# Developing categories and concepts

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The literature on concept development is highly contentious because there is a lot at stake. The processes that give rise to categories are at the very core of how we understand human cognition. In broad strokes, the debate is about whether categories reflect internal representations that are highly stable symbolic proposition-like and manipulated via logical operators or, whether they are probabilistic, context-dependent, and derived from bundles of correlated features and ordinary processes of perceiving and remembering (for reviews, see, Komatsu, 1992; Murphy & Medin, 1989; E. Smith, 1989; E. Smith & Medin, 1981. The literature appears to cycle through these two classes of accounts, advancing with each pass through but never quite leaving these two general points of view. Many of the contentious issues in the developmental literature on concepts and categories are variants of this debate. Accordingly, this review begins with a brief history of theories of categories. This is as history of back-and-forth transitions between a focus on more the more stable and the more probabilistic aspects of categories and it is a debate that is not resolved. However, by either view, categories result from internal representations that capture the structure in the world. Accordingly, the review of the developmental literature is organized with respect to recent advances in understanding outside-the-mind factors that organize and recruit the cognitive processes that create categories: the statistical regularities in the learning environment, the cognitive tasks and the nested time scales of the internal processes they recruit, and the body which is the interface between the external world and cognition.

## Back – and – forth theories.

Traditionally, categories are viewed as discrete bounded things that are stable over time and context. In this view, categories are enduringly real, object-like, truly out there in the world and also in our heads. Thus, theorists in this tradition write about categories being acquired, discovered, and possessed. The boundedness and stability expected of categories is well exemplified in the following quote from Keil (1994):

> Shared mental structures are assumed to be constant across repeated categorizations of the same set of instances and different from other categorizations. When I think about the category of dogs, a specific mental representation is assumed to be responsible for that category and roughly the same representation for a later categorization of dogs by myself or by another. (p. 169).

Within this framework, the only important question about categories is the structure of the internal representations that give rise to this stability. The classic approach is derived from the logic of classes and distinguishes between the extension of a class and its intension. The extension is all the possible instances. Thus the extension of the class "triangle" is all possible triangles. The intension is the rule that picks out all and only members of the class, for example, the intensional definition of a triangle might be a "closed figure having three sides”. Traditional theories assume both the extension and intension of a category to be fixed.

In the 1960s, theories of categorization attempted to explain the assumed fixed category extensions by internally represented intensive definitions that were lists of necessary and sufficient features. This approach came to be rejected on both theoretical and empirical grounds. First, there is no psychological basis for determining the features that form the primitives for concepts (Murphy & Medin, 1985). Second, no successful version of the theory was ever formulated; no one could find the defining properties of such everyday categories as dog or cow or game (see Rosch & Mervis, 1975). Third, there were data that directly contradicted the idea of necessary and sufficient features. Necessary and sufficient defining features imply all instances of a category should be equally good members. But the data say otherwise; people reliably judge some members of a category to be better than others. For example, a robin is a better example of a "bird" than is a penguin (e.g., Rosch. 1973). As a consequence, in the 1970s, the field turned to probabilistic theories (Rosch, 1973; Smith & Medin 1981).

These theories by their very nature weakened the idea of fixed category representations by focusing on dynamic and context dependent general cognitive processes of memory, attention, association and generalization by similarity (see Smith & Medin, 1981, for review). By the 1980s there were two versions of these probabilistic accounts and also arguments that the two versions were empirically and formally indistinguishable (Estes, 1986). By one account, prototype theory, concepts are lists of characteristic rather than defining features, a move that readily elevates robins over penguins as examples of birds (see Smith & Medin, l98l). By the second, more radical version known as exemplar theory, concepts do not really exist in the sense of intensional definitions that determine category membership. Instead, people remember instances and associated properties (including associated language), and then general processes of memory retrieval, association, and generalization by similarity give rise to in-task category judgments (e.g., Nosofsky, 1984; see also Smith & Medin, 1981), a move that opens the way for shifting and context dependent categories and also for ad hoc categories such as "things on my desk with which I can pound in a nail" (Barsalou, 1983

). These accounts also readily explain typicality effects and other effects suggesting probabilistic decision making in determining category membership. These theories also explain a wide array of experimental results on category learning, recognition, recall, and generalization (e.g., Nosofsky, 1984; Zak1 & Nosofsky, 200l). Despite the success of these approaches in explaining adult category learning in the laboratory, they have had relatively little impact in the developmental literature. This is primarily because prototype and exemplar theories were not readily extendable as explanations of people's knowledge of natural categories such as dog and chair and animal and furniture. This inability to explain reasoning about natural categories (and the acquisition of natural categories) constitutes a significant failure.

The fundamental problem with probabilistic feature theories as theories of the real categories that people use and that children learn is in specifying the relevant features. There is, at present, no principled basis for feature selection. Moreover, different categories are structured in different ways. For example, colors are relevant to categorizing foods but not to categorizing trucks (e.g., Macario, Shipley & Billman, 1990; Murphy & Medin, 1985). This is a fact about natural categories that has attracted considerable attention from developmental researchers because children seem to acquire these regularities as young as 2 or 3 years of age, as we review in a later section (cite). Further, some categories are decidedly incoherent and not the sort of category that people might form. For example, people do not form categories that include fish and elephants but not lions (e.g., Keil, 1991; Sloman, 1987; Murphy & Medin, 1989). A complete theory of human categorization must explain how different kinds of categories, and how some categories but not others are selected. Feature selection and category coherence are deeply related and core *unresolved* issues in theories of categorization.

Feature theories also have difficulty accounting for how people reason about categories. Specifically, people often make category judgments that seem more in accord with a defining feature view than a probabilistic view. For example, people will maintain that an organism that has no bird-like properties -- other than bird DNA --- is, nonetheless, a bird (e.g., Rips, 1989; Keil, 1994). In light of these last results, a number of researchers in the 1990s suggested the peoples concepts were more like naïve theories with causally related systems of features rather than mere lists of characteristic features. (e.g., Murphy & Medin, 1985; Keil, 1994; Sloman, 1997). Sometimes called the “theory-theory” if concepts and categories, the main idea that feature relevance is determined by the causal relatedness of different kinds of properties, both observable and non-observable, across systems of categories and features. For example, such a theory might include the following: Birds have wings and are lightweight because they fly and these behavioral and physical properties arise because of the genetic structure of birds. Accordingly, researchers began studying people's beliefs about feature relevance, "really makes something what it is," and their reasoning about the causal relatedness of properties relevant to category membership (e.g., Carey, 1985: Gelman & Markman, 1987; Gelman & Bloom, 2000; Malt 1994). The results of these studies suggest a distinction between the core characteristics of things (and often not directly observable properties such as DNA) and the surface characteristics of things (for example, being bird shaped). That is, within intuitive theories some features are more important, and have more causal force, than others.

One version of the intuitive-theory account posits that people's theories about kinds are "essentialist" (see Gelman, 2003). The idea here is that people believe there is "an essence" that determines whether or not an instance is a member of a category. By this account, the reason that an organism that looks and acts nothing like a bird might still be judged to "really be a bird" is because the subject believes the organism possesses the essential but non-obvious properties that are true of all and only birds. These essentialist ideas thus resurrect the criterial-property concepts of the 1960s and the idea that a believed intension (a belief in an essential property) determines the extension (the belief in what really is a bird). However, by the modern day essentialist perspective, it is not that instances actually share these properties or that these essential properties are even useful in recognizing instances in the world, but rather that fixed beliefs in the existence of these essential properties govern how people reason about category members. That is people believe categories have some necessary and sufficient property that determines its membership in the category (that distinguishes *real* water, for example, from a substance that looks like but is not water, see; Malt, 1994 ) Moreover, these essentialist beliefs appear stronger for natural kinds than for artifacts (Gelman & Coley, 1990)

Much contemporary research has been devoted to the study of intuitive theories and their development, opening up new domains of inquiry such as induction, conceptual combination, and causal reasoning (e.g., Carey, 1985; Gelman & Coley, 1990; E. Smith, 1989; Medin, 1989; Keil, 2003, 2006). Research on intuitive theories has also led to interesting insights about how reasoning differs in different domains (e.g., for biological versus non-biological kinds, see Gelman, 2003). The theory theory of concepts also makes the significant advance in highlighting the importance of *systems* of properties interconnected to each other and systems of categories.

Still, the naive-theory view has its own problems. First, there is no consensus as to what a naive theory is, the formal nature of the representations, or the kinds of knowledge included (see Ahn et. Al., 2000 for a discussion). In general, naive-theory theories have not been formalized as the probabilistic-feature sort and the rigorous testing of predictions has been difficult. Second, naive theories clearly do not explain the full range of data traditionally viewed as the province of a theory of categorization. Instead, certain phenomena (induction, conceptual change, conceptual combination, and judgments of causal relatedness) are singled out as theoretically more important than phenomena concerning the recognition of instances. Thus, naïve-theory accounts do not explain how one knows a bird when one sees (or hears) one, nor do they explain why robins are judged to be psychologically better birds than penguins. Indeed, the fact that people readily make these judgments is seen as pretty much irrelevant to the intuitive-theory account of human categories (e.g., Armstrong, Gleitman, & Gleitman, l999). Third, naive theories may not be able to explain the very data they take to be their core phenomena. Keil (2006; Rozenblit & Keil, 2002) have presented compelling data that adults' naive theories are typically explanatorily *in*adequate and incoherent. People believe they understand a phenomenon when they do not. Keil (2003) suggested that people have at best coarse, not quite right, and gap-filled understandings of the causal structure of even basic things, such as how electricity works or gravity. His experiments suggest that adults' seemingly causally - based reasoning in the laboratory may not reflect well formed theories but rather a few bits of (not necessarily correct) knowledge coupled with in-the-moment reasoning. That is causal reasoning in experimental tasks appears much like Barsalou's (1983) ad hoc categories. Nonetheless, these bits and pieces of knowledge, assembled in the service of some specific task, do reasonably well.

Now, not quite a decade into the 21st century, accounts of categories based on general processes and probabilistic feature correlations are again on the ascendancy; but this time, borrowing on advances from theory-theory, they are focused on natural categories and systems of feature, category, and language correlations, (e.g., Cree, McNorgan, & McRae, 2006; Rogers & McClelland, 2005; Xu & Tenenbaum, 2007; Colunga & Smith, 2006), and with new emphases on how tasks recruit cognitive processes over nested time scales to soft-assemble "concepts" on line (Colunga & Smith, 2007; Samuelson & Horst, 2007), and on the role of bodily action in organizing concepts (Maouene, Hidaka, & Smith, 2007; Richardson, Spivey, Barsalou & McRae, 2003). As a backdrop to reviewing these new domains of research, we first consider a distintiction about kinds of features and categories that has figured prominently in the study of category development.

## Perceptual or Conceptual Categories

In the developmental literature, the back-and-forth battle between the two views of concepts is typically couched in terms of whether young children's concepts are fundamentally different from older children's and adults in being based on static perceptual properties (such as shape or having wheels) whereas more mature concepts are based on conceptual properties or relational roles (such as being edible or growing). One way of putting the developmental debate is whether there is a developmental transition from "probabilistic" feature accounts (immature concepts) to but theory-theory accounts for more fully developed concepts. Perceptual features such as "having wheels" or "having a mouth" are generally seen as more relevant to the first kind of theory and relational roles ("carries peoples places" or "eats") as more central to the causal relatedness of properties.

Although there are many confusions in this literature about just what should count as "perceptual" or "conceptual" (see, Colunga & Smith, in press; Samuelson & Smith, 2007), there is clearly something to the distinction. A large set of findings suggest a developmental shift from more perceptually based to more conceptually based categories (Carey, 1985; Jones & Smith, 1993; Sheya & Smith, 2007; Keil & Batterman, 1984). The developmental literature is replete with experiments pitting perceptual versus conceptual properties with perhaps the main conclusion emerging being that both static perceptual properties and relational roles matter in children's early category learning, (Booth & Waxman, 2002b; Gelman & Bloom, 2000; Kemler Nelson *et al.*, 2000; Madole & Oakes, 1999; Mandler & McDonough, 1996; Nelson & Ware, 2002; Rakison & Butterworth, 1998b; Smith *et al.*, 1996).

Certainly mature knowledge would seem to include many different but inter-related components. For example, our understanding of dogs must include knowledge that dogs have a characteristic shape, four legs, eyes, and mouths, but also knowledge of the roles in which dogs participate, like fetching, playing, sleeping, and eating. Thus the better developmental question may be how children build such a system of knowledge. Figure 1 illustrates three kinds of relations relevant to such a system that have been studied in children's categories.

Figure 1 about here

**Property-Property Correlations.** The first relation is among perceptual properties; that is, children's knowledge about categories might include not just perceptual properties but also knowledge about the co-occurrence of properties, for example, knowledge that things with eyes typically have mouths, and things with mouths typically have feet. Knowledge about association among properties has been hypothesized to underlie basic level and superordinate level categories (McRae *et al.*, 1999). Knowledge about such co-occurring clusters of properties could help children recognize novel instances, for example to recognize a novel animal as an animal because it contains the relevant cluster of properties (Jones & Smith, 2002).

Considerable evidence shows that infants readily learn about the properties typical of category members and that they also learn which properties regularly co-occur with each other (Mareschal *et al.*, 2002; Quinn & Eimas, 1996; Rakison, 2003; Rakison & Butterworth, 1998a, 1998b; Younger, 2003). For example, Quinn and Eimas (1996) showed that 3- and 4-month-old infants classify cats versus dogs on the basis of features such as head shape. Using methods in which 18- and 30-month-olds were presented with small (and randomly selected) portions of pictures, Colunga (2003) found they discriminated cows versus cars primarily on the basis of properties such as eyes, ears and head-shape versus wheels, windshields, and doors. Rakison and Butterworth (1998b) showed that in at least some tasks, 14- to 22-month-old children partition objects into the superordinate categories of animals versus vehicles primarily on the basis of the properties of legs versus wheels. From these results, Rakison (2003) has hypothesized that children may organize superordinate categories around a very small set of salient features.

Other studies show that infants readily learn about correlated properties. In one study, Younger (1990) presented 10- to 14-month-old infants with an array of objects in which the features were perfectly correlated. For example, animals with feathered tails had ears and animals with fury tails had antlers. After familiarization, the infants detected changes in feature combinations, treating an instance with a feathered tail and antlers as novel even though both features were highly familiar (see also (Younger & Cohen, 1983, 1986). Other evidence suggests that preschool children may make inferences from one perceptual property to another. For example, Gelman (1990) reports that 3-year-olds assume that objects with eyes and other animacy properties have feet (Jones & Smith, 1993; Macario *et al.*, 1990) Property-property co-occurrences thus appear readily learnable and an early part of children's developing category knowledge.

**Property-role correlations.** The second relation is among perceptual properties and roles. That is, children's knowledge about categories could also include knowledge about the co-occurrence of physical properties and roles, for example, that mouths are used for eating, eyes for seeing, or that things with eyes typically also have some manner of eating. Knowledge about these relations seems crucial to making inferences about the behavior and function of things and to building causal theories about why entities have the properties they do (Ahn *et al.*, 2000).

Research by Mervis and Mervis (1988), and Bates *et al.* (1988) among others shows that parents actively provide young children with information about the meaningful roles of objects in play. For example, parents make toy animals walk, eat, sleep, and drink but they drive, "zoom", and give rides with toy cars and planes. This kind of play – and the contingencies present in the everyday world – provide an opportunity for children to learn how the perceptual properties of things correlate with the roles of those things in meaningful events. Studies of young children's play suggests that they are aware of these property-role contingencies (Mandler & McDonough, 1998 1998). For example, children appear to know that that eyes enable seeing (McCarrell & Callanan, 1995), that wings enable flying (Gelman *et al.*, 1988; Goodman, McDonough, and Brown, 1998), that things with feet can move (Massey & Gelman, 1988), that round things can roll, that non-rigid materials can be folded (e.g., (Samuelson & Smith, 2000), and that things with brushes on them can be used for painting (Kemler Nelson et al, 2000). Goodman et al. (1998) even showed that very young word learners could use these relations to learn new words. For example, told "a wug eats…", children chose a picture of a novel animal over pictures of other novel kinds as the referent of "wug." Further, Madole & Cohen (1995) have shown that when functions such as twisting or rolling are linked to particular parts of objects, 18-month-old children attend to those parts more than to others (see also Gerskoff-Stowe, 2005; Rakison & Cohen, 1999).

Other evidence shows that infants also readily learn property-role correlations in experimental tasks. For example, Rakison and Poulin-Dubois (2002) found that 14-month-old infants readily learned how the parts of objects (e.g., arm-like projections) predicted their motion. Rakison (2003) has hypothesized that predictive relations between features and roles plays a causative role in children's parsing of objects into features and in their selective attention to some features over others in forming a category. Thus, the extant evidence indicate that young children learn a link between roles and the characteristic properties of things that participate in those roles and that these links strongly influence their category decisions.

**Role-role correlations.** A third relation that should be important to children's developing category knowledge is among roles, knowledge, for example, that things that eat also sleep, that they eat, drink and grow, and so forth. Direct associations among roles that do not depend on links to the perceptual properties of things might be particularly crucial for reasoning about abstract and hypothetical categories. For example, such knowledge would enable one to reason – in a conceptually coherent way – about possible life forms and to make inferences about entities from their roles in events despite unusual perceptual properties. Knowledge of role-role correlations would also seem crucial to developing a higher level (and causal) understanding about different kinds (Carey, 1985; Gelman & Coley, 1990; Keil, 1979).

There is less direct evidence on what young children might know about role-role correlations that is not linked through the perceptual properties of the participating entities. One relevant set of studies by Mandler and McDonough (1996,1998,2000) examined young children's imitations of category relevant roles across a diverse set of entities. For example, in one study, Mandler and McDonough (1996) presented 14-month-old children with a toy dog, demonstrated the action of giving it a drink from a cup, then asked children to do the same thing with similar and prototypical instances that drink (e.g., a cat), with dissimilar animals that one does not usually think of as drinking (e.g., a fish), and entities of a different superordinate category (e.g., a car). Children generalize the action broadly to items in the same superordinate category (cats and fish) but not to items in a different superordinate category. In addition, children only extended actions that were appropriate to the category (e.g. when the experimenter gave a vehicle a drink children did not imitate the action on the vehicle match). These results show that very young children's generalizations of roles are not based solely on overall similarity, but these results do not unambiguously show direct knowledge, unmediated by perceptual properties, of role-role correlations either.

Indeed, Rakison and Poulin-Dubois (2001) suggest that Mandler and McDonough's results could reflect children's use of a single prominent feature such as having a mouth or having eyes that are predictive of entities that engage in the role of drinking. Thus, Mandler and McDonough's results could reflect knowledge about how roles link to features rather than knowledge about roles that can be accessed independently of the perceptual features that co-occur with those roles. Mandler (2003) countered that a feature-role explanation cannot explain all her results because in several experiments, they included a "Flying Tiger" toy airplane that had a mouth painted on its nose cone. She notes that children never offered a drink to the airplane but did generalize the action to models of animals that had the barest hint of a mouth. If this observation is generally true, it might indicate that young children have knowledge of category roles – and perhaps their relations to each other – that is not dependent on, and can be accessed independently of, their knowledge about the characteristic properties of things. Alternatively, children's non-generalization of the drinking action to the airplane could reflect their use of predictive properties other than mouths (e.g., eyes) or could be due to idiosyncratic aspects of the particular airplane used in the Mandler and McDonough studies. Clearly, these are issues that merit further empirical study.

Other evidence in the literature on children's knowledge about role-role correlations derive mostly from verbal reasoning tasks, and these suggest a protracted developmental course. For example, Keil (1979) showed that older preschoolers could systematically judge which predicates could sensibly apply to nouns and in this way showed that they know that things that eat, also sleep, and so forth. However, the children in this task were not asked to directly link roles to each other but did so through familiar nouns. In her studies on conceptual change, Carey (1985) also found that 4-year-olds generalize non-visible properties such as breathes, sleeps, eats collectively (that is, generalizing breathes in the same way that they generalize sleep) to unfamiliar animal categories. However, 4-year-olds' judgments depended more than did older children's and adults on the similarity of the target category to people, a result consistent with the idea that these generalizations "go through" the object and its surface properties.

Two other lines of research – although not directly asking whether young children form and use role-role connections – suggest that they might. These studies show that preschool children can treat the very same perceptual object as a different kind - as an artifact vs. a material or as an animate vs. an inanimate – if given information about its relational roles. For example, Gelman and Bloom (2000) found that 3-year-old children when told that an object was intentionally created (e.g. folded, cut, sawed) labeled it as an artifact (e.g. hat, knife, belt) but when told the very same object was accidentally created (e.g. dropped, ripped, knocked), labeled it with a material term (e.g. newspaper, plastic, metal). Similarly, Booth and Waxman (2002b) showed that 3 year old children could interpret the very same object as animate if told it had a mommy and daddy, was happy, slept, and was hungry, but as inanimate if told it was made, was fixed, got worn, and was bought. Both of these results suggest that 3-year-olds have knowledge about co-occurring and kind-defining relations that may not depend on direct links to the perceptual properties of the objects that take part in those relations.

Recently, Sheya and Smith (2007) directly asked if children could make an inference from one role to another, for example, told an object like that in Figure 2a, eats could children infer that it also sleeps. Four-year-old but not 3-year-old children could do this. However, if shown an object like in 2b, with a defining feature of animate, 3-year-olds judged that it would sleep. Two-year-olds required a cluster of features like that in Figure 2c to make the inference. From these data, Sheya & Smith suggested that static object features serve as the glue that holds and aggregates information in this developing system. This may be because specific features (e.g., mouths) are causally tied to specific roles (e.g., eating). Alternatively, it could also be because statistically, static perceptual cues may simply be better predictors of roles than roles are of other roles. After all, the static surface properties of an object are regularly available to the learner whenever an instance is. In contrast, different roles (say drinking and hugging) are evident only in specific contexts and two roles relevant to the same kind may rarely occur together. Thus, the perceptual to conceptual trend could reflect –not intrinsic differences about different kinds of properties – but merely their statistical properties in the data available to learners.

Insert Figure 2 about here

This developmental distinction between perceptual and conceptual features is also related to one made in cognitive neuroscience literature between perceptual and functional features. In the literature on category-specific deficits as a function of brain impairment, perceptual features in the form of visual properties have been contrasted with functional features in the form of actions as a basis for distinguishing animals versus artifacts (and more specifically, tools, see Pilgrim, Moss, & Tyler, 2005; Moss & Tyler, 2003). This proposal different kinds of ontological categories derives primarily from the fact that different kinds of features and thus different brain regions (e.g., perceptual features for animals and functional ones for artifacts) matter for different kinds of categories is controversial (see Moss & Tyler, 2003, for discussion). One criticism is that there are patients with specific deficits involving categories of living thing deficits who do not have the expected perceptual deficits. One possibility is that although perceptual and functional features characterize all kinds of categories, functional/semantic information is particularly important to conceptual representations, more robust, and more resistant to damage. If one accepts the developmental evidence, functional features would also be later acquired. Importantly, the function of artifacts is also strongly lined to properties such as shape and biological functions (eating, sleeping, ) are crucial for categories of living things and that these functional features also link to specific perceptual properties and to modes of interacting with the environment. These ideas again reinforce the potential importance of understanding how perceptual and conceptual (or functional) features may be correlated and mutually support the developmental of a system of features and categories.

## Development as data-mining

Data mining is a process through which implicit but previously unknown regularities can be extracted from large volumes of data. This still-developing interdisciplinary field, using techniques drawn from statistics, database technology, pattern recognition and machine learning, has proven to be highly effective and to be of significant practical value. Can human concepts be understood as a form of data mining? Young children –as they observe their world and as they learn language – amass a large data set. Do their cognitive systems, in a sense, mine that data, discovering latent regularities that constitute what we call concepts and categories?

Perhaps the most promising new work on category development uses data mining techniques to examine how learning about *many* categories with *many* overlapping and correlated properties may enables higher order structure patterns (or categories) to be formed. The approaches which seek to understand the latent structure in feature, instance and category correlations include connectionist approaches (see, especially, Rogers & McClelland, 2005) and also Bayesian approaches (see, especially, Xu & Tennbaum, 2006). Both concentrate on the statistical feature structure of natural categories and the emergent higher-order relations in that feature structure.

One phenomenon which suggests the developmental potency of such latent structure is children's early noun learning. Although children initially learn words slowly, by the time they are 2 to 3 years old, they seem to be expert learners. Indeed, many studies have shown that 2- and 3-year old children need to hear only a *single* object named to correctly generalize that name to the whole category (e.g., Golinkoff, Mervis & Hirsh-Pasek, 1994; Markman, 1989; Smith, 1995; Waxman & Markow, 1995). Young children's facility in mapping nouns to categories is particularly remarkable because, as noted earlier, not all categories are organized in the same way. Instead, there are different kinds of categories --- animals, objects, and substances – with fundamentally different organizational structures. The ease with which 2- and 3-year-old children learn names for these different kinds suggests that they understand at a very early age the different organizations.

The key experimental results derive from what is known as the The Novel Noun

Generalization (NNG). This task was originally designed to measure the one-trial category learning that 2- to 3-year-old children seem to naturally show (see Katz, Baker, & Macnamara, 1974; Markman, 1989). In this task, the child is shown a single novel object, told its name (e.g.,*This is a toma*) and then asked what other things have the same name (e.g., *Where is the toma here?)* With no more information than this – a novel name applied to a single novel thing – 2- and 3-year-olds extend the name in systematic ways that seem right to adults. Experimenters have studied three kinds of entities (as shown in Figure 3) and found three different patterns of generalization. Given objects with features typical of animates (e.g., eyes), children extend the name narrowly to things that are similar in multiple properties. Given a solid inanimate thing, children extend the name broadly to all things that match in shape. Given a nonsolid substance, children extend the name by material. These are highly reliable and replicable results –obtained by many researchers – and in their broad outline characteristic of children learning a variety of languages (e.g., Jones, Smith & Landau, 1991; Kobayashi, 1998; Jones & Smith, 2002; Yoshida & Smith, 2001; Markman, 1989; Booth and Waxman, 2002; Gathercole & Min, 1997; Imai & Gentner, 1997; Landau, Smith & Jones, 1988, 1992, 1998; Soja, Carey, & Spelke, 1991; see also, Gelman & Coley, 1991; Keil, 1994). However, children's specific patterns of performances in this task are also highly dependent on the task, the stimuli, and specific language cues.

Insert Figure 3 about here

Children's use of different features to form new categories in these tasks appears to directly reflect the category likelihoods of those features for categories children already know. Samuelson and Smith (see also Colunga & Smith, 2005; Smith, Colunga and Yoshida, 2003) examined the category structure of the first 312 nouns typically known by children learning English (and in other studies the first 300 nouns learned by children learning Japanese). They measured category structure by asking adults to judge the shared properties of typical instances of individual noun categories on four dimensions -- shape, color, texture, and material. They found that individual artifact categories (chairs, forks, spoons, cups) were judged to have instances that were highly similar in shape but variable in other properties, that animal categories were judged to have instances that were similar in all properties, and that substance categories were judged have instances that were similar in material (and color). Thus, the importance of features to different kinds of categories for children may reflect the expected distributions of those features *for nearby categories*, a point we expand on below.

Several recent studies further indicate that children's different patterns of category generalization for different kinds of features may be geometrically organized in some larger feature space (Imai & Gentner, 1997; Yoshida & Smith, 2003; Colunga & Smith, 2005; 2007). For example, Colunga & Smith (2005) showed that children's generalizations of novel names by shape versus material shifted gradually as the presented novel instances varied incrementally from shapes typical of artifacts (complex, lots of angles) to shapes typical of substances (simple rounded shapes). Similarly, Colunga and Smith (2007, see also Colunga, under review; Yoshida & Smith, 2005) showed that children's generalization by shape versus material shifted systematically as (identically shaped) instances were incrementally varied from solid (brick like), to perturbable (play dough like), to nonsolid (applesauce like). We illustrate this idea in Figure 4. Individual categories of instances are represented as areas in a 2-dimensional feature space. The shape of the categories –that is, the distribution of features across the two dimensions of shape and texture/material –varies systematically as a function of location in that space.

Insert Figure 4 about here

This idealized representation illustrates the structure that appears to characterize the nouns that are learned early by young children and also to characterize children's generalizations of a newly learned noun to new instances. That is, instances of categories with highly constructed and angular shapes vary little in shape but vary greatly in texture and material whereas categories of animal-like shapes vary little in shape but are also constrained in their variation in texture/material. Finally, the unconstructed simple shapes of substances are correlated with category distributions of relatively variable shapes but limited texture/materials. This is a very interesting structure: Similar categories, that is categories that are close in the feature space, have similar patterns of category likelihoods for different features. Put another way, the categories in the same region of feature space have similar shapes (their generalization patterns) and there is a gradient of category shapes (range of generalizations across different features) across the space as a whole. They show the mathematical property of *smoothness* (Hidaka & Smith, in preparation): near (or categories with similar instances) have similar generalization patterns and far (or categories with dissimilar instances) have dissimilar generalization patterns. Understanding the developmental emergence of this structure would seem key to solving the feature selection problem more generally. In brief, "kinds" may be defined by a higher order property of the geometry of categories in feature space, an idea related to the proposals in the cognitive neuroscience literature (e.g., Moss & Tyler, 2003) that different kinds of categories emerge as a consequence of the different relevance of different kinds of properties.

The fact that children's novel noun generalizations --- by shape for angular solid things, by multiple similarities for animals, by material for nonsolid things – follows the statistical regularities that characterize early-learned nouns (Samuelson & Smith, 1999; Smith, Colunga & Yoshida, 2003) suggests that this smooth structure is learned. Two additional facts about children's novel noun generalizations suggest that these generalizations are, in fact, a learned consequence of learning object names.

First, experiments have included control tasks that are identical to the NNG task, except the object is not named. Instead, children are shown the exemplar and then are asked what other objects are "like" or "go with" the exemplar. With these cues, children do not systematically attend to the different properties of different kinds. (e.g., Imai & Gentner, 1997; Landau, Smith & Jones, 1988, 1992; Jones, Smith & Landau, 1991; Soja, Carey, & Spelke, 1991). This fact suggests a link between naming and knowledge about category specific organizations (see, Deisendruck & Bloom and also Colunga & Smith, in press, for a further discussion).

Second, kind-specific name generalizations emerge *with* vocabulary growth (Landau, Smith & Jones, 1988; Soja, Carey & Spelke, 1991; Jones, Smith & Landau, 1991; Samuelson & Smith, 1999, 2000; Smith, 1995). The evidence indicates that the tendency to attend to shape in the context of naming emerges only after children already know some 50 to 150 nouns. For children learning English, a bias to extend names for animates by multiple similarities and a bias to extend names for nonsolid substances by material emerge even later (see, especially, Jones et al, 1991; Samuelson & Smith, 2000). Thus, biases to attend to different properties when extending names for different kinds co-develops with increasing vocabulary, a fact consistent with the idea that children's word learning helps create these generalized expectations about different kinds.

Indeed, language learning may play the crucial role in enabling children to build the systems of generalizations that enable the rapid selection of just the right features for different kind of categories. In particular, kind-specific name generalizations are modulated by linguistic cues**.** One result is the influence of count and mass syntactic frames on English-speaking children's interpretations of novel object and substance. Count nouns are nouns that take the plural and can be preceded by words such as *a*, *another, several*, and *few*, as well as numerals. Count nouns thus label things we think of as discrete individuals --- chairs, trucks, shirts, studies, and wishes. Mass nouns, in contrast, cannot be pluralized but instead are preceded by words such as *some*, *much,* and *little*. Mass nouns thus label things that are conceptualized as unbounded continuous masses --- water, sand, applesauce, research, and justice. Past research shows that count syntactic frames (e.g., *a mel*, *another mel*) push children's attention to the shape of the named thing whereas mass syntactic frames (e.g., *some mel*, *more mel)* push attention to material (e.g., Gathercole, Cramer, Somerville, & Haar, 1995; McPherson, 1991, Soja, 1994). Other studies show that linguistic cues associated with animacy (descriptors such as *happy* or the personal pronouns *he* and *she*) push attention to multiple similarities even when the objects do not possess perceptual cues such as eyes that are diagnostic of animacy (Yoshida & Smith, 2005; Yoshida & Smith, 2001;

Booth & Waxman, 2002) and even when these words are not referring to the object in question (Colunga & Smith, 2004, Colunga, 2006). In brief, the evidence shows that language exerts an on-line influence on children's category formation in the NNG task.

The particular language a child learns also influences children's novel noun generalizations. Although there are overarching universals in the name generalizations of children learning different languages --- solid rigid things tend to be named by shape, nonsolid things by material, and things with features suggesting animacy by multiple similarities --- there are differences as well (Colunga & Smith, 2005; Gathercole, Thomas, & Evans, 2000; Imai & Gentner, 1997; Yoshida & Smith, 2005; Kobayashi, 1998). For example, Japanese speaking children are more sensitive to animacy cues than English speaking children (Yoshida & Smith, 2003); Spanish-speaking children are more sensitive to count mass syntax cues than English speaking children (Gathercole, 1997); and Japanese- and English-speaking children place the boundaries between animals and objects and between objects and substances in different places (Yoshida & Smith, 2003b; Colunga & Smith, 2005).

Colunga and Smith (2005) hypothesized that children's knowledge of different kinds –and their ability to systematically generalize a name to new instances --- emerged as a consequence of the higher order correlations among words, features, and categories. In a series of simulations in which they fed a connectionist network the statistical regularities of the first 300 nouns learned by children learning English or by children learning Japanese, they showed that the network could discover the latent structure across these words and categories ,and systematically form and generalize new categories in ways that fit the specific task performances of English and Japanese speaking children.

Two- and 3- year olds' generalization of names for different kinds of things in different ways is so robust that some have tried to explain this knowledge with fixed propositional representations, "over hypotheses," or theories about the causal structure of different kinds (e.g., Soja et al, 1992; Hall, 1996; Booth & Waxman, 2002; Deisendruck & Bloom, 2003). Others have suggested that forms of Bayesian statistical learning applied to symbolic representations may be used to explain the evidence that children learn these generalizations as they learn the noun categories (and related syntactic structures in their language) and that their knowledge reflects the statistical structure of their language (see Xu & Tennebaum, 2006). These proposals thus present an alternative view to the connectionist accounts of Colunga & Smith (2005; or relatedly, Rogers & McClelland, 2005). Again, we see the standard contrast in theories – propositions versus general processes of association and generalization by similarity. However, both of these new kinds of account have moved forward by concentrating on systems of statistical regularities and how the child might be "data-mining" those regularities for latent structure.

## Nested Time Scales in Tasks

Categories are evident to experimenters, theorists, and naïve observers only across large stretches in time. It only when an individual labels, for example, one thing as a "dog," and then sometime later labels something else as a "dog," and then sometime later recognizes another thing as a "dog," and so on that we have evidence of a "category." Categories are demonstrated and *acquired* in real time, in moment-by-moment encounters with specific things in specific task contexts. This is one fundamental problem with thinking of categories in terms of fixed and stable representations

(Samuelson & Smith, 2000). A second problem with thinking about categories in terms of fixed representations is that category decisions are simply repeated without variation. Instead, responses and judgments are bent, adapted and fine tuned to the context. For example, we think about (and classify) frogs differently when we are next to a pond then when we are in a fine restaurant. Experimental studies of adult categorization also show that adults make systematically different category decisions when asked to name things, when asked to judge their functional utility, when asked about typicality, when asked to predict certain properties, and when asked to make similarity judgments (e.g., Malt & Sloman, 2004; Malt, 1995: Rips & Collins, 1993). Such context effects are also seen in children's categorizations.

The smartness of children's noun learning is not just due to their data-mining the regularities, but also to their inventive extension of those regularities in novel contexts. A number of experiments have shown that very small changes in the stimuli, task context, and words, *systematically* shift children's novel noun generalizations. As noted earlier, children form categories by different properties –even given the very same instance ( say a solid irregular shaped thing), if the novel name occurs in the context of "a" (e.g., " a dax") versus "some" ("some dax'), if it has eyes versus if it does not, or if it is labeled as "happy" versus "bought in a store," (e.g., Gathercole, Cramer, Somerville, & Haar, 1995; McPherson, 1991, Soja, 1994;; Booth, Waxman & Huang, 2005). Such results suggest that children's category generalizations are the product of the integration of past knowledge with the current input.

Colunga & Smith (2007; Colunga, in preparation) building on the Attentional Learning Account first proposed by Smith, Jones, Landau, Gershkoff-Stowe &

Samuelson (2002; see also Colunga & Smith, 2007a, b; Smith & Samuelson, 2007) have proposed that this inventiveness may be understood as a product of the nested dynamics of attentional learning.

The original Attentional Learning Account (ALA, Smith et al, 2001; Colunga & Smith, 2005) was concerned with children's learning of statistical regularities among features, category organization, and words and not with the adaptive generalization of that knowledge across different tasks. More specifically, ALA explains children's novel noun generalizations through learned cues that shift dimension weights among potentially relevant dimensions. Previous versions of the attentional learning account of children's novel noun generalizations have concentrated on changes on one time-scale (the time scale of development and learning, see Colunga & Smith, 2005; Smith, Jones, Landau, Gershkoff-Stowe, and Samuelson, 2003). Nonetheless, within this account is that attention is dynamically tied to contextual cues in the moment that activate learned associations, and through these processes selects some similarities over others as relevant to the task at hand. Viewed in this way, attention is a powerful process because it is inherently multi-causal, integrating in the moment influences over multiple time scales. Further, attention in the moment will strongly constrain the future –and acquired statistical regularities -- by determining what is learned at that moment. In brief, attention is one important mechanism through which prior knowledge is brought into the present and through which the past constrains learning and thus future knowledge.

The Dynamic – Attentional Learning Account (D-ALA) extends this idea by integrating experience at three different timescales. Figure 5 (left) illustrates the three nested processes, each operating at a different time scale. The larger box represents earned correlations between properties, words, and categories. These feed into an attention map in which some areas of the feature space may be more highly weighted than others. The building of these representations operates over the slowest time scale. The next box represents processes that operate at the time scale of tasks. Relevant inputs include the attention map, the perceptual properties of the object, and what is actually being said in the task. These shift attention weights in the moment – integrating various forces on attention including the attention map which reflects statistical regularities in experience categories and any attention grabbing aspects of the current input such as glowing surfaces (Samuelson & Horst, 2007) surprising properties (Smith, Jones & Landau, 1992), opening or closing (Kemler Nelson et al, 2000). Finally, these attentional processes operate within the specific task, in for example, the comparison of a test object with an exemplar in the NNG task. Critically as shown in the right-side figure, these nested processes do not interact in just one direction, but also feed back on each on each other. Each decision – a mapping of a word to an object and to its attended property – feeds back into the accumulating correlations as does the task contexts and associated words.

Insert Figure 5 about here

The beauty of such nested processes is that they integrate these processes and inputs over different timescales, generating behaviors that are optimal, stable, generalizable --the behaviors that seems so essential to higher cognition-- but also generating category decisions that are flexible and inventive. Through such multi-layered and nested processes, the child’s noun learning can effectively adapt to different environments (say, English-speaking or Japanese-speaking), a changing world (moving from one activity to the next, one place to the next), and changing inputs and task goals (biting the cookie, but rolling the ball). Thus, this soft-assembly of attention out of unthinking and nested processes may lead to robust knowledge-based behavior and also to smart, flexible adaptability.

Colunga (in preparation, see also, Colunga and Smith, 2007) tested the model in two tasks that were designed to examine two kinds of such inventiveness – interpolation and extrapolation. For example, in the interpolation task, the objects fell between solids and non-solids (doughs and goops); in the extrapolation task, the objects had extra animacy features (e.g., five eyes), Children categorized the objects within the task contexts in new and inventive ways that were highly systematic, suggesting the integrative finding of new solutions through nested forces on attention. Samuelson (in preparation) tested a related model in a series of tasks that altered the attention grabbing properties in the moment – making solid things with glowing colors, for example, and also by changing aspects of the task at the decision (e.g., forced-choice versus other kinds or category responses). Both sets of results support the conceptualization of categorization,not as specific knowledge about fixed categories, but as momentary events that collect and integrate information over multiple processes and time scales.

Such dynamic systems account of categorization may be particularly important for understanding category development, its accelerating pace in the early preschool years, and findings of cross-linguistic differences in feature selection and ontological categories (see Yoshida & Smith, 2003; 2005; Imai & Gentner, 1997; Lucy & Gaskins, 2001). Self-organizing nested attentional processes build –moment to moment -- knowledge that makes for stable categorization patterns and also dynamically finds new solutions to tasks never encountered as in Colunga (2007). Understanding the interactions among these nested time-scales may also benefit the translation of these basic research findings into ways to help children with developmental delays in language learning. The front end of the system is attention in the moment; this is what provides the data upon which category-relevant shifts in attention, and rapid word learning, depends. Manipulating attention in the moment in ways relevant to those statistics may give delayed learners a leg up (see Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, ) for relevant data on these issues.

### *Embodiment*

There is a growing movement in cognitive science that suggests that the body creates higher order concepts through perception and action (see also, Varela, Thompson & Rosch, 1993; Glenberg & Kaschak, 2003; Clark, 1997; Gallese & Lakoff, 2005; Zwaan, 2004; Nunez & Lakoff, 2005; Yeh & Barsalou, 2006). *Nothing* gets into or out of the cognitive system (or the brain) except through the surface structure of the body. Parts of the body--head, hands, legs and feet--play a role in every experience, every second, every minute from birth to death.

How much of the human semantic system, then, – and children’s understanding about categories – depends on the body and bodily action? There are reasons to believe that the influence is considerable. Holmes (1922/1979) documented the representational role of the body early in the history of neuroscience, discovering the organizational system known as the “neural map.” This is a topographic array of nerve cells across which there is systematic variation in the value of some sensory-motor parameter. Maps organized by the body’s surface are a particularly common form of cortical representation (e.g., Grazianao, Cohen & Botvinick, 2002; Holmes, Spence, Giard & Wallace, 2004; Penfield & Rasmussen, 1950). Studies of neurological disorders and functional brain imaging demonstrate important roles for these body maps in the perception of one's own body (Holmes et al., 2004), in the production of action (e.g., Gallese, Craighero, Fadiga, & Fogassi, 1999), in the understanding of others' actions, and in the categorization of objects such as tools that are strongly linked to action by a particular body part (Hauk, Johnsrude, & Pulvermuller, 2004).

Studies of the world's languages also point to body parts as a universal representational medium (e.g., Heine, 1997; Svorou, 1993). Words derived from body parts are remarkably common in semantic domains of space, number, measurement, and emotion (de Leon, 1994; Lakoff & Johnson, 1980; Sakuragi & Fuller, 2003; Saxe, 1981, Yu, 2004). Indeed, researchers have proposed a universal semiotics of body parts to interpret and translate images and texts from ancient cultures (e.g., Bron, Corfu-Bratschi & Maouene, 1989: see also, Lakoff & Johnson, 1980). All this suggests that the body maybe more than a mere interface between mind and world; rather, it may be central to the origin and representational basis of meaning.

Bodily actions make things happen in the world, and in so doing create meaning. The body part most intimately involved in this meaning creation is the hands. As such, hands are near constants in children's visual fields as they learn about the world, a fact recently documented by experiments that places a head-camera on young children as they interacted with objects and others in naturalistic settings (Yoshida and Smith, 2006). Early category learning –prior to words – may well be constrained and shaped by action general and by hand actions on objects in particular (Ruff & Rothbart, 1996 ). The constraints on meaning from the body may be fundamentally of two different kinds, each worthy of investigation. First are constraints from bodily actions themselves; for example, the trajectory, starting point, and goal point of reaching, may provide the grounded meaning for the whole set of concepts related to "retrieval" (See Richardson et al, 2003). Second, the body also constrains the input by placing real physical limitations as to what can be perceived, known, and made to happen in the world (e.g., Clark, 1997).

Multi-modal interactions between action and perceptual experience may even play a role in defining relevant properties for categories. For example, in one experiment, Smith (2005) presented children with the object shown in Panel A of Figure 4. The children were told it was a "wug" and the child was then were given the object to hold and shown how to move up and down on a vertical path. The child then repeated this action three times. The experimental question was this: What other kinds of objects are also wugs? Children chose from new instances that were either elongated vertically or horizontally relative to the exemplar, as shown in Panel B. Smith's conjecture was that children would be more likely to categorize the exemplar with the vertically rather than the horizontally extended alternative *because* of the experience of *manually* moving the object vertically. This conjecture is right, at least for 2- to 3-year-old children. Children who *acted* on an object by moving it up and down, extended the name to vertically--but not horizontally--elongated objects. Children who acted on an object by moving it horizontally back and forth, extended the name to horizontally but not vertically elongated objects. Children who only watched the experimenter perform the action but did not do the actions themselves did not prefer test objects elongated in the direction of the watched action.

[Insert Figure 4 about here]

[Insert Figure 5 about here]

These results are reminiscent of an earlier adult experiment Freyd (1983) who showed an effect of action on the perception of letter-like figures. Freyd taught adults to recognize new letter-like characters by having them watch a letter being drawn. Subjects watched characters drawn by one of two drawing methods. Figure 6 illustrates a character and the two drawing methods. Although the drawing methods differed, the final static characters that resulted from the drawing in the two conditions were identical. After training with one drawing method, subjects were presented with static representations and asked whether they were instances of the modeled character. Some of these test characters were "sloppily" drawn versions of the modeled character. Freyd found that subjects were reliably faster at recognizing static characters distorted in a manner consistent with the drawing method they observed during training than they were at recognizing equally distorted characters that were inconsistent with the observed drawing method. For example, subjects who observed drawing method 1 during training recognized test item 1 more rapidly than test item 2, whereas subjects who watched drawing method 2 recognized test item 2 more rapidly than test item 1. In brief, the static visual features that mattered for category membership were influenced by dynamic information about how those features were made in real time. Again, the coupling of vision and manual action yields visual percepts that are a blend, a joint product, of the multi-modal experience.

[Insert Figure 6 about here]

One unexplored area is how the multi-modal interaction of vision and action may lead to higher-order and more abstract concepts. One potential example of how this might work is suggested by Kemler-Nelson's programmatic series of experiments on young children's attention to function in forming categories that also illustrates the potential power of hands and action in the formation of categories. In one study (Kemler-Nelson et al., 2000); two-year-old children were presented with novel complex objects with multiple parts like those shown in Figure 8. One object, the exemplar, was named with a novel name. In addition, the children were shown a function that depended on one of those parts. For example, they were shown how the hinged shape could open, close, and latch. They then manipulated the part causing the box to open and close. After seeing and manipulating the hinge, the children were more likely to extend the object name to the test objects that also had hinged parts rather than to those that were similar in global shape but lacked the hinge. How the children acted on the objects--and the outcomes generated by their actions--seem likely to have organized their attention to some aspects of the visual information over others, potentially changing how object shape itself was perceived. Multi-modal regularities emergent in the coupling of vision and manual action may, in this way, create such abstract meanings as "open". If so, then much meaning may reside in the hands--in their actions on objects and in the dynamic visual trajectories they create.

[Insert Figure 8 about here]

In the adult literature, the evidence for a role for  action and specific body parts is in action categories and verb meanings (Pulvermuller, 1999; Pulvermuller et al, 2005; Glenberg & Kaschak, 2005: Richardson et al, 2003). One relevant developmental result is a study by Huttenlocher, Smiley, and Charney (1983) of young children's early comprehension and production of action words. These researchers found that young children were more likely to comprehend and produce words when they were about their own actions than about the actions of others. For example, children would say ”kick” more frequently when they themselves were kicking than when they were watching someone else kick.

Self-action provides a richly inter-related set of immediate experiences out of which one might build meanings. As illustrated in Figure 9, these include the agent's goal, the motor plan for a specific bodily action by a specific body part, the objects one acts on, as well as information about the effects of the action. Critically, it may be the action *by a body part* that links these components, physically connecting goals to outcomes and realizing causes, effects, manners and paths. Yet the role of the body in verb learning has rarely been considered.

[Insert Figure 9 about here]

A recent finding by Maouene, Hidaka, and Smith (2006, 2007) demonstrates the potential importance of the body parts that perform actions to early verb meanings. They examined the body part associations of a corpus the first 100 verbs learned in English. The main data derive from a free association task in which adults were asked to indicate the single body part (at any level of scale) most associated with each verb. The results indicate strong and consistent body part associations. Overall, early-learned verbs are organized into four major bodily areas: the mouth, eyes, legs and feet, and hands. Further, many of these individual verbs –and particularly those that are acquired at the youngest age levels -- are systematically and strongly associated with a *single* region of the body.

Further analyses suggested a relation among verbs, body parts and age of acquisition as illustrated by the body maps in Figure 12. These were generated such that the overall size of the homunculus indicates the total number of verbs normatively known at a given age and the size of the body part indicates the strength association (by adult judgment) of those verbs to specific body parts. These maps illustrate the strong association of early-learned verbs with body-parts, the initial dominance of mouth verbs and subsequent growth of eye and hand verbs, and the overall dominance among these early learned verbs of associations to hands.

[Insert Figure 12 about here]

Traditional theories of cognition segregate the mind from the body, from perception, and from action. Sensory systems are seen only as input devices and motor systems as output devices. Some have argued for the outright against this conceptualization of the cognitive system (see, e.g., Barsalou, 2003; Clark, 1997; Thelen & Smith, 1994); however, even within this traditional conceptualization it seems highly likely that the body and its structure would leave its mark on internal cognitive processes and representations (Clark, 1997 ; Shepard, 2001). Our own body--how it moves, the location of its parts and sensors, how those parts interact with the physical world and create change in the physical world--is the most pervasive regularity in experience.

## What next in the study of category development?

Categories, be they fixed or momentary creations, are the very stuff of cognition. This review has attempted to place the study of category development in its larger context and to highlight several areas of contemporary research.  The review is far from exhaustive and complete. It would be especially hopeful if one could point to this moment in the history of the study of categories as being special, or particularly promising, or about to break away in new directions. But progress happens incrementally and non-monotonically. Theories of the very nature of categories and the underlying processes and representations that give rise to them seem to oscillate between two general views –one that focuses on representations and on stability, as if categories were fixed things (in heads or worlds) to be discovered and acquired, and the other which focuses on process and associations and the more probabilistic and context dependent nature of categories. Perhaps this is not surprising; categories fundamentally have both properties –providing stability, generalization and compositionality to human cognition but also being formed through one's real time interaction in a statistically data-rich world and inventively adaptive to the local statistics. Each cycle through –from a perhaps over-emphasis on one side of this duality to the other – seems to bring gains, both empirically and theoretically. Currently, there is a renewed interest in probalistic feature accounts but with the new emphasis on the structure available in a large system natural categories with many overlapping feature correlations, in integrating processes at multiple time scales, and in broadening the range of features and processes to include multimodal integrations across perception and action. These seem appropriate –perhaps even essential -- steps forward in the developmental trajectory toward a complete understanding of categories.

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Figure captions

Figure 1. Three kinds of correlations among perceptual features and relational roles .

Figure 2. Three stimulus types used in Sheya & Smith (2007): a. no defining features, b. one defining feature, c. clusters of correlated features.

Figure 3. Three different kinds of stimulus types commonly used in Novel Noun Generalization tasks: rigid solid things, things with eyes or other characteristic features of animates, nonsolid things.

Figure 4. A theoretical representation of a gradient of generalization patterns (or category shapes) for categories in a feature space defined by aspects of shape and solidity and material substance.

Figure 5. The three nested timescales of the Dynamic-Attentional Learning Account: Developmental time, task time, and decision/action time, shown separately on the left and in terms of their nested influences on each other on the right.

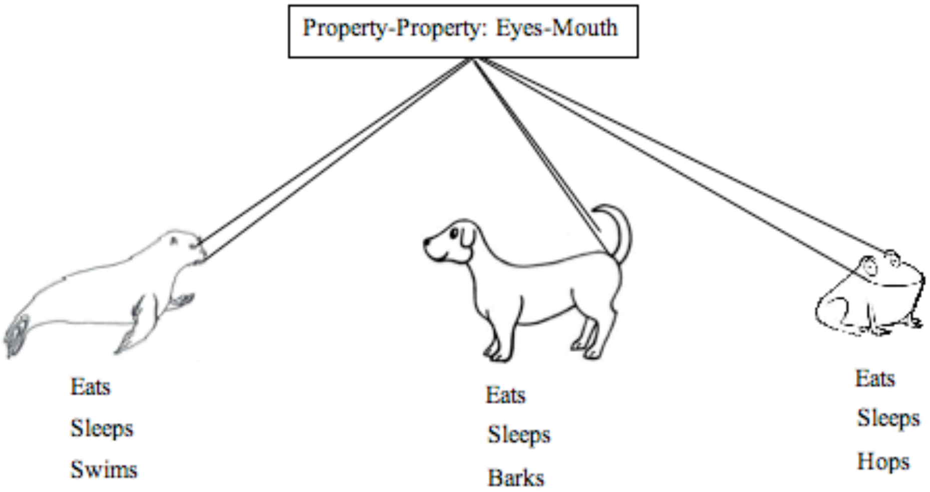
Figure 6. The exemplar (A) and two choice objects (B) used in Smith (2005)

Figure 7. Illustration of two drawing techniques and two test items used in the Freyd (1983) experiment.

Figure 8. Illustration of the objects used by Kemler Nelson et al (2000). Shown are the exemplar in its closed and open form and the “function” matching test object that closes and opens and the “shape” matching test object than cannot be opened.

Figure 9. Verbs are linked to momentary events that include goals, motor plans, body parts, objects and outcomes.

Figure 10. Body maps of body parts associated with typically known verbs at 5 ages. Size of figure illustrates number of known verbs at each age; area of body part region indicates percentage of associations (across all verbs known at that age).


Property-Property: Eyes-Mouth
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Sleeps
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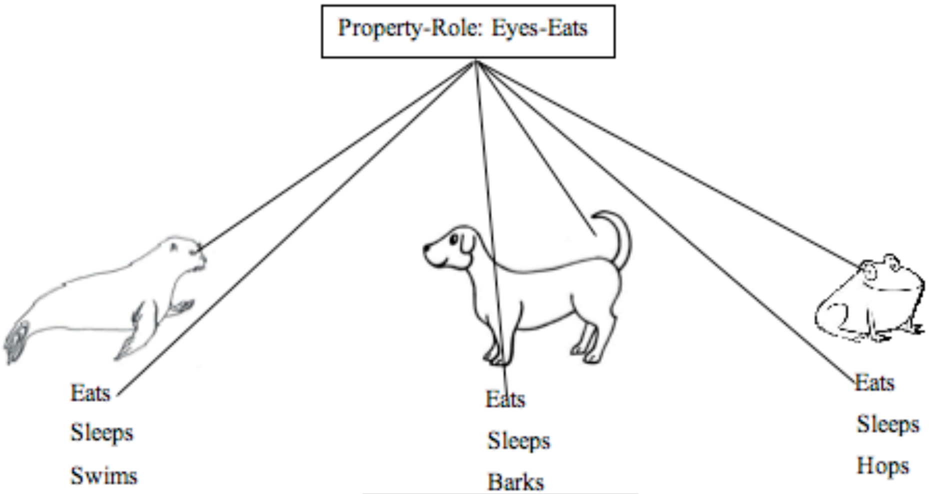
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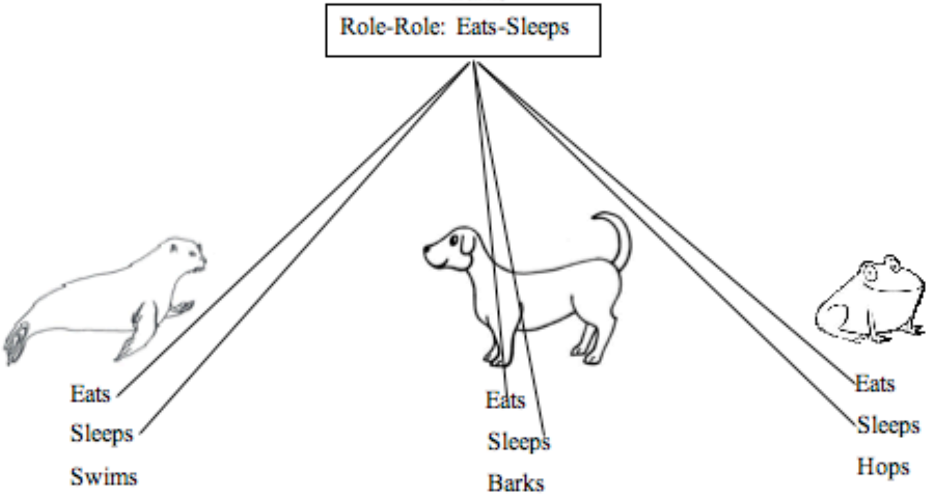
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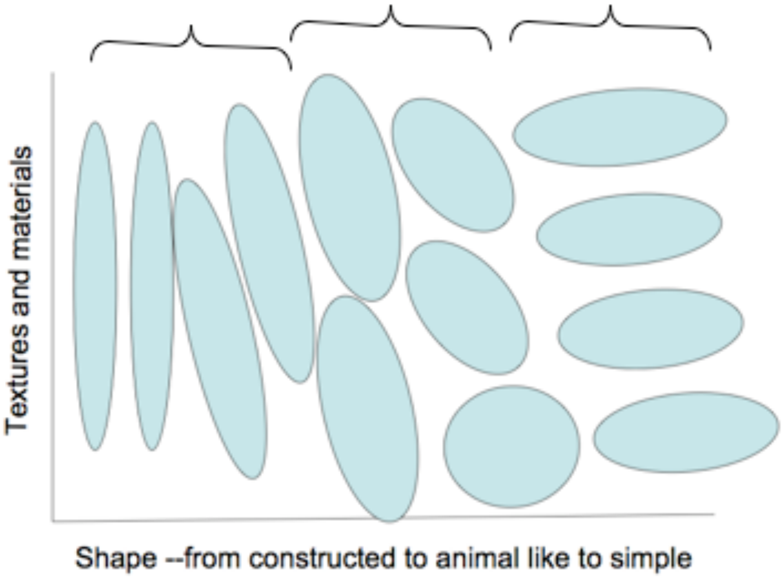
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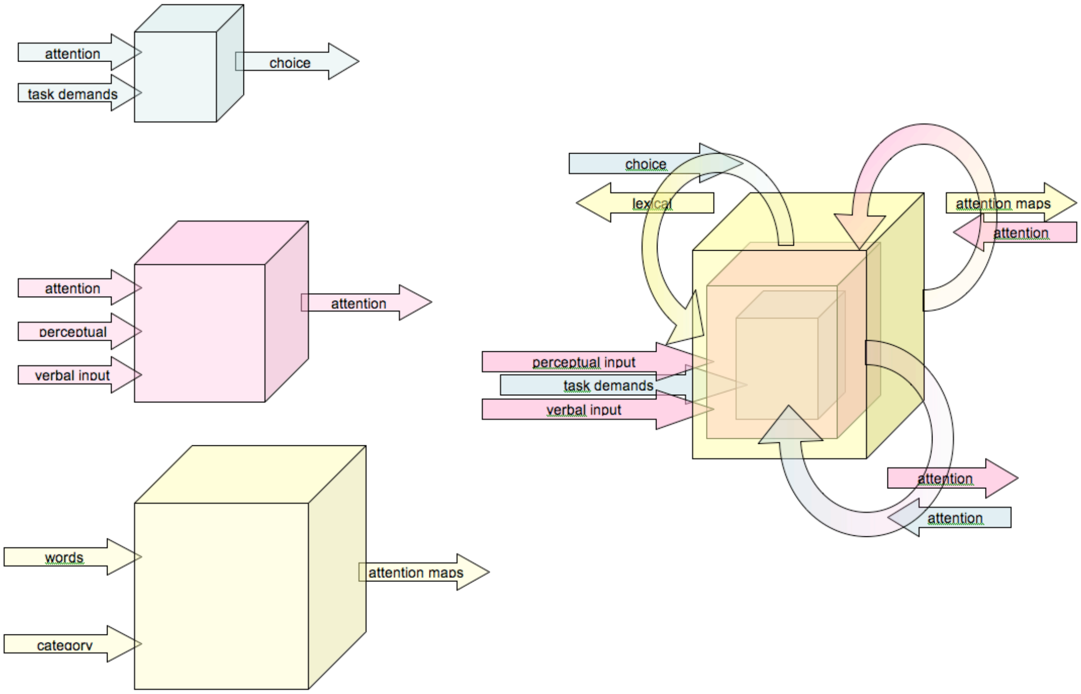
Shape --from constructed to animal like to simple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attention

A

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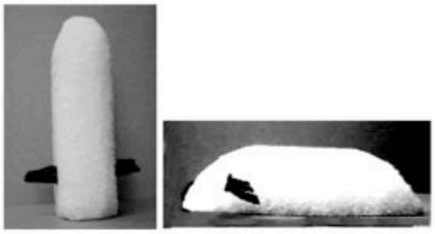

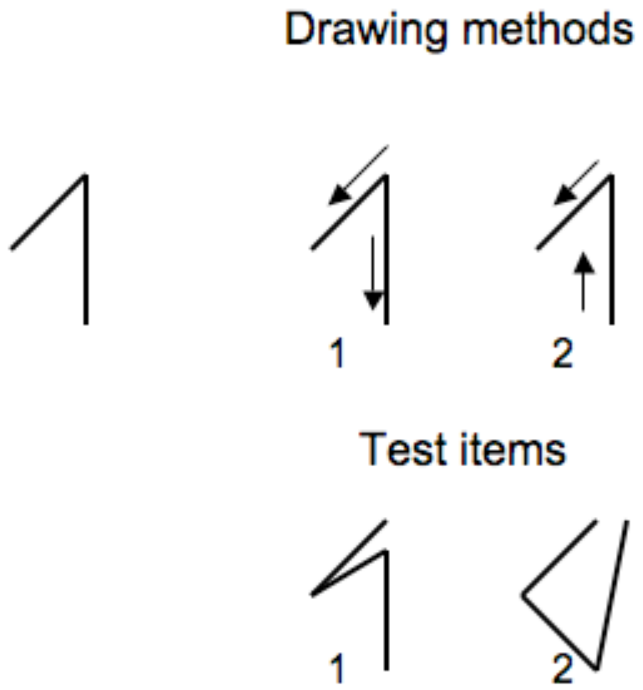
Drawing methods
1
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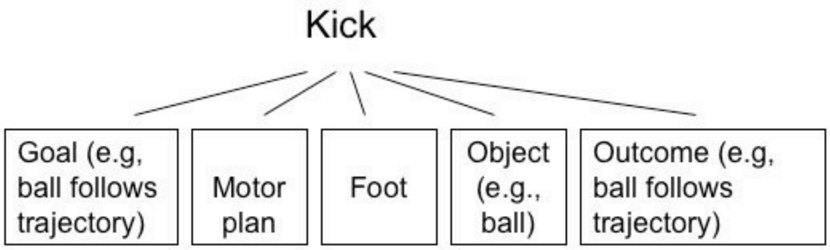
EXEMPLAR

FUNCTION MATCH

SHAPE MATCH


Kick
Goal (e.g, ball follows trajectory)
Motor plan
Foot
Object (e.g., ball)
Outcome (e.g, ball follows trajectory)


21 months
22 months
24 months
28 months
30 months