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CHAPTER 14

Core systems in human cognition

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Abstract: Research on human infants, adult nonhuman primates, and children and adults in diverse cultures provides converging evidence for four systems at the foundations of human knowledge. These systems are domain specific and serve to represent both entities in the perceptible world (inanimate manipulable objects and animate agents) and entities that are more abstract (numbers and geometrical forms). Human cognition may be based, as well, on a fifth system for representing social partners and for categorizing the social world into groups. Research on infants and children may contribute both to understanding of these systems and to attempts to overcome misconceptions that they may foster.

Keywords: core knowledge; infants; cognitive development; cognition

How is the human mind organized, and how does it grow? Does all human development depend on a single, general-purpose learning system? At the opposite extreme, are humans endowed with a large collection of special-purpose cognitive systems and predispositions? Research on human infants, non-human primates, and human children and adults in different cultures provides evidence against both these extremes. Instead, we believe that humans are endowed with a small number of separable systems that stand at the foundation of all our beliefs and values. New, flexible skills, concepts, and systems of knowledge build on these core foundations.

More specifically, research provides evidence for four core systems (Spelke, 2003) and hints of a fifth one. The four systems serve to represent inanimate objects and their mechanical interactions, agents and their goal-directed actions, sets and their numerical relationships of ordering, addition, and subtraction, and places in the spatial layout and their geometric relationships. The fifth system serves to identify members of one's own social group in relation to members of other groups, and to guide social interactions with in- and out-group members. Each system centers on a set of principles that pick out the entities in its domain and support inferences about their interrelationships and behavior. Each system, moreover, is characterized by a set of signature limits that allow for its identification across tasks, ages, species, and human cultures.

Objects

The core system of object representation centers on a set of principles governing object motion: *cohesion* (objects move as connected and bounded wholes), *continuity* (objects move on connected, unobstructed paths), and *contact* (objects influence each others' motion when and only when they touch) (Leslie and Keeble, 1987; Spelke, 1990; Aguiar and Baillargeon, 1999). These principles allow infants of a variety of species, including

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humans, to perceive the boundaries and shapes of objects that are visible or partly out of view, and to predict when objects will move and where they will come to rest. Some of these abilities are observed in the absence of any visual experience, in newborn human infants or newly hatched chicks (Regolin and Vallortigara, 1995; Lea et al., 1996; Valenza et al., 2006). Moreover, research with older infants suggests that a single system underlies infants' object representations. For instance, 5-month-old infants do not have more specific cognitive systems for representing and reasoning about subcategories of objects such as foods, animals, or artifacts (Shutts, 2006), or systems for reasoning about inanimate, non-object entities such as sand piles (Huntley-Fenner et al., 2002; Rosenberg and Carey, 2006; Shutts, 2006). Finally, infants are able to represent only a small number of objects at a time (about three: Feigenson and Carey, 2003). These findings provide evidence that a single system, with signature limits, underlies infants' reasoning about the inanimate world.

Investigators of cognitive processes in human adults have discovered evidence that the same system governs adults' processes of object-directed attention, which accord with the cohesion, continuity, and contact principles and encompass up to three or four separately moving objects at any given time (e.g., Scholl and Pylyshyn, 1999; Scholl et al., 2001; vanMarle and Scholl, 2003; Marino and Scholl, 2005). Of course, adult humans also have developed more specific knowledge of subdomains of objects such as foods and tools (e.g., Keil et al., 1998; Lavin and Hall, 2001; Santos et al., 2001). When attentional resources are stretched, however, the properties that mark these finer distinctions often fail to guide object representations, whereas core properties continue to do so (Leslie et al., 1998).

If core object representations are constant over human development, then they should be universal across human cultures. Recent studies of remote Amazonian groups support that suggestion. For example, the Pirahà are a highly isolated tribe whose language lacks most number of words and other syntactic devices (Everett, 2005). Nevertheless, the Pirahà distinguish objects from non-object entities (Everett, 2005), and they track objects with the signature set-size limit (Gordon, 2004).

Agents

A second core system represents agents and their actions. Unlike the case of objects, spatio-temporal principles do not govern infants' representations of agents, who need not be cohesive (Vishton et al., 1998), continuous in their paths of motion (Kuhlmeier et al., 2004; although see Saxe et al., 2005), or subject to the constraint of action only on contact (Spelke et al., 1995). Instead, infants represent agents' actions as directed towards goals (Woodward, 1999) through means that are efficient (Gergely and Csibra, 2003). Infants expect agents to interact with other agents, both contingently (Watson, 1972; Johnson et al., 2001) and reciprocally (Meltzoff and Moore, 1977). Although agents need not have faces with eyes (Johnson et al., 1998; Gergely and Csibra, 2003), when they do, even human newborns (Farroni et al., 2004) and newly hatched chicks (Agrillo, Regolin and Vallortigara, 2004) use their gaze direction to interpret their actions, as do older infants (Hood, Willen and Driver, 1998; Csibra and Gergely, 2006). In contrast, infants do not interpret the motions of inanimate objects as goal-directed (Woodward, 1998).

Research on human adults provides evidence for the same system of agent representations. Representations of goal-directed, efficient actions and of reciprocal interactions guide adults' intuitive moral reasoning (Cushman et al., in press; Trivers, 1971). Together, these findings provide evidence for a core system of agent representation that persists over human development, characterized by goal-directedness, efficiency, contingency, reciprocity, and gaze direction.

Number

The core number system shows its own distinctive signature limits. Three competing sets of principles have been proposed to characterize this system (Meck and Church, 1983; Church and Broadbent, 1990; Dehaene and Changeux, 1993). Although their relative merits are still debated (see Gallistel and Gelman, 1992; Izard and Dehaene, in press), there is broad agreement concerning three central properties of core number representations. First, number representations are imprecise, and their imprecision grows linearly with increasing cardinal value. Under a broad range of background assumptions, this ''scalar variability'' produces a ratio limit to the discriminability of sets with different cardinal values (Izard, 2006). Second, number representations apply to diverse entities encountered through multiple sensory modalities, including arrays of objects, sequences of sounds, and perceived or produced sequences of actions. Third, number representations can be compared and combined by operations of addition and subtraction.

Number representations with these properties have now been found in human infants, children, and adults. Infants discriminate between large numbers of objects, actions, and sounds when continuous quantities are controlled, and their discrimination shows a ratio limit (Xu and Spelke, 2000; Lipton and Spelke, 2003, 2004; Brannon et al., 2004; Wood and Spelke, 2005; Xu et al., 2005). Infants also can add and subtract large numbers of objects (McCrink and Wynn, 2004). In adults and children, cross-modal numerical comparisons are as accurate as comparisons within a single modality (Barth et al., 2003, 2005), and addition of two arrays in different modalities is as accurate as addition within a single modality (Barth et al., in prep.).

Because core representations of number are present throughout development, they should also be present in all cultures, independently of formal education in mathematics. Studies of a second remote Amazonian group with no verbal counting routine, no words for exact numbers beyond ''three,'' and little formal instruction, support this prediction. The Mundurukú discriminate between large numbers with a ratio limit on precision (Pica et al., 2004). Mundurukú adults who have received no instruction in mathematics can perform approximate addition and subtraction on large approximate numerosities (Pica et al., 2004).

Geometry

The fourth core system captures the geometry of the environment: the distance, angle, and sense relations among extended surfaces. This system fails to represent non-geometric properties of the surface layout such as color or odor, or geometric properties of movable objects. When young children or non-human animals are disoriented, they reorient themselves in accord with layout geometry (Cheng, 1986; Hermer and Spelke, 1996; see Cheng and Newcombe, 2005, for review). Children fail, in contrast, to orient themselves in accord with the geometry of an array of objects (Gouteux and Spelke, 2001), and they fail to use the geometry of an array to locate an object when they are oriented and the array moves (Lourenco et al., 2005). Under some circumstances, disoriented children fail to locate objects in relation to distinctive landmark objects and surfaces, such as a colored wall (Wang et al., 1999; Lee, Shusterman and Spelke, 2006). When such children do use landmarks, their search appears to depend on two distinct processes: a reorientation process that is sensitive only to geometry and an associative process that links local regions of the layout to specific objects (Lee et al., 2006).

Human adults show more extensive use of landmarks, but they too rely primarily on surface geometry when they are disoriented (Hermer-Vazquez et al., 1999; Newcombe, 2005). Recent studies of the Mundurukú again suggest that sensitivity to geometry is universal: children and adults with little or no formal education extract and use geometric information in pictures as well as in extended surface layouts (Dehaene et al., 2006).

In summary, research on human infants, children, and adults across very different cultural environments suggests that the human mind is not a single, general-purpose device. Humans learn some things readily, and others with greater difficulty, by exercising more specific cognitive systems with signature properties and limits. The human mind also does not appear to be composed of hundreds or thousands of special-purpose cognitive devices. Rather, the mind is more likely built on a small number of core systems, including the four systems just described.

US vs. Them

Recently, we have begun to investigate a fifth candidate core system, for identifying and reasoning about potential social partners and social group members. Research in evolutionary psychology suggests that people are predisposed to form and attend to coalitions (Cosmides et al., 2003) whose members show cooperation, reciprocity, and group cohesion. An extensive literature in social psychology confirms this predisposition to categorize the self and others into groups. Any minimal grouping, based on race, ethnicity, nationality, religion, or arbitrary assignment, tends to produce a preference for the in-group, or *us*, over the out-group, or *them*. This preference is found in both adults and children alike, who show parallel biases toward and against individuals based on their race (e.g., Baron and Banaji, 2006), gender (Gelman et al., 1986; Miller et al., 2006), or ethnicity.

Studies of infants suggest that these tendencies emerge early in development. Three-month-old infants show a visual preference for members of their own race (Kelly et al., 2005, Bar-Haim et al., 2006). This preference is influenced by infants' experience and depends both on the race of the infant's family members and the predominance of that race in the larger community (Bar-Haim et al., 2006). Race may not be the most powerful or reliable cue to social group membership, however, because contact with perceptibly different races rarely would have occurred in the environments in which humans evolved (Kurzban, Tooby and Cosmides, 2001; Cosmides et al., 2003). A better source of information for group membership might come from the language that people speak, and especially from the accent with which they speak it.

Until recently in human history, languages varied markedly across human groups, even groups living in quite close proximity (e.g., Braudel, 1988). From birth, moreover, infants show a preference for the sound of their native language over a foreign language (Mehler et al., 1988; Moon et al., 1993). We have asked, therefore, whether infants use language to categorize unfamiliar people, and whether they prefer people who speak their native language.

In one series of studies (Kinzler and Spelke, 2005), 6-month-old infants viewed films of the faces of two women who were bilingual speakers of English and Spanish. After the women spoke to the infants in alternation, one in English and the other in Spanish, the two women were presented side by side, smiling without speaking. Although each woman had spoken Spanish to half the infants and English to the others, infants tended to look longer at the woman who had spoken to them in English, their native language.

Further studies revealed that this preference extends to older ages and guides behaviors that are more directly social. For example, 12-month-old infants in Boston were presented with bilingual speakers of English and French who spoke to them in alternation, while each offering two different foods. When later given a choice between the two foods, infants reached preferentially for the food offered by the American speaker (McKee, 2006).

Further experiments reveal the same preference for speakers of the native language in older children from diverse cultures. When 6-year-old English-speaking children in the United States or Xhosa-speaking children in South Africa are shown pictures of two children, one speaking their native language and the other speaking a foreign language (French), the children preferentially select the native speaker as a friend. Variations in accent are sufficient to evoke this preference, both in infants and in children (Kinzler et al., in prep.).

These findings suggest that the sound of the native language provides powerful information for social group membership early in development. Together with the studies of infants' sensitivity to race, they raise the possibility of a fifth core system that serves to distinguish potential members of one's own social group from members of other groups.

Beyond Core Knowledge

Core systems for representing objects, actions, numbers, places, and social partners may provide some of the foundations for uniquely human cognitive achievements, including the acquisition of language and other symbol systems such as maps, the development of intuitive reasoning about physical and biological phenomena, and the development of cognitive skills through formal instruction. A core system for representing potential social partners may be especially useful, as it could guide infants' and children's "cultural learning" (Tomasello, 1999): their acquisition of skills and behaviors that sustain life within a particular human group. In all these cases, core knowledge systems may support and advance human cognitive development, because the principles on which they are based are veridical and adaptive at the scales at which humans and other animals perceive and act on the world.

Nevertheless, core systems of representation also can lead humans into cognitive errors. At the smallest and largest scales that science can probe, the core principles of cohesion, continuity, and contact do not apply. Mathematicians have discovered numbers and geometries beyond the reach of the core domains. Adults and children are prone to errors in reasoning about properties of object mechanics, non-Euclidean geometry, or numbers that violate the principles of core knowledge (e.g., McCloskey, 1983; Gelman, 1991; Randall, 2005).

The most serious errors, however, may spring from the system for identifying and reasoning about the members of one's own social group. A predisposition for dividing the social world into *us* versus *them* may have evolved for the purpose of detecting suitable social partners, but it can cause mischief in modern, multi-cultural societies. It even may support the ravages of discord, violence, and warfare among individuals, groups, and nations. For example, recent world history provides examples of linguicide paired with genocide of the Kurds in Turkey (Phillipson and Skutnabb-Kangas, 1994), and of forced language policies initiating anti-Apartheid riots in South Africa (Sparks, 1996). A preference for one's native language group influences contemporary politics in more subtle ways, as well, such as in debates concerning bilingual education.

Despite these examples, we believe that the strongest message, from human history and cognitive science alike, is that core conceptions can be overcome. The history of science and mathematics provides numerous examples of fundamental conceptual changes that have occurred as thinkers attempted to surmount the limitations of their systems of intuitive reasoning. Despite the pull of core conceptions of Euclidean geometry and object mechanics, cosmologists and particle physicists can test whether space is non-Euclidean and has higher dimensions (e.g., Randall, 2005) and they can use conceptions of massless, discontinuously moving particles to make predictions of astonishing precision (Hawking, 2002). Even preschool children change their conceptions of numbers when they learn to count (Spelke, 2000; Carey, 2001), and they change their conceptions of agents when they learn about biological processes such as eating (Carey, 1985, 2001).

These examples of conceptual change may be useful in thinking about ways to alleviate social conflicts. If core conceptions of social groups fuel such conflicts, they too should be open to change, because understanding of human cognitive development yields insight into its malleability. As the world shrinks in size and different social groups come increasingly into contact, studies of the development of social group preferences may yield valuable insights into the ways in which intergroup conflicts can be moderated or neutralized.

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