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7. Language and the career of similarity

DEDRE GENTNER AND MARY JO RATTERMANN

> It is probable . . . that man's *superior association by similarity* has much to do with those discriminations of character on which his higher flights of reasoning are based.
>
> William James (1890, p. 345)

> The brute irrationality of our sense of similarity, its irrelevance to anything in logic and mathematics, offers little reason to expect that this sense is somehow in tune with the world.
>
> Quine (1969, pp. 125–126)

Similarity has been cast both as hero and as villain in theories of cognitive processing, and the same is true for cognitive development. On the positive side, Rosch and her colleagues have suggested that similarity is an initial organizing principle in the development of categorization (e.g., Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), and Carey (1985) implicates a similarity mechanism in children's learning of the biological domain. It has also been suggested that similarity may play a role in word acquisition (Anglin, 1970; Bowerman, 1973, 1976; E. V. Clark, 1973; Davidson & Gelman, 1990; Gentner, 1982c). Others have taken a more pessimistic view, according to which similarity is either a misleading or at best an inferior strategy used as a last resort. Keil (1989), for example, posits that children begin with theories of the world and that

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similarity functions merely as a fallback strategy to be resorted to when theory fails.

A related issue is the course of development of similarity. Many researchers have suggested that children's use of similarity changes from an early and naïve form to a later, more enlightened form. Quine (1969) puts this view eloquently, describing the "career of the similarity notion" as "starting in its innate phase, developing over the years in the light of accumulated experience, passing then from the intuitive phase into theoretical similarity, and finally disappearing altogether" (Quine, 1969, p. 138). According to this view, there are different kinds of similarity, and the kinds of similarity children can use change with development. If this is true, then a further question is, what causes this development? Although Quine's description suggests a maturational change in the ability to perceive similarity, this is not the only possibility. In particular, we wish to explore the possibility that changes in similarity use might result from increases in children's knowledge rather than from changes in their intellectual competence.

Our plan in this chapter is as follows: First, we describe the development of similarity processes and give evidence for shifts in the kinds of similarity children use. Second, we consider the underlying causes of this evolution: whether developmental shifts in the processing of similarity result from global changes in intellectual competence or from the accretion of knowledge. Finally, we consider interactions with language, especially its possible role in the development of analogical similarity.

Distinguishing classes of similarity

Before beginning our survey, it is useful to distinguish three subclasses of similarity: analogy, mere appearance, and literal similarity. *Analogy* can be defined as similarity in relational structure, independently of the objects in which those relations are embedded (Gentner, 1982a, 1983, 1989). *Mere-appearance* matches are the complement of analogy: They are matches based primarily on common object descriptions. *Literal similarity* involves a greater degree of commonality: Both relational structure and object descriptions are shared.

There is considerable evidence that this distinction between relational similarity and object-based similarity is psychologically

real (Clement & Gentner, 1988, 1991; Gentner, 1988; Gentner & Clement, 1988; Gentner & Landers, 1985; Gentner & Rattermann, 1990; Goldstone, Medin, & Gentner, 1991; Medin, Goldstone, & Gentner, 1990; Schumacher & Gentner, 1990). For example, in similarity-based retrieval tasks, adults recalled more matches that shared object attributes than matches that shared relational structure. Yet when asked to rate inferential soundness (described as "the degree to which an assertion that is true for one situation would hold in the other"), the same subjects rated matches sharing relational structure as both more sound and more similar than those sharing object attributes (Gentner & Rattermann, 1990). This dissociation between the kind of similarity that best promotes memory access and the kind that (at least subjectively) best supports inferences suggests a psychological distinction among different similarity types. In other research we have found that subjects judging perceptual similarity behave as though attributional commonalities and relational commonalities function as two different psychological pools (Goldstone, Gentner, & Medin, 1989; Goldstone et al., 1991; Medin et al., 1990).

The career of similarity

Given this set of distinctions, we now ask about the development of similarity. Gentner (1988) proposed that there is a *relational shift* in the development of analogy and metaphor: Young children focus on common object descriptions, whereas older children and adults focus on common relations. In this chapter we seek to test this proposal and to extend it in three ways. First, we wish to explore its generality across different tasks and domains. Second, we wish to extend our account of the career of similarity to encompass early development as well as later development. Third, we wish to investigate the causes of developmental change in similarity processing. In particular, we want to ask whether changes in children's similarity processing can be accounted for by acquisition of domain knowledge rather than by changes in intellectual competence. Our extended account of the career of similarity draws on three proposals:

(1) The differentiation hypothesis proposed by E. J. Gibson (1969) and elaborated by Shepp, Kemler, and Smith and their colleagues (e.g., Shepp, 1978; Smith, 1989; Smith & Kemler, 1977), which postulates

that early similarity is holistic and global and that the ability to process various kinds of partial similarity – such as similarity of color or of shape – develops later.

(2) The relational-shift hypothesis, which postulates that the ability to process object-based commonalities precedes the ability to process relational commonalities (Gentner, 1988).

(3) *The further proposal that the ability* to process first-order relational commonalities precedes the ability to process higher-order relational commonalities.

The third hypothesis was originally proposed by Piaget (Inhelder & Piaget, 1958) and has been developed by Halford (1987) and by Sternberg and his colleagues (Sternberg & Downing, 1982; Sternberg & Nigro, 1980; Sternberg & Rifkin, 1979). We depart somewhat from these approaches in that Piaget and Sternberg focused on only one higher-order relation, namely, identity of first-order relations.[1] In our account and in Halford's account, other higher-order relations are included. A more important difference is that the consensus among the other researchers is that the shift is due to changes in cognitive competence: specifically, the advent of formal operations (e.g., Inhelder & Piaget, 1958; Piaget, Montangero, & Billeter, 1977). We emphasize instead the logical dependency of higher-order predicates on prior possession of their lower-order arguments. We therefore leave open the possibility that the progression may be governed by the degree of knowledge rather than by the child's stage of cognitive competence (e.g., Brown, 1989; Ortony, Reynolds, & Arter, 1978).

Combining these three hypotheses, we arrive at the following account of the career of similarity. The early use of similarity is characterized by a reliance on highly conservative holistic similarity matches: exact or nearly exact matches between all aspects of the two situations (e.g., the commonality between an *apple on the table* and another *apple on the table*). Early development is characterized by a gradual lessening of the closeness of the match required to perceive similarity. Thus, various kinds of partial matches become possible. Objects and other separable components of situations can be matched even when the rest of the situation does not match (e.g., an *apple on the table* can match an *apple in a tree*). Next, object attributes can be matched even when the other qualities of the objects do not match (e.g., a RED *apple* can match to a RED *block*), and it also becomes possible to respond to purely relational commonalities (e.g., the first-order relational commonality that an *apple* FALLING FROM *a tree* is similar to *a book* FALLING FROM *a shelf* [Gentner, 1988]).

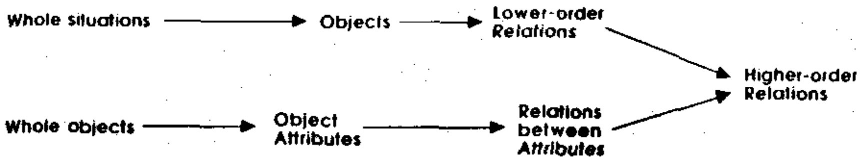

Figure 7.1. The career of similarity.

On the basis of Smith's (1989) discussion, we suggest that the first purely relational match that children can reliably extract is that of identity between whole objects (e.g., the commonality between *two identical apples* and *two identical books*). Identities between parts and along dimensions are extracted later (e.g., the *identical-color* commonality between *a red apple near a red book* and *a green lime near a green ball*), as are identities based on other first-order relations. Finally, children acquire the ability to match situations based on common higher-order relations (e.g., the similarity between *an apple falling from a tree,* PERMITTING *a cow to reach it* and *a book falling from a shelf,* PERMITTING *a child to reach it*) (Gentner, 1988; Halford, 1987). As we will discuss, throughout this developmental sequence there is often tension between perceiving object-based similarity and perceiving relational similarity. We do not wish to propose a strict ordering in which all object–attribute comparisons enter before all relational comparisons; as shown in Figure 7.1, these are not logically dependent on one another.

Thus, we follow Quine in hypothesizing a development from a naive to a more sophisticated use of similarity. Also like Quine, we leave open the possibility that adults continue to experience original "brute similarity" even after acquiring the use of theoretical similarity. Our account of the career of similarity also draws on prior psychological theories that have suggested a shift from holistic, unanalyzed, concrete concepts to more highly differentiated and/or more abstract concepts, notably E. J. Gibson's (1969) notion of differentiation and Bruner's proposed shift from reliance on perceptual information to reliance on functional information (Bruner, Olver, & Greenfield, 1966). However, we differ from most prior theorists in an important respect. Rather than seek to explain the development of similarity in terms of global stages of competence, we will ask whether a weaker explanation will suffice, namely, accretion of knowledge (Brown, 1989; Brown & Campione, 1984; Gentner, 1977a, b; Ortony et al., 1978). We will return to comparisons with other views after elaborating our position.

The relational shift

The relational-shift hypothesis is that the ability to process similarity based on object commonalities precedes the ability to process similarity based on relational commonalities. To support this hypothesis, Gentner (1988) cited several findings. For example, when asked to interpret a figurative comparison,[2] such as "A cloud is like a sponge," 5-year-olds produced object-attributional commonalities, such as "They're both round and fluffy," whereas adults mentioned relational commonalities, such as "They both store water and later give it back to you." Nine-year-olds produced a mixture of the two response types. Thus, the younger children responded mainly on the basis of object similarity, whereas the adults responded on the basis of relational similarity. Similar findings were reported by Billow (1975). He asked 5- to 13-year-old children to interpret a series of verbally presented metaphors, which embodied either object similarity (e.g., "Hair is spaghetti") or "proportional" (relational) similarity (e.g., "My head is an apple without any core"). He found that the ability to interpret metaphors based on relational similarity developed later than the ability to interpret metaphors based on object similarity. A possibly related development from naïve to sophisticated patterns in metaphor interpretation has also been observed by Gardner and Winner and their colleagues (Gardner, Kircher, Winner, & Perkins, 1975; Gardner & Winner, 1982). Finally, patterns consistent with the relational shift have also been observed in metaphor production. Winner (1979) analyzed the metaphoric productions of a child (Adam) from the time he was 2,3 years old to the time he was 4,10 years old. She found that shape-based metaphors (e.g., metaphors based on common contour, such as "A pencil is a big needle") were predominant (65%) and that relationally based metaphors (e.g., metaphors based on configuration, such as "Adam sleeping on Daddy" when putting a small alphabet letter on a larger one) were quite rare (12%).

Before interpreting this change in performance as due to an increase in children's facility with relation similarity, we must ask whether it could instead be explained simply as an increase in knowledge of metaphoric aesthetics. Perhaps it is not children's

fundamental apprehension of similarity that is changing, but rather their sense of what is considered clever or apt in discourse. The possibility is vitiated by the results of another task: an analogical mapping task conducted by Gentner and Toupin (1986), in which children had to map a plot structure from one set of actors to another. Two factors were varied: (a) the degree to which corresponding actors resembled one another (*transparency*) and (b) whether children were given an explicit summary of the higher-order relational structure (i.e., the social or causal moral that governed the plot) (*systematicity*). The plots themselves were identical across conditions. The performance of 6-year-olds was affected only by the transparency of the object correspondences; for example, they could accurately retell the story when *squirrel* mapped onto *chipmunk*, but not when it mapped onto *moose*. The presence of a higher-order relational structure had no effect on them. In contrast, 9-year-olds were affected by both variables. Without a systematic representation, their performance, like that of the 6-year-olds, was governed by object transparency. However, in the systematic condition they were able to transfer the story accurately regardless of the transparency of the correspondences. In summary, the younger children relied on object matches, whereas the older group, given explicit relational structure, could carry out an analogical mapping despite difficult object correspondences. Other studies of analogical transfer have found similar effects. For instance, Holyoak, Junn, and Billman (1984) found that 5-year-old children transferred a problem solution more successfully when object similarity was consistent with the correct solution strategy.

The finding of a relational shift in transfer tasks is a crucial addition to the findings of metaphor interpretation and production tasks. It means that developmental changes in the aesthetics of figurative language, though they may occur, cannot account for the whole phenomenon. However, there remain several possible explanations for the results obtained. First, the shift could reflect a *global change* in basic cognitive competence. As discussed earlier, Piaget posited that the ability to process analogical similarity is associated with formal operations (Inhelder & Piaget, 1958). Indeed, Billow (1975) interpreted his findings in this light and suggested that the performance of the children in his experiment was closely aligned with their Piagetian stage. This possibility is especially relevant here since the studies reviewed so far, as well as many others, have shown a shift during an age range roughly compatible with the onset of formal operations (see Goswami, 1991, for a review). Second, the relational shift could reflect the *acquisition of domain knowledge*[3] (Brown, 1989; Brown & Campione, 1984; Brown & DeLoache, 1978; Chi, Feltovich, & Glaser, 1981; Gentner, 1977a, b; Larkin & Simon, 1981; Ortony et al., 1978). On this account, young children's inability to perform relational mappings results from a lack of knowledge about the requisite domain relations (Brown, 1989; Goswami & Brown, 1989). There is a third possibility, namely, that the relational shift reflects the accretion of *learned mapping strategies*, in the spirit of Carey's (1984) discussion of acquired intellectual tools. That is, even given the basic intellectual competence and requisite domain knowledge to carry out an analogy, there might still be differences in performance due to the amount of practice (and, hence, the degree of acquired fluency) in the processes of carrying out a relational mapping.

These three classes of explanation make different predictions. The maturational-stage view predicts global changes in intellectual competence. The domain-knowledge view predicts that the relational shift will occur at different ages across different domains. The learned-strategy view is not as clear in its predictions, but roughly predicts an intermediate pattern of results. As in the domain-knowledge account, the relational shift should appear earliest in the simplest and most familiar domains; but as in the maturational-stage view, there should be some cross-domain linkage to the extent that the mapping strategies learned in one domain can be transferred to other domains. Although the learned-strategy view is appealing, its compatibility with a wide range of results makes it difficult to test. Therefore, we will concentrate chiefly on the other two explanations, which make very different predictions. Our method will be to survey research on the development of similarity across different domains. If the ability to perceive relational similarity develops at approximately the same age across different domains, this will constitute evidence for the maturational-stage view and against the domain-knowledge view. If shifts in similarity processing occur earlier for domains that are highly familiar to young children, this will be evidence for the domain-knowledge explanation and against the maturational-stage explanation. We begin by surveying children's performance on tasks utilizing familiar causal situations.

Tasks set in familiar causal domains

If the domain-knowledge hypothesis is correct, children's performance on similarity tasks should be better in familiar domains. Ann Brown and her colleagues have carried out many insightful studies that support this claim. Crisafi and Brown (1986) found that children's performance on a complex problem improved substantially when the objects and events used in the problem were made more familiar. Brown and Kane (1988) gave children a simple transfer task in which they had to carry across familiar relations such as *stacking*, *pulling*, and *swinging*. They found that even 3-year-olds were quite good at transferring solutions across situations when their task conditions promoted thinking about relational similarity. Brown (1989) used an especially simple task, in which children had to use a tool to reach for a desired toy. She found that even 24-month-old children were able to chose a correct pulling tool from a transfer set after initial experience with a similar tool that could be used in the same way. In another analogy task, Gentner (1977a, b) showed that young children can perform a spatial analogy between a human body – which is a highly familiar domain, even for preschoolers – and simple pictured objects, such as trees and mountains. She showed children simple pictures, such as a picture of a tree, and asked, "If a tree had a knee, where would it be?" Even 4-year-olds (as well as 6- and 8-year-olds) were able to perform the mapping of the human body to the tree. They were as accurate as adults, even when the orientation of the tree changed or when confusing surface attributes were added to the picture.

We have seen evidence that young children perform well on similarity-based tasks involving familiar domains, consistent with the domain-knowledge interpretation of the relational shift. However, in many of these tasks there was at least a partial correlation between relational similarity and object similarity. We need to know whether children can respond relationally when relational similarity is uncorrelated with, or even pitted against, object similarity. In a study aimed in part at testing the relational-shift hypothesis, Goswami and Brown (1989) manipulated relational similarity and object similarity independently. They presented children aged 3, 4, and 6 years with a set of pictures that formed the first three terms of a simple $A:B::C:D$ analogy and asked the children to pick the fourth. Other research on analogical transfer using similar $A:B::C:D$

analogies had found poor performance in grade school children (Sternberg & Nigro, 1980; Sternberg & Rifkin, 1979). However, previous research by Goswami (1989) had shown that when the relations in an analogy were made sufficiently accessible, it was possible for children to map relations. She presented 4- to 7-year-old children with analogies based on simple relations such as shape, color, and pattern and found that children as young as 6 years were able to solve the analogies. Goswami and Brown drew on this methodology in their studies of causal analogies. They attempted to control for the effects of domain knowledge and relational complexity by using familiar causal transformations such as *cut*, *burned*, and *dirtied*. They also pretested the children's knowledge of these relations to ensure that they understood the nature of the transformations. The children were then shown pictures forming the first three terms of an analogy (*A*:*B*::*C*:?) and were asked to choose which of several pictures correctly completed the analogy. Included in these choices were the correct object with the right transformation (the correct answer), the correct object with the wrong transformation, the wrong object with the right transformation, an object that shared a few object attributes with the *C* term of the analogy,[4] and other alternatives. Goswami and Brown found that all of their subjects, even the 3-year-olds, performed well in this task, selecting the correct alternative 52% of the time and choosing the same-attributes choice only 8% of the time. Four-year-olds performed even better: 88% correct and 1% attribute choices. The authors concluded that even 3-year-olds can resist object similarity and respond relationally when given simple causal relations to map.

The Goswami and Brown study admirably addressed the effects of familiar domains and relations on children's ability to carry out analogical mappings. However, we suspect that object similarity may have played a considerable role in the results. We obtained adult ratings of similarity for the stimuli used in this study.[5] The subjects were shown the stimulus pictures used by Goswami and Brown and were asked to rate the perceptual similarity of each possible response when compared with the *C* term of the analogy. In all cases, the correct answer was rated as more similar to the *C* term than the attribute match. Thus, these results do not tell us whether children can respond to purely relational similarity, particularly if pitted against object similarity.

In summary, the results of tasks set in simple familiar domains

provide evidence of transfer ability in young children. However, it is difficult to isolate relational similarity from object similarity in most of these tasks. Thus, in many of the tasks the relational structure was supported by various kinds of correlated object similarities. (In fact, had this not been the case, the tasks might have been quite unnatural, defeating the effort to simplify the domains.) Thus, although tasks involving simple causal situations have provided suggestive evidence, it is not yet possible to draw strong conclusions regarding children's ability to use purely relational similarity.

Similarity in perceptual domains

We now turn from studies involving causal relations to those involving perceptual relations – for example, first-order relations such as BIGGER (*X*, *Y*), SAME COLOR (*X*, *Y*), and ABOVE (*X*, *Y*) and higher-order relations such as *identity* and *symmetry*. Although tasks based on perceptual similarity lack the dynamic interest of tasks based on causal similarity, they have several advantages for our purposes. First, perceptual relations can be inferred directly from the stimuli, whereas the inferring of causal relations typically requires additional background assumptions. Second, perceptual relations have a wide latitude of application relative to causal relations.[6] Thus, in studies of perceptual similarity it is possible to vary objects and relations independently, permitting one to test different kinds of matches. Finally, since children are exposed from birth to spatial configurations of objects, even infants have some familiarity with perceptual relations. This allows us to extend our survey of similarity development to a much earlier age.

Very early similarity use. Assessing the similarity perceptions of young infants poses something of a challenge. One method that has proved successful is that of sequential touching, in which the order of spontaneous manipulations of objects is observed (Nelson, 1973a; Ricciuti, 1965; Starkey, 1981). Infants as young as 12 months will sequentially touch or group identical objects. For example, Sugarman (1982) presented children aged 12 to 36 months with a collection containing two identity classes – for example, four plates and four square blocks. One object from each class was placed on the table, and the child was allowed to place the other six objects. As in comparable studies, all age groups engaged in some similarity-based grouping behavior (Nelson, 1973a; Ricciuti, 1965; Starkey, 1981), with younger infants producing simple one-class groupings (e.g., making a row of plates while ignoring the blocks) and older infants often producing two-class groupings (e.g., making a row of plates and a row of blocks), a process that requires comparing items to determine similarity and difference.

Thus, very young infants can respond to identities among objects. Other research suggests that close similarity among objects may be sufficient. Mandler and Bauer (1988) used object manipulation and sequential touching as the dependent measure in a study with 12-, 15-, and 20-month-old subjects. They presented the infants with objects from two different basic-level categories (e.g., *dogs* and *cars*), two superordinate categories (e.g., *animals* and *vehicles*), or two contextual categories (e.g., *bathroom things* and *kitchen things*). The objects in the superordinate and contextual categories were physically quite dissimilar. By using these different sets of objects Mandler and Bauer hoped to determine whether categories with a high degree of within-category similarity (e.g., basic level) are easier to form than categories with a low degree of within-category similarity (e.g., superordinate and contextual categories). They found that at all ages the infants tended to touch objects sequentially from the same basic-level category (50% of the 12-month-olds did so) and, to a lesser extent, objects from the same superordinate (25%) and contextual (35%) categories. Mandler and Bauer also found that the infants' propensity to respond to superordinate categories increased with age. Here, too, similarity influenced the infants' performance: Mandler and Bauer reported that "children find it easier to differentiate sets of objects from two superordinate classes when the objects look alike than when the sets are physically less similar."

Young infants appear to be guided by object identity or very close similarity in sequential exploration of collections of objects. This is consistent with our suggestion that the first stage in the career of similarity is marked by the use of massive overall similarity matches. We now turn to an insightful and revealing set of studies by Baillargeon and her colleagues (Baillargeon, 1987, 1990, 1991, in press; Baillargeon, Spelke, & Wasserman, 1985) that (a) reinforces the claim that very early similarity is highly conservative and (b) suggests that a shift toward the ability to process partial matches begins very early. This study uses a different paradigm than the previous studies, and

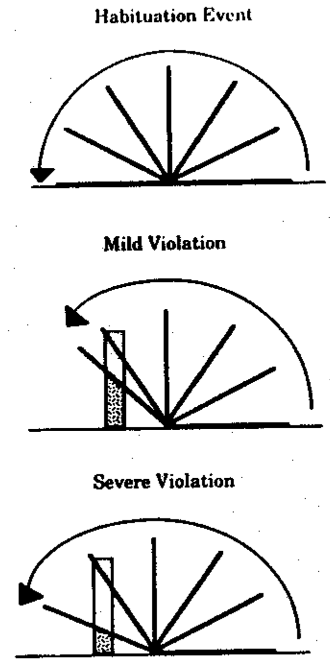

Figure 7.2. Apparatus from moving-screen study. (Adapted from Baillargeon, in press.)

the reasoning is rather subtle. Therefore, we begin by laying out the basic task.

Baillargeon habituated $4\frac{1}{2}$- and $6\frac{1}{2}$-month-old infants to a screen that rotated back and forth through a 180-degree arc from a position flat on the table at one end of the arc to the same position at the other end of the arc. After the infant had become habituated to the movement, a 25-cm-tall box was placed 12.5 cm behind the screen, and the infant saw one of two events. In the *possible* event, the screen rotated until it hit the box (112 degrees). In the *impossible* event, the screen rotated 135 degrees, seemingly passing through the top 50% of the box (a mild violation), or 157 degrees, seemingly passing through the top 80% of the box (a severe violation), or 180 degrees, seemingly passing through the entire space occupied by the box (an extreme violation) (Figure 7.2).

The question was whether the infants in the impossible-event condition would look reliably longer at the display than the infants in the possible-event condition. If so, they were assumed to have detected the violation. The younger infants ($4\frac{1}{2}$-month-olds) showed such a pattern only for the extreme violation, when the screen passed entirely through the box. The $6\frac{1}{2}$-month-olds could detect the violation when the screen passed through the top 80% of the box. (They readily accepted the milder 50% violation.)

In a subsequent study, Baillargeon (1991) again presented $4\frac{1}{2}$- and $6\frac{1}{2}$-month-olds with the occluded-box task. However, this time an identical box was placed beside the first box out of the screen's path; this second box remained visible through the test trials. When the visible box was in place, (a) the $4\frac{1}{2}$-month-old infants detected both the mild (50%) and severe (80%) violations and (b) the $6\frac{1}{2}$-month-old infants detected the mild (50%) violation. The infants seemed to use the visible box as a standard on which to base expectations regarding the target box behind the screen. If so, this would constitute a kind of mapping from the visible box – its size and position – to the invisible box. Having shown that the infants used an identical visible box as a standard, Baillargeon (in press) went on to manipulate the degree of similarity between the visible box (which was always a red box with white dots) and the target box. In the *high-similarity* condition the target box was also red but with green dots. In the *moderate-similarity* condition the target box was yellow with green dots, and in the *low-similarity* condition the target box was yellow and decorated with a clown face (Figure 7.3). When Baillargeon presented infants with the mild violation (the screen passing through 50% of the box) under these three levels of similarity-of-standard, she found an interesting pattern of performance. Only in the high-similarity condition were the younger infants ($4\frac{1}{2}$-month-olds) surprised. In the low- and medium-similarity conditions they failed to detect the violation. The older infants ($6\frac{1}{2}$-month-olds), in contrast, detected the violation in both the high-similarity and the moderate-similarity conditions, but not in the low-similarity condition.

These results suggest two fascinating possibilities. First, young infants may be able to map inferences from a visible object to an occluded object; that is, they can carry out an early form of analogical mapping. Second, this inferential process is extremely conservative. It requires massive overall similarity between the standard and the target. Younger infants ($4\frac{1}{2}$ months) are highly reliant on object similarity; anything less than a perfect match between the two stimuli

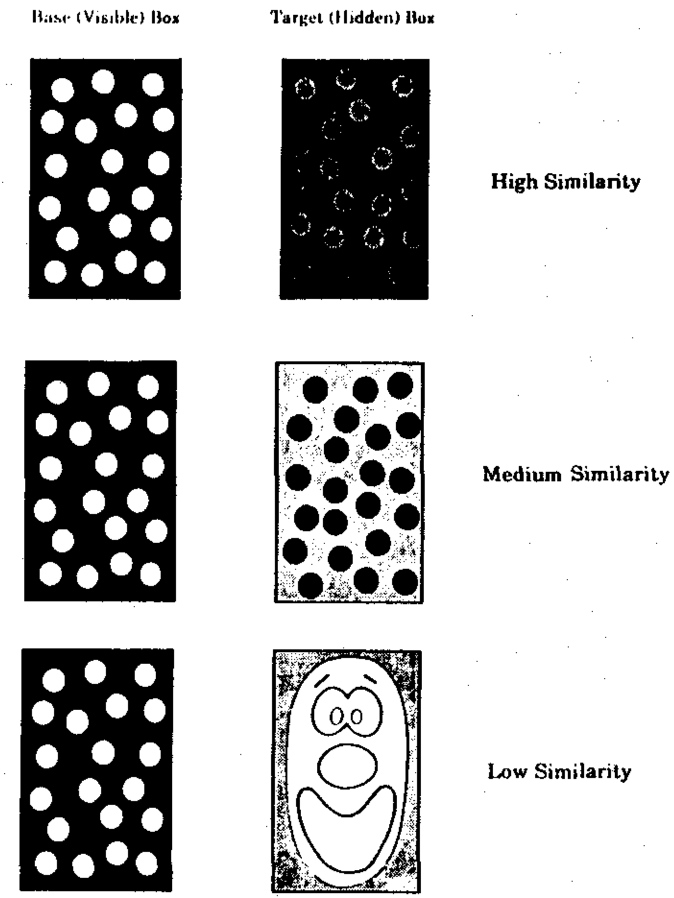

Figure 7.3. Stimuli from moving-screen study. (Adapted from Baillargeon, in press.)

diminishes the infants' ability to transfer. By $6\frac{1}{2}$ months there is slightly less reliance on massive similarity, although the infants' transfer is still quite restricted.

So far we have discussed evidence for an early reliance on close object similarity, with a gradually developing ability to use less complete similarity matches. We now discuss an intriguing study that suggests something akin to a relational shift occurring in the first year of life. Kolstad and Baillargeon (1990) familiarized $5\frac{1}{2}$-, $8\frac{1}{2}$-, and $10\frac{1}{2}$-month-old infants to an event in which a silver-gloved hand held a yellow cylindrical container decorated with red hearts upright in the center of a display. Then, as the infant watched, the hand rotated the container forward, so that the infant could see the opening, and backward, so that the infant could see the bottom of the container. After the container was returned to an upright position, it was moved to the back of the display, where there was a tap. The infant watched as salt poured from the tap and filled the container. The hand then moved the container to a hole in the center of the display and poured out the salt. This sequence of events was repeated two more times with two different, but perceptually similar containers (a blue cylinder decorated with purple diamonds and a pink cylinder decorated with black dots).

After these three familiarization events, the infant was shown two test events. The test events were identical to the familiarization events except that different containers were used. In the *box* test the container was a rectangular box covered with white paper and pastel flowers. In the *tube* test the container (a yellow cylinder decorated with black diamonds) was similar in appearance to the cylinders used in the three previous familiarization events; however, it appeared to have no bottom (in fact it had a transparent plastic bottom). If the infants watching these test events were basing their inferences of containment on surface similarity, one would expect that they would be surprised when the perceptually different box contained salt. If, in contrast, the infants were basing their inferences on the relationally relevant feature of having a bottom, they would be surprised when the (bottomless) cylindrical tube contained salt. Baillargeon found that $5\frac{1}{2}$- and $8\frac{1}{2}$-month-old infants looked reliably longer at the box event, suggesting that they were surprised that an object that differed in appearance from the original cylinder events could hold salt. In contrast, the $10\frac{1}{2}$-month-old infants looked reliably longer at the cylindrical-tube event, suggesting that they were surprised that an object that had no bottom could contain salt. This research suggests that a shift from a focus on overall object similarity to a focus on relational similarity begins to occur even in the first year of life, at least for some very familiar relations such as containment.

Now we turn to research by DeLoache (1989, 1990) on preschoolers' ability to map between entire situations. DeLoache's task utilized relations and objects likely to be highly familiar to preschool children, namely, dolls, dollhouses, and an ordinary room. Children aged 31 months and 38 months watched as a large Snoopy doll was hidden in the regular-sized room. Then the children were told that a miniature Snoopy was hiding in the same place in a small scale-model room. The children's task was to find little Snoopy in the model room. When given this task, 38-month-old children could find little Snoopy in the model room (about 80% correct retrieval); however, 31-month-old children were virtually unable to perform the task (about 15% correct retrieval). (Yet, like the older children, they were able to retrieve the large doll from the original room 80% of the time, showing that they had no trouble remembering the locaton of the original doll.) What makes these findings remarkable is that the two rooms were nearly identical except for size – they contained the same furniture in the same arrangement. Moreover, before the task began, all of the children were shown both the original room and the model room and the correspondences were pointed out (e.g., "This is big Snoopy's couch; this is little Snoopy's couch").

Since both object similarity (in that the pieces of furniture were alike except for size) and relational similarity (in that the relative locations of the furniture were alike) were present, this task can be viewed as a literal similarity mapping from the large room to the small room.[7] Indeed, for adults this seems to be such a strong case of literal similarity that it is difficult to grasp that a 2-year-old might fail. Yet even under what seem to be conditions of very strong overall similarity, we see a marked difference from the performance of 31-month-olds, who generally failed the mapping task when there was a difference in size, to the performance of 38-month-olds, who seemingly shared the adult sense that a simple change in scale does not greatly diminish similarity.

In another study, DeLoache tested the older children's abilities by manipulating the object similarity – that is, the similarity of furniture – between the original room and the model. In the high-object-similarity condition the furniture in the model was highly similar to the furniture in the room (as in the previous task). In the low-object-similarity condition each piece of furniture in the model room shared the same basic shape and size (and relative location) as the corresponding object in the original room, but was otherwise dissimilar in appearance. Performance was markedly lower in this low-object-similarity condition. The 38-month-olds could perform the mapping in the high-similarity condition (70% correct) but performed badly in the low-similarity condition (20% correct). (Not surprisingly, this similarity manipulation had little effect on the 31-month-olds, who were already performing badly even in the highest-similarity condition.)[8] Thus, the results indicate a strong dependence on literal similarity: For 38-month-olds, changing the appearance of the objects is disruptive.

As in the research discussed in the preceding section on familiar domains, the objects and relations in the DeLoache studies have been perfectly correlated. Consequently, there remains the question of the relative contributions of common objects and common relational structure to the children's performance. DeLoache performed a further study that addressed this question. In this task the object similarity between the furniture pieces was high, but the model was rearranged so that the spatial relations between the furniture in the original room and the model were different. There were two conditions: (a) the toy was hidden behind the corresponding piece of furniture (*same object*), or (b) the toy was hidden in the same relative position in the two rooms (e.g., both toys were hidden in the southwest corners of the rooms) (*same spatial relation*).

Before experiencing this rearranged model, the 3-year-olds in both conditions of the study were first run in the standard retrieval task. One day later, they were given the rearranged search task under one of the two experimental conditions. The Day 1 results replicated those found for 3-year-olds in Experiment 1: The rate of correct retrievals was approximately 80%. The results when the furniture was rearranged on Day 2 were quite striking: The children performed well in the same-object condition (approximately 80% correct retrieval) but very badly in the same-spatial-relation condition (approximately 5% correct retrieval). Thus, the children could perform a mapping based on object similarities, but not a mapping based solely on common relations. This rules out the possibility that the children in DeLoache's task were using a purely relational mapping.

We might ask whether the reverse possibility is true: that performance on the tasks described so far might have been based entirely on object matches. There is evidence, however, that this was not the case. In the study just discussed, the children received the normal mapping task (in which model and room had the same arrangement of furniture) before performing the rearranged mapping task. When DeLoache gave 3-year-olds the rearranged mapping task as their initial task, they performed very badly, even in the similar-object condition (20 to 30% correct performance, as opposed to 80% correct performance when the task was preceded by the normal mapping task). The fact that their performance on the object-mapping version of the different-configuration mapping task was so much better after they had experience with the standard-configuration mapping task suggests that the children may have required an initial literal-similarity match encompassing the entire situation. They apparently used both object similarity and relational similarity in their initial detection of the correspondence between model and room. However, these results also suggest that one outcome of making this initial mapping was that the children then went on to extract a partial match, namely, one based on object similarity.

The results of this series of studies suggest a striking degree of conservatism in young children's similarity matches; the children seemed to rely on an exact match between the two situations, even in the very simple mapping task. Indeed, for 31-month-olds, similarity in shape, color, texture, and category was not sufficient; similarity in size was also necessary. Children's ability to carry out similarity mappings appears to be sensitive to both relational commonalities and object commonalities.

Attributes and dimensional relations. Much of the early research on attributes and dimensions was based on Garner's investigations of stimulus structure and its effects on classification and memory (Garner, 1974). Before discussing this work, we need a bit of terminology. Our distinction between attributes and dimensions follows that of Garner (1978). An *attribute* is a component property of a stimulus, such as color, size, or form, that helps to define the object but is not equivalent to it. A *dimension* is a set of mutually exclusive attributes, or, as Palmer (1978) puts it, a set of mutually exclusive relations between an object and a value. For example, "three feet tall" can be an attribute of an object, but it is clearly a *dimensional* attribute since "three feet tall" precludes "four feet tall" or any other member of the same dimensional class. Gibson (1969) further noted that dimensions are often continuous and ordered sets of attributes. For our purposes, it is important to note that for children to perceive a set of attributes as a dimension[9] they require some knowledge of the relations between those attributes (mutual exclusivity, ordering, etc.).

Garner and Felfody (1970) hypothesized that pairs of dimensions differ in their combinatorial properties (as perceived by adults). Integral dimensions, such as hue and brightness, are perceived as one combined dimension, whereas separable dimensions, such as size and shape, are seen as two perceptually distinct components. Shepp and his colleagues reported a developmental progression whereby some combinations of dimensions that are seen as separable by adults are perceived as integral by young children (Shepp, 1978; Shepp & Swartz, 1976). For example, 5-year-olds show a redundancy gain in a speeded sorting task when color and form are correlated. This redundancy gain is taken as an indication of integral processing and suggests that color and form are perceived integrally by young children, though separably by adults (Garner & Felfody, 1970). Similarly, young children classify stimuli varying in size and brightness according to overall similarity, again treating as integral two dimensions that for adults are separable. On the basis of these findings, Shepp (1978) proposed a developmental trend from perceived overall similarity to perceived dimensional structure.[10]

Smith and Kemler (1977) provided further evidence for a developmental trend from holistic similarity processing in young children to analytic similarity processing based on common dimensions in older children and adults. Smith (1989) has amplified and extended this proposal into an admirably specific framework. Of particular importance here is her suggestion of a progression in children's similarity processing from overall similarity to object identity to common values on a particular dimension to common dimensional relations. For example, Smith (1984) used a follow-the-leader task to investigate 2-, 3-, and 4-year-old children's ability to process similarity defined in terms of object identity, common attributes, common identity relations, or common dimensional relations. Two experimenters chose objects from sets of toys that shared one of the following:

(1) *Object identity* – for example, both experimenters chose green planes, so that the child had only to match X1 and X1; the correct response was another green plane.
(2) *Identity relation* – for example, Experimenter 1 (E1) chose two red cars and E2 chose two white daisies, so that the child had to match IDENTICAL (X1, X2) and IDENTICAL (Y1, Y2); the correct response was two cars of the same color (but not necessarily white or red).
(3) *Common attributes* – for example, both experimenters chose red objects, so that the child had to match RED (X) and RED (Y); the correct response was another red object.
(4) *Common dimensional relations* – for example, E1 chose two green objects and E2 chose two yellow objects, so that the child had to match IDENTICAL (color, (X1), color (X2)) and IDENTICAL (color, (Y1), color (Y2)); the correct response was (e.g.) two red objects.

All of the children performed extremely well on the object-identity trials (all of the 2-year-olds achieved criterion of 75% correct), as well as on the identity relations trials (90% of the 2-year-olds achieved criterion). They also performed well on the common-attribute trials; 70% of the 2-year-olds achieved criterion on color and 80% on size. However, performance dropped sharply on the trials involving common dimensional relations; in fact, none of the 2-year-olds reached criterion for either color or size. In this and in other studies, the order of emergence seems to be matching *identical objects* – which Smith (1989) suggests has a special place in the development of similarity – followed by matching the *identity relation* and then by matching simple *object attributes*. Still later, attributes become organized into dimensions such as color and size, and children can match *relations between attributes* along the same dimension.

Comparing the effects of object similarity and relational similarity

As discussed earlier, an advantage of perceptual domain is that it is possible to decompose relational similarity and object similarity. In collaboration with Judy DeLoache, we investigated the performance of 3- and 4-year-olds on a perceptual mapping task in which relational similarity was pitted against object similarity (Rattermann & Gentner, 1990; Rattermann, Gentner, & DeLoache, 1987, 1989). In this task, the child and the experimenter each had a set of three objects (clay pots or blue plastic boxes), which displayed *monotonic increase* in size. That is, the objects increased in size along a continuum from left to right. The child watched while a sticker was placed under one of the objects in the experimenter's set and then searched for the sticker under one of the objects in the child's set.[11] The task was designed so that the relational response was always correct; that is, the correct response was always based on relative size (e.g., largest object to largest object).[12] The child was always shown the correct answer and, if correct, was allowed to keep the sticker.

We introduced a tension between object similarity and relational similarity by staggering the sizes of the two triads. For example, if the experimenter's set contained objects of size 1, 2, and 3, the child's set contained objects of size 2, 3, and 4. This arrangement created a cross-mapping between the two triads: If the experimenter chose object 3 in her triad, the child should choose object 4 (the object of the same relative size) in his triad, resisting the perfect object match between the experimenter's object 3 and the child's object 3. Thus, Stimulus Sets

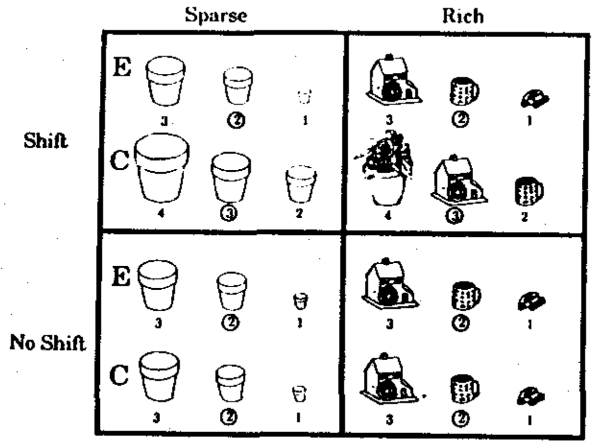

Figure 7.4. Stimulus sets from Rattermann, Gentner, and DeLoache (1987, 1989).

the logic of this task was to pit object similarity against relational similarity and observe whether the child would carry out the relational mapping between the two structures.

To carry this logic further, if indeed the tension between object-based and relation-based similarity in the cross-mapping condition hampers children's performance, then this disrupting effect should vary with the degree of similarity. To test this, we compared the simple stimuli discussed so far with complex, distinctive objects such as a large red flower, a medium brown wooden house, and a small green and pink coffee mug (Figure 7.4). This manipulation should enable us to address the issue of effects of object similarity more precisely, for the richer an object (i.e., the greater the number of features it possesses) the greater should be its similarity to an identical object (Tversky, 1977). Therefore, the disruptive effects of the object matches in the cross-mapping condition should be greater with the richer stimuli. The results of the richness manipulation were as predicted. The children performed worse with the rich than with the sparse stimuli (33 vs. 54% for the 3-year-olds and 38 vs. 63% for the 4-year-olds). Consistent with the competing-similarity account, we also found significantly more object identity responses with the rich stimuli than with the sparse stimuli. Performance was disrupted when object similarity was in conflict with the correct relational similarity, and this decrement was worse with richer stimuli and for younger children.

As an additional check on the consistency of the predictions, we ran a literal-similarity condition, in which object similarity was correlated with relational similarity. To accomplish this we restructured the experimenter's set and the child's set such that both contained objects of size 1, 2, and 3. Thus, the experimenter's choice (e.g., the object of size 3) could be mapped onto the child's correct choice (also size 3) on the basis of relational similarity, object similarity (the objects were identical), or both. As expected, children performed extremely well in this condition. The 4-year-olds performed virtually perfectly with both rich and sparse stimuli. In contrast, the 3-year-olds performed well only with the rich stimuli (86% correct, as opposed to 55% correct with sparse stimuli). The 3-year-olds appeared to benefit from the additional similarity conferred by a rich object match. These two tasks present a consistent picture: In a task that requires attention to relational similarity, 3-year-olds benefit from rich object similarity when object similarity and relational similarity are correlated and are distracted by it when the two are in competition. Four-year-olds show greater ability to extract purely relational similarity when necessary, though they too find the task easier when both relational and object similarity point in the same direction.

The shift from lower-order relations to higher-order relations. The last step in our proposed career of similarity is the shift to the ability to perceive similarity solely on the basis of common higher-order relations. Kotovsky and Gentner (1990a, b) studied children's ability to perceive similarity based on perceptual higher-order relations such as monotonicity and symmetry. They gave 4-, 6-, and 8-year-old children a forced-choice triads task in which they were shown a standard embodying some relational structure – say, symmetry (e.g., XoX) – and asked to say which of two other figures it was most similar to: another instance of symmetry (HiH) or a second figure that lacked the symmetry relation (iHH). Four-year-olds chose randomly, whereas 6- and 8-year-olds were progressively more likely to select the figure with the common higher-order relations. Additional evidence is provided by Chipman and Mendelson (1979), who presented 5-, 7-, 9-, and 11-year-old children with pairs of patterned displays and asked them to judge relative complexity. They found an age-related increase in the effect of structure on these complexity judgments. The older children judged stimuli that contained higher-order visual structure as relatively less complex than did the younger children. Similarly, Halford and Wilson (1980) found that 4-year-old children were able to learn mappings based on first-order relations but not those based on higher-order relations, whereas children over 5 years of age were able to learn both.

Taken together, these results suggest that in perceptual similarity (a) there is a shift toward greater perception of common higher-order relations and (b) some higher-order relational commonalities are perceived well before the advent of formal operations. Recently, Kotovsky and Gentner (1990b) have found that even 4-year-olds can be taught to choose on the basis of higher-order relations with training. The fact that higher-order commonalities can be taught to young children is further evidence for an experiential, rather than a solely maturational, basis for this progression.

Summary and comparison with other views

In our summary of the development of similarity in causal domains, we found a progression from the ability to perceive overall similarity between two situations to the ability to perceive various kinds of partial matches: matches between particular objects, matches between *object attributes* and between *first-order relations*, and finally matches between higher-order relations. A similar, though more detailed, developmental sequence appears to hold in perceptual domains. The ability to perceive overall similarity between scenes is gradually augmented, first by the ability to perceive identity matches between objects, then by the ability to perceive matches between object attributes and first-order relations (including identity relations between objects and, later, dimensional relations between object attributes), and finally by the ability to perceive matches between *higher-order relations such as symmetry*. In both perceptual and causal domains, this evolution is cumulative, so that later abilities supplement prior abilities rather than replacing them. Further, the evidence suggests that the shift in similarity use is not based on age. As can be seen in Figure 7.5, the shift from objects to relations and from conservative literal similarity to partial matches can be seen at several different ages. The fact that similar shifts occur at different

	INFANCY		EARLY CHILDHOOD		LATE CHILDHOOD	
Kolstad and Baillargeon Infants habituate to a cylindrical container then see a square container or a cylindrical non-container	5 months Dishabituate to square container but not to cylindrical non-container (object-similarity inference)	10 months Dishabuate to cylindrical non-container but not to square container (relational inference)				
Baillargeon Infants watch frame pass through object (impossible event); A similar object is available as standard	4 months Can use highly similar standard to make inferences about possible events	6 months Can use moderately similar standard to make inferences about possible events				
DeLoache Children see a toy hidden in a room and must find a miniature toy in a model room			31 months Cannot find the toy in the model room	38 months Can find toy when similarity is high between room and model		
Rattermann, Gentner & DeLoache Children must use relational similarity to select correct object. A Ⓑ C initial set; B Ⓒ D target set			41 months Succeed with sparse stimuli; fail (i.e., make object identity error) with rich stimuli	54 months Succeed with (i.e., transfer relations) with both rich and sparse stimuli		
Gentner Verbal interpretions of metaphors such as "A cloud is a sponge"					5-7 years Mainly attributional responses: "Both are round and fluffy"	7-9 years Many relational responses: "Both can hold water"
Gentner & Toupin Retell a story (with or w/o explicit causal structure) using new characters. *original:* A B C; high sim: A' B' C'; X-mapped: B' C' A'					5-7 years Performance depends only on object similarity; hi sim >> X-mapped	8-10 years Performance depends on both object similarity and presence of causal structure

Figure 7.5. A sampler of research on the career of similarity, showing shifts occurring at different ages in different domains.

ages from infancy to late childhood[13] suggests that it is not maturation but increases in a child's knowledge that drives the evolution of similarity.

This view of a developmental course from a naïve to sophisticated use of similarity is not new. In addition to Quine's characterization discussed earlier, it draws upon prior theories of development. An important influence on this framework, as already discussed, is E. J. Gibson's (1969) differentiation hypothesis. We have incorporated her view that the environment is rich in stimulus information and that the main task of the perceiver is to make sense of the information. Young children perceive this input in an undifferentiated fashion, whereas older children and adults analyze stimuli into their constituent features and dimensions. Our position has much in common with Bruner's proposal that children shift from a reliance on perceptual-configural information to a reliance on functional information, since the function of an object is one aspect of its relational structure (Bruner et al., 1966). Thus, both accounts predict that children will acquire the ability to utilize functional relations later than the ability to utilize perceptual attributes of an object. The accounts differ, however, in that for Bruner the cut is between perceptual and functional information, whereas for us the most important theoretical cut is between objects and relations, with perceptual versus functional (causal) information being a lesser issue. A more fundamental difference between our view and many of these prior views concerns the *cause of the shift*. The evidence presented here indicates that shifts in similarity processing occur at very different times in different domains. Therefore, we depart from prior theorists who have proposed maturational-stage accounts of the shift in similarity. We suggest instead that changes in the kinds of similarity a child can perceive are driven largely by the accretion and gentrification (as discussed later) of knowledge of the world.

A theoretical perspective that shares Gibson's emphasis on the role of the environment in learning and development is that of *situated cognition* (e.g., Brown, Collins, & Duguid, 1989). According to this view, the environment in which learning occurs has a marked effect on what is learned and how well it can be transferred. Our view of the initial conservative use of similarity is akin to the claim that initial learning is contextually situated. We stress, however, that part of learning is the "desituating" of cognition, that is, an increase in the ability to extract and use partial matches. This is compatible

with the suggestion that the use of multiple contexts of learning can lead to more abstract, generalizable knowledge (Collins, Brown, & Newman, 1989). One process by which the initial conservative use of overall similarity might give way to selective matches is the abstraction process whereby the result of a similarity comparison is a slightly more abstract data structure, as discussed by Ross (1989) and others (Elio & Anderson, 1981; Forbus & Gentner, 1986; Gick & Holyoak, 1983; Hayes-Roth & McDermott, 1978; Medin & Ross, 1989). These accounts imply a role for conservative literal-similarity comparisons, since these are likely to be noticed initially and can gradually lead to more abstract matches.

There are also positions that differ markedly from our own. For instance, Bryant (1974) proposes that children are able to use relational information developmentally before they are able to use absolute information (object attributes). He offers as evidence results from many tasks in which children are more adept at using relations such as *bigger* than at using an absolute attribute such as *six inches tall*. A partial resolution between Bryant's position and our own is that the evolutionary shift we postulate is between objects and relations, not object attributes and relations. (As will be remembered from the section on perceptual development, making object matches precedes making either attribute matches or relational matches.) In most of the tasks Bryant considers, the objects were quite sparse; in fact, they typically differed along only one dimension (i.e., in one attribute). Thus, a possible rapprochement is as follows: Object matches are made before relational matches (as stipulated in the present hypothesis), except when the objects are so sparse as to reduce to single-attribute comparison (as in some of the transposition studies considered by Bryant). As we have seen with the Rattermann, Gentner, and DeLoache search task, the effects of object identity may vary with the richness of the objects being matched.

Another contrasting position is that of Frank Keil (1989). He proposes that children are natively endowed with rich theoretical structures that guide much of their behavior and suggests that they fall back on their sense of similarity only when their theory of a domain fails them. He points out that adults display behavior similar to that of children when they are placed in domains in which they do not have knowledge of the true mechanisms. We agree with many of Keil's insights, including the observation that reliance on naïve similarity varies inversely with knowledge of the correct domain theory.

However, Keil's theory and our *career of similarity* hypothesis differ in their account of the causal relationship between similarity and theory building. For Keil, the use of similarity not only is unsophisticated but is a *relatively* unimportant aspect of development; it is merely a strategy to fall back on when theories fail. In contrast, we see similarity as contributing to the development of theories. Children's similarity comparisons allow them to extract commonalities, which can then be the grist for theory building. Conversely, as children gain theoretical insight into a given domain, their representations of situations in the domain will begin to incorporate the relations sanctioned by the theory, so that subsequent similarity comparisons come to be more illuminating. A compelling example of this process is provided by Carey's (1985) studies of children acquiring biological knowledge. Carey found that children's attribution of biological attributes to animals was based in part on their similarity to humans (possibly because children's knowledge about humans is rich enough to serve as a kind of prototype). An even more striking use of humans as a universal base is Inagaki and Hatano's (1987) finding that preschool children base inferences about how plants take nourishment on a mapping from humans. With development, children become more selective and theory-guided in their use of similarity. Carey attributes this change in performance to changes in the nature and organization of their domain knowledge.

Language and the career of similarity

So far, we have discussed the relational shift as a purely conceptual phenomenon. Now we turn to its interactions with language acquisition: specifically, with the acquisition of word meaning. At least three directions of influence are possible. First, we might expect similarity processing to influence word meaning. To the degree that children's word meanings are based on the commonalities they perceive when they hear a word applied to several exemplars, the kinds of similarities children can extract in a given domain will influence the word meanings they will derive. Second, there could be influences from language to similarity. Perhaps, in a variant of the Whorfian hypothesis, the possession of certain words (e.g., relational terms) confers a greater ability to extract certain kinds of similarities, or perhaps practice with language confers the habit of extraction. Third, there may be parallels between the development of meaning and

the development of similarity caused by their both being constrained by a third factor, such as the child's current cognitive stage or current domain representations. For example, it has been suggested that the acquisition of early relational expressions, such as *allgone*, coincides with the child's stage of understanding of object permanence (Gopnik & Meltzoff, 1984; Tomasello & Farrar, 1984). We will consider the evidence in the following order: (a) general developmental parallels; (b) influences from similarity to language; and (c) influences from language to similarity.

General developmental parallels

Order of vocabulary acquisition. If we apply the patterns we have found for the development of similarity to the development of meaning, several predictions follow. First, we might expect an early holistic stage in word acquisition before object meanings are extracted. Second, we would expect words for objects to enter children's vocabulary before words for attributes and especially before words for relations. Finally, words for higher-order relations should be acquired later than words for first-order relations.[14]

There is evidence that children do not immediately catch on to the notion of reference. Several investigators have reported an early stage at which they use a kind of prereferential vocalization between babbling and true words.[15] Prewords often appear to be contextually embedded parts of routines rather than true referential symbols. For example, Gillis (1986, 1987) observed the early form *brrrm-brrrm*, at first uttered only when the child was pushing a certain toy car. A common next step is for the child to experience a spurt in vocabulary at around $1\frac{1}{2}$ to 2 years. This vocabulary spurt consists chiefly of concrete nouns (both common and proper) and has been called the "nominal insight" (Macnamara, 1982).[16] Stern (1914) refers to this as the "greatest discovery of the child's life" – that "*each* thing has its name" (Stern, 1914, p. 108; quoted in Vygotsky, 1962, p. 43). Thus, the child's first truly semantic achievement is to extract and name objects separately from their contexts. This suggests another parallel with the development of similarity: Words for objects should be acquired before words for relations. Indeed, this appears to be the case. Concrete nouns (including both proper and common nouns) outnumber verbs and other relational terms by a large margin in children's early production vocabularies (Dromi, 1982; Gentner, 1982c;

Huttenlocher & Smiley, 1987; Macnamara, 1982; Nelson, 1973b) as well as in their comprehension vocabularies (Goldin-Meadow, Seligman, & Gelman, 1976).[17] Gentner (1982c) used cross-linguistic vocabulary evidence to establish the generality of this early noun advantage and to rule out various explanations specific to English, such as SVO (subject–verb–object) word order and the greater morphological variability of verbs as compared with nouns, both of which are presumably disadvantageous to verbs in acquisition. Even stronger evidence for the generality of the noun advantage comes from studies by Schwartz, Camarata, and Leonard in which children were presented with novel words, either as nouns or as verbs, and then tested for the production of these words. Even when stress, frequency, phonological makeup, and word order are equated, children are more likely to produce words experienced as nouns than as verbs (Camarata & Leonard, 1986; Camarata & Schwartz, 1985; Schwartz & Terrell, 1983). Thus, it appears that the reasons for the early noun advantage are conceptual or semantic factors. We suggest that part of the explanation is that objects are easier to extract from the stream of experience than are relations.

Even after relational terms have entered the vocabulary, children are slow to acquire their full meanings (Berman, 1980; Bowerman, 1978a, b; Gentner, 1982c). The correct usage of common verbs such as *come* and *go* (Clark & Garnica, 1974), *buy* and *sell* (Gentner, 1975), *mix, beat*, and *stir* (Gentner, 1978), and *pour* and *fill* (Bowerman, 1982; see also Pinker, 1984, pp. 309–312) is not fully mastered until rather late (5 or 6 years of age and, in some cases, as late as 8 years or older). Relational adjectives, such as *high/low, more/less*, and *big/little*, are also slow to be fully mastered. For example, children about 4 or 5 years old sometimes interchange opposite members of dimensional pairs (H. H. Clark, 1970; Donaldson & Wales, 1970; Wales & Campbell, 1970).

More to the point, relational adjectives are sometimes used attributionally at first, as though they referred to properties of objects instead of to relations between objects. The clearest cases of this kind of usage occur with dimensional terms, as reported by Smith and her colleagues (Sera & Smith, 1987; Smith, Rattermann, & Sera, 1988). For example, Smith, Rattermann, and Sera asked 3- and 4-year-olds to judge which of two butterflies was "higher" or "lower," given pairs of butterflies placed at various heights. The 4-year-olds correctly responded according to the spatial relations between the butterflies. In contrast, the 3-year-olds responded as though "higher" and "lower" were object attributes meaning "high" and "low," respectively; that is, they might call both butterflies "higher" if they were more than three feet from the floor and otherwise "lower."

In summary, there appear to be parallels between the order of vocabulary acquisition and the developmental progression found for similarity. As Macnamara (1972, p. 4) states:

> Children learn names for colors, shapes, and sizes only after they have learned names for many objects. . . . A further hypothesis is that the child will not learn the name for states or activities until he has firmly grasped the name for at least some entities which exemplify such states and activities. Thus the order of learning would be as follows: names for entities, names for their variable states and actions, and names for more permanent attributes such as color.

This order differs slightly from the order we have suggested, but it still roughly parallels the order of extraction of partial similarities that we postulated in the first part of this chapter.

Mutual influence between similarity-based categories and word-based categories. One factor that affects whether a set of objects receives the psychological status of a category is the degree of similarity among the objects. Another is whether they receive the same linguistic label. Thus, there is a constant potential for interaction between similarity acting as a bottom-up influence and word reference acting as a top-down influence. In this section we first consider evidence that early in acquisition children rely heavily on physical similarity to determine the extensions of words. We then consider evidence that later in acquisition, category labels may prompt children to look beyond overall physical similarity.

Applying words to new instances: Do young children expect the referents of a word to be similar to one another? In a highly influential paper, E. V. Clark (1973) reviewed diary studies of early vocabularies and showed that early overextensions typically involved perceptual commonalities, notably shape (e.g., "mooi" [moon] for cakes, round marks on a window, round shapes on books, tooling on leather book covers, postmarks, and the letter *O*). She suggested that an important aspect of early word meanings is the child's expectation that the referents of a term will be perceptually similar to one another.

Many subsequent studies have corroborated this pattern: Children's early overextensions of nominal terms appear to be based primarily on perceptual commonalities, especially shape (Anglin, 1977; Bowerman, 1976, 1978a). This suggests that young children may be operating under the assumption that the extensions of object names are based on physical similarity.

Other evidence that young children bring an assumption of physical similarity to the learning of word meanings comes from a study by Gentner (1982b). Children were taught names for two objects with different forms and functions: a "jiggy," a yellow box with a face that wiggled its eyebrows when the child pulled its lever, and a "zimbo," a red candy machine that dispensed jelly beans when the child pulled its lever. The two toys were simply presented as toys left in various rooms of the experimental suite, and their names were taught in a naturalistic manner. (Whoever came by would refer to them by saying, "Have you played with the jiggy? See how it works?") When the children could produce both words spontaneously, they were shown a new object that looked like the jiggy, but that (to their astonishment) dispensed jellybeans when they pulled its lever. When asked to name this new object, the preschoolers (aged 2 to 5 years) were governed by physical similarity. More than 80% called it a "jiggy," despite the fact that it shared a highly salient function with the zimbo. Children aged 5 to 9 years gave more function-based responses (about 60% "zimbo").[18] An interesting feature of these results is that the zimbo's function of dispensing jelly beans was quite salient to the children, especially to the preschoolers. Indeed, we informally noticed that preschoolers learned the term "zimbo" more quickly than the term "jiggy" and used it much more often. Yet in choosing which term to extend to the new object, they chose on the basis of form, even though that meant using the "less preferred" term. As Gentner (1982b) noted, this suggests that children impose implicit selection criteria as to which aspects of objects enter into word reference. In this initial stage, it appears that perceptual information predominates in their implicit theory of reference.[19]

Another early-word-learning task was that of Tomikawa and Dodd (1980), who taught 2- to 4-year-olds names for categories that were based either on common shape or on common function. They used a 3 (shapes) × 3 (functions) matrix of objects. Each child was taught three words, each applying to three objects, in a storytelling format.

The key variable was whether the three objects had a common shape (e.g., "mep" applied to a rectangular magnet, a rectangular box that could be opened and closed, and a rectangular rattle) or a common function (e.g., "mep" applied to a rectangular magnet, a circular magnet, and an L-shaped magnet). After hearing the story, in which the nine objects were named and their functions demonstrated, the child was given a comprehension test. Three of the objects, each differing in shape and in function from the other two, were held up in turn and their functions demonstrated again. Then they were placed before the child, who was asked to point to the "mep." The child was then shown two more triads of objects in the same pattern, each with a different word (thus receiving one test on each of the three words learned). Corrective feedback was given on each trial. Then the story was retold and the child retested, up to six times or until the child could pick out all three objects.

The results were quite striking. The children readily learned names for the common-shape categories but performed dismally on the common-function categories. Combining the results of two experiments (Experiments 3 and 4), 10 of 12 children in the common-shape condition could correctly identify the referents of the names they had learned, and none of the 12 children in the common-function condition were able to do so. It is interesting that when children of the same age (2 to 4 years) were asked simply to group the objects without linguistic labels, their groupings, though still dominated by physical similarity, were more mixed: 72–76% common-shape and 15–13% common-function groupings (in Experiments 1 and 2, respectively).[20] Consistent with the results of the previous study, it appears that the use of words increased young children's (already [illegible]) focus on physical similarity. Tomikawa and Dodd concluded that perceptual similarity is a strong determinant of early word reference.

A growing body of research, much of it by Markman, Waxman, [illegible]man, and their colleagues, has explored the ways in which the use of common nouns as linguistic labels can influence children's categorization choices. For example, Markman and Hutchinson (1984) contrasted children's categorization patterns with and without linguistic labels. They gave 2- to 3-year-olds a triad sorting task, for example, putting a police car where it belongs, either with another car (same category, and also highly similar) or with a policeman (thematically related). The children shifted from roughly chance sorting (59% categorical sorting) to predominantly categorical sorting (83%) when a novel object name was used. ("This is a dax. Put it with the other dax.") It is important that the children did not have to know in advance what the word meant in order to show this shift. They apparently believed that words pick out categories of like (rather than thematically related) objects. An interesting question is whether the scope of this effect varies with age, as might be predicted from what we have said so far. For 2- and 3-year-olds, the effect has been demonstrated only for highly similar objects (members of the same basic-level class, such as *birthday cake* and *chocolate cake*). Four-year-olds were tested on a broader range of stimuli and showed the switch to category-based responding even when the named object did not resemble its fellow category member.[21] For example, given a car to group with either a bicycle or a car tire, they would put the car with the tire in a nonlabeling task but put it with the bicycle in a labeling task. It remains to be seen whether the younger children would show the labeling effects without the benefit of strong object similarity.

A study by Taylor and Gelman (1989) provides further evidence for the role of similarity in early word meanings. Taylor and Gelman were interested in the way children learn subordinate categories. First they taught $1\frac{1}{2}$- to $2\frac{1}{2}$-year-old children a novel word for an object; for example, they referred several times to a large green beach ball as a "tiv." (Because the study concerns subordinate categories, they used objects such as dogs and balls that already had generic names in the child's lexicon.) They then asked the child to "put the tiv in the box," choosing from the original object and another possible "tiv" exemplar as well as other objects. The other possible "tiv" could be either quite similar to the original "tiv" (e.g., a red beach ball) or very dissimilar (e.g., an orange and black soccer ball). The results showed striking effects of similarity. When the new possible exemplar was highly similar to the original one, the children distributed their "tiv" responses across both exemplars. But when the new exemplar was dissimilar, most of the children chose only the original named toy. These results suggest that children $1\frac{1}{2}$ to $2\frac{1}{2}$ years of age are able to form a subordinate category and to extend it to other instances but that this ability may be limited to conditions of strong physical similarity.

Finally, research that directly addressed the effects of language on children's classification abilities was performed by Waxman and Gelman (1986). They presented 3- and 4-year-olds with a free classification task in which the children were placed in one of three conditions: (a) the *label* condition, in which superordinate category labels were provided, (b) the *instance* condition, in which common instances of the category were provided, and (c) the *group* condition, in which common instances of the category were provided and the children were instructed to consider the instances as a group. Waxman and Gelman found that the 4-year-olds classified virtually perfectly in all three conditions (approximately 98% correct classifications). The 3-year-olds, in contrast, classified perfectly only in the label condition (approximately 95% correct classifications as opposed to approximately 80% in the group condition and 74% in the instance condition). In a further study Waxman and Gelman found that the young children classified equally well with known English or novel Japanese labels. The children's performance with the Japanese labels shows that children's categorizing behavior is based not on particular word meanings but on a general understanding of what words do. This research suggests a relationship between children's linguistic competence and their ability to form taxonomic structures.

More precise information on how words focus children's attention was contributed by Landau, Smith, and Jones (1988). They found that the use of a nominal label prompts young children to pay attention to the common shape of objects. Their results suggest that young children very early on have specific opinions concerning *which aspects* of the referent enter into word meanings, at least for object names. Their first guesses as to the meanings of object terms are perceptual similarity, particularly shape.

Words taken as signals of nonapparent commonalities. Other studies have shown that children can overcome the effects of object similarity when they are given the same category label for dissimilar objects. Gelman and Markman (1987) investigated the role of similarity and common word labels in determining whether 3- and 4-year-old children would extrapolate characteristics from one object to others. They showed children a picture of a standard – for example, a bluebird – and told them a new fact about it – for example, "This bird feeds its babies mashed-up food." The children were then asked whether this property would apply to each of four new objects: a bluebird (highly similar to standard and same category as standard), a black-bird (low similarity, same category), a blue butterfly (high similarity, different category), and a dog (low similarity, different category). In one condition, the *picture-only* condition, the children were told, "This one feeds its babies mashed-up food" when shown the standard, and asked of each of the test pictures, "Does this one feed its babies mashed-up food?" In the *word-and-picture* condition, the children were given labels for all the objects – for example, "This bird feeds its babies mashed-up food," and "Does this bird/butterfly/dog feed its babies mashed-up food?" As would be expected, children in the picture-only condition were more likely to base their inferences on the degree of similarity between the standard and the new item (53% similarity-based responses) than the children in the word-and-picture condition (29% similarity-based responses). In contrast, when labels were added, the children's inferences were strongly influenced by the category information provided by the label; they attributed the characteristic "feeds its baby mashed-up food" to the items given the same label as the example (63.5% category-based responses in the word-and-picture condition vs. 46% category-based responses in the picture-only condition).[22] Yet even in the labeling condition object similarity did have an effect. Within a category the children drew more inferences from one picture to another when their appearances were similar.

Taken together, these findings suggest that children initially expect that words apply to sets of physically *similar* objects, as evidenced by the fact that they (a) spontaneously extend words to other similar objects; (b) find it easier to learn new words that apply to sets of physically similar objects than to learn new words for sets of functionally similar objects; and (c) choose a physically similar object when asked to find another instance of a new word. However, if an established category label is applied to a *dissimilar* item, the child (at least by 3 or 4 years of age) may accept this extension of the category and base further inferences on it. For older children, a word can function as a promissory note, signaling subtle commonalities that the child does not yet perceive (Gelman & Coley, Chapter 5, this volume). In either case, children strongly assume that the objects labeled by a common word will be similar. Early in the career of similarity, children are limited to overall physical similarity, with perhaps an early emergence of similarity of shape. Later in the career of similarity, although overall similarity within labeled categories remains the initial presumption, children can set aside

this assumption when it fails and seek other kinds of similarity, such as relational commonalities.

Effects of language on the relational shift

We have considered influences from conceptual development to language acquisition. We turn now to the reverse question, the perennially intriguing Whorfian issue of whether the acquisition of language changes children's cognitive processing – in this case, their perception of similarity. Vygotsky proposed that "thought development is determined by language, i.e., by the linguistic tools of thought and by the sociocultural experience of the child. . . . The child's intellectual growth is contingent on his mastering the social means of thought, that is, language" (1962, p. 51). He postulated a developmental progression from social speech to egocentric speech and then to inner speech. Once inner speech is available, he suggested, the course of cognitive development is fundamentally altered.

Returning to our specific focus, we may then ask whether the acquisition of language influences the kinds of similarity a child can use. One affirmative speculation comes from Kuenne (1946). Working within the Hull–Spence tradition, she invoked language to explain children's capacity to learn relational responses in a transposition task, despite their assumed bias for absolute stimulus–response learning. However, clear evidence for such an influence is hard to find, since it requires comparing children *with and without* language. Fortunately, some insightful inquiries have been conducted with nonhuman subjects. We turn now to Premack's research on teaching chimpanzees an artifical language.[23]

Premack's investigations of nonhuman primates. Premack (1983) found an intriguing relation between analogy and language in his research on teaching artificial languages to chimpanzees. Seven chimpanzees that were closely reared and trained by humans – three that were exposed to language training, four that were not – were tested on various kinds of cognitive tasks, such as reasoning, map reading, conservation, and match-to-sample. Premack found that the two groups were comparable in their performance on most tasks, with the nonlanguage group perhaps slightly superior. However, there was evidence that language training may have conferred benefits on certain kinds of similarity tasks and, in particular, analogy tasks.

We begin with the analogy tasks. Unfortunately, these tasks were given to only one member of the language-trained group, Sarah, who may have been an unusually intelligent animal. However, as discussed later, some corroborating evidence has been found using new populations. One task was a matching-proportion test utilizing cut-up fruit and partly filled containers (Woodruff & Premack, 1981). All the chimps successfully solved a literal-similarity match; for example, they passed a test given one-quarter apple as the sample, with one-quarter apple and three-quarters apple as alternatives. However, only the language-trained chimp, Sarah, could solve an analogical proportion problem – for example, a half-filled container as sample, with half apple and three-quarters apple as alternatives. The difference in performance was sharp: All four non-language-trained animals failed, whereas Sarah passed the analogical problems from the beginning. A further test of the ability to perform relational matches was a match-to-sample task using pairs of items – for example, *XX* goes with *YY* or *CD*, or *XY* goes with *BB* or *CD*. Whereas Sarah was 100% correct on both same–same trials and different – different trials, the non-language-trained chimpanzees performed at chance level and showed no progress, even after 15 sessions of 12 trials with corrective feedback.

As already discussed, one difficulty with the tasks is that only one language-trained chimp (Sarah) was tested, leaving open the possibility that the differences were the result of higher than average intelligence rather than of language training. However, this possibility is vitiated somewhat by two further results. First, all seven chimpanzees were tested on another relational task. In this task, each chimp was shown two samples and had to indicate whether they were same or different – for example, apple/apple (same) or apple/banana (different). Though this task might seem simple, Premack argues that explicitly *labeling* similarity and difference involves another level of difficulty than simply *responding* to sameness, as in match-to-sample tasks. Even after 900 training trials, the four non-language-trained chimpanzees failed to learn the use of the *same/different* labels. In contrast, all three language-trained animals readily learned the task. Finally, Premack (1988) trained four new animals, utilizing a lag procedure so that all the animals received the same training at different times. Premack gave the animals four kinds of language training: (a) learning a lexicon, (b) learning sentences, (c) learning the terms *same* and *different*, and (d) learning the interrogative construction. He then tested their performance on analogy tasks similar to those already described. Their performance was markedly improved by language training. Further, the gain appeared to be specifically related to learning the terms *same* and *different*.[24]

These results suggest that some aspects of language training can lead to improvement in analogical ability. In particular, learning to use the labels *same* and *different* appears to be important. Premack (1983) suggests two other ways in which language training may lead to cognitive benefits. First, it can teach the idea that one thing can stand for another. But noting that this would not be sufficient to account for the improvement in analogical ability, Premack goes on to suggest, second, that language training "appears to change the animal's unit of computation, moving it upward from an element to a relation, thus from a relation between elements to a relation between relations" (Premack, 1983, p. 160).

Spontaneous speech about similarity. We return now to studies of infants' sequential touching patterns to consider the language children spontaneously use during this task. Although this line of study properly belongs to the category of "parallel development" (since there is no telling which direction of influence applies) we have included it here because, like Premack's work, it bears on the relation between language *about similarity* and similarity processing. As discussed earlier, in the sequential touching task infants are given objects drawn from two identity classes, and their spontaneous touching and grouping patterns are observed (Nelson, 1973a; Ricciuti, 1965; Starkey, 1981).

Sugarman (1982) found that 12-month-olds tended to group objects to form one identity group, while 24- to 36-month-olds tended to form two identity groups. However, within this second group, the 24-month-olds formed groups sequentially (e.g., by forming a set of boats followed by a set of dolls); 30- to 36-month-olds formed these two groups by alternating the placement of objects between them (e.g., by placing a boat, then a doll, then a boat, etc.), suggesting that they could compare the two similarity classes. Sugarman further noticed that many of the older children spontaneously engaged in discussion of similarity and difference. The children's language use also showed a progression with age: (a) no reference;

(b) isolated reference: for example, "boat" while grasping a boat (dominant in 18-month-olds); (c) iterative reference to one or both classes: that is, repeated reference to one class sometimes followed by repeated reference to the other class, as in "*lady, lady, lady . . . boat, boat, boat*"; (d) coordinated reference to two classes: as in "*lady, boat, lady, boat.*" Children used iterative reference from 24 months on, but only the 30- and 36-month-olds used the more sophisticated coordinated reference. These parallels between language and grouping behavior suggest a relation between them, although, as Sugarman points out, they do not tell us about the direction of influence.

Can relational labels help children focus on relational similarity? So far we have considered the effects of using words on children's use of object similarity. Now we ask whether the use of labels can help a child to extract relational similarity. To test this question, we conducted a follow-up study to the mapping task described earlier (Rattermann, Gentner, & DeLoache, 1987, 1990). Recall that 3-year-olds performed at chance level in the original task, which required children to use a relational rule ("same relative size") to map from one triad of objects to another to find a hidden sticker. They were unable to map relative size when a competing object similarity was present. We wondered whether the use of relational labels could improve their performance. We taught 3-year-olds to apply the words *Daddy, Mommy,* and *Baby* to the objects in each triad (large, medium, and small, respectively). We also used the following labels in our questions: "My sticker is under my mommy. Where do you think your sticker is?" Under these conditions, the children correctly performed a relational mapping despite a tempting object foil. Thus, the use of explicit common labels for the relational roles of the objects appears to have highlighted the relational similarity between the triads and permitted an earlier appreciation of relational likeness.

There is also evidence that the choice of relational labels can affect children's performance on a metaphor interpretation task. Vosniadou, Ortony, Reynolds, and Wilson (1984) asked preschool, first-grade, and third-grade children to act out short stories. These stories ended in metaphorical sentences describing an action of one of the characters in the story. The key manipulation was whether the verb in the metaphoric completion sentence was *general* or *specific*. For example, in a story describing how a boy (Paul) became frightened, the *general-verb* version of the final sentence was "Paul was a rabbit *running* to his hole," and the *specific-verb* version was "Paul was a rabbit *hopping* to his hole."[25] The metaphors were designed so that the general verbs could apply naturally in the target domain (Paul's actions) and therefore could be interpreted literally. In contrast, the *specific* verb was inappropriate if interpreted literally. The specificity of the verb affected the younger but not the older children. Younger children were likely to act out the metaphor incorrectly when the verb was specific; for example, they would make Billy hop to his bedroom. In contrast, older children were able to reinterpret the verb in the metaphorically correct manner: Given either verb, they simply made Billy run to his room. Thus, for younger children, the ability to extract the common relation was sensitive to the word used to describe it.

Re-representation. We now discuss a process that we think may be important in learning, which we call *re-representation* (Gentner, 1989). To explain this notion, we consider the mapping process necessary in the Vosniadou et al. task. For simplicity, we suppose that the child already knows (from the story) that Paul is running to his room. To understand this metaphor, the child must map her representation of the rabbit scenario onto her representation of what Paul is doing. Let us assume that she can guess that *rabbit* should map onto *Paul* and *hole* onto *room.* If the verb *running* is used, the alignment is straightforward. But when *hopping* is used in the base, the direct result of the mapping is not quite right, since Paul is not hopping.[26] To align the two representations, the child must drop the *manner* of motion, retaining only *rapid movement by foot.* This requires *re-representing* the verb in a more abstract form. Depending on theoretical preferences, we could describe this as decomposing the verb *hop* and stripping away some of its predicates (e.g., Burstein, 1986) or as moving up an abstraction hierarchy (Falkenhainer's "minimal ascension principle," 1988) or as extracting a common schema (Gick & Holyoak, 1980, 1983; Hayes-Roth & McDermott, 1978).

We conjecture that re-representation induced by trying to align partially similar situations may be one way that children gradually come to an appreciation of abstract commonalities. We further speculate that re-representational efforts may serve gradually to increase the uniformity of children's internal representations. This is because the representation derived from the effort to align two situations is likely to be less idiosyncratic than the representations of either of the prior situations. An arena where this suggestion may be especially workable is the learning of dimensional relations, as discussed by Smith (1989). If the child somehow succeeds in aligning "*A* bigger than *B*" with "*X* louder than *Y*" (perhaps by trying to understand a metaphor such as "a big voice"), it is possible that this results in more uniform representations – for example, "GREATER-THAN (size (*A*), size (*B*))" and "GREATER-THAN (loudness (*X*), loudness (*Y*))."[27] In many cases the impetus to make such an alignment will be common language labels, as in the the earlier example. This leads us to suggest a bootstrapping interaction between the acquisition of meaning and the processing of similarity in a given domain. To the degree that a child has learned words that denote relations, he may be better able to match situations containing these relations. Conversely, to the degree that a child has uniform representations of two situations, he can learn the meaning of a new word applied to both situations. We can imagine that each successful alignment leads to a slightly more uniform representation, which in turn increases the probability that the next two situations can be aligned, and so on. We could think of this gradual process as a kind of *gentrification of knowledge*, by analogy with the regularization of formerly complex, idiosyncratic local domains.

Conclusions

We set out in this chapter to characterize the development of similarity and to inquire about its causes. We found evidence that early similarity is highly conservative and that later development is characterized by an increasing ability to extract partial matches, including matches based only on common relations. Our theme throughout has been one of extraction. Paradoxically, it appears that children progress from complex to simple matches, rather than the reverse. Even infants can achieve matches based on massive overlap between two situations; what expertise confers is an increasing ability to extract sparse, abstract matches. However, despite the manifest differences, we see a continuum between massive global similarity matches and elegant relational isomorphisms. Thus, we find support for Quine's "career of similarity" from brute similarity to theoretical similarity.

Turning to the causes of the changes in similarity processing, we

found no evidence for the claim that the shift to relational and higher-order relational similarity depends on reaching the formal operations stage. Very young children – even infants – can apprehend relational similarity when given materials whose relational structure is fully available to them. We cannot rule out maturational effects, but our survey suggests that knowledge is a more important determinant of similarity use. We then turned to another experiential factor: the acquisition of language. We drew on the research of Premack, along with some promising current investigations, to suggest that the possession of names for relations, including *same* and *different*, may be important for the appreciation of analogical similarity. This in turn suggests that the changes in knowledge that drive changes in similarity do not simply consist of accretion of domain facts, but also include the deepening and systematization of the knowledge base.

Notes

1. That is, they focused on analogies of the form *A*:*B*::*C*:*D*, in which the implicit assertion is of a (higher-order) identity between the relation (*A*, *B*) and the relation (*C*, *D*).
2. For present purposes, we consider metaphors and analogies together as nonliteral similarity comparisons.
3. One widely acknowledged difficulty here is that the concept of a domain is ill-defined. In this discussion we will roughly characterize a domain as a cluster of mutually interrelated concepts around a common topic.
4. This was termed the *mere-appearance* choice; however, in general these items were not similar enough to the C term to qualify as mere-appearance matches in the sense defined in the text. For example, the mere-appearance match to a girl with long brown hair was the fringe on a purple scarf.
5. We thank Usha Goswami for kindly providing us with the stimulus materials.
6. Causal relations are typically quite constrained as to the kinds of objects they can apply to, whereas perceptual relations can apply to a wide variety of objects. For example, the relation *BURN* (*x*, *y*) requires *y* to be a combustible object, but the relation *ABOVE* (*x*, *y*) can accept practically any pair of concrete objects.
7. The results did not depend on direction: Large-to-small and small-to-large were equally difficult for 31-month-olds. We will discuss only the large-to-small mapping for clarity of exposition.
8. DeLoache also manipulated the similarity of the surrounding walls of the rooms, but this manipulation had no significant effects. The percentage of correct retrieval is collapsed over this factor.
9. In our computer simulation of similarity processing, we represent dimensions as *functions*.

10. Shepp did not propose that dimensional structure ever entirely supplants overall similarity, noting that the work of Rosch and her colleagues indicates that many natural concepts may be structured by overall similarity rather than by a few criterial features or dimensions (Rosch & Mervis, 1975).
11. During a training phase it was explained to the child that the hiding place of the experimenter's sticker in her set could be used as a clue to where the child's sticker was hidden in his set.
12. Relative size and relative position were perfectly correlated, so the child actually had two relational cues to the correct response.
13. Indeed, the work of Chi, Feltovich, and Glaser (1981) comparing novices and experts in physics suggests that similar shifts from object-based to relation-based sorting can occur in adulthood.
14. Because word frequency differences and other differences confound this comparison, we cannot address this prediction adequately.
15. These vocalizations have been called "phonetically consistent forms" (Dore, Franklin, Miller, & Ramer, 1976), "indexical signs" (Dore, 1986), "sensorimotor morphemes" (Carter, 1979), "protowords" (Halliday, 1975; Menn, 1976; Menyuk & Menn, 1979), and "quasiwords" (Stoel-Gammon & Cooper, 1984).
16. Gillis (1984) has argued that the nominal shift is a gradual emergence rather than a sudden insight; but this does not alter the main point here.
17. Gopnik and Meltzoff (1986) appear to disagree with this claim, but the disagreement seems to be more apparent than real. They report the predicted pattern of more object words than relational words in their corpus of early language (Gopnik, 1980, 1981), but note that more *tokens* of each type occurred for the relational terms, a pattern that Gentner (1982c) also noted. Thus, there seems to be agreement that object-reference types outnumber relational types. This is all the more noteworthy because Gopnik and Meltzoff utilize a broad construal of the notion *relational term*. Along with terms that are generally agreed to be relational, such as *off*, *down*, and *more*, they include many terms that are commonly classified as social-interactional terms or as indeterminates, such as *there*, *hooray*, *no*, and *bye-bye*. The latter terms were counted as relational when the context was judged to warrant a relational interpretation (A. Meltzoff, personal communication, January 1991).
18. Adults typically produced combinations like "jiggy–zimbo," but chose on the basis of physical similarity if forced to select one term (75% "jiggy").
19. This suggests a resolution to the form–function debate in early language (E. V. Clark, 1973; Gopnik & Meltzoff, 1986; Nelson, 1973a, 1988). It may be that "function determines *which* [word meanings are learned] while form determines *what* [information is stored in early word meaning]" (Gentner, 1982b, p. 142).
20. Since all nine objects were of the same color and approximate size, the common-shape objects were perceptually quite similar.
21. Markman and Hutchinson (1984) describe this shift in terms of whether the objects are related at the basic level or at the superordinate level.
22. To be sure that the children's responses were based solely on either object similarity or category information, we computed these means based on the children's responses to the *same category/different appearance* stimuli and the *different category/similar appearance* stimuli.
23. Following Bickerton (1983), we are less interested in the question of whether Premack's system was a true language than in considering the effects of the language-constitutive properties that it did have, that is, whether the use of symbols to refer to objects, properties, relations, and relations between relations has implications for other cognitive activities. It can be argued that Premack's chimps were simply given exercises in the use of relations. However, this kind of exercise is certainly a component of natural language use as well. Therefore, any benefits conferred by this kind of practice are of interest in theorizing about the effects of language on cognition.
24. As Premack notes, because the four tasks were always given in the same order, it is not possible to separate the effects of task (c) from the cumulative effects of tasks (a), (b), and (c).
25. Vosniadou et al. used the terms *literal* and *nonliteral*, whereas we have used the terms *general* and *specific*.
26. Note that in simplifying the situation we are avoiding one alternative explanation of the Vosniadou et al. age differences, namely, that the results were due to age differences in children's subjective plausibility for "Paul hopping to his room" rather than to differences in re-representational fluency.
27. Note that this representation separates out the dimensions *size* and *loudness* and allows them to be put into correspondence, permitting one to preserve abstract commonalities such as transitive dimensional structure (Gentner, 1989; Smith, 1989).

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