016; Gentner & Christie, 2010).

There are substantial parallels between relational nouns and other relational terms like verbs, stemming from the central parallel that they convey extrinsic relationships with other concepts. For example, relational nouns often have arguments attached by prepositional or adverbial particles.[5] For example, in a distributional analysis, Goldwater and Willits (2010) showed that relational nouns are far more likely to be followed by *of* than are entity nouns (e.g. the brother *of* Anna; the destruction *of* the temple). Some relational nouns can take a set of distinctive argument markers: for instance, if Jesse James *robbed* the gold from the Glendale train, then we can speak of the *robbery of* the gold *from* the train *by* Jesse James.

Beyond these syntactic parallels, some of the processing differences between verbs vs. nouns also hold for relational nouns vs. entity nouns. Gentner and Kurtz (2005) have proposed the following analogy as a framework for research.

Relational Nouns : Entity Nouns :: Verbs : Nouns

Our research (Asmuth & Gentner, 2017) has explored the above analogy further, asking whether the phenomena that differentiate verbs and nouns also hold between relational nouns and entity nouns. Specifically, our studies ask whether relational nouns are more contextually mutable than entity nouns, and whether this leads to poorer memory for relational nouns. We have found when people are asked to interpret noun-noun combinations consisting of relational nouns and entity nouns (e.g. *camera response*), and are then tested with new phrases, they show more accurate recognition of entity nouns than of relational nouns. We suggest that this occurs because people naturally adapt the interpretation of the relational noun to fit the entity noun it occurs with. For example, if *camera response* is interpreted as "trying to look good for Instagram," it's unlikely that the person will later recognise *response* in the phrase

door response (which might be interpreted as "a portal that opens automatically)." In contrast, because the entity concept tends to be stable, participants are more likely to recognise *camera* in a new phrase such as *camera limitation*.

One further parallel between relational classes such as verbs and prepositions and nominal relational categories is that they tend to be more abstract than entity nouns. For example, Asmuth and Gentner (2017) noted informally that when trying to control for level of abstractness, it was far easier to find abstract relational categories than to find concrete relational categories, and the reverse for entity categories. Intuitively, this fits with the role of relational concepts as connector; specific features of the relational concept will often be suspended to fit the surrounding entity concepts.

We next take up our claim that many relational concepts arise by abstraction from more concrete or embodied concepts. As noted above, we take the process of abstraction to be one of decreasing the specificity (and thereby increasing the scope) of a concept. For example, the concrete concept *anchor* (meaning a device attached to a rope that holds a boat in place) has been abstracted over time so that it can now refer to a religion, or a loved one, or any other enduring force that provides a sense of security (See Table 1). This new sense of *anchor* is more abstract; its referents do not need to have the concrete features of a boat anchor. However, it preserves the key relational structure of preventing something from moving in an adverse direction. As this example suggests, there is a natural correlation between relationality and abstractness (Asmuth & Gentner, 2017). But it is important to note that not all abstract concepts are relational. For example, the concept *thing* is highly abstract in that it has few perceptual properties – and indeed, few inherent properties of any sort – but it is not a relational concept.

How do relational concepts arise?

We propose that many – perhaps most – abstract relational concepts (e.g. *anchor, sanctuary, signal*) come about through analogical abstraction of concrete concepts. We lay out this proposal using a theoretical framework called the Career of Metaphor (Bowdle & Gentner, 2005; Gentner & Wolff, 1997; see also Chiappe & Kennedy, 2001; Jamrozik, McQuire, Cardillo, & Chatterjee, 2016). According to this theory, abstract meanings (which are often, though not always, relational) often develop gradually over repeated instances of metaphor use. On this account, metaphors (like analogies) are comprehended by a process of structure-mapping (Gentner, 1983, 2010). For example, processing a figurative comparison (such as "A child is like a snowflake.") involves a process of structural alignment between the two representations that renders their common structure more salient. Because the structure-mapping process favours common relational structure over common surface properties, this process is likely to lead to a relational abstraction (in this case, perhaps "something delicate and ephemeral"). If further analogical comparisons are made, the relational abstraction may become an alternate word sense of *snowflake*, creating a conventional metaphor. As the metaphoric abstraction becomes more established, there is a shift from simile form (An x is like a y) to metaphor form (An x is a y) (Bowdle & Gentner, 2005), as in "These sophomores are snowflakes." That conventional metaphors can be stated using the same syntax as for categorisation is evidence of an existing abstraction (Glucksberg & Keysar, 1990).

There is considerable evidence for the Career of Metaphor account of figurative language. As suggested above, people prefer novel figuratives in simile form (e.g. "A newspaper is like a telescope" is preferred to "A newspaper is a telescope") and conventional figuratives[6] in metaphor form (e.g. "A soldier is a pawn" is preferred to "A soldier is like a pawn") (Bowdle & Gentner, 2005, Expt. 1). More importantly, novel figuratives are comprehended faster in simile form than in metaphor form, and the reverse is true for conventional figuratives, which are comprehended faster in metaphor form than in simile form (Bowdle & Gentner, 2005, Expt. 2; see also Blank, 1988; Gentner & Wolff, 1997). As proposed in the Career of Metaphor, people implicitly assume that when metaphor form ('An X is a Y') is used, the base term already has an associated abstraction. When that form is used for a conventional figurative, this expectation is met, and processing is highly fluent. But metaphor form is infelicitous (and perhaps even misleading) when used for a novel figurative, for which there is no pre-existing abstraction. In these circumstances, the "X is like a Y" format is more felicitous, because it directs the listener to compare the two literal terms to derive the common structure. Studies by Giora (1997, 1999) indicate that for conventional bases, the abstract meaning is often the default sense, accessed early in processing regardless of context. Finally, Bowdle and Gentner (2005, Expt. 3) demonstrated a kind of *in vitro* conventionalisation: if given a set of similes in which the same base term is used with different targets, people later prefer to use metaphor form for figuratives with that base term. No such shift occurs if people see literal similarity comparisons with the same base. In addition to these behavioural studies, the abstraction process laid out by the Career of Metaphor idea receives

support from historical linguistics, neuroscience investigations and language acquisition.

Language evolution

This account of abstraction via repeated extensions is consistent with work in historical linguistics (Heine, 1997; Traugott, 1978). For example, Heine, Claudi, and Hunnemeyer (1991) examined the historical derivation of five spatial relational concepts (*on*, *under*, *front*, *back* and *in*) across a sample of 125 African languages. They found that *on* was often derived from the term for head, *front* from the term for face, and *back* from the term for back. Heine et al. (1991) suggest that these abstract relational terms emerge through metaphorical extensions of more concrete terms. Consistent with strong embodiment views, in many cases the human body appears to be the initial source of the terms. However, the human body is not the only source of spatial terms. For cattle-herding groups such as the Maasai of East Africa, the initial source for some prepositions appears to be animal bodies. This is consistent with the idea that metaphoric abstractions tend to be based on familiar, easily individuated things, of which the human body is but one example.

The Career of Metaphor process of metaphorical alignment and abstraction also appears to be operative for nominal relational concepts. Zharikov and Gentner (2002) traced the early history of a set of relational nouns and found evidence that many of them evolved through the figurative extension of concrete physical objects (see also Maravilla & Gentner, 2016). For example, *bridge* once meant a physical structure that spanned water; it now also possesses an abstract meaning of *something that connects two things or ideas*, which can range from musical passages to political positions. Table 1 shows examples of the shift from early concrete meaning to more abstract figurative uses.

Development of relational categories

Paralleling the historical evolution, relational terms lag behind concrete entity nouns in children's language acquisition. Verbs are slower to be acquired than nouns, not only in English but cross-linguistically (Bornstein & Cote, 2004; Braginsky, Yurovsky, Marchman, & Frank, 2015; Caselli et al., 1995; Gentner, 1982; Gentner & Boroditsky, 2001). Likewise, relational nouns are acquired later than entity nouns (Gentner, 2005; Gentner & Rattermann, 1991); and when children begin to use relational nouns, they often initially interpret them as entity terms (Gentner, 2005; Gentner & Rattermann, 1991). For example, a child may interpret *uncle* as "a man with a beard" before developing the full relational meaning used by adults (e.g. *the brother of a mother or father*) (Clark, 1973). An important process driving children's abstraction is *progressive alignment* (Gentner & Medina, 1998; Kotovsky & Gentner, 1996). In progressive alignment, a learner initially aligns two closely similar concepts, and this paves the way for aligning other pairs with the same relational structure but less concrete similarity (Gentner, 2010; Gentner & Medina, 1998). For example, a young child whose family has a pet dog may fail to understand the term *pet* as applied to the neighbour's python. But if the child compares her dog with another pet dog, and perhaps with a pet cat, she is likely to develop a partial abstraction (that is, one that still contains many specific details). There is considerable empirical evidence that even these "semi-abstractions" can facilitate the further mappings – in this case, aligning her pet dog with a pet python. (For reviews, see Gentner, 2010; Gentner & Medina, 1998).

Evidence from neuroscience

There is support for the progressive alignment sequence proposed in the Career of Metaphor from studies that have examined the neural activation of sensorimotor metaphors. (For excellent reviews, see Chatterjee, 2010; Jamrozik et al., 2016.) For example, Chatterjee and colleagues have found that literal sentences involving action verbs – e.g. *The servant ironed out the wrinkles* – are processed in left occipito-temporal motion processing areas. However, metaphorical sentences involving the same verbs – e.g. *The boss ironed out the wrinkles* – led to greater activation in the IFG and more anterior areas of the MTG, suggesting a more abstract interpretation of the metaphorical verbs (Chen, Widick, & Chatterjee, 2008). Likewise, Raposo, Moss, Stamatakis, and Tyler (2009) report that action verbs presented in literal sentences generated activation in the motor cortex, as well as in fronto-temporal regions associated with language processing; but presentation of these verbs within idiomatic sentences (while still associated with fronto-temporal activation) was not associated with activation in the motor or premotor cortex. Desai, Binder, Conant, Mano, and Seidenberg (2011) found that both literal and metaphoric action phrases (e.g. *the daughter grasped the flowers, the jury grasped the concept*) generated activation in secondary sensorimotor areas involved in action planning. However, activation in the primary motor areas was greater for novel phrases than for familiar phrases. Further, Desai, Conant, Binder, Park, and Seidenberg (2013) found that activation in sensorimotor areas decreased as the level of abstraction increased. Consistent with the Career of Metaphor predictions

(Bowdle & Gentner, 2005), as the phrase is interpreted less literally and more metaphorically (e.g. from *The instructor is grasping the steering wheel very tightly* to *The congress is grasping the state of affairs*), the emphasis shifts from characteristics associated with the specific, literal interpretation (physically and firmly holding an object) to the more abstract patterns that hold across uses in that metaphoric sense (holding/apprehending a concept), and this is reflected in the decreased sensorimotor activation.

There is also evidence consistent with the idea that progressive alignment supports abstraction. Using an fMRI adaptation paradigm, Kable and Chatterjee (2006) demonstrated that the posterior superior temporal sulcus, the extrastriate body area, and area MT/MST showed neural adaptation to repeated actions even when the actions were conducted by novel actors. This means that neural circuits within the lateral occipito-temporal cortex can become sensitive to specific action patterns. With repeated actions, these circuits may be important in shifting attention away from intrinsic features of the agent to the relational structures indexed by action verbs. Further evidence for the role of progressive alignment in the Career of Metaphor comes from research by Cardillo, Watson, Schmidt, Kranjec, and Chatterjee (2012), who traced shifts in the pattern of neural activation as sensorimotor metaphors become conventionalised. They introduced participants to novel metaphors and varied the degree of exposure to the phrases via a variety of judgment tasks. They found decreased activity in the left and right inferior frontal gyri as familiarity with the metaphor increased. The left inferior frontal gyrus (LIFG) is involved in many processes, including the need to choose between competing semantic representations. Cardillo et al. suggest that novel metaphors initially recruit the LIFG in order to suppress an irrelevant literal interpretation of the base term (see Gernsbacher, Keysar, Robertson, & Werner, 2001). As the nonliteral sense of the base term becomes more familiar and more readily activated, there is less need to suppress the literal meaning of the base. In future research, it would be interesting to study the neural effects of *in vitro* conventionalisation, as in Bowdle and Gentner's (2005) study, in which the same base term is repeatedly used with different targets.

Other support for the Career of Metaphor account comes from studies by Chettih, Durgin, and Grodner (2012), which found that for conventional metaphors (e.g. *an insult is a razor*), comprehensibility judgment response times were facilitated only by matched-sense metaphorical primes (e.g. *a betrayal is a razor*). In contrast, those for novel metaphors were facilitated by both literal primes (e.g. *a scalpel is a razor*) and metaphorical primes with alternative senses (e.g. *her mind is a razor*). This pattern suggests that metaphors with novel bases are interpreted in terms of the best current alignment between the literal base and target terms; in contrast, metaphors with conventional metaphoric bases (which already have an associated metaphorical abstraction) are primed only by metaphors that fit this abstraction.

Conclusion

Relational abstractions are a key component of human cognition. An adequate theory of conceptual structure must include an account of their nature and their evolution and acquisition. We have made the case that repeated alignment across multiple exemplars results in a gradual metaphorical abstraction, and that this process often retains key relational characteristics of a concept while attenuating more concrete properties. Further, a relational concept's role as a connector among entities requires it to accommodate its meaning to the less mutable entities it relates – resulting in further abstraction. This account is consistent with the Career of Metaphor theory (Bowdle & Gentner, 2005) and offers a path from concrete, embodied representations to abstract relational concepts. It is supported by research in cognitive psychology, language development, historical linguistics, and cognitive neuroscience. In sum, natural processes of structure-mapping and progressive alignment drive the emergence of abstractions in language and cognition.

Notes

1. As used in cognitive science, *abstraction* generally conveys not just any loss of specificity, but one that reveals important or enduring characteristics (Burgoon et al., 2013). However, not all abstractions – even relational abstraction – capture important information. For example, *things smaller than Jupiter* is highly abstract, yet we would not consider it particularly informative.
2. A distinction is often made between the terms *concept* (the intension of a word's meaning) and *category* (the extension). However, their use in the current literature is mixed, and the term "relational categories" is generally used in work on nominal relational concepts.
3. Relational categories include temporally bound categories, such as *passenger* or *bride*, as well as enduring ones, such as *carnivore* or *ratio*.
4. We are not saying that relational concepts lack concrete features entirely. As discussed later, many relational concepts are derived historically through gradual abstraction from concrete concepts, resulting in a continuum of concreteness.

5. Indeed, some relational nouns are derived from verbs (e.g. *robbery* / *rob*) and preserve the argument structure of the verb (Barker & Dowty, 1993).
6. We use the term "conventional figurative" to mean a figurative expression for which the base term has a conventional metaphoric meaning. Thus the figurative "An X is (like) a Y," would count as a conventional figurative as long as Y has an applicable associated abstraction, even if X is novel in combination with Y.

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