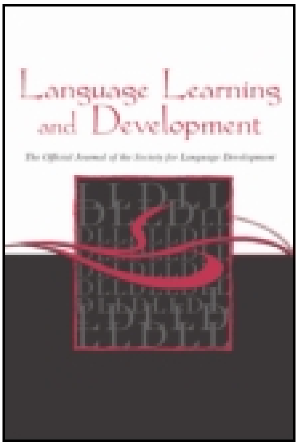

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Prelinguistic Thought

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Prelinguistic Thought

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Chomsky (1988) has suggested that human language depends on the evolution of a unique computational capacity that makes possible recursively constructed symbolic representations of the experienced world. I review evidence from the animal cognition literature suggesting that the construction of abstract representations that support complex inferences is widespread. It is found even in insects. This widespread symbol processing capacity supports the construction of complex data structures (symbolic propositions). In vertebrates at least, there is evidence that the representation of actions takes the predicate-argument form characteristic of human language. Thus, the symbol processing capacity underlying the thoughts expressed in human language appears to be evolutionarily ancient. What is unique to humans is the ability to translate these private representations into a communicable symbol system of comparable representational power.

Philosophers of mind have often assumed that language was a *sine qua non* for abstract thought, because it was the medium of thought (Quine, 1960; Sellars, 1969; Davidson, 1984). On the strong form of this view, if you had no language, you could not think. However, Chomsky's (Chomsky, 1957) early writings on language assumed that the thoughts expressed in a learned spoken language had a mental representation that preceded their rendering into spoken language. Our thoughts were represented in deep structure symbol strings, from which the sentences of a learned spoken language were generated by transformations and by the substitution of words for the world-referencing symbols in the deep structure. Fodor (1975) elaborated on the many reasons for believing that there was a language of thought that was distinct from any spoken language and, presumably, universal in humans. This view implies that thought is independent of any learned/spoken language, but it says nothing about whether thought and language rest on the same computational capacities. Chomsky (1988) has suggested that both language and the capacity for abstract thought rest on the evolution in humans of a computational capacity that is absent in nonhuman animals. Language and abstract thought may, for example, be manifestations of a uniquely human capacity to construct symbolic structures by recursion (Hauser, Chomsky, & Fitch, 2002).

Here, I argue that findings in the animal cognition literature suggest that species with which humans have not shared a common ancestor since the Cambrian era represent the experienced world at a high level of abstraction. Their behavior is routinely informed by complex inferences

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drawn from these representations. These nonlinguistic representations appear to involve symbolic structures, that is, multiple symbols stored in memory in such a way as to encode experienced relations among the entities to which the symbols refer. Actions appear to be represented as functions (predicates) that have arguments (i.e., agents, objects) as to-be-bound variables, just as do verbs in spoken language.

REPRESENTING SPACE AND TIME IN NAVIGATION

A major function of language is to locate events in space and time: “here,” “there,” “then,” ”now,” and “soon.” The abstract representation of space and time is broadly spread among the animalia. Commonly studied species of birds and insects navigate in part by dead reckoning, which is the real-time estimation of one’s position by integrating one’s velocity with respect to time. In its most basic form, this is not a complex computation. It rests on the principle that if you have been moving northeast for 100 seconds at an average speed of 1 m/s, then you are now 100 meters northeast of where you were 100 seconds ago, so if you knew where you were then, you know approximately where you are now. There are substantial measurement challenges in implementing this computation because the result depends critically on the accuracy of the speed and direction estimates. However, the computation itself is of modest complexity. That said, it is hard to see how it could fail to be a symbolically mediated activity of the brain. The essence of the activity is the adding (in the arithmetic sense) of symbols for one’s most recent displacement (change in position) to the symbols that represent one’s earlier estimate of position. If there is a proposal for a machine that can do this without symbols that refer to position and velocity (or displacement) and machinery capable of combining these symbols arithmetically to yield a new symbol that refers to the new position, I have never heard of it. The models for the process that I know of, including neural net models (Samsonovich & McNaughton, 1997; Burak & Fiete, 2009), are symbolic models. The locus of neural activity is taken to represent location, speed, and direction. These loci of activity are unequivocally symbols; that is, they refer and they are operated on to generate other loci of activity that also refer. In my opinion, they are not very good symbols, but symbols they certainly are. (For a discussion of the physical properties of good symbols—distinguishability, constructability, compactness, and efficacy—see Gallistel and King (2009).)

Dead reckoning requires a means of determining compass direction (direction relative to the earth’s axis of rotation). Many animals, including bees and birds, prefer to use the sun for this purpose. The sun is so far away that its compass direction does not change as the animal moves. However, its compass direction changes continuously throughout the day as the earth rotates. To use it as a directional referent, an animal must know the solar ephemeris, that is, the direction of the sun as a function of the time of day. The local solar ephemeris is a spatio-temporally contingent aspect of experience; it varies as a function of both latitude and time of year, so it must be learned.

The learning of the solar ephemeris by bees has been studied using brooder-reared bees whose life-time experience of the sun’s location can be experimentally manipulated. The results illustrate two of Chomsky’s most influential contentions (Chomsky, 1975): the poverty of the stimulus in learning and the resulting necessity for problem-specific structure in learning mechanisms (Gallistel, 1999). Bees that have seen the sun only in the late afternoon when it is declining in the west represent it as being in the east in the morning (Dyer & Dickinson, 1994). Bees in Germany represent the sun's direction at midnight as due north, although they have never seen the sun in the north nor at midnight (Lindauer, 1957, 1959). Thus, what bees learn from their limited experience of the sun's direction at different times of day—a complete 24-hour solar ephemeris—transcends what is justified by their experience (the poverty of the stimulus). Bees (and very likely other animals) appear to have a genetically specified parameterized function that embodies what is universally true about the solar ephemeris (it has a 24-hour period and is in the east in the morning and the west in the afternoon). The values of the parameters of this function are adjusted on the basis of minimal experience with the location of the sun relative to local terrain features at a few different times of day. This explains the extreme rapidity with which bees learn this complex function. The do not learn the function itself; they learn only values for its parameters. The inherited function plays the role that the universal grammar plays in Chomsky's theory of language acquisition.

DATA STRUCTURES

A solar ephemeris function represents the direction of the sun relative to some local terrain features as a function of the time of day. This would seem to require what computer scientists call data structures, which I take to be what linguists and philosophers call symbolic statements. In both cases, there are symbols referring to different aspects of the experienced (or potentially experiencable) world. The arrangement of the symbols encodes relations between the referenced aspects of experience. A machine or a brain that learns the solar ephemeris would appear to require symbols for time, symbols for direction, symbols for the sun, symbols for terrain features, and a means of arranging those symbols so as to encode the relation between time and the sun's direction. The burden of proof would seem to be on those who imagine that it is possible to build a machine that takes its direction of movement through local terrain from a learned relation between the time of day and the sun's direction, without having any symbols for these aspects of its experience or any means of representing the relations between them.

Foraging bees communicate to their fellow foragers the compass direction and distance of a rich food source from which they have just returned. They do so by means of a "dance" performed on the vertical surface of the comb, inside the hive, out of sight of the sun (von Frisch, 1967). The dance is in the form of a figure 8, the key component of which is the waggling run through the central link between the two loops (see Figure 1). The angle of this waggle run with respect to vertical symbolizes the direction of the source relative to the sun, while the number of waggles symbolizes its distance from the hive. This communication relies on the bees' shared knowledge of the solar ephemeris.

An internalized solar ephemeris anchored to a representation of the local terrain makes possible experimentally induced false belief with causal efficacy. This has been demonstrated in experiments that move a hive during the night to another location, chosen because it has prominent terrain features easily mistaken for those with reference to which the solar ephemeris was learned (Dyer & Dickinson, 1994) but with a different compass orientation. Bees foraging the next morning under heavy overcast, with the sun invisible, fly along what they assume to be the old familiar east-west oriented field boundary—but which is in fact a new north-south-oriented field boundary—to a food source that they find where they expect to find it. On their

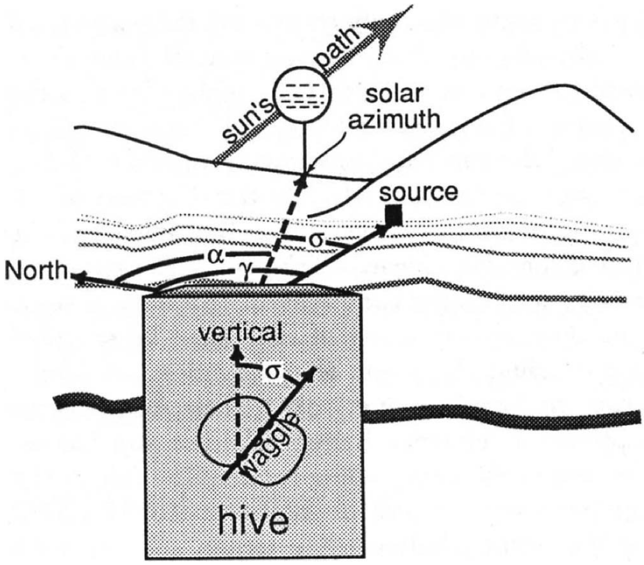

FIGURE 1 The dance of a returning forager indicates the solar bearing, σ, of a food source by the angle of the waggle run relative to vertical. The greater the distance to the source, the more waggles there are in each run. Although the dance refers to the solar bearing, what it communicates is the compass bearing, γ, because when the bees attending to the dance act on the information gained from it, they fly the compass bearing, not the solar bearing. That is, they compensate for the change in the solar bearing through the passage of time (a time-compensated solar compass). The compass bearing is the sum of the sun's current direction, α, and the solar bearing indicated by the dance. [Reproduced from Gallistel (1998, p. 20) by permission of the publisher, MIT Press].

return to the hive, they dance on the mistaken assumption that the salient field boundary outside the hive is the one that they and the other foragers have learned to use as an orienting feature of the terrain. Thus, their dance misrepresents the solar bearing (hence the compass bearing) of the source from which they have returned. Fortunately, the foragers to which the dance communicates a direction share the dancer's erroneous belief about the current direction of the sun relative to the field boundary, so they fly along that boundary in the right direction, albeit not on the solar bearing (nor in the compass direction) indicated by the dance. The shared false belief about the relation between the field boundary and the direction of the sun enables effective communication.

For reasons to be explained shortly, it is probably more accurate to say that what the bee dance communicates is not compass direction and distance but rather map coordinates. The navigation of ants and bees depends on both dead reckoning and piloting. Piloting is navigation by reference to recognizable landmarks (Gallistel, 1990). It requires the encoding of landmark appearance so that a terrain feature may subsequently be recognized, and location so that the recognized landmark may be used to estimate the location of points of interest remote from it. At least two recent experiments give reason to believe that the different points of interest (e.g., food sources) and salient terrain features that may be used to locate them are arranged on a cognitive map and that the information conveyed by the dance of a returning forager specifies a point on this map (that is, map coordinates). Menzel et al. (2011) taught selected foragers to come and go from one source, then had them observe the dance of another forager returning from a different source. When the selected foragers subsequently found the previously visited source empty, they flew directly from it to the location they knew of only secondhand (from the dance of another forager), but only when the angle subtended by the rays from the hive to the two sources was below some critical value. This result has three important implications: 1) Bees attending the dance of a returned forager locate the indicated location on their map; 2) bees can set a course from any location on their map to any other; and 3) in doing so, they take angles and distances between possible destinations (hive or other source) into account. These latter quantities only arise when they consider the relations between two or three locations recorded on their map at different times in the past.

Another result in the bee navigation literature implies that bees attending a dance both locate the indicated source on their map and then take into account other information on the map before deciding to go there. When foragers are induced to visit a feeding station on a rowboat in the middle of a pond, they dance when they return to the hive, but their dance fails to recruit other foragers (Gould & Gould, 1995; Tautz et al., 2004). This result has been questioned (Wray et al., 2008), but if it holds up, it implies that bees observing the dance consult their map before deciding to go to the location indicated by a dance. If the information on the map indicates that the location is unlikely to be a source, they do not go. When the station is moved close to the shore of an island, recruits do appear, but not at the rowboat; they appear on the shore of the island near the rowboat (Tautz et al., 2004). This last result implies that they do a kind of Bayesian integration of spatial likelihood function centered on the location indicated by the dance and a spatial prior probability distribution that is nonzero only over land, generating a posterior likelihood function that peaks at the shore nearest the boat. The posterior likelihood function takes into account both the information provided by the dance and the prior information on the map. This is an example of the sophisticated inferential processes that operate on the symbolic representations of experience stored in memory. It makes clear why an essential feature of a useful memory is that it carry information forward in time in a manner that makes it accessible to computation (Gallistel & King, 2009), including most particularly probabilistic inference.

A map is another instance of a data structure. Although there is a voluminous literature in philosophy and psychology that argues for an important difference between map-like representations and symbolic statements (Kosslyn & Hatfield, 1984; Jackson & Braddon-Mitchell, 1996; Galaburda et al., 2002; but see Pylyshyn 2003), the distinction has no currency in computer science, the science concerned with the physical realization of representations. Indeed, contemporary maps live mostly in computer memory, where they are interrogated for route-finding and from which they are printed out on demand. What makes it possible to store a computationally accessible map in a computer is the computer's addressable read/write memory. The functional structure of this memory makes possible data structures of all kinds (Gallistel & King, 2009), both those that underlie maps on the Internet and those that underlie the ability of a computer to compete on Jeopardy. Thus, one may wonder whether at the level of hardware (neurobiological realization) there is a distinction to be made between "map-" or "image-like" representations and symbolic predicates that take arguments (cf Pylyshyn, 2003). An addressable memory with indirect addressing (pointers) makes both possible.

An addressable memory enables DNA to encode organic structure at a high level of abstraction. Genes have the same bipartite structure as random access memory in a computer: One part of a gene (the "coding" part) carries inherited information forward in time. The other part (the "operon" or "promoter/repressor") allows the genetic machinery to address (i.e., find and transcribe) the contents of the coding part. As in computer memory, what is stored in the coding part is more often than not the address of another bit of information (a pointer). In genetics, a pointer is called a *transcription factor*. If the coding portion of a gene codes for a transcription factor, then the function of the gene is to control the expression of other genes. Similarly, in RAM, the coding portion of a memory location often stores the address of another location. When it does, it is called a pointer. The function of this stored address information is to control or channel access to the information at other locations. This functional structure (pointers aka transcription factors) makes possible a gene for an eye as well as genes for "anterior," "dorsal," "distal," and other highly abstract aspects of organic structure (Gallistel & King, 2009). There is also a kind of pointer arithmetic in that basic computational operations (AND, NOT, OR) are mediated by interactions between transcription factors. Simple computational operations performed on pointers are an important aspect of information access in computers. In both computers and DNA, pointers and pointer arithmetic (transcription factors and their interactions, such a dimerization = ANDing) make possible symbol hierarchies and reference to one symbol by virtue of its location relative to another symbol. In short they physically realize symbolic statements or data structures.

Data Structures Encoding What, Who, and Whose

The returning bee forager carries flower odor on her hairy body and legs. Bees attending her dance incorporate this odor information into their representation of the source, and it guides their search for that source when they have flown to the location indicated by the dance (Gruter & Farina, 2009). This implies the ability to store information in data structures that indicate the *what* as well as the *where* and *when* of experience.

Data structures integrating diverse aspects of single episodes are implied by the results of a lengthy series of experiments on the cache memory in food-caching jays done by Clayton, Emery, and Dickinson (2006). Jays cache food by burying single beakfuls in locations spread over square kilometers. The jays that Clayton and her collaborators work with make thousands of these caches as winter approaches. During the winter, they survive by harvesting the food from them, itself an astonishing feat of spatial memory. They are like squirrels in that regard but on a grander scale.

Clayton et al. exploit the fact that these birds are omnivores and, like us, they like some foods much more than others. They tend to harvest first the foods they like best. There is, however, the problem that some foods rot much more quickly than others; a fresh meal worm is delicious, but a rotten one is inedible. Clayton et al. have capitalized on this to demonstrate that jays remember *where* they cached *what* and *when, who* was watching, and *whose* cache they are emptying. When it comes time to retrieve the caches, they go first to the ones that contain what they like most, unless they made that cache so long ago that its particular contents will have rotted. In making the latter judgment, they compare the time elapsed since they made the cache to what they have subsequently learned about how long it takes for the kind of food they put in that cache to rot.

Experienced jays are sensitive to whether another jay is watching when they make a cache. If they make some caches while another jay watches and some when no other jay is present, they return later and selectively retrieve and rebury the caches made while another jay was watching. What is most interesting from a linguistic standpoint, and perhaps also for those interested in the ontogeny of moral thought, is what makes a jay an "experienced" jay, that is, a jay suspicious of the intentions of other jays. Jays that have never plundered the cache of another jay are insensitive to the presence or absence of another jay when they make their own caches. Only birds that have plundered the cache of another are sensitive to this variable (Emery & Clayton, 2001). This result reveals a behavioral consequential distinction in the bird's memory between caches it made and caches made by others. The roots of the possessive would seem to lie here.

More generally, these results imply the existence of a complex data structure in the memory of jays. It must represent different kinds of food, different points of time in the past, different temporal intervals (rotting times and times elapsed since a point in the past) different locations, different observers, and different agents (self or other)—in a way that captures the connection of all these variables to a single episode.

PREDICATE-ARGUMENT STRUCTURES?

The generalization from a jay's own behavior to the likely behavior of others seems to me of particular interest for the light it sheds on the relation between thought and natural human languages. I would suggest that the jay's generalization is most readily understood if one assumes that in the thought of a bird, as in, I believe, every language, the symbol for an action is independent of the agent and the direct and indirect objects (*<I>***take** *<your>< food>*, *<you>* **take** *<my>< food>*). The inferences that birds draw from their own behavior to the possible behavior of others suggest to me that this way of representing actions predates by hundreds of millions of years the emergence of natural human languages.

The bird's representation of actions—if, indeed, it could be said to have one at all (there are doubters)—need not have this language-like aspect. From the world view of a neurobiologist, such a thing would have seemed exceedingly unlikely until the discovery of "mirror neurons " in the premotor cortex of rhesus monkeys (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Mirror neurons, which have subsequently been found in other species and in other parts of the brain, are activated when the monkey grasps some object. This is not surprising from the neurobiologist's perspective because the premotor cortex has long been supposed to play some role in the preparation of actions, as its name suggests. Nor would many neurobiologists be surprised that the activation is more or less independent of the object being grasped because neurobiologists tend to think in sensorimotor terms. Motor elements control muscles, sensory elements respond to stimuli. The object of a grasp is a stimulus (first visual, then tactile); hence, its representation will fall to sensory elements of the nervous system, not to its motor elements.

The premotor cortex, on the other hand, has long been believed to be a higher-level *motor* area. That is, it has been thought to be involved in the control of muscles, albeit at some remove. No one doubts that the activation of motor neurons (the lowest level neural elements in the motor system, the elements that directly control the muscles) represents the commanded contraction of the particular muscle fibers to which it projects, insofar as it can be said to "represent" anything. This last qualification is necessary because not all neurobiologists have embraced the computational theory of mind and, with it, the idea that it is valid, or at least useful, to talk about neurophysiological processes in computational/representational terms. In any event, no one supposes that neural activity at the lower levels of the nervous systems represents action independent of the actor.

The sensorimotor perspective tends to extend into thinking about higher levels of the nervous system. Thus, many neurobiologists would tend to think that activity at higher levels of the motor system represents action in an exclusively egocentric framework. In such a framework, the actor (agent) is not a variable that is free to take on different referents. For that very reason, it need not be explicitly represented. Apparently, not only neurobiologists tend to think this way about the brain and action because the discovery of mirror neurons made such big waves in neuroscience that it got into the popular press, and it became a hot topic in the philosophical literature (Goldman, 2006). What makes mirror neurons remarkable is that they are activated when the animal observes other agents perform the same action. However, for reasons I have already suggested, this seems to me what a linguist would have thought if she thought that basic aspects of the structure of language were prefigured in the structure of prelinguistic thought. Predicate-argument structure would appear to be an ancient aspect of the manner if which brain's represent actions.

CONCLUSION

The results from the behavioral effects of cognition in nonhuman animals, which is what I have focused on, are complemented by similar results from human infants and from toddlers with limited or no command of a natural human language (Baillargeon, 1995; Gelman & Williams, 1998; Spelke, 2000; Carey, 2004; Song & Baillargeon, 2008). Thus, the "pre" in "prelinguistic" should be understood in both evolutionary and ontogenetic terms. It would appear that animals have represented the experienced world at a highly abstract level in a richly structured symbolic system for eons and that the human infant is heir to this powerful and versatile representational system. What is unique in humans is the machinery for mapping what they represent in the privacy of their own brain into a *communicable* system of symbols of similar power and versatility to the private system. In that, the human far outstrips the bee.

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