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Social Complexity and Distributed Cognition in Olive Baboons (*Papio anubis*): Adding System Dynamics to Analysis of Interaction Data

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Abstract

Applying a systems perspective to both social complexity and cognition in primates critically addresses the Social Function of Intellect hypothesis formally proposed by Humphrey (1976). A systems approach to social complexity (Hinde, 1987) entails framing social dynamics hierarchically from individuals, through interactions, to relationships and group structure, empirically building up from interaction data. A systems perspective on cognition (Hutchins, 1995) entails identification of a cognitive unit of analysis that is inclusive of the participants and other elements that affect a regularly observed outcome. This system is then studied as a process. We sketch a methodological framework using two data sets from a field study of Olive baboons (*Papio anubis*) in Kenya. The first data set, on 2,913 male-female-infant (MFI) triadic interactions, was employed mainly to illustrate applying a systems approach to social complexity. The second data set, on 180 sexual consort turnover (CTO) events, illustrates the use of a systems approach to study cognition. Adding dynamics changes the understanding of trends and the detection of the sources of variance in social interaction data. The MFI analysis included a multilayered visualization that shows group effects while maintaining the richness of an individual's contribution. The CTO analysis showed how researchers can shift from looking at outcome (performance) to process (profiles of participation), which has much more relevance to the nature and development of cognition. A single CTO event captured on video provides an example of microanalysis at high temporal resolution (0.1 s) as well as the conferred advantage in shifting from discrete to continuous descriptions of behavior. Relations between system states and dynamics of individual elements can thus be systematically examined. The combined analyses suggest a flexible toolkit for addressing complex behavioral phenomena that can easily be extended to the study of other contexts and other species.

Key Words: systems, social complexity, cognition, baboons, analysis, dynamics, interactions, state-space, time-series, primates, *Papio*

Introduction

Social Function of Intellect

The research linking social complexity to cognition has matured from its original fixation on primates and its search for simple single measures (e.g., group size vs neo-cortex volume) that would fuel a clean argument, namely, that challenges of social life provided the selective pressure for the evolution of cognitive adaptations (for an alternative framing, in terms of environmental complexity, see Godfrey-Smith, 1998; Sterelney, 2003). The inconclusive results of the original efforts, as well as the accumulating data from ever larger samples and diverse species, have contributed to a shift in focus so that researchers nowadays emphasize individualized societies that have longitudinally stable relationships and that are learning-oriented (de Waal & Tyack, 2003). Here, we revisit the Social Function of Intellect hypothesis proposed by Humphrey, (1976; see also Jolly, 1966, and the review in Byrne & Whiten, 1988) by applying a systems perspective (von Bertalanffy, 1968) to both social complexity and cognition/mind. Although this hypothesis was originally an evolutionary argument, the most pressing need in the study of long-lived social mammals is a comprehensive understanding of the nature and development of cognition. We articulate a methodological approach that enhances the ability to address complex social dynamics and speaks more directly to their cognitive entailments.

Systems Thinking

von Bertalanffy (1968) was one of the first to articulate a shift in framing, one that occurred in parallel in many fields, and proposed a General Systems Theory to address the growing notion that (the same) organizational principles operate on systems regardless of their material instantiation. Starting with a simple definition of a *system* as "a set or complex of elements in interaction," the key contentious concept was, and remains, that of emergence, often expressed in the refrain "the whole is more than the sum of the parts." For many systems thinkers, the notion of emergence implies not only that there are system-level properties that are different from those of their constitutive elements, but also that the system's organization can constrain what the elements in the system can do. Causality now turns circular, with dialectical relations between levels in a system's hierarchy. The power of a General Systems Theory was not in the notion of a system per se but, rather, in the tools it provides for probing organization, of behavior, of matter, of conceptual frameworks, etc. For here was the crux of the paradigm shift from classical analysis that traditionally probed phenomena by taking things apart then looking for atomic units that can be (linearly) re-combined into the original whole. Classical analysis of this sort worked very well for many phenomena, but, as von Bertalanffy and recently Ward (2002) pointed out, systems that interest biological, social, and cognitive scientists are typical of organized complexity. As Ward writes,

> For very large systems, then, we can find statistical regularities. On the other hand, for very small systems, such as simple machines, we can successfully analyze behavior in terms of the interactions of their individual components. For systems of medium size . . . we observe fluctuations of many sizes, irregularities and lack of predictability. . . . Unfortunately, systems of medium size, such as cognitive systems and even brains, are the rule [and] . . . *the simplification we must undertake will cause us to omit many important elements, relations, or both.* Thus we can expect deviations from theoretical predictions to occur with regularity, whereas regularity in system behavior will seldom be seen. . . . [W]hat we must deal with . . . especially in cognitive systems [is] *organized complexity*, the most difficult type of system to understand, but also potentially the most rewarding (first italics ours). (pp. 47-48)

As Ward (2002) goes on to caution, it is not enough to acknowledge these limitations. As researchers search for regularities (statistical and otherwise) in data, they need to recognize simplified models and look for alternative perspectives on the same phenomena. von Bertalanffy (1968) laid out the myriad of descriptive and analytical tools relevant to systems research, making the choice between them a matter of relevance to the particular research program. Similarly, Simon Levin (1999) more recently noted, "Any system is a mass of overlapping hierarchies of aggregations, limited in any particular description only for the convenience of the observer." A system, then, is best thought of as a theoretical construct, a tool, used to study phenomena and, as such, has more of an epistemological than ontological status. Subjective, perhaps, but by no means arbitrary, and we will emphasize the limiting but also liberating power of this perspective.

There is a rapidly growing body of cross-disciplinary work that operates within the systems thinking paradigm, and an exhaustive list is beyond the scope of the paper (for relevant references, see Strum et al., 1997; Strum & Forster, 2001; Forster, 2002) Although informed and inspired by a variety of sources, the arguments built in this paper focus specifically on explicit theoretical and methodological moves made by two researchers: Robert Hinde (1987) on social complexity, and Edwin Hutchins (1995) on cognition.

A Systems Approach to Social Complexity

Hinde (1987) was the most explicit in addressing social complexity in primates within a systems perspective, articulating a framework of hierarchical levels that manifest behaviorally: individuals, interactions, relationships, and group structure. Methodologically, Hinde showed how studying social complexity builds up from social interaction data along two routes of generalization, by either following individuals over time to study relationships or by examining a type of event across the same level of complexity. Hinde's framework allows addressing the relations among levels of social complexity by focusing on properties that are uniquely relevant to each level but not to those below it. He writes,

> Each of these levels has properties that are simply not relevant to the levels below. Thus the behavior of two individuals interacting, but not that of a single individual, can be described as synchronous or well-meshed. . . . Indeed . . . properties concerned with temporal patterning of interactions, or with their relative frequency, can apply only to relationships. . . . And within a group the relationships may be arranged hierarchically, centrifocally and many more complex ways—issues not applicable to individual relations. . . . It is equally important to remember the two-way relations between (levels). The nature of an interaction or a

> relationship depends on both participants. At the same time, the behavior the participants show in each interaction depends on the nature of the relationship: what an individual does on each occasion depends on his assessment of and expectations about the interaction in which he is involved, or of the relationship of which it forms a part. . . . At the next level, the participants' view of the relationship affect the nature of interactions within it, and the nature of the relationships is determined by its constituent interactions . . . etc. (p. 25)

A Systems Approach to Cognition

Hutchins (1995) developed a framework for Distributed Cognition in the context of highly structured human practices that are also rich in technological artifacts (e.g., navy ship navigation, aircraft piloting, etc.). These contexts provided a rich setting for tracing the trajectories of representations as they transformed from text to speech to marks on a chart, and so on, getting coordinated by a plurality of individuals, their actions, and the media in their work environment. This approach made it clear that representational processes (considered the currency of cognition) often leak across the traditional boundaries of individual cognition—that is, from inside the head of an individual to other individuals and/or media in the environment. Methodologically, extending the boundaries of the cognitive unit of analysis to include all the elements, some internal and some external, that effect the outcome of a process, made it possible to capture the dynamics of cognitive processes more directly. Hutchins' strong claim was that cognition, by its very nature, is a distributed process and would manifest as such even in nonsocial settings. Regardless of scale, decentralized dynamics of elements (here, bits of representational structure) would be brought into coordination to produce system-level cognitive properties.

What is representational in the world of a savannah baboon may be less obvious and more likely to be discovered experimentally (e.g., through the playback experimental methodology used in birds, primates, and other mammals). Hutchins, though, made another move that we depended on heavily in our cognitive analysis. By defining a cognitive system by a regularly observed outcome (e.g., navigating from point A to point B), Hutchins allowed us to analyze cognitive processes without having to make a bet on the goal-states of individuals prior to analysis. In fact, Hutchins claimed, we often attribute to individuals (cognitive) properties that are more appropriate to attribute to the system as a whole.

Although developing these frameworks independently, Hinde (1987) and Hutchins (1995) shared a relational perspective on behavior, a view of dialectical relationships between levels of description, and an appreciation for the social and historical context of activity. We build on these sensibilities and explore the methodological implications of taking a systems perspective on social complexity and cognition in nonhuman mammals. We sketch a framework that engages behavioral data on social interactions in a variety of ways that can act together as a toolkit. The analyses are not novel, but their combined strength is twofold: (1) they address both social behavior and cognition as complex systems and (2) they provide multiple perspectives on the same phenomena.

Materials and Methods

Study Site

These data were collected at the Uaso Ngiro Baboon Project in Laikipia, Kenya, between the years 1989 and 1991, with supplemental video data during the summer of 1993. Project records from the same period of time were used for independent assessment of friendships, dominance rank, alliances, and other demographic data. For a description of the study population, see Strum (1987).

Socio-Ecological Clusters

Olive baboons (*Papio anubis*) live in multi-male/multi-female matrilineal groups. They leave their sleeping site in the morning for a day's travel and foraging. In the late afternoon, they return to one of three to five sleeping sites they frequent within their home range. Although baboons are rarely found alone, they do not spend every moment of their day *en masse*, even when the total troop size is small. One finds members of the group in recognizable socio-ecological clusters. The size, location, stability, and activity of a cluster are dependent on social and ecological factors that co-constrain each other and are ideally not considered independently (although researchers often do so, this paper being no exception). A cluster's size and location at any moment in time may be influenced, for instance, by the size of the canopy on a flowering acacia or the richness of a corm site. Similarly, its membership may be influenced by kinship, friendship, politics, or the reproductive state of one or more individuals involved.

Females give birth after a 6-mo gestation and usually resume cycling after 1 y of lactation. They may cycle several times before conceiving, each cycle consisting of several days of sexual activity in the week prior to ovulation. A male will try to monopolize access to a sexually receptive female by forming a consort with her in the face of competition from other males. These male followers and other troop members coordinate their activity with that of the consort pair in a cluster or a consort party. The plurality of individuals and their agendas inevitably results in a switch in male partners, several times a day, hence the term Consort Turnover (CTO).

Occasional droughts in the study area are at times severe enough to inhibit reproductive cycling in the females so that when conditions improve, the females resume cycling simultaneously, producing a birth spurt. Data presented here are from such a period of concentrated births, as well as from the period of (less concentrated) sexual activity that followed a year later.

Observing Interactions

It is from socio-ecological clusters that observers extract the behavioral data that are deemed relevant to particular research questions. Here, we construct system boundaries around configurations of male-female-infant (MFI) triads during a concentrated birth spurt (baby boom) in one case, and around events leading to sexual CTO events in the other. It is important to realize that both systems often overlap and may share membership within a single cluster. We created two data sets, from two consecutive study periods, as will be shown in the following sections.

MFI Data Set (Baby Boom Study)—This data set consists of 2,913 triadic interactions over a 6-mo period. Two infants were already present in the troop when data collection began, and six additional infants were born by the end of the second month into the study. Sampling consisted of 187 1-h focal samples on eight female-infant pairs, recording continuously all the interactions with males, as well as other interactions, which were recorded as context. Interactions were recorded by preserving their sequential order (rather than tally columns). In this analysis, we are looking only at the triadic interactions with males, maintaining distinctions between seven mother-infant configurations based on their contact and proximity, as well as their differential coordination with the males.

CTO Data Set (Sexual Consorts Study)—From an 11-mo period (1,414 h of observation) in which 292 switches in male partners were noted, a data set of 180 CTO events, in which more complete information was available on participants and dynamics, was used. The sampling during this study period consisted of ½-h focal samples on females six times a day of every sexually active day. Focal samples on males who left or lost access to the consort female, social scans, *ad libitum* notes, and focal samples of females during nonconsort periods were also collected. For the CTO data set, information was assembled across all these data sources. A microanalysis of a single CTO event captured on video (from the same troop a couple of years later) is added to the analysis presented in this paper.

Analytic Approach

Our analysis follows closely on Hinde (1987) and Hutchins' (1995) conceptual and methodological principles. Following Hinde's two routes of generalizing from interaction data, we tracked individuals over time to study relationships (MFI data) to explore relations among levels of social complexity. We shifted to tracking a type of interaction/event across individuals (CTO data) and apply a distributed cognition framing in which we study the CTO system as a process, identified by its observable outcome.

A few key analyses are presented here, selected from a more comprehensive series, to demonstrate ways to investigate social complexity and cognition. We did so by expanding the traditional boundaries of the unit of analysis while preserving individual contributions to system-level effects. We identified system boundaries using different criteria (i.e., triadic configurations for MFI data and dynamics leading to a specific outcome for CTO data) to emphasize the flexibility of a system perspective as an investigative tool. Across both studies, we add temporal and social dimensions that reveal more dynamics by alternating between searching for trends and looking for sources of variance. We tracked individuals and system-level properties on multiple time scales, and across levels of social complexity, to reveal patterns of coordination and interdependency that often remain hidden otherwise. The suite presented should not be taken as sufficient or universally necessary, but we believe the examples will be transferable to other species and situations.

Results

Systems: Social Complexity (Male-Female-Infant Interactions)

For a period of several months after the birth of an infant, triadic configurations between males, females, and infants are the norm. This setting provides an opportunity to explore how dyadic relationships are influenced by a period of enhanced triadic configurations. Specifically, we examined how male-infant special relationships may be influenced by an already established relationship between a male and the mother or how an infant's birth may influence the initiation of such relationships.

Female Rank and Rate of Triadic Interactions—This is an example of exploring the relations between two levels in Hinde's social complexity hierarchy (interactions vs individual characteristics). Female rank and infant date of birth are only two of many factors that may influence the differential rates of interactions. Other individual characteristics may include the infant's gender, as well as the male's age, residency, and agonistic dominance rank. At higher levels of social complexity, relationship status (of male-female friendships, male-infant special relationships, and male-male alliances) and their ramifications for the group are also important factors.

Figure 1a (left-hand box) shows rates of interaction (between males and each female-infant pair) over the study period that visually corresponds to female rank, a pattern that conforms to the conventional model (i.e., higher female rank confers higher interaction rate). When considering the variance and plotting the interaction rate across time (Figure 1b – center box), one might expect to find noisy time series that still maintain a rank order. Instead, there appear to be nonlinear trends. In particular, there are some definite peaks (e.g., females of Ranks 3 and 6) that follow the infant date of birth. If aligned by date of birth (Figure 1c), this pattern can be seen a bit more clearly for at least three of the females.

Interactions vs Relationships—To explore the relationship level of social complexity, we summarized each male-female-infant triad in a grid (Figure 2a) that extends the representation of male-female and male-infant relationship status (presence/absence, assigned independently from project records, at 3-mo intervals) before, during, and after the 6-mo study period. For the triadic configurations during the study period, we maintain a distinction between female-biased and infant-biased interactions for each male. The majority of female-biased interactions were interactions between a male and a female-infant pair in which it was not clear that the male was in coordination specifically/differentially with one or the other. Infant-biased interactions, on the other hand, include interactions between males and female-infant pairs in which the coordination was clearly with the infant (e.g., the male was contact-greeting or grooming an infant while it was close or physically attached to its mother). Although we distinguished between seven female-infant "actor" combinations in these data, for this analysis, we collapsed them into two categories—mother- or infant-biased—for ease of visualization. For the same reason, we assigned actual rates of interaction into one of three—high, medium, and low—categories.

The MFI configurations we observed were not equilaterally triangular. Most cases could be read as a "two plus one" configuration: male-female + infant, male-infant + female, or female-infant + male. In *The Primary Triangle* (Fivaz-Depeursinge & Corboz-Warnery, 1999), comparable distinctions were employed to study interactions between human parents and their infant. The "truly" triadic configuration, in the human case, was described as both mother and father engaging the infant simultaneously. In the MFI data set, there were situations in which a single individual engaged simultaneously and differentially with the two other members of the triad (e.g., a female greeting a male while grooming her infant or a male greeting a

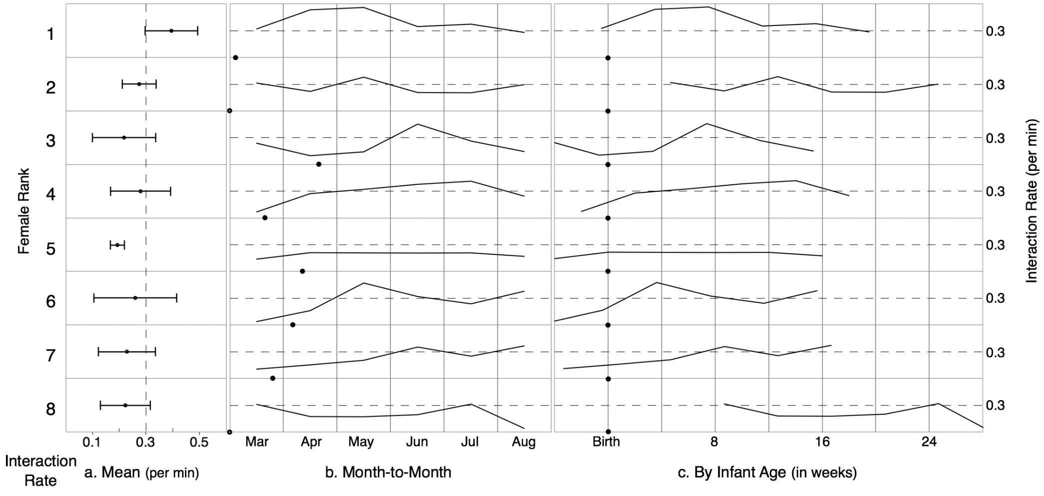

Figure 1. Triadic interaction rate and female rank; triadic interactions ($n = 2{,}913$) among eight female-infant pairs and eight adult males over a 6-mo period (187 h-long focal samples). a. Mean interaction rate (interactions per min) by female rank (high = 1); b. Stacked line graphs of interaction rate broken down by month—data points placed in middle of each month block, and black dots at accurate date-of-birth (infants of females #2 and #8 were present at study outset); c. Study data aligned by infant age (in weeks).

female while carrying her infant). How should these situations be treated? Past studies of relationships in baboons have considered the "third party" to be a contextual factor in the study of a primary dyad (see Altmann, 1980, for a focus on the mother-infant; Stein, 1984, for a focus on male-infant; and Smuts, 1985, for a focus on male-female).

Of the 13 triads (see Figure 2b) in which males had an established friendship with the female before she gave birth, ten incorporated a special relationship with an infant during the study period and beyond. Two others incorporated a special relationship with an infant after the study period was over, and one dropped the friendship with the mother after the study period. There are eight triads in which the male has a special relationship only with the infant, however, and four triads in which the male has a friendship only with the mother. This pattern suggests that although the inherent proximity between mother and infant after birth may facilitate the establishment of a special relationship with an infant, there are other factors involved, perhaps from adjacent levels of the social complexity hierarchy (individual characteristics on one hand, and group level factors on the other).

There is no clear evidence in baboons that triadic configurations lead to triadic relationships. As the infant gains independence and spends more time separate from its mother, the opportunities to interact with each independently may reduce the potential for a triangular cohesiveness. Although most male-female friendships coincide with male-infant special relationships, that was not always the case.

Thus, the triadic grid raises two questions directly relevant to social complexity: the first is whether there is anything inherently triadic (i.e., emergent) about these configurations. Could they be the result of a simple combination of (i.e., reducible to) pair-wise interactions? In other words, can the variance in the triadic data be explained by mapping a dyadic structure (two plus one) on triads? The second question regards the interdependency of male-female friendships and male-infant special relationships. Namely, are these relationships a simple/direct outcome of the inherent and physical overlap of mother and infant after birth? For example, does a male, who already has an established relationship with the mother, inevitably incorporate a special relationship with her infant after birth?

From Triad to Social Network—Clearly, baboon relationships do not happen in a vacuum and cannot be treated as independent of one another. The interdependencies between male-female friendships and male-infant special relationships are only partially expressed in triadic grids. Beyond the interdependency within a single female-infant pair, the number and types of other relationships, as well as other group factors (e.g., adult sex ratio, the number of young infants present, the number of cycling females), can influence the pattern of relationships in a social network. The multitude of factors and their potential interdependencies make it unlikely that we could predict group-level patterns reliably, if at all. And yet most field researchers contend that the complex patterns observed in a social network are clearly not random and are far from being arbitrary, even if they are not easily captured by summary statistics such as means and variances across individuals.

To visualize and explore some of these group-level patterns, we present the triadic summary grids in a 64-cell matrix (Figure 2b). This matrix consists of eight female-infant pairs and eight males and represents male age along the y-axis and female rank along the x-axis. It also marks the alliance status among males. Even though this matrix represents only a portion of the whole troop, we find this kind of group matrix very illuminating, especially in its ability to represent simultaneously multiple levels of social complexity: individual characteristics, relationship status, and interaction rates.

At the gross level, each male or female has a persistent relationship with two or three primary females or males and that persistence is confirmed in the more detailed analysis of triadic interactions. Namely, strong male-female and male-infant relationships are often accompanied by high rates of interactions. For example, using the initials of the individuals represented in this matrix, consider PH/MC_MZ, RL/DE_ID, CB/RM_RX, HW/AA_AE, etc.

As we described in the previous section on the triadic grids, there are a variety of ways in which male-female friendships and male-infant special relationships play out in the group and over the course of the period represented here. Some male-female friendships, which existed prior to the study period, continue steadily and later incorporate a special relationship with the infant (e.g., RL / ZL_HZ, ND / DA_DJ, CB/TE_JY). Others do not (e.g., RT/MV_GN), while still others start a friendship with the infant and/or the female several months after the study period is over (e.g., RT/RX; HK/DJ). In the group matrix representation (Figure 2b), we can further examine these patterns in relation to the rank of the females as well as in regards to the age order and alliance patterns among the males.

For example, looking at the strongest allies (males RL and ND), we see a complementary pattern of friendships with females, a pattern we observe also during sexual consort dynamics (strong allies will avoid situations which would put them in direct competition). The pattern of

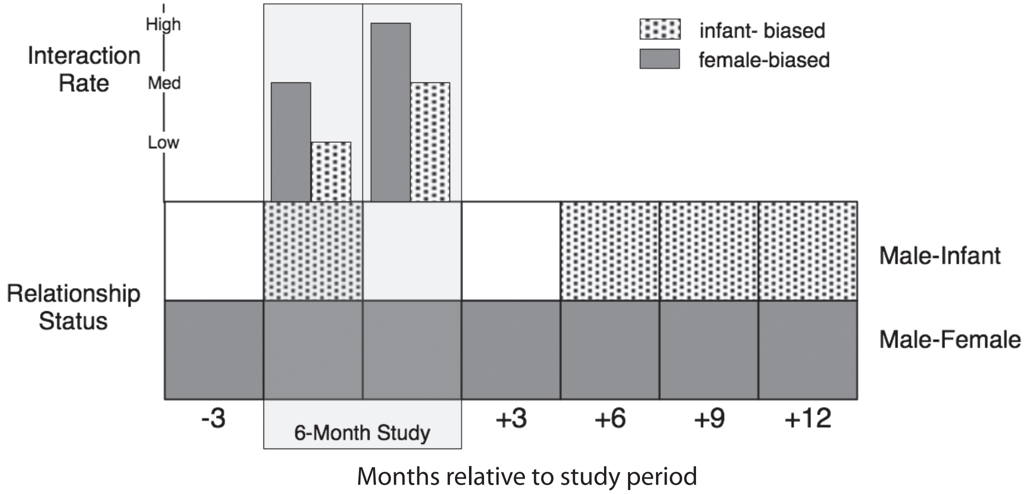

Figure 2a. MFI triadic grid; 3-mo values of interaction rate and relationship status of one male-female-infant triad. *Top half:* Rate of female-biased and infant-biased interactions of one female-infant pair (RM_RX) with a single male (PH) during the 6-mo study period in two 3-mo clusters. *Bottom half:* Independent assessment at 3-mo intervals of presence/absence of a special relationship between the male and female (lower) and male and infant (upper). These assessments, from project records, extend from a 3-mo interval prior to the study through a full year after the study was completed.

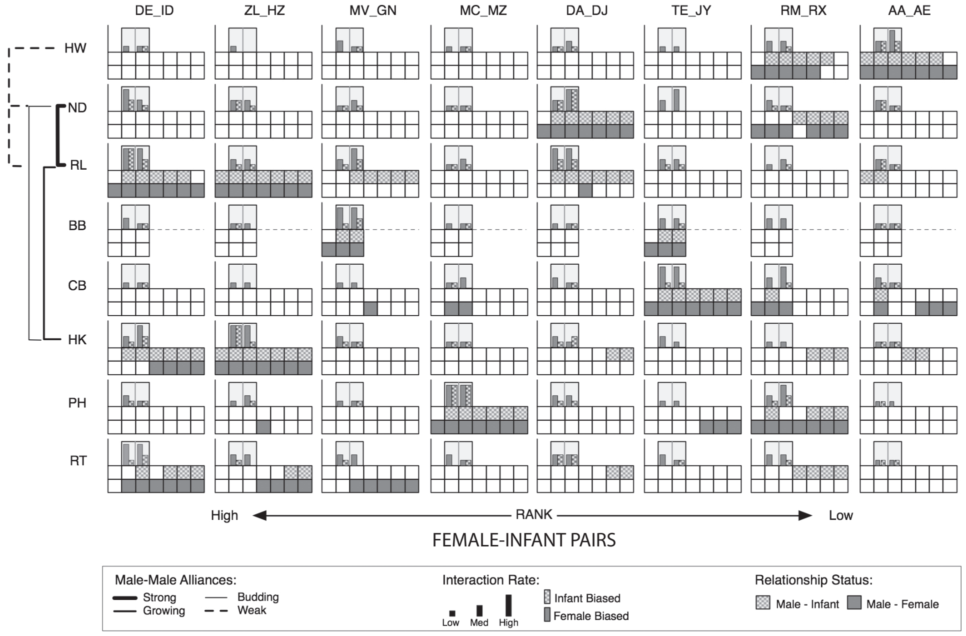

Figure 2b. Group Matrix (8 x 8) based on MFI triadic grids (see Figure 2a): 8 female-infant pairs ordered by rank, and 8 adult males ordered by age. Male-male alliances marked along left-hand side by relative strength (strong, growing, budding, weak). Representation of interaction rate and relationship status same as Figure 2a. Independent assessments of female rank, male age, male-male alliances, and relationship status come from project records. Male BB disappeared shortly after the 6-mo study.

male relationships with females and/or infants may be influenced, as well, by an overall tendency of males to concentrate on either high-risk or low-risk resources. The alliance between males RL and HK presents, alternatively, a pattern of parallel friendships with the same female-infant pairs (DE_ID and ZL_HZ). Curiously, this alliance also presents several cases of infant-only male relationships (one pair of male-infant relationships, with infant DJ, starts early for male RL, but long after the study period for male HK). This raises a question about the causal direction of male-male alliances and male friendships with females and/or infants. Do males who are establishing an alliance end up having friendships with the same female because they share proximity to her? Or, does their mutual interest in the same female-infant pair provide the context for establishing an alliance? In this case, HK is younger than RL, and the lag time in picking up DJ as an infant friend may suggest that he is influenced by his older, more experienced, ally.

When male-male alliances are also consistent with pairs of male-female relationships, such as HK and RL, it might suggest the presence of larger cliques (vaguely understood as regular members in the socio-ecological clusters that are likely to be found sharing proximity throughout the day's activity cycle). Male RT, who has parallel friendships with the same females (and more weakly, with their infants) yet has no allies, was usually found in direct competition with both HK and RL. Even so, cliques may be inclusive/tolerant of such conflict patterns as are other relationships (see literature on conflict resolution, e.g., Aureli & de Waal, 2000). Are cliques real social structures in the sense of Hinde's (1987) social complexity hierarchy? To answer that question, we would have to define more clearly and examine whether cliques are emergent from the constituent dyadic relationships and whether they have dialectical relations with other levels (dyadic relationships on the level "below" and overall group patterns "above").

Male RT also presents an atypical profile for a young high-ranking baboon. It is usually the older, more established troop residents who have friendships with several females at the same time as their dominance rank, highest in their first year of residency, decreases (Strum, 1987). In male RT's case, this pattern may have been possible due to the small size of the group and the absence of new immigrant males, which would introduce instability into the male dominance hierarchy.

In male RT's case, the specific unfolding of events provides a narrative in which the highest ranking female (DE) actively solicited grooming interactions with RT, in spite of objections from other male friends (RL and HK), right around the birth of her infant. After the establishment of a friendship with DE, it was not long before RT had friendships with the next two females, ZL and MV (although not with their infants). RT, then, for a short period at least, had an unusually high resource-holding potential, although he was clearly at the limit of his social efforts. Maintaining these bonds required constant monitoring and possessive and/or punitive interventions, when any one of these females engaged in affiliative or sexual interactions with another male. We add these case-study-like observations to emphasize the power of individual and idiosyncratic histories to influence system-level patterns in ways that make sense, at least to human observers, and we suggest that rather than consider them anomalies or noise, we should systematically look to them for guidance in revealing the sources of variation affecting social complexity.

It is important to emphasize the advantage of a single visualization representing multiple factors from different levels of social complexity. The patterns we describe here (and their potential interdependencies) are not strong enough to have risen from an accounting summary alone, and the deviation from a central trend (i.e., an established relationship between a male and a female correlates with incorporating a relationship with her infant) might be dismissed as noise. It is reasonable to expect that the factors involved (at a minimum, rank, age, and relationship status) will interact in sensible ways, even though there are not enough data for, nor do they meet the assumptions of, a statistical analysis of variance. We propose these types of visualizations, which preserve individual contribution as they depict system-level patterns, as arenas in which sources of variance can be systematically explored. Moreover, we claim that examination of such visualizations will likely generate testable hypotheses, perhaps more reliably than intuitive or theoretical interpretations of anecdotal observations.

These sorts of curiosities can be further explored by going deeper or wider in our observations. We can go deeper into the details of interaction data to look for confirmation about timing and the types of interactions involved. Equally powerful would be an exploration of similar "group photos" from the same troop at different time periods, or of different troops in comparable situations. Would we see the same pattern in a larger troop? How might a different pattern of male-male alliances arise? What if there were more or fewer infants available? What different resources could be at stake? We suggest that group-level social-network representations are the proper unit of analysis for addressing the interdependencies among the different levels (individuals, interactions, relationships) of social complexity.

Groups are not closed systems, of course, and groups with overlapping home ranges interact and influence each other. Yet, we cannot emphasize enough that by taking a system perspective on social complexity, we are doing anything but taking the individual "out of the loop." We observe group-level patterns that are often strongly influenced by a particular individual only to see the influence recede with the disappearance of that particular individual. Thus, Strum (1975, 1987) observed a semi-collaborative hunting tradition that emerged and then faded with a single male's tenure in the troop.

To summarize, we see the following: (1) with multiple factors at play, we are not likely to find a one-size-fits-all strategy, even when central trends do suggest an overall linearity (e.g., high female rank confers high interaction rate). Moreover, the variance in the system is not mere noise. We also saw that (2) history matters, and that (3) individuals make a difference. Multiple strategies and combinations of factors are possible, each with their own internal coherence; yet even though they are not random, these sorts of findings would likely go unnoticed or unreported—at most delegated to the anecdote pile.

So far, then, we seem to have met all of Ward's (2002) expectations regarding organized complexity. We have observed fluctuations of many sizes, irregularities and deviations from theoretical predictions, and difficulty in finding regularities in system behavior. In the next section, we show how finding system level regularities (or defining a system-based on observed regularities), lets us probe the nature of social cognition in baboons in new ways.

Systems: Cognition (Sexual Consort Turnover [CTO] Events)

The curiosities we saw in the social network representation are suggestive of choice and decisionmaking and, as such, may point indirectly to cognition. In analysis of CTO events, we will also increase the dimensionality of investigation to a point at which cognitive features can be directly addressed.

CTO Events and Male Performance Scores—As with the above data, we start with a conventional summary-level description of the 180 CTO events. In this account, CTO events are presented as decisive binary outcomes from the male's point of view. The new consort male is deemed a winner and is assigned points in a scoring scheme to evaluate overall performance.

Table 1 presents a tabulation of outcomes from the CTO events in our data set. Three scores were calculated: Score 1 = win to loss ratio; Score 2 = win to challenge ratio; Score 3 = win over total CTO events participated. The adult males are ordered by four distinct age categories: (1) very old, (2) old, (3) mature, and (4) young. The two subadults (males GR and SQ) were not active competitors, although they are an example of what Lave and Wenger (1991) termed *legitimate peripheral participators* in humans (see also Forster, 2002).

Table 1 shows a remarkable consistency across the adult males, regardless of age assignment, in performance Score 3 (win/total participated), suggesting a constant benefit-to-cost or benefit-to-effort ratio. In contrast, Score 1 (win/loss) shows the oldest male HW to have a much higher score than the other males. If we look at absolute numbers, we see that he participated in very few CTO events, which is suggestive of selective participation in consort dynamics and is consistent with the notion that age and experience impact effective performance. Note, however, that the hypothesized increase in effective performance with age does not confer an overall advantage as seen in the consistency of Score 3. A constant cost-to-benefit ratio over the life cycle of individuals may make sense from the perspective of behavioral ecology models on evolutionary reproductive strategies, although it says little about the cognitive processes involved.

Another point of interest is the contrast presented by mature males (HK and CB). Occupying the same age category, they differ across all counts and measures (assignment of male age is speculative since birth dates of immigrant adult males are rarely, if ever, known for certain). Male HK looks more like the adjacent older age category, although his

Table 1. Male roles and scores for CTO events (n = 180); roles were either CTO winner, loser, challenger (but not winner), or follower (but not winner or challenger). Three calculated scores were used: Score 1 = win/loss; Score 2 = win/challenge; and Score 3 = win/total participated. *Each of the two subadult males gained and lost temporary access to a consort female without settling into stable consort dynamics.

Male	Win	Loss	Challenge	Follow	Total	Score 1	Score 2	Score 3	Age
HW	7	3	5	8	23	2.3	1.4	0.3	Very old
ND	34	31	24	9	98	1.1	1.4	0.4	Old
RL	29	25	25	5	84	1.2	1.2	0.4	Old
HK	41	36	39	10	126	1.1	1.1	0.3	Mature
CB	22	26	6	7	61	0.9	3.7	0.4	Mature
PH	21	24	16	4	65	0.9	1.3	0.3	Young
RT	25	34	10	2	71	0.7	2.5	0.4	Young
SQ	0.5*	0.5*	3	16	20	1.0	0.2	0.0	Subadult
GR	0.5*	0.5*	1	2	4	1.0	0.5	0.1	Subadult

younger age may be reflected in the high number of CTO events he participates in, regardless of role category. Male CB, on the other hand, shows a participation pattern more like the younger age category, except for his unusually high Score 2 (win/challenge). Behaviorally, male CB fit a low-risk profile in his tenure in the troop, a variation on the more typical high-rank new immigrant pattern (yet another variation from the one described for male RT in the MFI analysis). Male HK, though, followed the typical immigrant profile, including forming alliances with mature males, friendships with females, and special relationships with infants (see MFI analysis), all the time remaining highly active and visible. Curiously, we must add, male HK had an occluded (and visibly swollen) penis sheath which prevented him from achieving intromission when attempting to copulate. As far as we could tell, this visible congenital condition did not alter the normal range of behavioral reaction by either of the sexually receptive females, who were very cooperative with him, nor by the other troop males, who consistently responded to him as a successful competitor and/or ally. The implications of the response to this oddity for the cognitive limitations of baboons are, of course, completely speculative.

Types of CTO Events—The tabulation of performance scores, although suggestive of selective abilities, does not directly reflect the cognitive processes involved in CTO events. The types of CTO events may provide additional information on the nature of decisionmaking and negotiation taking place. Others (e.g., Smuts, 1985) have made distinctions between CTO events that were either primarily aggressive, employed social strategies, or exhibited a hybrid of aggressive and social behavior.

A subset of the CTO events in this data set followed a pattern that has been previously (partially) described for baboons (e.g., Smuts, 1985) by which an older mature male, in consort with a female late in the day, is nonetheless replaced by a young male, found by her side early the following morning. Gone unobserved in the past, such actual CTO events were recorded repeatedly in the present study to reveal a surprising pattern. The older consort male, although possessive of the consort female all the way back to the sleeping site, would refrain from following her once she began her ascent on the face of the rocks. The younger male follower, as they approached the sleeping site, would shift to moving ahead of the consort pair, as if anticipating the opportunity. The few exceptional cases in which the older male attempted to guard the consort female, often by preventing her ascent to the rocks, all occurred on the day closest to ovulation for that female's cycle. This pattern, which we termed "sleeping near the enemy" (Forster & Strum, 1994) suggested additional monitoring and decisionmaking abilities by the males. The older male's apparent choice not to fight questions the binary depiction of a male as winner or loser. Elsewhere, we also provide a distributed cognition interpretation of this pattern (see Appendix of Strum et al., 1997).

Where Is the Cognition?—CTO events, then, are not all made equal, and mean trends do not help us understand or predict outcomes on a case-by-case basis. So far in our discussion, if we ask "Where is the cognition?," we have to admit it is not explicitly in our data but, rather, in our theories and interpretations. The challenge we face, then, is how to collect and represent behavioral data so that they more directly reflect and reveal cognitive processes as they happen. On this account, collapsing the richness and complexity of a CTO event into a binary assignment of points, contributing to a (male's) performance score, is a frustrating limitation.

If we attempted a task analysis (a favorite alternative to performance scores in cognitive studies), we would still have to assign an objective to the task (e.g., monopolize access to a sexually receptive female) and assume that at least one of the participants has that objective as its goal. We would then examine the trends in the data to test how effectively each participant achieves its goal, and we may decide to count cases in which the objective is not reached to assess error rates. This is prohibitively challenging in the face of fast-pace polyadic dynamics, especially if analysis depends on our assumption that we can identify and keep track of multiple and rapidly changing, in-the-head, goal structures.

Yet, with detailed observations and systematic analysis, insights are forthcoming. Smuts (1985) presented a comprehensive exploration of sexual consort behavior as it relates to male-female friendships in baboons, attempting to link the interpretation of the observed behavior to psychological factors. She calculated nonresponsiveness among males, for instance, and found correlations with male consort success (a nonresponsive male to challenges by others had higher scores). Rich narrative descriptions of CTO events provided Smuts the context for psychological interpretations of individual baboons as cognitively sophisticated manipulators of emotions. Yet, the interpretive leap Smuts made from observed behavioral dynamics to cognition still remains largely within a framework limited to identification of internal psychological states. For Smuts, we argue, behavioral data act as indicators to individual cognitive characteristics. In contrast, we would like to push our data further to where they systematically capture and reflect cognitive processes.

CTO in State Space—Although anecdotal, Smuts' (1985) narrative descriptions are careful records of unfolding behavioral dynamics. In our study, when we systematically observed and recorded such dynamics, regularities emerged which made it possible to label/categorize states that are inclusive of the consort party as a system. These states are characterized by a combination of the identities of participants involved, their roles, spatial-temporal arrangements, and occurrence of specific types of behavior.

While similarities in dynamics could be seen whether or not an actual turnover occurred, in this distributed cognition framing, we began analysis by considering only cases in which the outcome is an actual switch in consort male partners. This was the most important move in our approach to cognition. By first studying systems which are defined by an observable outcome, we can defer the attributions/assumptions about the mental goal or plans that may (or may not) organize the behavior of individual participants. Once we gain insight into the regularities in this system, we can use them as a yardstick against which to explore similar dynamics with different outcomes.

Notice that by describing system states independently from individual behavior we can characterize something about the system that may be different from the state of each individual. The same individual behaviors can contribute to different system states, and different behaviors by individuals can contribute to similar system states (a many-to-many relationship). In Table 2 we identify four gross-level states leading to a CTO, each state representing a configuration of participants and their interactions. The CTO system is comprised of the consort party members. In a consort party, the consort pair can be considered metaphorically as the nucleus of the system. Every system state relevant to analysis involves some change in the pattern of activity in the nucleus.

A state space description represents all the possible ways a specific CTO event can unfold (a specific path through the state space). Each instantiation is represented by a chain of states that can be repeated in a different order and with varying length. One can tabulate all the pair-wise transitions between states and construct a transition matrix, which can be represented as a finite state machine (or transition graph) as shown in Figure 3. Each arc represents a transition between states, and the number near the arc represents the transition probabilities, which are also reflected in the arc's width. By visually tracing a path following the thickest arcs, we can see the most likely trajectory. Figure 3 shows that a major pathway through the states unfolds from a stable configuration (STA), to disruption (DIS), to negotiation (NEG), to a new configuration (NEW).

Rather than identifying a CTO event by its outcome for two of the participants (the winner and the loser), a state space description offers a way to characterize how each event unfolds, giving us a common language to describe the system from the "point of view" of each and every participant. Once again, a systems perspective can preserve rather than diminish the contribution of individual participants, in this case by identifying their profiles of participation. For each participant in the system (not only the new consort male), we can identify characteristic ways in which it responds to a disruption (DIS) or engages in negotiation (NEG) under varying circumstances. How does a consort female respond to a disruption by a follower male who is also her friend? How does a male negotiate with two male followers who are also allies? Even

Table 2. CTO system state definitions; the states are mutually exclusive so that the CTO system can only be in one state at any given moment. Finer distinctions and substates are recognized but are beyond the scope of this paper.

Label	CTO state	Definition
STA	Stable configuration	Steady pace and stable coordination and/or synchrony in activity between the consort partners, as well as among the male followers and the rest of the consort party.
DIS	Disruption	Any change in distance, movement pattern, visual attention, or activity that reduces the stability of association and/or coordination between the consort male and female. This state may be initiated by either the consort party or by a third party and is marked by uncoordinated activity of the consort partners. May or may not reverberate through the rest of the consort party.
NEG	Negotiation	Unstable and heterogeneous movement or interaction patterns that extend beyond the consort pair (asynchronous at the system level; i.e., not all consort party members are doing the same thing). Relatively faster pace than STA.
NEW	New configuration	A new male is in contact with the consort female and/or is in considerably closer and more coordinated proximity to her than the male who was in consort until that point. NEW does not require the stability and synchrony of STA.

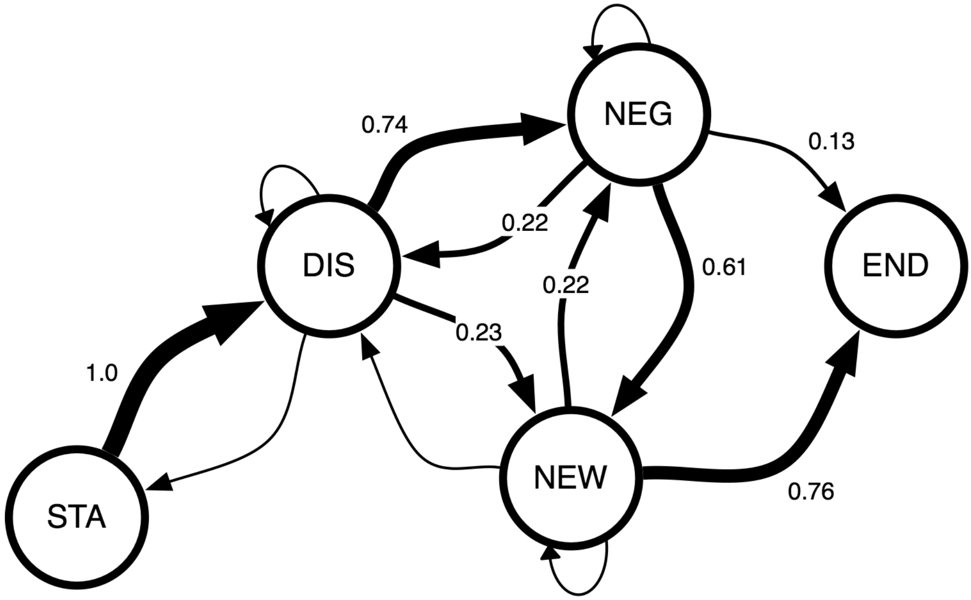

Figure 3. CTO State-Space Diagram based on a transition matrix constructed from 180 CTO events (total of 747 state transitions); circles represent CTO system states (see Table 2), and arrows represent transitions between states. Numbers on/near arrows represent transition frequencies ≥ 0.10. Transition frequency is also represented visually in arrow thickness.

more intriguing for our cognitive quest, we can explore how profiles of participation change over life cycle transitions, from subadult to adult, from newcomer male to long-term resident, etc.

Delineating when a state transition occurs is problematic and somewhat arbitrary. Since we are dealing with unfolding dynamics in time, how do we distinguish between states and transitions (for instance, why isn't DIS a transition instead of its own state?) To add to the confusion, the tempo and complexity of CTO events in baboons is high, and the observations, especially those recorded by hand, are at best approximations in time and necessarily vague in the details of the coordination among all the participants. To simplify the task, a dyadic interaction structure is often imposed on events, and parallel actions are noted grossly and sequentially. Many of the details are lost altogether as becomes intriguingly, and painfully, obvious when recorded footage is available. Yet, video not only confronts us with our limitations as observers, it provides us with the opportunity to engage the missing elements. With the growing ease of capturing moving images on digital media, video recording has turned into a popular form of data collection. Interestingly, this medium simultaneously expands and limits our horizons of analysis. The expansion is in sheer quantity and in the preservation of original temporal and spatial information, all the while limiting our view to what is visible through a camera lens.

CTO Video Data

To examine our state delineations and/or to discover new ones, it is necessary to probe the unfolding events at a higher temporal resolution that captures the actions of multiple actors simultaneously. Video footage allows us, through repeated viewing at variable speeds, to track elements of the system independently without compromising accuracy and without losing the system level of description. Here, we demonstrate the potential of video analysis by presenting a transcription of a single CTO event captured on video (from the same troop but at a later point in time).

We transcribed the CTO event on several levels of description, although only the two ends of the continuum are presented here. At the grossest level, we assigned system states at 1-s intervals, using the same criteria we used for the paper data. We then tracked each individual independently and repeatedly to record social and sexual behavior, and nonsocial activity such as resting, traveling, and foraging. We went "down" another level to track (at 0.1-s intervals) shifts in position of various body elements: limb movement, body and head movement relative to one another, etc. At such a high resolution, transcription of behavior can shift from discrete to continuous, producing a time-series representation. Time series are powerful representations since the dynamics can be described along many dimensions and can be used to examine their relation to system-level states.

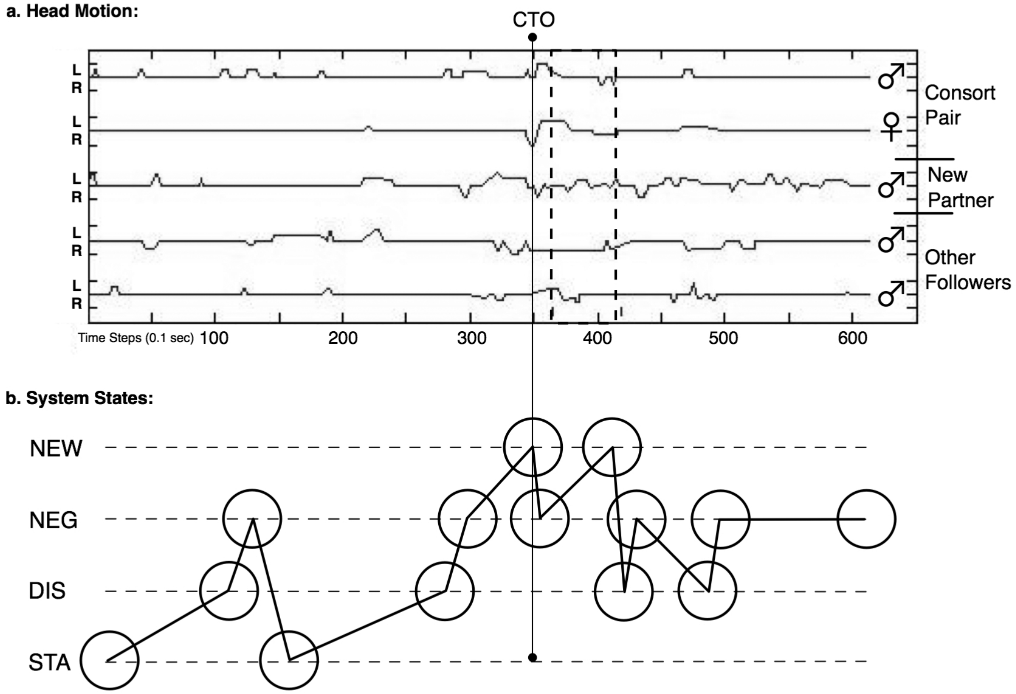

Figure 4. CTO head motion and system states; video analysis of 1 min (at 0.1-s resolution), capturing a CTO event at time step 350. 4a. Head motion relative to body orientation of five consort party participants (consort pair plus three male followers). Time series represents head movements to the left as departures above the line and head movements to the right as departures below the line. Dotted box represents the duration of copulation between the consort female and her new partner; 4b. System state (see Table 2) transitions.

In Figure 4, the time-series representation of head motion for all five participants in the CTO are laid out in parallel with the system states on the bottom half, along the same timeline. Other levels of description, such as individual activity states and social behavior, are left out of this figure for ease of presentation.

Conveniently, head motion relative to body orientation is relatively straightforward to track in baboons, and it is easily converted to a continuous representation. It is also intriguingly suggestive of attention allocation—an example, perhaps, of epistemic action (Kirsh, 1996). That is, if a baboon is looking in a direction that is different from its body orientation, we would argue that it is likely checking/monitoring something of informational value. Since CTO systems are often comprised of upward of five individuals, it is not likely that any one participant will remain aligned in body and head as the system moves through the more unstable states of DIS and NEG. Comparing the consort male and female's pattern of head motion, we note a regular glancing pattern by the male (checking on male followers) while the female, especially if older and high ranking, is mostly "looking where she's going." An experienced and confident consort female, in this case, she pursues her trajectory of movement without much checking or monitoring until shortly before the critical transition to NEW. At that point, all the participants are engaged in vigorous head motion as they anticipate and respond to each other's actions.

Thus, a time-series representation of changing elements in the system can provide a "validity" check on our chosen state delineations. That is, system state choices should not be arbitrary if they are to confer explanatory power. For example, we might see a flurry of activity across system elements just prior to a state transition. Thus, we may begin to discern the dynamic patterns contributing to the stability of system-level states and/or the conditions that may precede state transitions.

The new consort male is of particular interest in the post-CTO phase. Traditionally, we assume the goal of the male is to gain access to the female and, when he does, his "goal" is achieved. Yet, here we see the new male, after gaining access to the female and copulating with her (for the length of the dotted box in Figure 4), looking from side to side. In the video, it is clear that he is monitoring the spillover aggression between the previous consort male and the other followers. Even though he already has "his prize," the new consort male stops to watch (as does the consort female, but to a lesser degree) and even participates from a distance in a mock charge and aggressive vocalization.

The unfolding dynamics of relationships are obviously important to baboons beyond their immediate task, and we, as researchers, are interested in the cognitive processes involved in sexual consorts in general as well as in other activities and contexts. We represent both pre- and post-CTO phases in Figure 4 to remind us that our choice of system boundaries, in this case determined by the CTO outcome, is just the first step in a distributed cognition analysis. Once the CTO system is analyzed, it can be used as a yardstick, as we extend our exploration to similar systems with different outcomes or to the same system across life cycle transitions (in order to address development). In this case, as we learn about the regularities that operate in CTO systems, we may be able to explore why some post-CTO phases take longer to settle back into a STA while others do so immediately.

The tradeoff between temporal and spatial information in this analysis is not trivial. In a captive setting (a fixed cage; a rat maze) a bird's-eye camera view on a completely stationary and known space allows tracking that preserves both spatial and temporal dimensions. In contrast, field conditions, and their transformation into shaky video images, make distance and other absolute spatial judgments difficult if not impossible. Relative spatial orientation, in contrast, is easier to call-out, and we are experimenting with annotation schemes that can add a layer of spatial-social information to the head motion graphs. Marking each glance of male followers as directed towards or away from the nucleus of the system (the consort pair) is one possibility. Other levels of description (individual activity and relational states, omitted here) may provide additional constraints to assist in interpretation.

Discussion

Dynamics, Dynamics, Dynamics

The progression of analyses presented here can be read, on one hand, as adding temporal dynamics to interaction data. For example, in the MFI study, we added the month-to-month resolution to the 6-mo study (Figure 1), as well as the pre- and post-study periods (Figure 2a). In the CTO study, we shifted to looking at an event as a temporal unfolding of characteristics system states (Figure 3) and went further to explore a CTO event at the resolution of 0.1 s (Figure 4b), producing a continuous representation of head movements relative to body orientation. Temporal dynamics are increasingly explored on a larger time scale as well, as long-term projects accumulate data and make it possible, even in long-lived species, to look at cross-generational patterns. This analysis also used spatial dynamics, represented as the social interaction space that results from increasing the traditional unit of behavioral and cognitive analysis beyond the individual and the typical dyadic approach to observing interactions.

A dynamical approach is at the very core of systems perspectives. We ask of such complex systems how things come to be rather than how they are in a snapshot. When systems are taken to be linear, one may expect that by recording snapshots we would be able to complete the picture; however, the pervasive nonlinearities in the phenomena we observe force us to shift our effort to the tracking of dynamics. As our technologies develop, these aspects become more accessible to data collection and, thus, amenable to systematic analysis.

Social Context

Even as research on complexity becomes more acceptable, there is still a tendency to approach analysis by focusing on the individual as the unit of analysis and delegate everything else to "context." Similarly, systems studies are usually limited to a two-layer depiction of systems and their elements. Yet, as we have tried to demonstrate, in both the MFI and CTO studies, context and system are relative constructs amenable to further structuring in (social) space and time. Moreover, we feel strongly that every effort should be made to push beyond the comfort zone of binary and dyadic limits on analysis. Kelso (1985) argued that to understand boundary conditions between phase transitions and other dynamics in complex systems, one needs always to track at least three levels: (1) micro, (2) medium, and (3) macro dynamics.

Socio-Ecology

Clearly, concentrating only on the social context of interactions is a gross oversimplification. The occasional occurrence of a "baby boom" in this olive baboon population, for example, is a direct result of a cycle of droughts in the area. As such, it provides a kind of cognitive experiment because baboons are not by nature seasonal breeders. While the socio-ecological cohesiveness of behavior makes it difficult to consider social cognition on its own, various attempts have been made to examine social vs foraging complexity and to explore whether cognitive skills transfer from the social to the ecological tasks primates face (e.g., Cheney & Seyfarth, 1990). Recently, Byrne (2003) provided an elegant systems-state-space analysis of foraging behavior in gorillas to explore links to the cognitive skills required for imitation and observational learning. We find the generality of systems thinking very promising in its potential to explore dynamics of behavior across contexts and species so that some of these issues can be addressed more effectively.

Cognition

Studying embodied situated distributed cognition requires two shifts: (1) increasing the boundary of the unit of analysis and (2) shifting from counting outcomes to tracking process. One bonus of this perspective on cognition is that by starting with a regularly observable outcome, we are able to avoid the trap of having to assign/assume individual goals at the outset (Hutchins, 1995; Johnson, 2001; Forster, 2002). Once the dynamics of such a system are understood, we can extend our analysis to similar dynamics with alternate outcomes. Following this route, we believe, provides data-driven constraints (rather than theory-driven hypotheses) on our understanding of cognitive behavior.

Choice of Systems Boundaries

Even though they may be unfamiliar to some researchers, no novel analysis methods were introduced here. Dynamics and sequential analysis of behavior have a long history in behavioral ecology, primatology (e.g., Altmann 1965), and psychology (Bakeman & Gottman, 1997). Transition matrices and directed graphs have been widely used, and Markov models exploring the structure of streams of behavior are not uncommon. The difference in our framework is the choice of system boundaries. Sequential analysis is often used on a stream of behavior produced by individuals (the system is usually assumed to be some internal mechanism that controls the behavioral output) so that a social interaction is depicted as two systems running in parallel. Analysis of such an interaction is then as difficult as the analysis of two interacting systems. By choosing a system to include multiple individuals as elements, each system state is an interaction-level description and so becomes "open" to investigation. We now are not asking how two or more systems (one for each individual) combine to produce the dynamics we observe, but, rather, how each individual (element) participates in the system we identified. As in the CTO analysis on this treatment, we end up with profiles of participation and with patterns of coordination/negotiation that give us a more direct handle on cognitive dimensions of behavior.

A Toolkit of Complementary Methods

The strength of the framework we present is in the principles that guide us in addressing social complexity and cognition with equal force, using a systems approach that was specifically tailored to address each (i.e., Hinde's [1987] framework for social complexity and Hutchins' [1995] framework for distributed cognition). These principles guide us in a multipronged engagement with interaction data and, as such, provide a toolkit which we can apply to other phenomena and species. Video data can add significantly to the ability to track and study complex behavior at high temporal resolution, and tracking even a minute of video in detail can provide new descriptions and questions. Yet, we can be selective of when to employ such labor-intensive methods—for example, the higher resolution and the repeated viewing capabilities are useful especially when looking at new phenomena or when trying to focus on transitions between states; however, at other times, the grosser-level categories are sufficient and are worth the tradeoff if they allow for a larger sample size.

The Social Function of Intellect hypothesis was originally formulated as an evolutionary argument. Yet, the kinds of data that would be required to support such a claim conclusively are difficult to collect and analyze (van Schaik & Deaner, 2003). Theoretical predictions based on evolutionary "logic" (e.g., individual performance should maximize behavioral correlates of reproductive success and, ultimately, inclusive fitness), even when born out in mean trends, do little to inform us on the proximate, developmental, and functional levels of behavior, levels which are the most pertinent to understanding cognition in long-lived social animals. This is especially true when the phenomena under scrutiny display organized complexity, guaranteeing fluctuations, irregularities, and deviations from theoretical predictions (Ward, 2002). As sophisticated cognitive animals ourselves, there is reason to believe that our intuitions and snapshot observations will not suffice to gain insight into how cognition really works (Sterelney, 2003), and we believe these challenges require a shift from an over-reliance on theory-driven hypothesis testing. A more data-driven approach that holds promise of generating testable hypotheses can be achieved by using observed regularities to identify boundaries of a system, for example, and systematically searching multiple representations (i.e., different levels of description) of the same data for sources of variance.

Stengers (1997), in a chapter entitled "Is Complexity a Fad?," noted that one of the ways complexity has been used in scientific discourse is as a critique of reductionism, often also used as a critique of analysis. Complexity, in this view, is often synonymous with defying analysis. Stengers, however, argued that the analytic method can both contradict reductionism as well as reveal, or capture, what has escaped it (i.e., complexity). We wrote this paper in the spirit of demonstrating how systematically capturing (social) complexity can be done while building on, and extending, what reductionist framing has to offer our understanding of behavior. We hope the generality of these ideas is easily recognized, making this approach applicable to the study of other long-lived social species.

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