Distributed Cognition in Apes

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Abstract

Socio-cognitive complexity, as manifest in dynamic multi-party interactions, is central to many theories of hominid cognitive evolution. To assess the rudiments of these abilities in apes, we chose to study the triadic interaction known as "social tool use". In this scenario, one animal (the User) is said to interact with a second (the Tool) to in some way influence the behavior of a third (the Target). The "Machiavellian" model typically used to account for such behavior depends on folk theoretical descriptions of intentional manipulation and deception and has mired the field in unproductive attempts to define such mental states and justify their inference based on observable behavior. As an alternative, we conducted a distributed cognition analysis of these interactions among a group of seven bonobos (*Pan paniscus*) at the San Diego Wild Animal Park. Assuming that attentional behavior was critical, we gained insights from a wide range of research including human developmental, neurological, ethological, and comparative experimental work on social gaze in primates. This work lead us to perform a micro-analysis of 16 video segments (12 of social tools, 4 controls) in which we recorded all changes, at 1/6 second intervals, in relative trajectory, relative body and head orientation (open, peripheral, or closed to other animal) and, whenever possible, gaze. We also recorded the source, timing and duration of social interactions (groom, aggress, etc.) that occurred in those segments. In addition, data on patterns of association and social interaction collected over several years were used to establish long-term relationships such as rank and affiliation to situate and thus help interpret the micro-analysis. To facilitate cross-dimensional comparisons, the results of the micro-analysis were represented along time-lines (X axis = time) such that, for a given dyad and a given attentional dimension, each animal's proximity to physical or eye contact was indicated by the proximity of its line (along the positive or negative Y axes) to zero. Transitional probabilities for a change in any one of Animal A's dimensions being immediately followed by a change in any one of Animal B's dimensions ("triggering"), and for simultaneous changes ("syncs"), were computed for each dyad. Our results indicate that, while overt social behavior was directed by the User to the Tool, of the three dyads involved, the User/Target dyad were disproportionately responsive to one anothers'

attentional behavior (while their counterparts in the control segments were not). Thus, this distributed approach has generated evidence that bonobos can and do monitor and respond to the attentional states of others, and that "social tool use" in these animals can best be characterized as a rudimentary capacity for multi-tasking.

Introduction

Studying Socio-Cognitive Complexity

Among the practices that set humans apart from other animals are the complex multi-party interactions in which we frequently engage. Comparative research suggests that the cognitive processes involved in such interactions are unusual in that they enable us to deal with a variety of dynamic social parameters simultaneously (e.g. Humphrey 1976). However, the elaborate collaborations (including conversation and other cultural activities) typical of our species present a daunting challenge to the evolutionary theorist concerned with their origins and course of development. By studying complex, polyadic interactions in our closest genetic relative, the ape, we hope to help identify rudiments shared by the less sophisticated system which, during hominid evolution, may have been subject to additional adaptive specialization.

"Social complexity" has been fairly well defined and documented in nonhuman primates. While in most social animals, power relations can be represented by a simple linear hierarchy and get played out in dyadic interactions, in many higher primates (monkeys and apes), rank and power are not necessarily equivalent (De Waal 1986). That is, for example, through triadic interactions such as coalitions or third party interventions, lower ranking animals can sometimes jointly gain access to resources over higher ranking individuals. Furthermore, the actions taken by a given participant have been shown to take into account not only that individual's own relationships to the others, but the relationship that exists between the others as well (e.g. de Waal & Van Hoof 1981; Cheney, Seyfarth & Silk 1995). For example, a subordinate macaque will

recruit aid against an opponent based more on the ally's rank relative to the opponent than on its own rank relationship with the ally (Silk 1999).

However, the concomitant models of the cognition involved are much less well developed. This is, in part, due to the difficulties inherent to studying social cognition. Gaining experimental control over the relevant variables in a social negotiation, for example, is extremely difficult and the relatively few attempts made with nonhuman primates have produced data that are ambiguous and controversial (see Heyes 1994; Povinelli 1994). Furthermore, the theoretical framework typically used to describe such interactions depends on "folk theoretic" accounts of "Machiavellian intelligence" (Byrne & Whiten 1988). That is, the animals involved are anthropomorphically portrayed as engaging in maneuvers designed to outwit, deceive, or otherwise strategically manipulate one another. This approach raises issues concerning complex, internal mental states such as intentionality, self-consciousness, theory of mind, etc. and has mired the field in attempts to define such states and justify their inference based on observable behavior.

In some respects, given our close genetic relationship, our largely-shared repertoire of gesture and expression, and our many brain similarities, such anthropomorphic descriptions of, especially, ape behavior may not be entirely unjustified. However, they constitute an unsatisfactory model of cognition for several reasons. For one, folk-theoretic accounts of mental behavior are arguably metaphorical, and their validity has been challenged even when applied to humans (Churchland 1981). Second, they may well reveal more about the 'storyteller' than about the players to whom they are applied, however consistent the tales that are generated. Third and most critically, it is unclear whether or not, as hypotheses, they are ultimately falsifiable. In any case, while fermenting much interesting discussion over the past decade or so, this approach has yet to yield much in the way of useful data.

An Alternative Approach

In this paper, we are proposing an alternative approach to the study of the cognitive complexity involved in primate negotiations. The distributed cognition approach (e.g. Lave 1988; Rogoff 1990; Resnick , Levine & Teasely 1991; Fogel 1993; Hutchins 1995) takes cognition as a co-constructed, real-time process that occurs not only whithin but also *between* individuals. (See also Vygotsky 1978; Wertsch 1985.) As a result, the observable group processes that occur during social discourse can themselves be taken as cognitive events. Through a detailed analysis of changes

propagated across the "media" (Hutchins 1995) of such events, one can chart information flow, characterize task complexity, document developments in the roles of participants, etc. Thus, while not denying that internal mental states are involved, this model offers the advantage, especially as applied to nonhumans, of focusing on the cognition that is *apparent* in social interaction.

In particular, we have chosen to apply this model to the study of the triadic interaction known as "social tool use" (Kummer 1967; Jolly 1985; Goodall 1986) in the bonobo or pygmy chimpanzee. While no formal definition of "social tool" has been established in the primate literature, it is widely applied and commonly understood to involve one animal (the "User") interacting with a second (the "Tool") to in some way influence the behavior of a third (the "Target"). Such interactions are traditionally divided into five basic classes, all of which were included in our database. These include "recruitment" (User attempts to elicit aid from the Tool against the Target), "agonistic buffering" (User physically uses Tool as a shield or otherwise engages with it to diffuse a threat from the Target), "passport" (User positively interacts with Tool who has a special relationship to the Target, such as mother/offspring, to gain access to the Target), "incitement" (User positively interacts with Tool to incite investment from the Target) and "alibi" (User directs exaggerated attention at Tool to avoid responding to a solicitation from, or to disengage from interacting with, the Target).

While expressly avoiding attributing the implied mental states (manipulation, deceit, jealousy, etc.) to the animals involved, we explicitly acknowledge and even adopt these anthropomorphic terms for two reasons. One is that they are useful as 'shorthand' descriptions that readily communicate the essentials of the behavioral dynamics involved. The other is that it was on such an intuitive, anthropomorphic basis that we originally identified the incidents of social tool use from our videotapes of the bonobos' interactions. One goal of this study, then, is to discover, through a detailed analysis of the tapes, whether those intuitions have any basis in behavioral cues that are meaningful not only to us as observers but that also serve as salient, effective media in the animals' distributed cognition. It is from such an empirical base that we may build a stable comparative model of socio-cognitive complexity.

Methodological Challenges

Given that the distributed approach is still in its infancy, especially as applied to nonhumans (although for discussions see Cousi-Korbel & Fragazsy 1995; Strum, Forster & Hutchins 1997; Johnson, 2001) there are few

established protocols for research design and analysis beyond the essentials demanded by the theory. These essentials include using interactions (as opposed to the actions of individuals) as the units of analysis, charting change over time, and collecting observations at multiple time scales, including the historic and the micro-levels (see Hutchins 1995; Fischer & Granott 1995). The latter is generally done via detailed video analysis of particular interactions. The former is done using macro-level sampling techniques over the long-term, and is meant to provide background information (cultural constraints, social relationships, task exposure, etc.) that can help to "situate" and thus interpret the interactions. Beyond such guidelines, however, work in this emerging field faces several challenges in determining what to score, how to represent those data, and how to generate a meaningful interpretation of them.

Challenge I: What to score

For insights into what might be the most relevant parameters to document in the bonobos' behavior, we turned to the ethological traditions embraced by primatologists, the current experimental work by comparative psychologists, related neurological research, and the developmental study of "theory of mind' issues in human children. Interestingly, these approaches converge on some of the elements that they consider critical. For instance, in the developmental work, an emphasis has been placed on joint visual attention and, in general, on the social manipulation of attention, especially gaze (e.g. Baron-Cohen 1995; Moore & Dunham 1995). This has also become the focus of one of the few productive areas of comparative experimental work on social cognition. That is, for example, several primate species have recently been documented as being capable of "gaze following" (e.g. Anderson et al. 1996; Tomasello Call & Hare 1998; Peignot & Anderson 1999). However, with the notable exception of the chimpanzee (e.g. Povinelli & Eddy 1996; Itakura & Tanaka 1998), most respond to the direction of head orientation and seem incapable, even after extensive training, to respond to the eyes-only as a cue (although see Vick & Anderson 2000). Relevant physiological findings include an increase in cortico-steroids and other orienting responses to direct eye contact (e.g. Keating & Keating 1982; Perrett & Mistlin 1990), as well as cerebral cortex cells in monkeys that are sensitive to the direction of head orientation and/or gaze of another (Perrett et al 1985). Our subject, the bonobo, has not yet been tested on any of the above.

Ethologists, likewise, have long been tuned to the attentional behavior of their subjects (see Smith 1977; Alcock 1978). This can be traced to some simple structure/function relationships. For example, across the phyla, animals with forward-facing eyes (like primates) tend to move in the direction their gaze is oriented, making gaze direction a predictive signal for others. Similarly, body orientation (judged in primates by the orientation of the shoulders and degree of proneness) is also a cue as to one individual's readiness to engage with another. However, these measures are complicated by the fact that orienting toward another individual can also be a function of information-gathering. In fact, this dual role of attentional behavior - both sending and receiving information - is responsible for an inherent ambiguity that can be exploited by the likes of primates.

For example, a monkey that does not look directly at another who is threatening it, and thereby does not 'acknowledge' the threat, can sometimes effectively hold the aggressor at bay. Similarly, a subordinate not looking at a contested resource is much less likely to stimulate an overt conflict over it than another who openly displays its interest. In 1967, Chance described a more general relationship between primates' attentional behavior and rank, with subordinates looking to dominants more often than the reverse. This presumably serves to gather information about likely troop movement or other important group developments. Nevertheless, in most primates a direct stare is a threat and the avoidance of eye contact is common in most species (Kummer 1967).

Subject and Procedures

The subjects of this study were seven bonobos (*Pan paniscus*) living as a coherent social group since 1993 at the San Diego Zoo's Wild Animal Park. The group consists of four mature animals - one adult male, two adult females, and one female who went from adolescent to parturient adult over the course of the study. The group also includes three juveniles born, one to each of the females, in 1991, 1994 and 1996.

In response to the above-described research, we chose to score the following dimensions of the bonobos' activity. Historic data on association patterns (per inter-animal distances) and gross social interactions (such as groom, follow, food-sharing, aggress, etc.) were taken in instantaneous scan samples, at two minute intervals, in twenty minute sessions, for months to years preceding the video segments. These data were used to establish long-term rank and affiliative relationships, as well as to document more short-term developments like disputes or alliances, changes in reproductive status, etc.

Approximately fifty hours of videotape taken of the group since 1993 were reviewed by the authors and twelve incidents of 'social tool use' were identified. (Additional putative examples were also found, but

these did not meet practical criteria such as video quality sufficient to assess gaze, or all three animals being visible for at least 80% of the interaction.) These selections were based on the strength of a combined total of ten years of experience watching these animals. The control segments involved the same configuration of animals, from the same periods of time, engaged in the same gross interactions (e.g. a pair grooming in the vicinity of a third) as the test segments, but which did not, in the authors' estimation, involve social tool use.

For each segment, a User, Target and Tool (or their correspondents in the control segments) were identified and data collected on each dyad (User/Target, User/Tool and Target/Tool). The segments, which varied from 15 to 50 seconds long, were analyzed at intervals of 1/6 of a second (ten frames), which was determined as the shortest interval in which any relevant event (e.g. a glance) could take place, For each interval, the following states were recorded for each individual within each dyad: 1) Inter-animal distance, in fractional body widths, 2) Focus of gaze, whenever it could be determined, 3) Relative body orientation and 4) Relative head orientation, the latter two scored as OPEN, PERIPHERAL, or CLOSED. OPEN was defined as (body or head) oriented directly toward the dyad partner. PERIPHERAL was defined as the partner being positioned from about 20o to about 110o right or left of a sagittal plane between the animal's eyes. (This estimate is based on bonobo visual and cranial anatomy and is assumed to include the area in the animal's peripheral visual field. Ankel-Simons 1983) CLOSED was defined as the partner being behind and thus not within the animal's visual field. For any *change* in state across intervals, the individual responsible (i.e. whose movement resulted in the change) was scored as having shifted TO or FROM its partner. If an individual actively maintained a state (e.g. turned its head to track another's movements, thus actively maintaining an OPEN) this type of 'change' was scored as a KEEP. In an ongoing, time-locked narrative, we also recorded all social interactions (such as groom, play, sex, etc.) and individual tension/relaxation indicators (such as scratch, flinch, clap, playface, etc.).

Challenge II: How to represent

When continuous data are collected over multiple media simultaneously, representing the results in a comprehensible form poses another challenge. In general with such data, some sort of time-line charting the course of changes is commonly employed. But, for example, warranting the ordering of the Y axis values, or aligning the valences of such changes across multiple lines (so that, for instance, movement away from the X axis at time T along one dimension is augmented by movement away from the X axis, at the same time, along another dimension) demand a careful assessment of the media being studied. We again looked to behavioral and physiological data on primates to facilitate this assessment.

In our own earlier work with the bonobos, we found that 70% of all incidents of eye contact were followed by a decrease in inter-animal distance and/or direct interaction (of both positive and negative kinds). Bonobos are also unique among nonhuman primates in that they regularly engage in face-to-face sex, during which eye contact is typically made (Savage-Rumbaugh & Wilkerson 1978). In keeping with the above-described primate research, such data make it clear that eye contact should be treated as central in any representation of the bonobos' gaze relationships. That is, head and gaze states can be organized according to their 'proximity' (i.e. ease of transition) to eye contact. Similarly, body orientations and inter-animal distances can likewise be organized according to the accessibility they offer to (physical) contact.

As a result, we have chosen to represent these data in the following manner. For each medium (gaze, body orientation, etc.), each dyad is represented along a single X axis of Time, marked at 1/6 second intervals. One animal's behavioral values are represented along the positive Y axis and the other's along the negative Y axis. In both cases, the Y values farthest from 'contact' are farthest from the X axis, so that when the pair are far away from each other or oriented away from (CLOSED to) each other, their time-lines are far from the X axis. As each makes a move toward, or turns toward, the other, their lines draw closer, until when contact (physical or eye contact) occurs, the lines meet at the X axis. Using these multiple time-lines, we can then chart a "cognitive trajectory" for each dyad, as informative changes move across and between the media. Plus, since the various time lines are constructed according to similar criteria, we can collapse or blend them into a single (paired) line that depicts all the changes (i.e. all TO's, FROM's and KEEP's) in a given dyad's attentional access to one another. Such summary lines are also useful for examining *inter*-dyad relationships, facilitating the search for the constraints imposed not just by the activity of an individual's partner, but also by the joint activity of the other dyad.

Challenge III: Analysis

While we can reasonably assume that the media we are scoring are perceptually accessible to our subjects, we are primarily concerned with whether these media are *functionally salient*. More specifically, we are questioning whether the three dyads involved

differentially produce and respond to changes in each other's attentional behavior.

To address these questions, we will first compare the transitional probabilities (see Bakeman & Gottman 1997), across dyads, of any change in one partner's media being followed, in the next 1/6 second interval, by any change in the other partner's media. We will also compare the occurrence of partners' simultaneous changes and coordinated active maintenance (i.e. simultaneous KEEPs) across dyads. Thus, both synchrony ("SYNCS")and immediacy of reaction ("TRIGGERS") will be taken as measures of the sensitivity of our animals to the attentional behavior of others. In addition, by assessing patterns of change initiation (e.g. Animal A:TO, followed by Animal B:FROM) we aim to establish a motivational valence for these interactions, based on the basic assumption that organisms approach stimuli they consider desirable and avoid those they consider undesirable. Ethologists have long maintained that "approach/avoidance" conflicts provide a reasonable account of much inter-animal positioning as well as the thresholds for dynamic change. Finally, we will also examine our data for large-scale temporal patterns, both in specific state changes as well as along the more general TO/FROM/KEEP dimension.

Preliminary Results

Defining social tool use as: "One animal using another to manipulate or influence the behavior of a third", we asked two additional observers, familiar with the animals but blind to the cognitive model being tested, to judge whether or not the test and control segments met those criteria. These observers each disagreed only on a single different example. In interviews after the tests, the observers indicated that the User's behavior toward the Tool seemed "insincere", at times because of the abruptness of its termination but most often because of "furtive" looks directed by the User to the Target (although neither mentioned a co-sensitivity to attention between both User and Target - see below).

We are currently conducting the micro-analyses of the video segments. Preliminary results indicate that, in all 12 social tool examples, the User/Target dyad can be identified by their disproportionately high level of responsiveness to changes in one another's attentional behavior. That is, both more Triggering and more Syncs occur in the User/Target dyad than in either the User/Tool or the Target/Tool dyads. In contrast, in the control segments, the pair that was engaged in the primary interaction (i.e. that of the User and Tool in the corresponding social tool examples) show a tendency to be the most responsive to one another's attentional behavior. The additional level of attentional sensitivity

between what would be the User and the Target does not appear in the control segments.

As expected, the cognitive trajectories of these interactions frequently jump across media (e.g. an approach by one animal triggers a look-away by another). The most intense (simultaneously multi-media) interactions occur in the User/Target dyad. The directionality of triggers (i.e. who initiates an exchange) often varies between and even within segments. In fact, it may be the case that a tendency to 'vacillate' in the direction of triggers is especially characteristic of the User/Target dyad. In addition, the Target appears more sensitive to attentional interactions between the User and Tool than either of them do to his interactions with the other.

At least two types of larger-scale patterns have thus far been identified. "Cascades" involve a sequence of triggers, often alternating in source animal, and culminating in some intense level of attentional coordination. In "Suspensions" a prolonged lack of response is maintained by one animal, who remains visually fixated on a particular point (its hand, the grass, etc.), until the partner removes itself from probable engagement (e.g. "closes"), at which point the first finally glances at the partner. Both patterns are most often seen between User and Target. Such interactions provide additional evidence for the functional salience of attentional behavior as well as for the motivational dynamics that characterize social tool use.

Discussion

In summary, we have chosen to conduct a distributed cognition analysis of the triadic primate interaction known as "social tool use". Through this work, we have been able to show that bonobos can and do monitor and respond to the attentional states, including eye gaze, of one another under natural social conditions. Furthermore, rather than relying on a folk-theoretic description of "social tool" that involves attributing humanlike mental states to the animals involved, we have been able to generate an operational definition of social tool. That is, social tool use can be said to occur when one animal (the User) directs some overt social behavior toward a second (the Tool) while keeping its attention primarily fixed on the attentional behavior of a third (the Target) who is likewise attuned to the first.

By examining these interactions in moment-to-moment detail, we can clearly see the co-constructed nature of the cognition involved and the level of complexity that the animals can jointly attain. It would be particularly interesting to do a similar analysis of humans engaged in such interactions, to compare the media, transitional patterns, and levels of sophistication involved. In addition, as a result of this analysis, we can

characterize the individual cognitive abilities of the bonobos not as involving intentionality, deception, or theory of mind, but as reflecting a rudimentary capacity for multi-tasking. Considered one of the most complex of primate behaviors, social tool use is rare even in apes, and thus may be viewed as lying at the limits of those animals' abilities. As such, it suggests that speculation on the critical changes in hominid cognitive evolution might do well to focus on traits that would enable the manipulation of one's own and other's attentional behavior and the capacity to engage in multiple social trajectories simultaneously.

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