Title

A state-space approach to social complexity and distributed cognition in olive baboons (Papio anubis) : rethinking the role of behavioral analysis in socio-cognitive research

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Publication Date

2012

UNIVERSIT OF CALIFORNIA, SAN DIEGO

A State-Space Approach to Social Complexity and Distributed Cognition in Olive Baboons (*Papio anubis)*:
Rethinking the Role of Behavioral Analysis in Socio-Cognitive Research

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy

in

Cognitive Science

by

Deborah Forster

Committee in charge:

Professor Shirley Strum, Chair
Professor Edwin Hutchins, Co-Chair
Professor Patricia Churchland
Professor Jeffry Elman
Professor James Hollan
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2012

The Dissertation of Deborah Forster is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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2012

DEDICATION

To the memory of my parents, Arvin Forster (1920-1984) and Dorothy Kreisler Forster (1927-1993,) who left all the necessary clues strewn about in their too brief, very casual, yet gracefully humanist lives.

In celebration of one of the earliest 'clues' from my parents' library, the writings of Eugéne Marais (1871-1936), who, amongst activities as varied as poetry, law, journalism and social advocacy, followed his pioneering heart and troubled mind to wander for long periods in the South African bush observing his baboon friends, and studying termite hives as single organisms–social complexity and distributed cognition, indeed!

To the memory of my colleague and friend, Stanley K. Fevens (1947-2009,) who modeled a way of being in the world in good faith, in spite of challenges, with uncompromising integrity, more-or-less.

EPIGRAPH

The development [in the 19th century] *of the general concept of energy, as a relation rather than a substance, took many decades to clarify, even though it was a defining feature of that era. It was ultimately tamed by recognizing that it was not a substance, but a difference that could give rise to either the potential for or the expression of non-spontaneous change. It was an abstraction from a process. But this abandonment of substantialist explanations did not result in the concept of energy becoming either epiphenomenal or mysterious. Both the conceptions of energy as ineffable ether and of substantial substance were abandoned for a dynamical account. Similarly, we will be required to give up substantialist thinking about information and representation in order to develop them into scientifically useful concepts. Neither the physical identification of information with pattern nor the phenomenological conception of an irreducible intentional relationship that is 'always already there,' will survive this reformulation.*

(Terrance Deacon: Shannon Boltzmann Darwin: redefining information Part1, 2007)

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ACKNOWLEDGEMENTS

I want to single out my loyal committee members, first and foremost for outliving my resistance. Especially my committee co-chairs, Shirley Strum and Ed Hutchins, for inspiring me in equal measures social complexity and distributed cognition – deeply ecological ways of seeing and being primates. Jeff Elman for steadfast encouragement and clear vision regarding the relevance of animal behavior to the study of human communication. Pat Churchland for letting me in her experimental philosophy den, tolerating very fuzzy thinking as I cut my teeth on basic discernments. Marty Sereno for extreme curiosity, making exposure to brain science seem a worthy struggle. Jim Hollan for not blinking once along the winding path connecting baboons to car drivers, technology and design. Roy D'Andrade–from committee version 1.0– for pointing out the significance of what animals do incessantly, and encouraging me to translate data retroactively into state-space for quantitative analysis.

Paul Rodriguez–my shadow committee of one–for an unbroken thread of intellectual and personal friendship. From 1996 Santa Fe Institute summer school–where he first suggested describing baboon sexual consorts in state-space–then holding fast as I made him responsible for getting me through the trials and tribulations of analyzing baboon behavior in all manner old and new.

Others in and around UCSD and the Cognitive Science community influenced my thinking on this project. Amongst them: Jean Mandler, Aaron Cicourel, Don Norman, Michael Cole, Yrjö Engeström, Rik Belew, Rafael Nünëz, Gilles Fauconnier, David Kirsh, Rick Grush, Stefan Heck, Oron Shagrir, Seana Caulson, Nili Mandelblit and Morana Alac. Barb Holder for, among many things, a parallel state-space analysis of baboon consorts and helicopter piloting. Irwin Boer, Jean-Baptiste Haué & Pierre Fastrez for similar extensions to car driving. To the periodic French connections: Bernard Conein, Jacques Theureau, and, through Strum, the early exposure to Bruno Latour later renewed my faith in doing risky science by ways of ANT. Writing my dissertation rekindled my appreciation for an excellent training in behavioral ecology, especially by Jack Bradbury, Sandy Vehrencamp, Mike Gilpin, and David Woodruff.

Uniquely, Rachel Mayeri, for providing thought-provoking and hilariously rewarding collaborations that kept me artistically engaged and creatively intrigued by baboons and other primates, even as I strayed.

The dissertation solidified in the context of the inclusiveness I experienced at Calit2 through Ramesh Rao, and at the Temporal Dynamics of Learning Center: Judy Reilly tugged gently back to academic research, where the behavioral analysis of the baboon data gained a contemporary relevance. TDLC's refreshing environment of academic rigor and collaboration invited me to rethink and enrich my intellectual and computational horizons. Andrea Chiba, Janet Wiles, Tony Bell, Leanne Chukoskie, Jake Whitehill, Reilly's lab, Gedeon Deak's lab, and especially Gwen Littlewort, Marni Bartlett & Javier Movellan of MP lab for providing the push and pull and final push. Alex Khalil and Victor Minces for parallel motivation on the Gamelan project pilot. Finally, Kaya de Barbaro's inspiring trajectory and the Sequential-Analysis-Working-Group diehards: Paul Ruvolo, Jamie Alexandre, Nan Renner, Chris Johnson, Whitney Friedman, Linda Salamanca, for grappling opportunities with analysis in non-baboon settings.

At the center of this endeavor, of course, Shirley Strum and the staff of the Uaso Ngiro Baboon Project in Laikipia, Kenya – they opened and trained my field research eyes so that I could learn directly from the baboons about their life on the savannah. I also received great field training from Jeanne & Stuart Altmann in Amboseli, and benefited from discussions with Thelma Rowell, Andy Whiten, Dick Byrne, Jonah Western, Michael Tomasello, Jim Moore, Terry Deacon, Robert Sapolsky, Chris Johnson, Denise Herzing, Barb King and Heather Bond-Poje. Becky Frank also for her stamina in prohibitively labor-intensive video analysis.

Ultimately, the baboons were teaching me, far from their natural habitat, about how we humans make meaning, for their images and stories were my best (and *only*) calling card while wandering hallways knocking randomly on doors of car designers, architects, artists, horse owners, organizational development consultants, Feldenkrais practitioners and local café dwellers.

To say that learning to live well with a faulty mind is a long-term project is a radical understatement. Conditionally dovetailing the completion of my thesis on such a process meant carrying on beyond what anyone thought possible, yet guaranteed that a completed dissertation would reflect a level of integration and coherence truly worth celebrating. It also means that many of those mentioned above and yet many more in my life contributed to making this journey a success. You are too numerous to mention and the connections too intimate to recount, yet your traces on this work are in its very completion, teaching me lessons in generosity, humility, forgiveness and friendship along the way. You will find me fully engaged in reciprocity and gratitude, to each and every one of you, for a long time to come.

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ABSTRACT OF THE DISSERTATION

A State-Space Approach to Social Complexity and Distributed Cognition in Olive Baboons (*Papio anubis*):

Rethinking the Role of Behavioral Analysis in Socio-Cognitive Research

by

Deborah Forster

Doctor of Philosophy in Cognitive Science

University of California, San Diego, 2012

Professor Shirley Strum, Chair

Professor Edwin Hutchins, Co-Chair

This dissertation reexamines the role of behavioral analysis to propose a modified ***research program for socio-cognitive phenomena***–demonstrating its potential by presenting a two-step proof-of-concept on baboon data. I build on two ***Complex Systems Thinking*** approaches to behavior – Hinde's *model of* ***social complexity***, and Hutchins' *theory of* ***distributed cognition***. By giving Hinde and Hutchins a ***state-space framing*** I can apply a well-established tool-kit of ***sequential analysis*** for social interactions. These analyses represent a shift in emphasis from asking 'what-is-it-for' to 'how-does-it-work'.

First, I examine male-female-infant relations in the period after birth to demonstrate how to create a more *systematic tracking of social complexity,* emphasizing *context*: By building *immediate context* directly into the data-structures I can use the same data structure to look at study factors from

long-term *cumulative context* of both *relationships* and *group structure*. By analyzing state-transitions over independent tallies I am able to relate interaction dynamics more directly to successive levels of social complexity

Second, I track distributed cognition by looking at consort turnover (CTO) events as socio-cognitive systems that resolve 'who will be the next consort male?' Instead of performance measures based on outcome, the system-level regularities allow me to track individual *profiles of participation*. Behavioral traces of *Extended-Embodied Distributed Cognition* 'leak' outward from the skull to the physical and social environment and spread to the whole body. I use a video segment of a CTO event to demonstrate how to capture embodied attention by tracking head movements relative to body orientation.

The proof-of-concept demonstrate how a state-space approach and the tools of sequential analysis–multiway contingency tables analysis for categorical data and timeseries analysis for continuous data representation–provides a shared framing that allows integrating the pieces of social complexity and distributed cognition into a single research program to look at socio-cognitive phenomena in other contexts and across species. Polyadic interactions offer opportunities to see inside the black boxes of social complexity and cognition. Analyzing socio-cognitive behavior at multiple levels of social complexity can be viewed as an *extra-somatic* extension of Senjowski & Churchland (1990) now famous hierarchy of structural levels of brain investigation.

CHAPTER1:

Socio-Cognitive Behavior: The Social Intelligence Hypothesis, Reconsidered

1.1 Aims, Scope & Boundaries

1.1.1 Socio-Cognitive Project Overview

This dissertation addresses the shifting role of behavioral research methods in cognitive and evolutionary explanations, particularly as they pertain to linking cognition to its social dimensions. The project is motivated by a desire to make behavioral analysis of nonhuman primate field observations more relevant and better articulated (Latour, 2000) for contemporary cognitive science. In particular, it presents a critical reading of field primatology, and behavioral ecology, through the lens of system approaches to mind and behavior (e.g., von Bertalanffy, 1976/68; Bateson, 2000/1972, 2002/1979; Hinde, 1976a, 1987; Hutchins, 1995; Oyama, 2000; Sterelny, 2003, and see below).

Center stage is a strategic reevaluation of an evolutionary argument claiming a causal link between the increase in social complexity in primate groups and 'advanced' or 'higher' cognitive adaptations, an argument generally known as the *Social Intelligence Hypothesis* (Humphrey, 1976; and see Byrne & Whiten, 1988a, for overview). It generated a cross-disciplinary flurry between field primatologists and behavioral cognitive scientists in the late 1980s, lasting over a decade, then rapidly fizzling out, even as the general thrust of the argument continued to garner acceptance, finding increasing resonance with accumulating research that links brains, genomes and behavior in both primate (e.g., Charney, In press; Liu, Somel, Tang et al., 2012) and non-primate (e.g., Donaldson & Young, 2008) species.

Why the rise, then the demise, of active cross talk between behavioral researchers interested in a similar topic (social and cognitive dimensions of behavior) in closely related species (human and nonhuman primates)? Is there potential, and, moreover, is there good reason, for renewed productive crosstalk given what has transpired in these fields in the interim? I argue that a renewed dialog is critical to our understanding of how social and cognitive aspects of behavior are linked, and I advocate for a more integrated research program based on a critical reading of the relevant history of ideas and research methods, using three interrelated *modes of investigation* (see Table 1.1).

The first mode examines the *paradigmatic* contention that the *Social Intelligence Hypothesis* flourished during a reductionist 'wrinkle' in the cognitive sciences' more dynamically *holistic* landscape, perhaps resonating with the reductionist bias of behavioral ecology at the time, a bias that became and still remains the mainstay of field primatology. Even as both reductionist and more holistic system perspectives were in circulation in the behavioral research arena, proponents of the *Social Intelligence Hypothesis* tracked a fairly narrow reductionist contour, which had significant impact on both theory and research methodology.

The second mode of investigation examines the implications of a reductionist stance on the *theoretical* entanglement in cognitive and evolutionary arguments, as both are often couched in teleological terms. The ambiguity of 'real' and apparent goal-directed phenomena permeates the discourse even as cognitive and evolutionary processes depict vastly different timescales and units of analysis, confounding what would seem straightforward conceptual distinctions. The *Social Intelligence Hypothesis* presents a further discursive challenge as it tries to account for the *evolution OF cognitive* phenomena by relying on behavioral data. This effort is hampered by the differential *methodological* constraints (see next level) of an adaptationist evolutionary logic in field primatology, constraints largely absent from the cognitive sciences.

In the final, but primary mode, I investigate the role of *behavioral methods* of data collection and analysis in constructing (cognitive and/or evolutionary) explanations. Starting with Darwin, who argued adamantly for treatment of behavior as any other biological unit of heredity, we are still challenged, particularly when dealing with long-lived social species exhibiting large and flexible behavioral repertoires, to find productive mappings between observable behavior and evolutionary or cognitive processes; in the case of the *Social Intelligence Hypothesis,* we require both.

Weaving between these modes of investigation, the dissertation is structured as a three-tier commentary, linking the paradigmatic stance of *Complex Systems Thinking*, through the specific theoretical formulation of the *Social Intelligence Hypothesis*, to a methodological approach, derived from *Dynamical Systems Theory*, applying *State-Space* descriptions and *Sequential Analysis* to *social* *interaction data* (e.g., Bakeman & Gottman, 1997/1986). These interrelated tiers are engaged through an examination of their impact on current issues in field primatology, made relevant specifically to the behavioral cognitive sciences.

Table 1.1: Three-Tier Structure of Thesis Investigation

Mode of investigation	Focus	What is at stake?
Paradigm	*Complex Systems Thinking*	• Reductionist vs. Holistic worldviews • Simple vs. Organized Complexity • Atomistic vs. Relational Phenomena • Directionality of Cause & Effect
Theory	*Social Intelligence Hypothesis*	• Evolution OF Socio-Cognitive Behavior: ***Extra social complexity*** in primate groups led to ***super creative intelligence***. • Cognition & evolution – similar 'logic' in spite of different time scales, unit of analysis & agent of change
Method	*Dynamical Systems, State-Space & Sequential Analysis*	From Social Interaction Data: • How to measure social complexity? ***Complexity AS Context*** – Hinde's *relationship* approach to social complexity (State-space & multiway contingency tables–Chapter4) • How to *see* cognition? ***Cognition AS Process–*** Hutchins' Distributed Cognition approach to social *interactions* (State-space & timeseries representation–Chapter5)

My thesis argument hinges on *Complex Systems Thinking* challenges to reductionist assumptions about how brains and genomes manifest behavior (e.g. Oyama, 2000/1985; Lewontin, 2000). Behavioral research frameworks based on such assumptions were deployed in support of cognitive and evolutionary explanations, especially in the last decades of the 20th Century – the *Social Intelligence Hypothesis*, a case in point. The implications of these Complex Systems challenges, when extended 'outward' from brains and genomes to extra-somatic behavior, organize my thesis project. Specifically, they allow me to reconfigure existing links between phenomena, theories and methods into a modified *behavioral research program* for linking cognitive phenomena to their social dimensions.

Throughout this dissertation, I will use the term ***'socio-cognitive'*** to indicate ***'social and cognitive dimensions (mostly, of behavior) and the links between them'***, distinguishing it as an agnostic *relational construct* from other shorthand terms such as 'social cognition', in which 'social' qualifies *a type of* cognition. I demonstrate the empirical applicability of this *socio-cognitive research program* for field primatology on two datasets from field observations of social dynamics in Olive baboons (*Papio anubis)*. In the process I trace the relevant developments in these fields as they parallel and intersect with what many (e.g., Capra, 1996; Prigogine, 1996, Gleick, 1987) consider a definitive shift away from mechanistic reductionism to the paradigmatic stance I am loosely referring to in this dissertation with the umbrella term *Complex,* or *C-Systems, Thinking*.

Yet, the history of *C-Systems Thinking*, either going back as far as Aristotle or "just" post WWII, does not read as a unidirectional paradigm shift, alternating, instead, between holistic and reductionist worldviews (Capra, 1996,) or, alternatively, finding *complexity* as a meeting point between them. Herb Simon (1962:468), for example, reflecting on the hierarchical nature of complex systems, noted: "In the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist" (see also Wimsatt, 1972, 2006a-b.) Moreover, the contention over which worldview prevailed at any given period, or in any given domain, seems to have played out mostly within the *interpretive* products of 'doing science' (i.e., theories and explanations,) their impact on the *empirical* products (i.e., methods of data collection and analysis) more locally, technologically and *historically* contingent (Simon, 1962; Wimsatt, 1972; Mitchell et al., 1997; and see Figure 1.1 & Box 1).

What emerges, not trivially, from a critical reading of this history through the lens of Figure1.1, is that at stake in the controversies over reductionist and holistic worldviews are the *validity of our claims*, especially those regarding (cognitive and/or evolutionary) causal relations in our data, and the *reach of our explanatory aspirations*. In the modified behavioral research program I develop for the *Social Intelligence Hypothesis*, I therefore refrain from the impulse of some C-Systems proponents to dismiss previous findings (e.g., King 2004). I advocate, instead, plurality of empirical methods, yielding alternative interpretations of cause/effect directionality (see Bertalanffy, 1976/1968; Gould & Lewontin, 1979; Levins & Lewontin, 1985; Oyama, 2000/1985; Wimsatt, 1994; Heji et al., 1997; Ulanowicz, 1997; Lewontin, 2000; Lewontin & Levins, 2007; Stengers, 1997; Stephens et al., 2005), not dissimilar to Sandra Mitchell's (2009) formulations of *integrative pluralism*.

Complicating this landscape further is the deployment of formalisms developed in the context of C-Systems Thinking (e.g., game theory, information theory, graph theory), within overarching more reductionist frameworks (e.g., the adaptationist program of behavioral ecology). There is no a priori reason to reject such perspective shifts when moving between ‘inside’ and ‘outside’ a system boundary. Indeed, systems composed of few elements with simple rules can generate staggering phenomenal complexity (e.g., fractals, crystals), and, conversely, systems composed of many disorganized elements can generate system level regularities that are amenable to simplified analysis (think *gas laws* relative to Brownian motion of gas molecules). Yet, as I will show, in the case of the *Social Intelligence Hypothesis*, the prevailing methodological reading of behavioral ecology by most field primatologists prevents the necessary and productive mapping between postulated levels of biological and social *organization* and appropriate levels of *description* and *analysis* (and see B. Cole, 1994, for considerations of chaos in behavior).

Senjowski & Churchland (1990) made a critically cogent argument for an inclusive pluralist epistemology regarding *levels of investigation* in brain research–a now classic model–that when extended “outward” in, between and across individuals, proves extremely relevant to the issues addressed in this project (see section 1.4.1). Even as Senjowski & Churchland (1990:344) describe their proposed approach as *reductive integration* their specifications easily map onto the *integrative pluralism* of S. Mitchell mentioned above, perhaps manifesting Herb Simon’s observation that “In the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist”.

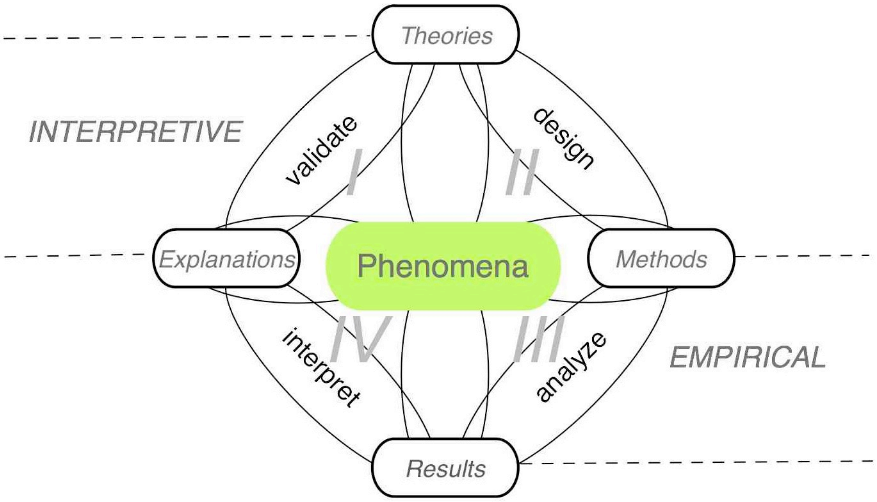


Figure 1.1: Products (horizontal shapes) **and Activities** (diagonal shapes) **of 'Doing Science'**

BOX1:
Figure1.1 is an idealized framework of *doing science* that emerged from and helped organize my thesis project. It distinguishes the *products* of the scientific process (methods, results, explanations, theories) from the *activities* that both produce and are constrained by them (study design, analysis, interpretation, validation), in quadrants that suggest the possible interplay with the studied phenomena at each 'stage'. Quadrant I may represent the default state, not necessarily scientific, of conceptual knowledge, where our engagement with phenomena, empirical or otherwise, produces explanations we use to validate ideas about how the world works. *Doing* science begins when we carry out systematic empirical investigations, which take us through quadrants II, III and IV, spiraling back to quadrant I, and so on.

This figure serves to highlight two aspects central to this project: The first is the distinction between *interpretive* products (explanations, theories) and *empirical* products (methods, results) of the scientific process. The impact of theoretical biases on empirical research is often pointed to as a hopelessly subjective liability. Yet clearly identifying this boundary allows me to examine alternative interpretations of empirical evidence (dominance rank and friendships in primate groups, for example,) as well as note where an interpretive stance has NO bearing on research design (e.g., evolutionary speculations in the behavioral cognitive sciences). Second, this figure advocates for the *centrality of study phenomena*. Reevaluating faltering theories may require more than using the same analysis on more data or different analyses on the same data. In Chapter 2 I revisit the phenomenological history of baboon field observations in order to motivate the construction of *modified data structures* from social interaction dynamics around infant birth (Chapter 4), and during sexual consort dynamics (Chapter 5)

1.1.2 The Social Intelligence (SI) Hypothesis, Reintroduced

I set out to examine the role behavioral data play in cognitive and evolutionary explanations that link social and cognitive (read, *socio-cognitive*) dimensions. I begin by revisiting a dialog between field primatology and cognitive science which flourished in the 1980s and 90s around such topics as 'tactical deception,' 'theory of mind', 'imitation,' etc. (e.g., Byrne & Whiten, 1988a-b; Cheney & Seyfarth, 1990; Whiten, 1991), topics (see below) that seemed to zero in on elements of primate cognition that were particularly relevant to negotiating social relationships, and were studied by relying almost exclusively on behavioral data collection and analysis.

Central to this examination are the following questions: ***(Q1) What warrant did cognitive and evolutionary arguments have then, and how were their analytic frameworks structured in order to traverse the conceptual and empirical distance from observable behavior to evolutionary explanations of cognition? Moreover, (Q2) what can behavioral data contribute to socio-cognitive arguments today, given our growing understanding of how brains and genomes participate in organizing behavior, and given the shifts in the methodological landscape since then?***

The context of the dialog at the end of the last century was a growing interest in what became known as the *Social Intelligence (SI) Hypothesis*, which argued for the evolutionary impact increase in social complexity of primate groups had on 'higher' cognitive adaptations (Jolly, 1966, Humphrey, 1976; and see history in Byrne & Whiten, 1988a, and in Whiten, 2000). Rather than a generalized argument linking any and all cognition to any and all types of social dynamics, the SI-Hypothesis was from the outset an argument of 'extras'– *extra* social complexity in primates relative to other social mammals led to *extra* ‘higher’ cognition, or, as Humphrey (1976) referred to it, a *creative intellect*.

As I examine the background of the SI-Hypothesis and C-Systems Thinking I argue that this ‘extra’ in the SI formulation complements C-Systems Thinking’s own pivotal focus on a special type of complexity–*organized* complexity (Weaver, 1948) in *evolved* systems (Levins, 1970)–more than the *simplicity* of *composed* systems that can be tracked exhaustively, and yet smaller, if more ordered, than the *disorganized* complexity (Weaver, 1948) of *aggregates* (Levins, 1970)–large numbered systems (Weinberg, 1975; Ward, 2002) that can be treated probabilistically (see section 1.4.2). How the SI-

Hypothesis managed to neglect these parallels, which, if noted, would have contributed to a more productive research agenda, will be examined through the lens of behavioral analyses (see below and Chapter 2) that contribute to both cognitive and evolutionary explanations.

The impact of the SI-Hypothesis during the 1980s and 1990s was nevertheless significant, on at least three counts: First, it loosened the moratorium field primatologists adhered to, since the days of Skinner's behaviorism, on discussing and studying the mental life of their subjects outside the lab. Although the link between animal sociality and evolution was made strong by sociobiology, as formulated mathematically by Hamilton (1964) and Trivers (1971), and conceptually by Wilson (1975) then popularized by Dawkins (1976) and others, it may have been losing ground among field primatologists in favor of the more comprehensive accounting of *behavioral ecology* (see below). Initially these sociobiology argument discounted mental tactics and strategies explicitly and lodged them in the gene. It was the field data (and ape language studies) that helped move them from the gene to the head (Strum, personal comm.) Yet *sociobiology*, and its sequel, *evolutionary psychology* (e.g., Tooby & Cosmides, 1989), provided the fertile ground for slippage in the discourse used to describe evolution in directed-agency terms such as 'gene *strategies'*, too easily extended to 'brain strategies', employing a symmetrical, if faulty, adaptationist logic (see section 1.3.1). The speculative mood about animal cognition was fueled in equal measures by behavioral researchers (e.g., Premack &Woodruff, 1978; Griffin, 1981) and philosophers (e.g., Nagel, 1974; Dennett, 1983).

Second, the SI-Hypothesis re-focused the discussion of the human/nonhuman primate boundary, offering the arena of *social dynamics* as the new border zone, drawn thinner or thicker with the dictates of researchers' agendas. Potentially agreeing on *the* special thing about *all* primates made the task of finding how they *differ* more targeted. This renewed focus on the social aspects of cognition produced a flurry of shared cross-boundary interests as researchers of human cognition, eager to explain cognitive deficits such as those seen in autism spectrum disorders (e.g., review in Baron-Cohen, 1993), found resonance with field primatologists eager to explain mental abilities and limitations of their nonhuman primate subjects (see Whiten, 1991 and chapters therein). More recent human vs. nonhuman primate cognition discussions express the need to find compatible behavioral characterizations with advances in microscopic brain studies and anticipated genome sequencing from more primate species (Premack, 2007; Hermann et al., 2007) or reevaluate 'Darwin's mistake' (Penn et al., 2008). Premack (2010) considers the implication for human uniqueness.

Finally, the SI-Hypothesis and the dialog that erupted around it in the 1980s and 90s, provided a glimpse into what a unifying approach to evolution, cognition and sociality may offer, if the theoretical foundation on which it was being based actually held. This theoretical foundation bet on a reductionist mapping between genes, behavior, and brains that would more-or-less pan out as more findings accumulated. That a *behavioral* accounting could serve as an adequate portal into such a grand view, excited psychologists, primatologists and philosophers alike (see the range of contributors to Byrne & Whiten, 1988a).

1.1.3 Behavioral Research in this Dissertation

A gradual shift in perspective has taken place among biologists (e.g., Lewontin, 1983; Levins & Lewontin, 1985; Lewontin, 2000; etc.), and only more recently among *behavioral* ecologists (see reviews in Laland, 2008; Laland et al., 2008: Laland & Gillian, 2011) although first seeds were planted much earlier (Lewontin, 1983; Odling-Smee, 1988), a perspective by which *all* behavior is to be construed in terms of *organism-environment interaction,* partaking in the process of ***niche-construction***. Rather than considering a niche as a static environment to which an organism adapts, behavior is seen to actively shape and, in turn, constrained by an organism's environment. In as much as an organism's environment includes social dynamics with conspecifics, Flack et al. (2006) propose the notion of ***social niche construction,*** to emphasize the potential for social interactions between individuals to change and shape the social environment within which the same individuals and their group members will engage further (see also Ikiri & Osamu, 2008; Wcislo & Tierney, 2009). This formulation contrasts with the adaptationist view (Day et al., 2003), which prevailed till recently in behavioral ecology, which sees the relatively stable environment as "static" nevertheless "active" in providing selection pressure to individual adaptation. The assumption I base my own thesis project on treats behavior, indeed, as the mediating interface and the phenomenological stage on which the cognitive and evolutionary dramas unfold *How this mediating interface gets organized*, however, is subject to a critical reevaluation.

My aim, then, is to capture behavioral patterns and track their dynamics in ways that correspond more directly to what we are fast learning about the biological substrates and the complex network dynamics from which behavior emerges. In confronting different levels of biological and socio-ecological organization at multiple spatiotemporal scales we no longer expect to find simple mappings that are easily extrapolated from one level to the next (see Senjowski & Churchland, 1990; Mitchell et al 1997; Heji et al., 1997), a C-Systems view that is transforming how we address causality and interpret predictability in scientific explanations (e.g., Weinberg, 1975; Kellert, 1993; Prigogine, 1996; Lewontin & Levine, 2007).

To recap, this dissertation examines the ways methods of behavioral research contributed to the dialog on the SI-Hypothesis and how (and why) the landscape shifted since then, so that naturalistic observations of spontaneous behavior, the kind that inspired the SI-Hypothesis in the first place, contribute only fragmented piecemeal bits, failing to coalesce into a comprehensive explanatory framework. Most all field primatologists subscribe to a systematic accounting of behavior strictly geared towards adaptationist evolutionary explanations (e.g., Hinde, 1976a; Gould & Lewontin, 1979; Lewontin, 2007) as they are framed by *behavioral ecology* (Krebs & Davis, 1984/1978; Dukas, 1998, and see discussion below). Yet it is precisely this adaptationist bias I claim, that uniquely inhibits field research when it is applied to long-lived social species–clearly *not* the prototypical species around which methods of behavioral ecology were originally established. These constraints keep field primatologists from fully examining behavioral patterns between and across the spatial, temporal and relational scales that would be necessary to flesh out the SI-Hypothesis as a comprehensive research program. A *comprehensive research program*, most behavioral ecologists agree with and cite Tinbergen (1963), is one that can addresses 'the four whys'– *proximate mechanism*, *ontogeny*, *function* and *phylogeny*–of behavior, from within a single explanatory framework.

1.1.4 Thesis Challenges Preview:

My thesis project is an attempt to renew the dialog between field primatology and cognitive science by going back to the SI-Hypothesis and reconfiguring it into ***a behavioral research program for the study of socio-cognitive phenomena***. I choose to focus on behavior and unpack an evolutionary argument not only because behavioral observations and evolutionary speculations were at the origin of the SI-Hypothesis but also because their roles are shifting dramatically in contemporary research environments, shifts that force us to reconsider current theoretical assumptions and empirical methods (see section 1.5).

The thesis thus responds directly to the two questions *(Q1)* and *(Q2)* posed in section 1.1.2, which can be translated as follows: ***(Q1) How to address the SI-Hypothesis with Behavioral Data?*** And ***(Q2) How to integrate behavioral data into contemporary socio-cognitive research?***

My first claim in response to (Q1) is that an appropriate explanatory framework to address the SI-Hypothesis, requires C-Systems Thinking sensibilities that would shift how we link between theory, phenomena and methods, moves which will expand on and reinterpret, but not dismiss, previous empirical evidence. The second claim, in response to *(Q2)* is that integrating behavioral data into contemporary socio-cognitive research will require tracking dynamics at multiple levels of description and analysis in order to reveal levels of organization that would bring behavior into the same analytic frames of reference in which we increasingly encounter brains and genomes. A fleshed out articulation of the thesis statement is presented in section 1.5)

1.1.5 Structure of Dissertation

In the rest **Chapter 1** I introduce the kinds of (behavioral) explanations that were deployed in the hay-day of the SI-Hypothesis, and examine how these threads were pursued in the decades that followed. While the research matured and grew in sophistication since the 1980s, the central challenges of SI-Hypothesis remain. How to measure social complexity and how to see cognition in social interactions? The C-Systems Thinking challenges to the assumptions on which these methods are based guide me in organizing my thesis project, establishing an overall stance from within which this dissertation is written, via the three tiers (paradigm, theory, methods) I identified at the outset. This examination flags two salient trends: the symmetry in logic between cognitive and evolutionary explanations of behavior, and the absence of a more direct C-Systems Thinking impact on the SI-Hypothesis. Field primatologists have not been able to operationalize social complexity consistently, nor have they been able to reliably track/capture cognition in spontaneously occurring behavior, and this thesis aims to address both shortcomings.

In order to clarify what sort of behavioral accounting would be appropriate for the SI-Hypothesis I first revisit (in **Chapter2**) the phenomenological history of field observations on baboons, and retrace how current field methods construct social interaction data. Next, by selecting two behavioral C-Systems-friendly models (Hinde, 1976a, 1987; Hutchins, 1995), I trace the methodological route that makes it possible (in **Chapter 3**) to address the SI-Hypothesis more comprehensively, and show how a well established set of methods (sequential analysis, and multiway contingency table analysis), inspired in part by C-Systems Thinking, can be used to extend these models to the study of nonhuman primates. I propose a framework to support this effort to address the behavioral link between social complexity and cognition.

The *modified behavioral research program for addressing socio-cognitive dimensions of spontaneously occurring behavior* is applied in a two-step process to datasets from field research on olive baboons: **Chapter4**, on male-female-infant relationships, addresses primarily social complexity, by giving Hinde's (e.g.,1987) C-Systems Thinking approach a reading of *Complexity AS Context*. **Chapter5**, on a key event in sexual consort dynamics, addresses relational dimensions of cognition, by applying Hutchins (1995) C-Systems Thinking approach of *Distributed Cognition AS Process*.

The two data chapters (Chapters 4 & 5) in this dissertation serve the dual role of addressing a relevant 'baboon' issue as well as *demonstrating* the steps in the modified research program that is my thesis, and are written as a multi-layered commentary, leading (in **Chapter6**) to a synthesis that integrates them. Although no novel methods or theories are deployed, the reconfiguration I propose expands the types of research questions addressing socio-cognitive phenomena. Instead of comparing individual performance measures, in terms of differential reproductive success or differential cognitive abilities, I propose to describe individual *Profiles of Participation* in relational systems on multiple time scales, so that the local immediate contingencies of moment-to-moment interactions (social) and decision making (cognitive) can be linked to longer-term patterns and dynamics of association, the kind of relationships and group structure that make up the social complexity advocates of the SI-Hypothesis were originally responding do. Treating the SI-hypothesis this way means relational and cognitive dynamics could be critically examined and applied by primatology and cognitive science to other contexts and species.

1.2 Behavioral Explanation for the SI-Hypothesis – Then, and Since

While I will focus in this thesis on the *behavioral* strands of *socio-cognitive* research, it is important to note two additional strands of research activity that emerged from the SI-Hypothesis. In one, behavioral data are bypassed in favor of looking for correlations between simple indexes of cognition on one hand (e.g., brain size) and social complexity on the other (e.g., group size). These queries grew in sophistication along with the growing understanding of brain research, and along growing considerations of social dimensions (Jerison, 1973; Dunbar, 1992, 1995). The basic logic, however, of correlating independent indexes for each 'side' of the SI-Hypothesis equation, is continually argued for in *behavioral* studies as well (e.g., Whiten, 2000).

The other strand of research involved a secondary claim of the SI-Hypothesis, namely that social complexity not only was the main pressure on the evolution of higher cognition in primates, it also defined the very nature and architecture of cognition (for review, Kummer at al., 1997; Gigerenzer, 1997; Whiten, 2000). This claim, of domain specificity, potentially rejects notions of cognition as a general-purpose mechanism. It lead to research that tests the generality of cognitive skills (e.g., Cheney & Seyfarth, 1990), and to alternative hypotheses proposing *foraging* complexity as the factor that pushed for higher cognition in primates (e.g., Milton, 1988). Foraging complexity could be attributed to the problem of searching for food, as well as to the challenge of extraction and technical manipulation of food items, aka the *technical complexity hypothesis* (Richard Byrne, 1995, 1997).

Nevertheless, by the kick-off of the SI-Hypothesis, Byrne & Whiten (1988a, 1988b) settled on a special kind of socially manipulative cognition–dubbed Machiavellian–which became the center of attention and contention. It is to this core strand I turn my focus, as it is in this arena that the logic of explanatory frameworks of socio-cognitive *behavior* is most directly revealed.

1.2.1 The SI-Hypothesis, Then – A Machiavellian Intelligence?

The topics that became a preoccupation for primatologists, cognitive scientists and philosophers of mind, engaged in the SI-Hypothesis dialog, were all variations on the debate over content of mental representations, especially when such postulated internal mental states might consist recursively of the mental states of others. Here I briefly describe three variations on this theme that showcase the interaction between field primatology and cognitive science at that time: the first, *tactical deception*, started from within field primatology; the second, *orders of intentionality*, began as a unique collaboration between field primatologists and a philosopher of mind; and the third cluster, *Theory of Mind* and related issues, were already developed in experimental psychology of both human and nonhuman primates, but in the context of the SI-Hypothesis they received an extra dose of evolutionary speculation. I use these examples to crudely illustrate the grounds on which rested explanatory pathways from behavior to evolution and from behavior to cognition.

Tactical Deception*:* In field primatology, the focus on the SI-Hypothesis in the final decades of the last century centered on the proposal that primates possess a *Machiavellian Intelligence* (Byrne & Whiten, 1988a; Whiten, 2000), inviting the interpretation of certain behavioral patterns as *tactical deception* (Whiten & Byrne, 1988 BBS), in which an individual is seen as willfully and deliberately misleading another by taking advantage of the difference in their knowledge of, or perspective on, local conditions. On this reading, tactical deception would require 'mindreading', or in other words, understanding others as intentional agents with desires and beliefs that may be different from one's own, and thus provided a *provocative* case of a cognitive ability that seemed intuitively advantageous in group-living primates. It could *hypothetically* mean that a chance genetic mutation, affording 'mindreading' to an individual, would garner it differential reproductive success over its own lifecycle and, over time, an increase of that genetic variation in the population gene pool. *'Lucky mutation' evolutionary scenarios* of even such complex patterns were generally accepted in scientific publications (e.g., Seyfarth & Cheney, 1994).

Orders of Intentionality: The SI-Hypothesis dialog also included an unusual collaboration between philosopher of mind Daniel Dennett and field primatologists Dorothy Cheney and Robert Seyfarth (see Dennett, 1988:198, and Cheney & Seyfarth, 1990). They co-developed what they considered to be a species-level empirical measure for mental sophistication, 'orders of intentionality', an index tracking the recursive extent to which one can claim 'A knows that B knows that A, or C, know…' inferred form observations or carefully put to controlled 'intentaionlistic litmus tests', inspired by no less than Sherlock Holmes (Dennett, 1988:192). Theory of Mind (see next example) requires 2nd order intentionality, and yet, as Dennett conceded, this scale did not go beyond three to four iterations even in humans [3rd order intentionality was deemed requisite for narratives and 4th order for literature that goes beyond the narrative (Dunbar, 1998:188). Moreover, *intentionality* in this case was the kind carefully defined by philosophers, following Franz Brentano, to mean 'aboutness', in that mental states were always *about* something *outside* their own activity, and the slippage between that and more common notions of intentions as referencing mainly mental plans and goals, only contributed further to producing inferences from observing behavior that were messy and unreliable, their overall explanatory relevance unclear and disputable (see Whiten & Byrne 1988 BBS commentary)

Theory of Mind, Self-Awareness, Imitation: The SI-Hypothesis dialog found resonance in human developmental psychology where laboratory experiments with nonhuman captive primates were already probing whether nonhuman apes, for example, had a theory of mind (Premack & Woodruff, 1978), which, like tactical deception and 2nd order intentionality, required an understanding of others as intentional agents with beliefs states that may be different from one's own. The developmental markers of Theory of Mind (ToM) in humans, such as mirror self-recognition, and imitation, were now considered fair game in the quest for evolutionary scenarios, so that studies comparing the 3-4 year old human subjects to *the* chimpanzee or *the* monkey found an eager audience (contributions in Parker et al., 1994). As human research focused on the *social* behavioral deficits in the autism spectrum disorders (see contributions in Baron-Cohen et al., 1993), *black-box models of the hypothetical brain modules* necessary to accomplish ToM feats proliferated and were hotly debated (e.g., Whiten, 2000).

Summary: Most all topics that received attention in the context of the SI-Hypothesis, regardless of their starting point (deception, teaching, imitation, self-recognition, ToM, symbolic reference, tool-making) ended up in the murky territory of recursive intentionality as the defining feature of mental sophistication, and, for many, the definitive battle on the human vs. nonhuman frontier (e.g., Penn et al., 2008). Similarly, most all topics looked to lucky mutation just-so scenarios for plausible phylogenetic accounts, even as no plausible corroborating evidence of dedicated mindreading brain modules or genetic mutations were forthcoming.

Seyfarth & Cheney (1994: 384-5), for example, take almost two pages to set up a complex scenario of smart baboon social dynamics and then propose: “Now imagine that into this group of nonintentional baboons comes a *mutant male* capable of attributing states of mind to others and recognizing that these states of mind may be different from his own…” (italics mine) and then they go on to describe how he would still be vulnerable to cheaters “…but it is likely to make him more skeptical in subsequent interactions.” (ibid). This completely untethered, unexplainable, out-of-the-blue mutant ninja baboon, with full-blown ToM capacities, and a healthy dose of *skepticism* to boot, slips into the narrative as the final linchpin in a long-winded evolutionary argument. Contrast, for example, with Byrne (2000) thorough evaluation of current evidence and appropriately *measured* speculation.

In all these cases, studies tended to rely *solely on behavioral data collection and analysis* in order to elaborate on or test an explanatory framework (see Figure 1.2), one that postulated a direct mapping between behavioral regularities and the relevant underlying biological substrate – DNA for 'lucky mutation' evolutionary scenarios, and the Central Nervous System (CNS) for Black-Box flow charts of postulated highly modular cognitive abilities. This is *not* to say that behavioral researchers completely ignored relevant findings on genomes and brains, but rather to say that *their behavioral data confronted only their explanatory frameworks*, selectively construed, so that all the links between behavioral patterns and biological substrates remained hypothetical and speculative.

As I demonstrate in the next section, the shifts in the SI-Hypothesis-related research over the last two decades reflect the attempts to negotiate these challenges, while strengthening the conceptual and the methodological rigor in alignment with mainstream evolutionary theory. I will show why these shifts are not sufficient to fully address the SI-Hypothesis, and why a deeper and broader reconfiguration of links between theory, methods, and phenomena, is required.

1.2.2 Shifts in the SI-Hypothesis Research Landscape:

The main shift among *field* primatologists was an increasing methodological realignment with ***Behavioral Ecology*** (e.g., Krebs & Davies, 1984/1978; Dukas, 1988; Dunbar, 1988; see next section) as a benchmark for systematic functional accounting of behavioral data alongside a less primate-centric agenda. While this shift had a dramatic impact on the rigor of field research and the ability to make direct comparisons across field-sites, and species, the 'extras' of the SI-Hypothesis (*extra* social complexity and *extra* special intelligence) remained challenging and empirically illusive. This shift had a notable impact on the research agendas of SI-Hypothesis proponents in terms of their emphasis on cognition, on social dynamics, and, to a lesser degree, on the link between them.

***What happened to (emphasis on) Cognition**:* The challenge of inferring in-the-head cognition (or *intra* psychological states) and discerning *orders of intentionality* from observations of spontaneously occurring social behavior increasingly drove the researchers pursuing these topics to experimental studies, mostly in captive laboratory settings (but see *field experiments* below.) The trajectories of the two researchers who kick-started the official swirl of interest in the SI-Hypothesis (Byrne & Whiten, 1988a) are perhaps demonstrative of how paths diverged: Andrew Whiten gradually migrated to working almost exclusively in laboratory settings (Whiten et al., 2009) increasing his connections with human researchers on mindreading (Whiten, 1991), while Richard Byrne remained committed, not exclusively, to field studies, continuing his focus on *technical intelligence* (e.g., Byrne, 1995, 1997) in the context of extractive foraging, a more well-defined 'task space', expanding even further his reach to other primate as well as non-primate species (e.g., Byrne, 1999, 2000a; Bates et al., 2011; etc.). Both remained very active in the theoretical debates and links with researchers in other fields (Whiten & Mesoudi, 2008; Whiten, 2011; Byrne, 1999, 2000a, 2000b, etc.)

Non-Intervention Studies: Byrne and others' studies on foraging techniques, tool use, and social learning (see below) made it possible to address cognition in behavior in ways that were less controversial than the ambiguous attributions of intentions and goals in *social* interactions. The 'task space' afforded fairly straightforward performance analysis, and complex sequencing of actions (Harrison, 1996; Byrne 1999; Genty & Byrne, 2010) fueled discussions over what sort of cognitive abilities particular extractive foraging techniques demanded. I will show how social dynamics can be similarly analyzed, adapting Hutchins (1995) Distributed Cognition, or D-Cog, to nonhuman primates (Strum, Forster & Hutchins, 1997; Strum & Forster, 2001; Forster, 2002; Forster & Rodriguez, 2006).

Field Experiments: Experimental interventions are by no means limited to laboratory settings. The most successful methodology relevant to the SI-Hypothesis is the continued development of *field playback experiments*, first adapted by Cheney & Seyfarth from methodology developed by Peter Marler in the study of birds (see Cheney & Seyfarth, 1990, 2000, 2007). It involves using playback of vocalizations recorded in very specific contexts (e.g., reconciliation greetings among baboons) made by specific individuals, and then measuring the carefully selected subject's (e.g., the *sister* of the baboon recipient of a the above reconciliation grunt) response to the transmitted vocalization–the sister, upon hearing the reconciliation grunt by a previous aggressor toward her sibling, is less likely to show hostility toward the reconciling individual in subsequent encounters (Cheney & Seyfarth, 2000:208; Silk et al., 1996; Silk, 2002b). These experiments show the extent to which members of a group recognize the identity and relational status of others in the group, and use their knowledge of *third party relations* to manage their own interactions. Yet, even as these experiments offer a unique portal into the social knowledge of individual primates in a group, the tests are limited by what researchers already presume is possible, and the potential evolutionary links are not clearly articulated, neither are developmental trajectories or the extent of individual differences.

Laboratory Experiments: Controlled experiments allow more detailed testing of alternative hypotheses, and more nuanced distinctions of the phenomena under scrutiny. The literature on ***imitation***, for example, quickly expanded to categories of distinct behavioral patterns it considered, from *stimulus enhancement* to *goal emulation*, as did the requisite methodology (e.g. Whiten & Ham early review 1992, more recent, Whiten et al., 2009). Similarly the controversy over ***Theory of Mind*** (ToM), especially the distinguishing characteristics of humans vs. nonhuman primates focused on *attention* and then zeroed in on *joint-attention*, then *shared-joint attention* (see Tomasello & Call 1997) and finally *shared intentionality* (Tomasello et al., 2005) whereby humans, the argument goes, have a species-unique motivation to share experiences and activities with others, quite coordinated by the first 14 months of life. In these studies, the evolutionary relevance, as before, came from the comparative methodology deployed across species. Since ToM (see section 1.2.1) was of interest in human research prior to the SI-Hypothesis flurry, it continued to be an active focus in human development, an area Whiten remained involved with, under the banner of ***mindreading***. The debate over the content of mindreading surfaced as the possibility that reading (and predicting) behavior of conspecifics may be cognitively distinct from reading (and predicting) desire and belief states in others (see also discussion in Dunbar, 1998). The nuances that can be discerned in experimental settings continue to develop. Moll & Tomasello (2007) for example, focus on whether human infants know what others experience, after Tomasello & Haberl (2003) showed that infant humans know what is new for other persons – what they have attended to. Some of the more successful recent studies that speak directly to linking social and cognitive dimensions of behavior focus on ***cooperation*** in ***collaborative*** tasks, as they are presented, for example, to both human and chimp toddlers (e.g., Warneken & Tomasello, 2006, 2008).

The evolution of intelligence / Mind: These behavioral studies continued to play into and expand two threads of discourse regarding the evolution of intelligence, one centered on human intelligence (e.g. contributions to Novartis Foundation Symposium 233 on *The Nature of Intelligence*, 2000), the other on cross-species perspectives in behavioral ecology regarding *social learning* and *animal traditions* (e.g., Laland, Richerson & Boyd, 1993). The human-centered discourse pitted *general-purpose intelligence* against an *adapted mind* (Tooby & Cosmides, 1992) to specific conditions in our evolutionary past. Was human intelligence domain-specific or domain general? Evolutionary psychology (e.g., Cosmides & Tooby, 1989, 1994) put forth the notion of the brain-as-a-Swiss-Army-Knife, extending Fodor's (1983) modularity of mind (Gigerenzer, 1997; Sterelny, 2003). Primatologists such as Whiten (2000) found resonance in evolutionary psychology with the specificity of the Machiavellian Intelligence Hypothesis, supported by Cheney & Seyfarth (1990) observations of vervet monkeys–that suggested they do not reason about their physical environment as adeptly as they negotiate social relations. How can we integrate behavioral patterns into a sound evolutionary framework is far from clear, as Byrne & Bates (2007) note: 'While the cause of an evolutionary increase in intelligence may be domain-specific (sociality, for example), and the brain specialization that results may largely implicate a single perceptual system, such as vision, the intelligence shown in consequence can be very "general-purpose".'

Within behavioral ecology of nonhuman animals an active pursuit of *social learning* and *animal traditions* had a long history as local behavioral patterns spread through populations under the nose of field researchers studying birds (Fisher & Hinde, 1949) and primates (Kawai, 1965). The observable and measurable diffusion patterns of learned behavior provided an empirical niche for the study of cognition that need not engage the controversies that plagued ToM and intentionality ala SI-Hypothesis. When could novel patterns of behavior be considered *innovations*? Can they be defined by outcome (Kummer & Goodall, 1985) or by process (Wyles & Kunkel, 1983; Lee, 1991)? Questions of process, via observational learning, imitation, or teaching, could now interface with the experimental work on imitation, technical intelligence, and problem solving in both primate and non-primate species.

The problematic issues of *intentionality* and *ToM* in regard to imitation or teaching (e.g. Caro & Hauser, 1992; King, 1994) persisted, especially with regard to the human / nonhuman dividing features (e.g. van Schaik & Burkart, 2011), yet the accumulation of data across populations, species, and taxa, is producing a wealth of information so that many hypotheses might be tested in a variety of conditions. The integration of these strands can be seen in a recent meeting titled *Culture Evolves* (June, 2010), organized by Whiten, Hinde, Stringer and Laland (Whiten et al., 2011:938) the proceedings of which were published in a dedicated issue of Philosophical Transactions of the Royal Society B. vol. 366. These are promising developments in terms of bringing primate-centric researchers into the broader discourse of behavioral ecology, and for behavioral ecologists to expand their models to include the variability and flexibility of primate behavioral repertoire. The hybrid zone this thesis occupies is toward the human social sciences, but is ultimately responsive to this research arena as well.

(Social) Brain Evolution: In contrast to the debates on the evolution of intelligence, which included only very general references to brains, active neuroscience research has been consistently and increasingly productive in identifying CNS structures and neural pathways implicated in social

behavior. While some of the earlier proponents of the SI-Hypothesis (Chance & Mead, 1953) already noted such links, the explosion over the last couple of decades counts two notable landmarks: Leslie Brothers' (1990a-b) *Social Brain* framework based on her research with monkeys' brain activity in response to visual social stimuli, and the discovery of the so-called *mirror neuron system* (Di Pellegrino et al., 1992; Gallese et al., 1996) in monkeys, consisting of visuomotor neurons that discharge both when a monkey does an action and when it observes that action done by others (Rizzolatti & Craighero, 2004). These findings were integrated into more theoretical frameworks as potential underlying mechanisms for autism (Baron-Cohen et al., 2000; Oberman et al., 2005) as they are considered to impact imitation, and empathy (e.g., Gallese, 2003, 2007).

The less specific brain evolution arguments, those that began by looking at overall brain size (e.g., Jerison, 1973) developed more nuance as data accumulated on differential growth of sub-brain systems, as well as on cross-species comparisons (e.g., Harvey & Pagel, 1988; review in Barton & Dunbar, 1997; Dunbar, 1998; Semendeferi et al., 2002), including comparison with extinct Neanderthals (e.g., Ponce de Leon et al., 2008). Researchers differ in whether they focus their own empirical work on brain neuroanatomy (e.g., Semendeferi) or testing of hypotheses based on the predictions of external environments (e.g., Barton, Dunbar).

What happened to (emphasis on) Social Complexity? The difficulty finding reliable operational measures of social complexity persisted, and even as proposals for relevant factors and feature-clusters appeared in discussion papers (e.g. Strum & Latour, 1987; Sambrook & Whiten, 1997; Whiten, 2000; de Waal & Tyack, 2003) no empirically tested consensus emerged (see recent review in Whitehead, 2008).

Whitehead (2008:11) resurrects an approach to social complexity developed by Robert Hind in the 1970s, and while this model of social complexity in primate groups (a center piece of my thesis, see next chapters) existed by the SI-Hypothesis kick-off in the late 1980s, only a portion of earlier iterations of the model got acknowledged and regularly referred to (e.g., Humphrey, 1976; Cheney & Seyfarth, 1990; Cords, 1997; de Waal, 2000; de Waal & Tyack, 2003; King, 2004, etc.). Hinde contributed early

(Hinde, 1970, 1973, ETC) to the idea and study of social relationships clearly articulating how relationships emerge from a patterning of (dyadic) interactions over time.

While Hinde developed methods for data collection (e.g., Hinde, 1973) and analysis (e.g., Hinde & Herrmann, 1977), his approach was by and large descriptive, in contrast with Kummer's (e.g., 1978) functional approach in which relationships were evaluated by their value to the individuals involved (Cords, 1997:25). As Cords points out these approaches are by no means mutually exclusive, yet a functional approach was more amenable to asking evolutionary questions. It seems that the near monopoly of behavioral ecology on field research also influenced the primacy of functional analysis *of individuals* over any other (see Whitehead, 2008:21 dismissal of the adaptive value of a social structure because it cannot be made empirically relevant to accounting of individuals.)

Moreover, Hinde's main application of his now dialectical C-Systems Thinking perspective on social complexity developed as he himself shifted focus from nonhuman primates to humans, contributing perhaps to the neglect of his work by previous students and colleagues (but see Sambrook, 1995; Sambrook et al., 1995; Flack et al., 2006). Field researchers refrained from studies of social dynamics that required direct inferences about cognition yet the social dynamics they tackled fit the 'extra' flavor of SI-Hypothesis (see below). A noted exception is the computational modeling of Charlotte Hemelrijk (e.g., 1990a, 1990b, 1999, 2002). She used agent-based modeling to show group level patterns that are impacted by individual differences, etc.

<u>*Focus on Social Relationships:*</u> Within the framework of behavioral ecology, the focus on non-kin bonds and long-term alliances expanded to other primate as well as non-primate species. Inferences on the adaptive value of relationships followed a common logic: A *relationship quality Index* was applied as a metric, to be correlated with various dependent measures of survivorship and/or reproductive success. Invariably the relationship quality index involved a combination of grooming and proximity (e.g., Smuts 1985; Silk et al., 2006; Nguyen et al., 2009; but see Cords, 1997 for critical discussion, and Weaver & de Waal, 2002 for a more recent alternative). Non-kin female bonds have been now shown to impact inclusive fitness (Silk et al., 2003); and long-term friendships between adult males and adult females in olive baboons seem to incur support beyond reproductive access (Smuts,

1985; Nguyen et al., 2009). In these analyses, relationship quality is deemed invariant, at least over the study period, even when the richness of their chronological trajectory is acknowledged and elaborated upon (e.g., Smuts 1999/1985). All these analyses aim for assessing fitness advantage to individuals. I will explore alternatives to this emphasis as I explore a more systematic way apply Hinde's model of social complexity (see Chapter 4).

Focus on Types of Interactions: As with the study of relationships, the types of interactions that inspired the SI-Hypothesis continued to be studied and were expanded upon and extended to other primates and non-primate species (e.g., Harcourt & de Waal, 1992; Aureli & de Waal, 2000; de Waal & Tyack, 2003) Interactions ranged from grooming and agonistic buffering to conflict resolution and alliance formation, where cognitive sophistication may be implied but without empirical commitment. Researchers typically add an explicit refrain from addressing cognition-in-the-head in their writing. A good example is the edited volume by Harcourt & de Waal (1992) on coalitions and alliance formation in humans and other animals. Not only did they include non-primate species (hyenas, dolphins) they made a deliberate effort to set aside issues of purpose, intention, and cognitive strategies. In the introductory chapter they note:

> With regard to animal behavior, definitions including terms such as 'purpose' and 'decision' pose a problem. Animal behavior may be perfectly intentional, but this is not substantiated in the field. In addition, there are alternative explanations that often appear adequate. For example, a team of individuals may benefit from concerted action without having known this beforehand. They may simply have learned that their rivals are less likely to fight back and more likely to retreat if they act together. This effect may have reinforced cooperation. In other words, the supportive relationship does function to improve their position vis-à-vis conspecifics, but as a result of conditioning rather than foresight. It seems judicious, therefore, to avoid terms such as 'purpose' and 'decision' in the definition of animal coalitions, and to emphasize the *effects and functions* instead of intentions and motivations. [italics, mine]
>
> (Harcourt & de Waal, 1992:3)

The inferential analysis of such research takes one of two forms: where differential outcomes are clear (winner/loser or some other performance measure) optimization models can be applied. Where outcomes are not so decisive, on the other hand, various economically inspired models have been proposed to assess costs and benefits that could be counted towards survivorship and reproductive success. The notion of a *Biological Marketplace* was proposed (Noë et al., 1991; Noë & Hammerstein, 1994, 1995) as an alternative framework to Seyfarth's (1977) version of the *Priority of Access* model (Altmann, 1962), in which rank is the main determinant in symmetric interactions with pre-selected partners: over access to sexually receptive females (Altmann, 1962) or female grooming partners (Seyfarth, 1977). Instead, in *biological markets*, interactions are seen as exchanges of commodities between *asymmetric* trader classes.

Henzi & Barrett (2002) proposed one such biological marketplace where female chacma baboons trade grooming of mothers for access to their newborn infants. In this context they recently began reconsidering cognitive dimensions of social interaction more explicitly (Barrett & Henzi, 2002, 2005; Barrett et al, 2007), setting up a tension (Frank & Silk, 2009a, 2009b) between relationships and interactions that begins to frame what I consider the socio-cognitive challenge facing primates (see Chapter 4 discussion).

Hinde's model of social complexity, when taken in its entirety (Hinde, 1976, 1987, 1997 but even comments in Hinde, 1970), precisely articulates not only the dialectic between interactions and relationships but also the circular influence of group structure. Sambrook, Whiten & Strum (1995), for example, examined grooming patterns to test the priority-of-access model against several alternatives in *two troops*–showing the opposite effects of distance in rank and rank-of-groomee between the *small and large group*–arguing for the importance of addressing multiple levels of social complexity, but with no reference to cognition. The modified research program I set out to develop in this thesis deliberately capitalizes on the tension between interactions, relationships, and group structure, in order to better address links between social complexity and cognition.

From Interactions to Relationships to Groups: The case for Conflict Resolution

In spite of wide acceptance of Hinde's descriptive framing of social relationships as *emerging* from patterning of interactions, the focus on individual adaptation biased the functional measures and tallies, essentially removing much of the temporal and sequential structure from unfolding events and trajectories of interactions. Frequency, duration, and outcomes took precedent over context and sequential structure. Exceptionally, the "discovery" of *reconciliation* and *consolation* in captive chimpanzees (de Waal & van Roosmalen, 1979), and the development of a sound empirical method (de

Waal & Yoshihara, 1983; Veenema, 2000:21-23), made it possible to study phenomena (post-conflict affiliative behavior between or towards the conflicted individuals) that were described before, in vaguer functional terms, and reported only anecdotally (de Waal, 2000: 16-20; Rowell, 2000b: 227).

The ability to *see* and measure conflict as negotiation (de Waal, 1996b) required a decidedly *relational model* of social behavior (ibid, de Waal, 2000:26-28), a sensibility de Waal attributes in no small part to the articulation of descriptive (Hinde, 1976a) and functional (Kummer, 1978) models of relationships in nonhuman primates, as well as Gottman's (1994) longitudinal study of relational dynamics in married human couples. Moreover, the functional question being addressed in considering reconciliation as a "speculative formulation serving as a guide for the solution of a problem" is at the *relationship* and *group* levels as well as that of the individual: "The problem under consideration is how animals manage to maintain *group cohesion* despite occasional conflict." (de Waal, 2000:20).

Settling on empirically grounded (de Waal & van Roosmalen, 1979) *functional* definitions (i.e., reconciliation, consolation,) over descriptive ones (i.e., post-conflict affiliative behavior) guided the development of empirical controls to prove that *post-conflict* (PC) affiliative behavior is significantly different from the interactions between the same individuals at a *matched control* (MC) sample. The methodology was an important departure from the ethological emphasis on instinct and motivation, as it was from the sociobiological emphasis on selfish competition (de Waal, 2000; Rowell, 2000:227). The procedure was also a reversal from typical sampling methods, since the matched control (MC) sample is identified only *after* the post-conflict (PC) sample is taken, since it is the conflict context that identifies the constraints on the MC – same time of day, similar proximity, etc.

Conflict resolution has been studied in many species (see contributions to Aureli & de Waal, 2000) and even as other researchers debate the validity of considering reconciliation gestures functionally as relationship maintenance devices (Cords & Aureli, 2000) or only within their immediate context, merely as honest signals of affiliative intent (Silk, 2000:179-181), it is clear that *relational thinking* made it possible for researchers to return to previously encountered phenomena (Rowell & Rowell, 1993; Rowell, 2000) with re-configured concepts (reconciliation) and data structures (PC & MC) that allowed for inferential analyses to be developed in a well articulated *research program*. In fact, it has been deployed specifically to test the SI-Hypothesis by comparing *reconciliation* and *consolation* in captive chimpanzees and macaques (de Waal & Aureli, 1996). While studies of reconciliation are accumulating, many questions remain to be addressed: are their individual differences in conflict resolution patterns and do they point to differential abilities? Is there a developmental trajectory? and if relationship repair is so important, why is reconciliation such a small percentage of conflicts in any species, including chimpanzees (see examples in Aureli & de Waal, 2000)

In this thesis, I show how to extend the kind of sensibilities de Waal and his colleagues apply to reconciliation to a broader and more integrated study of social complexity and cognition in long-lived social species, so that *socio-cognitive* aspects of behavior may be better understood in their immediate context as well as during development, learning and evolution.

Measuring Social Complexity: Even lacking clear operational definition there is a growing convergence among behavioral researchers over the types of features social complexity referred to, that go beyond group size and discern more than statistical treatments of aggregates. Whiten (2000) proposes dimensions of social complexity that include the levels of social structure, dyadic and polyadic relationships, variability of response, instability and predictability, as well as demographic components. Tyack and de Waal (2003) identify features of complex individualized societies, with overlapping generations and where learning and memory play important roles. But how might they be operationalized? Whitehead (2008) reviews various proposals and then makes a wish list:

> My ideal would be to find a measure that (1) indicates the degree to which individuals in a population prefer or avoid the companionship of, or preferentially interact with, other particular individuals (2) is approximately unbiased by the population size or features of the sampling regime, and (3) is virtually unchanged by the addition into the study population of separate communities
>
> (Whitehead, 2008:247)

Whitehead admits that no robust measure has been identified, and perhaps it is an indicator of the inherent nature of the issue, that no one single measure can capture an effective abstraction, and a more context-specific set of measures is required. In the case of the SI-Hypothesis, the quest may be for a measure of social complexity that is predicted to require more intelligence in a way that would enhance biological fitness (Sambrook & Whiten, 1997; Whiten, 2000). Societies would possess differential complexity if members in one faced more cognitively demanding social challenges. The apparent circularity of such a definition, Whiten contends, does not invalidate an empirical investigation in which,

> The aim is instead to define components of social complexity that are predicated to afford more complex processing, to define components of intelligence that are predicated to handle social complexity and then, have independently measured examples of each, test for the relationships expected between them.
>
> (Whiten, 2000:190)

Linking Cognition to Social Complexity: Whiten's (2000) logic in the quote above proceeds by identifying components of a Machiavellian intelligence including social knowledge, sensitivity, curiosity, etc. none of which are empirically readily defined. Yet the overall logic, of defining measures that can be quantified independently and then tested for expected relationships, is akin to the practice of cross-species comparison in correlations between brain size and group size, and the more nuanced variations that have emerged since (see social brain evolution above; Dunbar, 1998; Marino, 1996).

In what might be considered an inverse move (a single instead of two independent measures) Humphrey's (1976) original article proposed that if a laboratory test of social skill could be devised it would be found that it doubles as a test of high intelligence. Gigerenzer (1997: 284) warned against such intuitions, which he found analogous to the long history of IQ testing which '…has not noticeably increased our understanding of the mechanisms of human intelligence." Gigerenzer sees these attempts as theoretically empty, in that tests are devised for vague (often lay) notions of intelligence or social skill, in the hope that the testing results will yield insight into underlying mechanisms.

Instead Gigerenzer advocates staring "boldly and theoretically" using the logic of design. If one takes on the challenge of designing a possible mechanism for social intelligence, its predictions can be tested by means of simulation, observation and experiments (ibid). The proposal he puts forth is of a modular social intelligence, along the line of evolutionary psychology of the Cosmides & Tooby (1989, 1994, etc.) variety. Whiten (2000) converges on a similar proposal. In both cases, as with evolutionary psychology more generally, the proposals rely solely on behavioral patterns and a lot of theoretical speculation and have no support from contemporary neuroscience. Since then Gigerenzer's research has gradually shifted to more constrained ‘units’ of intelligence, focusing on technical definitions of heuristics and rules of thumb, in humans, returning more recently (Hutchinson & Gigerenzer, 2005a-b) to examine the compatibility with current practices in behavioral ecology.

The motion to propose an underlying mechanism and test its predictions does seem to have yielded more productive results in the arena of developmental trajectories in attentional processes, testing shared attention, joint-attention and shared intentions (e.g. Moll & Tomasello, 2007, etc.) as a potential pivotal distinctions between human and nonhuman primates (see lab experiments, above). In this case, the proposed underlying mechanism is not about general architecture of mind as it is about a type of understanding that can generate testable hypotheses. With the progress in the cognitive neuroscience of attention there is increasing potential of mapping from behavior to brain, with sound experimental controls over the content of understanding (Tomasello & Haberl, 2003: Moll & Tomasello, 2007).

The counterpart in the field to these experimental studies is the growing body of work on *social learning* from a behavioral ecology perspective. As we have seen above *social learning* seem to provide a convergence zone for many strands of research relevant to socio-cognitive behavior. The focus on learning came from studying patterns of diffusion of novel behavior, but more recently also looks at developmental trajectories of such learning. Beyond the cross-species survey of whether a particular cluster of features, or a potential indicator (e.g., teaching, reconciliation, culture) is present or absent, the accumulating research allows more nuanced explorations into socially mediated learning and how it may impact non-social abilities as well (van Schaik & Burkart, 2011).

In general, deliberate attempts address the SI-Hypothesis by examining the link between social complexity and cognition can be categorized into three broad trends: (1) cross-species correlations between independently measured indexes of cognition on the one had and social complexity on the other, (2) proposing an underlying mechanism, and testing predictions, and (3) identifying a single behavioral indicator or feature-cluster and surveying its presence and absence across species. Among the more theory driven frameworks, some were more directly relevant and empirically relevant to the

SI-Hypothesis than others, e.g., Godfrey-Smith's (1996) Ecological Complexity Hypothesis and Sterelny's (2003) similar but more human-focused exploration.

What About Genes? From Genetics to Genomes – linking genes empirically into the equation of the SI-Hypothesis, or behavioral ecology in general, or, for that matter, cognitive science, has received little beyond theoretical considerations till very recently. Yet the consideration for genetics in evolutionary theory is the foundation on which the "new synthesis" of Darwinian theory is based. Darwinian theory of speciation, depending as it does on (genetic) variability within a population, places evolutionary change as a measure of a particular gene- or allele frequency in the population gene pool. Ecologists are steeped in population genetics of the plant and animal communities they encounter, while behavioral ecologists, and especially those working with long-lived social mammals, only rarely gain access to genetic material of their subjects (see review in Altmann & Altmann, 2003). When genetic material was extracted from blood samples, and amplified using Polymerase Chain Reaction (PCR) techniques, many of the expectations developed from field observations were challenged, especially with regard to paternity. Chicks of monogamous bird species, for example, showed evidence of extra-pair mating, and the expectations of high dominance rank guaranteeing reproductive success, also came into question. The anticipated sequencing of complete genomes from many primate species is challenging behavioral researchers to develop comparable *phenotypic* characterizations, such as the Primate Cognition Test Battery (PCTB) proposed by Hermann et al. (2007). This test battery includes physical and social relations and markers for development, designed in the context of comparative studies between chimpanzees and humans.

While genetics can reveal patterns of heredity, it still seems a few steps removed from the issues raised by SI-Hypothesis, namely that a kind of social intelligence would confer reproductive advantage. Would we see this play out only on species level changes? How do individuals differences in intelligence impact population gene pool? The 'lucky mutation' scenarios were an attempt to reach / leap across many layers of biological organization that had little bearing on what population geneticists were figuring out (e.g. Lewontin, 2000)

The increase in ease of collecting material from which DNA can be extracted, and the sequencing of genomes, make possible studies of *genomics,* which focus on the genome as a whole as well as on interactions among genes, rather than genes in isolation across generations. Understanding the network dynamics in gene regulation is growing rapidly (see M. Mitchell, 2009). The results of these novel explorations continue to surprise in the speed with which change has occurred in the human genome (see Laland et al., 2010) and how straightforward it is to link these changes to human cultural practices, such as dairy farms providing selection pressure for adult lactose tolerance (ibid.)

The theoretical ideas of gene-culture co-evolution have been around for a while (e.g., Boyd & Richerson, 1982). The C-Systems Thinking approach to development and evolution, Developmental Systems Theory, aka *Evo-Devo* (Oyama, 2000/1985, 2000; Oyama at al., 2001), provides the conceptual structure that details the pitfalls of Darwinian evolutionary theory as it has been practiced by behavioral ecologists, yet has had little impact on proponents of field primatologists, although several Evo-Devo proponents have taken on variations on the SI-Hypothesis (e.g., Godfrey-Smith, 1996; Kim Sterelny, 2003). Some of the research that is more directly relevant to the SI-Hypothesis comes form recent work on differences and similarities in chimp and human brain genes. In another recent example, Donaldson & Young (2008) manage to link the relatively conservative evolution of the molecules of attachment (Oxytocin and Vasopressin,) to specificity of receptors in brain tissue – and it is this sequence (changes in brain receptors are more recent evolutionarily events) that distinguishes the monogamous pair bonding voles form the promiscuous species.

Summary shifts: The last couple of decades have seen an overwhelming increase in information and data not only on previously studied primates but many other species and taxa. The comparative perspective on such a wealth of information was helped in no small measure by increased theoretical and methodological rigor. Yet the basic challenges facing the SI-Hypothesis–how to measure social complexity, how to 'see' cognition in spontaneous behavior–remain. These challenges drove the decoupling between research that focused primarily on cognition and research that focused on social dynamics. While we see increased nuance in distinctions within a particular strand of research (e.g., the growing taxonomy of types of imitation, or kinds of attention), these fragments fail to form an integrated method that can address both cognition and social complexity on equal footing so as to reveal the links between them. The attempts to link social and cognitive dimensions occur mostly in discussion papers or with the use of simplified measures that do little justice to the rich phenomenological motivation for the SI-Hypothesis at the start. The few attempts to address SI-Hypothesis comprehensively are more theoretical in nature, lacking the empirical records to back them up (e.g., Whiten 2000).

The shift of field primatology towards a more orthodox take on behavioral ecology increased the rigor and sophistication of the field research since then, yet it also restricted the portal through which behavioral patterns were measured as data. The functional bias towards individual adaptation prevents more complex patterns of interactions and relationships to be considered. While relationships are evaluated through one particular lens – the impact on survivorship and reproductive success of the partners–Interactions are seen as a commodity. In the study of social dynamics, by and large, evolution is in the theory, not in the data.

1.3 Challenges for the SI-Hypothesis

The orthodoxy of behavioral ecology with which field primatologists chose to align themselves constrained the kind of behavioral data they could bring to bear on arguments regarding social complexity and cognition. To understand the challenges the original spirit of the SI-Hypothesis presents to mainstream behavioral ecology, it is important to consider the way behavioral data are counted and accounted for in evolutionary and cognitive explanation. A more comprehensive survey of behavioral accounting and methods of analysis in behavioral ecology and their relationship to other behavioral sciences will be detailed in Chapter2. Here I want to highlight the implications of the inferential logic deployed in cognitive and evolutionary explanations of behavior.

1.3.1 Failure of the Phenotypic & Representational Gambits

Referencing behavior in evolutionary and cognitive explanations goes back at least to Darwin's insistence that behavior participates in the evolutionary process as much as any other biological heritable feature such as eye-color or limb configuration. Although Darwin proposed the metaphor of selection as the main factor in biological evolution he was explicitly a pluralist, arguing for other influences besides natural selection (e.g., sexual selection, and see discussion in Gould & Lewontin, 1979).

Yet the quest for atomized ‘traits’ subject to the natural ‘laws’ of selection persisted. After Lorenz and other naturalists struggled with identifying *instincts* and *drives* as the *releasing mechanism* for behavioral patterns, ethologists settled on detailed description of more causally neutral *fixed action patterns*, intended to capture the 'units' of behavior that were the phenotypic expression of the underlying species genotype. *Behavioral Ecology* (Krebs & Davies, 1984/1978; Dukas, 1998) today, with its roots in ethology, and encompassing sociobiology, extends the methods of systematic description to more principled accounting and functional analysis of organism-environment interactions.

> Ecology is the study of interactions between organisms and their surrounding biotic and abiotic environments. Such interactions usually result in *differential survival and reproduction* of animals within a population due to individual variation in *phenotypic traits*. Typically, a sizeable proportion of the phenotypic variation between individuals results from *genetic variation*. Thus, *Individual differences in survival and reproduction, or fitness*, translate into *changes in gene frequency* and their associated phenotypic traits over generations. Such *genetically based phenotypic change is evolution caused by natural selection*. (italics mine)
>
> (Dukas, 1998:1)

The emphasis on functional accounting from the perspective of an individual organism could not be overstated. Telling is the statement of the International Society of Behavioral Ecology, or, ISBE (website as of Jan 2011):

> Behavioral ecology is the study of the fitness consequences of behavior. Research in this field poses the basic question: what does *an animal* gain, in fitness terms, by doing this rather than that? It combines the study of animal behavior with evolutionary biology and population ecology, and more recently, physiology and molecular biology. Adaptation is the central unifying concept.

These framings postulate two relatively straightforward correspondences: one between observable regularities in behavior and identifiable phenotypic *traits*, the other between phenotypic traits and variable gene frequencies in the population under study. The latter correspondence, often labeled ‘*the phenotypic gambit’* (Grafen, 1984), makes a host of simplifying assumption regarding genetic control of phenotypic expression (Borgerhoff Mulder et al, 1997; Wimsatt, 2006a) Thus, even when researchers cannot directly measure gene frequencies in a population, nor their precise phenotypic varieties, they consider their behavioral accounting of differential performance as a valid plug-in to this set of corresponding explanatory or intervening variables on the theoretical grounds that they reveal, or serve as reliable indicators of, the process of evolutionary adaptation by natural selection. The deliberate shift among field researchers in the 1980s from ethology, by way of sociobiology, to behavioral ecology (see Hinde, 1981, for an example of the bones of contention) meant an even more rigorous accounting in terms of *individual* differential fitness, in part as an antidote to group-selection arguments that fell from grace with the advent of explanatory models–of seemingly cooperative behavior–proposing kin selection (Hamilton, 1964) and reciprocal altruism (Trivers, 1971) as viable replacements. It was now legitimate to make evolutionary arguments, even about social behavior, by just accounting for individuals. How to compare individuals' inclusive fitness and how to rate their differences relative to the population gene pool became the central preoccupation. This thread began to mirror how psychologists consider cognition, even in social settings, to be only inside individuals.

Individuals. As an individual's behaviors / actions are recorded and tallied, they are evaluated relative to a task, as if the subject were being scored on a test. Even in non-experimental conditions a 'task space' is postulated, offering the functional framing by which to measure the patterns in the accumulating data. In as much as we find regularities and trends across individuals we consider these to reflect the functional tendencies of the population – or the species-typical pattern, the regularity that might reflect the underlying mechanism or rule that governs this behavioral pattern. In as much as differences between individuals are significant, they are considered an indicator of significant differences in the same underlying mechanisms.

Figure1.2 shows a simplified scheme of the symmetry in explanatory 'logic' of cognitive and evolutionary accounts of *behavioral patterns of individuals*. The most significant link in the hypothetical chain is on the 'inside' where a direct mapping is postulated between a measurable chunk of biological substrate (DNA-genes and CNS-neural circuit) and a functional unit (phenotypic trait for DNA and mental representation for CNS). Behavioral regularities are then assumed to correspond with the logic of these functional units in predictable ways, so that differential performance scores of individuals, corresponding, on the evolution 'side' for example, to genotypic variation as suggested by the quote from Dukas above, are typically tested against optimality models – maximizing life-time reproductive success, or optimizing information processing.

As I noted earlier, the starting point of this thesis is motivating reexamining explanatory pathways of the extra-somatic behavior patterns given the growing acceptance of the inadequacy of the intra-somatic functional links (between chunks of DNA and phenotypic traits, and between bits of CNS and mental representations) on which the external correspondences depend. The *phenotypic gambit* mentioned above, and what we may call, for symmetry sake, the *representational gambit*, both failed. The implications of this double failure for the study of *socio-cognitive behavior* in primates are the primary focus of this project. See Chapter2 for a detailed survey of relevant methods.

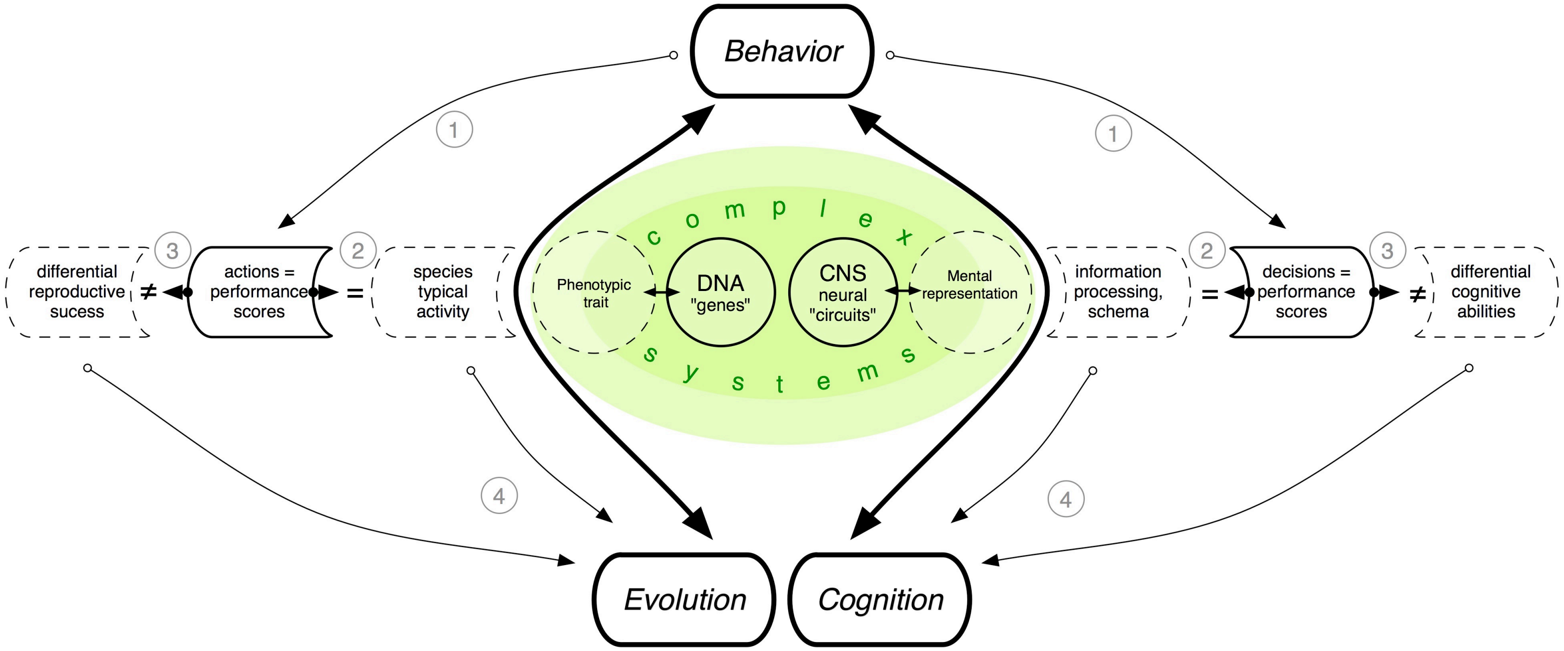


Figure 1.2: **Evolutionary and Cognitive Explanations of Behavior.** Shared parallel structure even though the time frame, unit of analysis, and underlying 'substance' (DNA and Central Nervous System, or CNS) are different. In each case the analysis of behavioral patterns depends on a set of postulated correspondences between several layers of explanatory entities. In each case, traditional approaches bet on a reductionist mapping between a functional unit (phenotypic trait or mental representations) and biological substrate (DNA or CNS). In both cases the mapping that emerge from current data analysis depict nonlinear dynamics in complex network. Thus the 'direct' correspondences previously assumed are now in question. Behavioral research proceeds by (1) data collection on individuals, which are then analyzed for (2) similarities to extract common 'universal' features, and for (3) differences that point to differential abilities supposedly linkable to difference in underlying biological substrate. The patterns of similarities and differences are (4) deployed to explain cognitive and evolutionary factors/processes/ etc.

1.3.2 Challenges to SI-Hypothesis: From "Below" and from "Above"

Thelen and Smith (1994) motivate their application of dynamical system theory to the study of human development with the "…conviction that the acquisition of mental life is continuous with all biological growth of form and function." They place their study 'subject' in the *middle* and ask what does development look like from '*above'*–at low magnification, the human scale of developmental phenomena–and then what it looks like from 'below'–at high magnification, closer to the biological processes and mechanisms from which behavior emerges. Their project is to show how very general dynamic principles can explain these apparent differences as continuous and emergent from multiple asynchronous processes unfolding without a prescribed outcome in functionally meaningful trajectories.

Similarly we can consider the challenges to the SI-Hypothesis, as far as observable extra-somatic *behavior* is concerned, by sandwiching it in the middle between what we may find 'above' (extra- and inter-personal) and 'below' (intra-somatic or intra-personal).

From 'below' Biological Substrates: That phenomena involving brains and genomes are better understood when described as dynamic networks provides a C-Systems Thinking challenge (see Figure 1.2) to behavioral research from 'below' (Thelen & Smith, 1994) or 'inside' an individual organism. How does C-Systems Thinking applied to brains and genomes influence the analysis of behavior and the way these analyses are deployed in explanatory frameworks? Does complexity of brains or genomes 'scale up' to behavior? If we cannot count on the direct correspondence of the behavioral regularities we find, how do we construct cognitive or evolutionary arguments about observable behavior? Does behavior exhibit nonlinear patterns (B. Cole, 1994) in its own right or would it correspond with 'what lies below?' How many 'levels' do we need to consider below the surface of the skin? Do the immune and endocrine systems constitute different hierarchical levels from the brain? Is the Central Nervous System below, above or on par with Autonomic Nervous System? And should extra-somatic behavior for that matter be considered uniformly?

The question of adjacent levels in hierarchical systems turns on the conditions under which the internal dynamics of a lower 'micro' level may be ignored in explanations of dynamics on a system level. That is not a rare occurrence, yet in the case of cognitive and evolutionary explanations of behavior, the whole framework of behavioral ecology and cognitive psychology stands on a very particular correspondence between selective micro and macro levels, so that we cannot ignore the challenge to the micro level and expect it would not impact the explanation of dynamics on the macro level. The correspondence itself is in question.

While my thesis project does not attempt to answer all these questions, it does regard the current growing consensus on the complexity of brains and genomes as a definitive challenge to the mainstream paradigm in behavioral ecology that counts on reductionist correspondences between observed behavioral patterns and their biological substrates. We do not expect an equally simple alternative to emerge. Rather we anticipate a realization that a lot more empirical research awaits us, with techniques that are already in our toolkits.

From "above" the 'extra' of the SI-Hypothesis: Leading long individualized lives, inclusive of long-term and multi-generational relationships, exhibiting flexible social behavior that is subject to strong learning effects (de Waal & Tyack, 2003), nonhuman primates defy the kind of data collection necessary for the strict correspondence postulated between observed behavioral patterns and the explanatory entities relevant to evolutionary theory, such as life-time reproductive success, survivorship, and inclusive fitness. Establishing and maintaining long-term field research sites, some now into their 4th and 5th decades, were not considering these issues at the outset, but study sites that followed were motivated in no small part, by the desire to accumulate the multi-generational perspectives needed to address behavioral ecology considerations with adequate scientific rigor (see Strum & Fedigan, 2000). Nevertheless, precisely such challenging characteristics lead field researchers observing primates in mid last century (Chance & Mead, 1953; Jolly 1966; Kummer, 1967; Humphrey, 1976 etc.) to propose the *SI-Hypothesis* in the first place. I claim the challenge is not just a matter of not enough data.

Even as field primatologists became better behavioral ecologists, perhaps even because of it, they were less able to bring social and cognitive complexity in all their glory to bear on their arguments. We still find mostly simple correlations between variables, and functional explanations of central trends over exploring sources of variance–avoiding anything beyond linear additive models, such as ANOVA postulates (Gigerenzer, 1997)

Even though Hinde (1976, 1987, etc.) articulated a hierarchical model of social complexity in primate groups that consists of at least 4 observable levels (individuals, interactions, relationships, group structure), as will be described in the next section, we still see only piece meal studies that are restricted to one or two levels, or that leap across many. How the social dimensions of behavior on each level may be linked to cognition is not well articulated. For example, the controversy in the reconciliation literature as to its function as *relationship repair* or as a signal of *benign intent* (see Cords & Aureli, 2000; Silk 2000, 2002) would require examination of post-conflict behavior across these levels of social complexity. Group structure would be important to consider beyond the level of interactions and the level of relationships, as would an examination of developmental trajectories and individual differences. This thesis project is geared towards such a comprehensive approach to socio-cognitive behavior.

1.4 Opportunities for the SI-Hypothesis: C-Systems Thinking

1.4.1 The Four Whys – Extended – Levels of Investigation, Units of Analysis

The over emphasis on individual adaptations and localized function in behavioral ecology is well recognized, and has been prescribed an antidote since the early days of ethology, when Tinbergen proposed a further distinction to that made earlier by Ernst Mayr (1961) between *proximate* and *ultimate* ‘problems’ in the study of biology. Arguing that most studies in biology tend to deal with the evolutionary, or ultimate, level of causality Mayr advocated a more balanced research program. Tinbergen (1963) noted that each of Mayr’s levels splits further (see Table 1.2) so that the proximate level–or “how?” questions–distinguishes causal mechanisms (internal) and development within the life cycle, while ultimate level–or “why?” and “what for?” questions–distinguishes current adaptive value from phylogenetic history (Sherman, 1988). This particular formulation became known as the “4 whys” and variations in emphasis emerged over the years. Sherman (1988) in reconstructing this history added a 5th ‘why’ splitting the proximate causes into physiological and psychological levels.

Table1.2: Levels of Explanation in Ethology

Mayr (1961)	**Tinbergen (1963)**	Sherman (1988)
PROXIMATE	***MECHANISMS***	PHYSIOLOGICAL
		COGNITIVE
	ONTOGENY	
ULTIMATE	***LOCAL ADAPTATION***	
	PHYLOGENY	

Behavioral ecology is, more so than ethology, overwhelmingly biased towards ultimate levels of explanation even as those explanations would require an accompaniment from the other levels, to be fully articulated. The journal *Behaviour* (Brill, online ISSN: 1568-539X), for example, is explicitly devoted to Tinbergen's four questions in research on both human and nonhuman animals, while the journal of *Behavioral Ecology* (see quote above) is explicitly selectively focused on *local adaptation*, the 3rd of the “4 whys.”

In the examples of SI-Hypothesis related topics I gave above, the accounting of behavioral data usually presents a cost/benefit analysis of a hypothetical local adaptation, involving crude speculations about the proximate mechanisms (psychological and physiological) as well as the phylogenetic history, such as “lucky mutation” scenarios, while the development throughout the lifecycle is barely considered. In long-lived social species proximate levels very likely play a significant role in their phylogenetic history. As we have seen more recently (see section 1.2.2) the developmental perspective is finally entering the social learning research (e.g., Thornton & Clutton-Brock, 2011).

The heightened focus on evolution by natural selection in behavioral ecology seems particularly misguided, since, not only is it not the only mechanism of biological evolution, it is not a *cause* in the normal sense of the word, as Mayr himself was known to say of *adaptation, that it is a posteriori effect, not an a priori goal-directed form of behavior* (Mayr, 1992). Thelen & Smith (1994:43) complain similarly of teleological explanations of development:

> The danger of teleology in developmental theory is that it finds its way into the mechanisms of development. The end-state is the mechanism in nativist-rationalist approaches. The end-state (in more or less complete form) is written into the organism and propels it to where it needs to go.

Equally unfortunate, for the SI-Hypothesis, is the fixation on adaptive value to *individuals* to the exclusion of other relational groupings. The conundrum in behavioral ecology, where natural selection trades in *population gene-pool frequencies,* while behavioral accounting is centered on individuals, is supposedly resolved by the theory of inclusive fitness. Yet the math of such accounting is repeatedly challenged, as was the case recently in a controversy over kin-selection (Nowak et al., 2010, and the commentary that ensued in Nature, 471, March 2011).

The 4-5 *levels of analysis* depicted by Mayr-Tinbergen-Sherman, point to the reality of multiple 'correct' answers addressing a specific behavioral phenomena. But are these the only levels? Or are there sub-levels, or other kinds of hierarchies, that make sense for particular questions? The levels in Mayr-Tinbergen scheme are appropriately considered levels of *analysis*, in that analytic techniques for each level are distinct and often very specialized. They may differ from levels of *description*, and may differ still from levels of *organization*, which might wishfully, if mistakenly, reference an ontological reality researchers are trying to reveal.

Levels of "organization" is a generic enough abstraction for it to be mapped onto multiple empirical and conceptual dimensions: spatial, temporal, relational, epistemological, functional, etc., and, not surprisingly, hierarchical models abound (e.g., Simon, 1962; Wimsatt, 1974, 1994, 2006a; Allen & Starr, 1982; Salthe, 1985). While organization, in principle, need not be hierarchical, complex systems are often described hierarchically with some form of nesting or repeated structure on various scales. The dimensions of systems depend on the question and perspective of the observer. Wimsatt (1994) proposed the following definition:

> By level of organization, I will mean here compositional levels--hierarchical divisions of stuff (paradigmatically but not necessarily material stuff) organized by part-whole relations, in which wholes at one level function as parts at the next (and at all higher) levels. Though composition relations are transitive (so one could collapse the highest level systems to the smallest parts), levels are usually decomposed only one level at a time, and only as needed.
>
> (Wimsatt, 1994:6)

Several C-Systems Thinking proponents (e.g., Rosen, 1991; Salthe, 1993; Ulanowicz, 1997) have attempted, to more-or-less satisfying degrees, mapping their choice formalisms onto Aristotle "4

Causes" (Material-Efficient-Formal-Final), while others, like Marr (1982) took on three levels of analysis in the context of computational approaches to the nervous system (problem decomposition – formal procedure or algorithm – physical implementation) with the implication that these levels were largely independent of one another. This approach was later criticized by others (see discussion in Senjowski & Churchland, 1990:303) for the poor fit these levels of analysis provided when attempting to define levels of organization in the nervous system.

Regardless of whether network approaches to brains and genomes necessitate network approaches to study extra-somatic behavior, it *is* necessary, I argue, to track unfolding behavior in order to examine its relationship to other levels of biological, *and socio-ecological*, organization. My aim, as I noted at the outset (Section 1.1.3), is to capture *behavioral* patterns and track their dynamics in ways that *correspond more directly* with what we are encountering of brain and physiology in contemporary research settings.

1.4.2 C-Systems Thinking in this Dissertation

The challenges and opportunities I just outlined point repeatedly to C-Systems Thinking sensibilities that are found wanting in the SI-Hypothesis research landscape. Yet so far I have kept a loose definition of Complex Systems by referring to them as a *style of thinking* rather than a specific theory or program since so many approaches to analysis and explanation of system phenomena cam be associated in one way or another. In this thesis I settle on more specific strands.

"My" C-Systems Thinking perspective attempts to draw on past research and thinking from three, not mutually exclusive, arenas: Research on brains and genomes, or what we can learn from 'below', including a critical evaluation of evolutionary theory; "soft" C-Systems non-computation approaches in the social sciences, from 'above'; and the research and thinking that focused on the special kind of *organized* complexity which I claim resonates with the 'extra' notion in the SI-Hypothesis. How can the research discourse from each of these arenas inform my thesis project? I look to both conceptual framing and empirical methods for insights.

Brains & Genomes as Complex Networks: The failures of the phenotypic and representational gambits (see section 1.3.1) raise two types of questions for C-Systems Thinking in regard to research on brains and genomes. The first question is whether there is any sense in which what we know now about brains and genomes has *direct* phenomenological entailments for how we understand behavior (see B. Cole, 1994; Giunti, 1995). This is a response to the challenges from 'below' in the previous section. Do neuronal or genomic network dynamics scale up between and across levels of biological and social organization?

The second question is more methodological in nature, looking to the trends in behavioral research to ask whether *principles of investigation* and computation transfer across domains? Are there any other constraints on how we should track behavior for future research? As I will demonstrate in Chapter 2, many of the analysis tools adopted by behavioral ecologists (game theory, information theory, graph theory & network analysis, and dynamical systems thinking more broadly) were developed within the context of C-Systems Thinking and have been applied across a variety of 'systems' from genomes to brains to behavior of individuals, groups, societies.

But the phenotypic gambit is at its core a critique of Darwinian evolutionary theory in general. It is not only behavior that ends up messing up the neat reductionist correspondence evolutionary biologists expected to find between phenotypic traits and genetic mechanisms. Hadfield et al. (2007), for example, test the phenotypic gambit on color and skeletal traits in birds. It failed.

Parallel to the history of SI-Hypothesis during the 1980s and 90s, an alternative C-Systems Thinking approach to development and evolution emerged (see section 1.2.2 on genetics and genomes) as Developmental Systems Theory/Thinking, aka *Evo-Devo* (Oyama, 2000/1985, 2000; Oyama at al., 2001), developing an alternative discourse to reductionist readings of Darwinian theory. In the process of dismantling the exclusive gene's eye view of evolution, they point to the misguided attribution of information and computation to genetic processes, articulating the implications for C-Systems Thinking when applied to evolutionary arguments.

There is one other way in which research on brains and genomes is confronting socio-cognitive research, and that is the growing accessibility of real time data in behavioral research settings. With the increase accessibility of genomic data in behavioral research, the theoretical orientation of evolutionary theory as practiced by behavioral ecologists will require significant updating. Evo-Devo was deeply impacted by ecologists confronting the limits of reductionist Darwinist interpretations, a confrontation *behavioral* ecologists managed to evade, given the limits on kinds of data that were easily accessible.

***Organized Complexity*:** As I noted earlier the 'extras' of the original formulations of SI-Hypothesis–'extra' social complexity leading to 'extra' super intelligence, resonate with the growing emphasis within C-Systems Thinking on special kinds of systems that are *organized* (Weaver, 1948) *evolved* (Levins, 1970) or *mid-size* (Weinberg, 1975). As Table 1.3 shows, the emphasized systems are often delineated on one end by simple/composed/small number systems that could be analyzed by exhaustive tracking, and on the other by large number aggregates in which the number of components is so large their behavior is considered random at least with regard to its relevance to system level dynamics.

Table 1.3: Tripartite Delineation in C-Systems Discourse

Weaver, 1948	**Levins, 1970**	**Weinberg, 1975**	**Methods**
Simple systems	Composed systems	Small Number systems	Tracking exhaustively
Organized complexity	***Evolved systems***	***Mid-Size systems***	***Multi-level, multiple perspectives, Functional analysis***
Disorganized complexity	Aggregates	Large Number systems	Probabilities & Statistical methods

This tripartite delineation is sometimes organized on a scale from low to high-end complexity (e.g., Kitto, 2008) where the kind complexity is on some sort of scalar continuum. Weinberg's (1975) labels may also seem like a scalar continuum in number of elements. Yet there is something very different about organized and evolved systems than just being *in between* very small and very big systems. The causal links between components seem to provide a qualitative jump, thwarting any 'hope' that understanding these special complex systems would be an easy matter of linear scaling (see Schrodinger's quote below).

This delineation showcases just how much what we know (ontology) is related to how we can interrogate the phenomena of interest (epistemology). Yet science in the 20th Century also had to come to terms with phenomenological realities that were quite different form the Newtonian ideals that were expected to work on ‘everything’. It turned out that the reductionist perspective in Newtonian mechanics and in Darwinian evolutionary theory were idealized cases, reference points no real system could come close to. (Ulanowicz, 1997.) Thus it is not just a question of which of the three kinds of systems our research questions happen to point to, but also the contention that *most* systems we are interested in are of the organized variety, and yet these are the systems that were looked over in science till recently.

Ulanowicz (1997:34) articulates a similar tripartite set-up in regard to how neo-Darwinism depicts biological evolution. While the reliability of genetics was considered to flow from the fact that there were numerous largely independent components (from ‘below’), the reliability of physical (and behavioral) events was a consequence of few components linked rigidly by laws (from ‘above’). Yet, Ulanowicz argues: “Ecology, and many of the social sciences, usually treat an *intermediate* number of components that are *incompletely linked.*”

Yet what lies below for Ulanowicz is too *organized* for Schrodinger (1967/49), who, in 1949, integrating what the leading geneticists such as Haldane and Darlington were learning with his own understanding of statistical physics, considered genetic systems too small to be treated as *aggregates*:

> ...[T]he gene contains certainly not more than about a million or a few million atoms. That number is much too small…to entail an orderly and lawful behavior according to statistical physics–and that means according to physics. It is too small, even if all these atoms played the same role, as they do in a gas or in a drop of liquid. And the gene is most certainly not just a homogeneous drop of liquid. It is probably a large protein molecule, in which every atom, every radical, every heterocyclic ring plays an individual role, more or less different from that played by any of the other similar atoms, radicals or rings.
>
> (Schrodinger, 1967/49:30)

The question in hierarchical systems turns on the point at which we can ignore ‘what lies beneath’ in our explanations of observed phenomena. When we cannot, how do we track adjacent levels and how do we understand the relations between them?

Many others have noted similar distinctions independent of or in reference to one another (e.g., Simon, 1962; Bertalanffy, 1976/1968; Allen & Starr, 1982; Wimsatt, 1994, 2006; Rosen, 1991; Lewontin, 2000; Kitto, 2008). Several common themes emerge, of which I have touched upon earlier: The first, is the implication for hierarchical systems in which levels of description / analysis cannot be expected to map onto adjacent levels in simple relations. The second is the multiplicity in potential and apparent causes, and the circularity of feedback. The third related aspect is that revealing relevant levels of organization requires a *functional* analysis that is by necessity empirically driven rather than a priori theoretically set up. I will return to these themes in chapter 2 as we revisit the methods of behavioral analysis and how they have been used in the service of cognitive and evolutionary explanations.

"Soft" C-Systems Thinking: I use the term 'soft' as a qualifier for relatively qualitative C-Systems approaches that have developed in the social sciences, philosophy, and the humanities. Within the C-Systems Thinking developments Post WWII, especially those associated with the Macy Foundation conferences (Dupuy, 1994), most noted was the soft branch of cybernetics, lead by Gregory Bateson, with Margaret Mead as they were inspired by the ideas presented by Norbert Weiner and others. They saw immediate relevance to their own work in anthropology, psychiatry and biology, as well as human organizations, and yet did not produce the kind of formal accounting that would be amenable to the computational techniques developed by the engineers, physicists and mathematicians (see recount in Gottman & Roy, 1990:10).

But 'soft' cybernetics was not the only non-computational approach that had a strong non-reductionist stance. Dialectical materialism had trans-disciplinary reach in Soviet Russia at the beginning of the 20th Century, and the impact on psychology, for example, manifested through Lev Vygotsky, Luria and their followers, translated into English only in the 1970s, influencing cultural (Cole, 1996) and social (e.g., Hinde, 1997) psychology. Developmental psychologists such as Fogel (1993) and Rogoff (1990), alongside situated approaches to action (e.g., Suchman, 1987) and learning (e.g., Lave & Wegner, 1991) built upon one another for a fleshed out theoretical orientation that was gaining relevance in rich cultural and socio-technological settings (e.g., Hutchins, 1995).

The ethnographic approaches often deployed in these fields did produce very rich accounts of the kind of complexity proponents of the SI-Hypothesis were seeing glimpses of in long-lived social mammals and birds. Moreover, the *cognitive* dimensions of human behavior are not in question as they would be in observational research of nonhuman species, and are also empirically more tractable, via speech, text, and other material artifacts. During the same decades in which field primatologists self-trained to become better quantitatively functional accountants of behavioral patterns that would point to differential survivorship and reproductive success, ethnographers honed recording techniques and descriptive methodologies in a myriad of cultural and technological settings.

I look to 'soft' C-Systems Thinking for insight into the rich social dynamics and ways of characterizing participation in complex social groupings. And it is from this arena that I pick a model of social complexity (Hinde, 1976, 1987, 1997) and a theoretical approach to distributed cognition (Hutchins, 1995) around which I reconfigure a behavioral research program for socio-cognitive phenomena.

1.4.3 Hinde & Hutchins: C-Systems Thinking for Socio-Cognitive Behavior

Although Robert Hinde and Edwin Hutchins developed their approaches independently both came to understand the situated contextual and contingent complexity of social relations. Both were trained in classical methods of naturalistic observation–Hinde as an ethologist and Hutchins as an anthropologist–and both were exposed to 'soft' C-Systems Thinking proponents such as Gregory Bateson and Lev Vygotsky. Each of them reached beyond their original training into another expert domain–Hinde to social psychology, Hutchins to cognitive science–moves that expanded their respective conceptual frameworks: Hinde developed a hierarchical model of social complexity in primate groups; Hutchins developed the theory of distributed cognition, or D-Cog, in technologically rich cultural practices. Most importantly for this thesis, their conceptual frameworks also have clear empirical guidelines for *behavioral* research. Table 1.4 summarizes relevant parallels.

Table 1.4: Hinde & Hutchins, Compared

	Hinde – Social Complexity	**Hutchins – Distributed Cognition**
Origin	Classical ethology	Cultural Anthropology
Settings	Birds, primates in field and captivity	Trobriand land litigation; inter-island navigation, navy ship navigation, airplane piloting, etc.
At Stake	Seeing relationships	Seeing cognitive systems
How	Quality and patterning of interactions/ over time	Tracking propagation and transformation of representational states across representational media
Cognition	In preferences and expectations of relationship partners	In coordination of representational structure within and between individuals and cultural artifacts
Social	Successive levels of complexity in primate groups: individual behavior, interactions, relationships, group structure	Cultural practices on multiple time scales (current activity, career pathway, history of practice)
Conceptual	Dialectical relations between levels of social complexity	Cognitive properties of systems different from cognitive properties of individuals. Cognitive challenge: bringing structures into coordination.
Empirical	Two routes of generalization from social interaction data	Identify system boundaries by regularly occurring outcome. Study as a process – track trajectories of representational states
Challenges	Dyadic only. Not clear how to get at *cognition* from spontaneous behavior	Identifying representational structures in behavior of nonhuman primates

Robert A. Hinde: Social Complexity–Seeing Relationships.

Hinde's model operates on two levels (see Hinde, 1984; Hinde et al., 1985; Hinde, 1987, 1997). *Conceptually (theoretically)*, it offers a view of dialectics between levels of social complexity, moving from internal physiological processes to observable individual behavior, through interactions, to relationships and group structure; two-way arrows in the model emphasize the circular causality between these levels and the *physical environment* as well as the *socio-cultural structures* in which primate social dynamics are embedded/situated. In this thesis project I confine myself to the four levels (individuals, interactions, relationships, group structure) that allow observable access to behavioral patterns in the typical nhp field study.

Operationally (methodologically), Hinde articulated two routes of generalization from social interaction data. One route, the ***relationship approach*****,** tracks the *same individuals* through time and across *different types of interactions*. This is the route pursued in the current chapter. The second generalization route, the ***interaction approach***, looks primarily at the *same type of interaction* across individuals and across other levels of social complexity, a route that will be explored through Hutchins' D-Cog lens. I first differentiate the two approaches although aspects of each typically, if selectively, appear in combination.

In essence, Hinde's model articulates the (contextual) dimensions of social interactions that contribute to (or from which emerge) the levels of social complexity identified. As Hinde points out, operationally it is not possible to proceed from generalization about interactions to generalizations about relationships without tracking individuals through time (Hinde, 1987, Hinde & Stevenson-Hinde, 1987)

The *relationship approach*, then, provides an effective portal into social complexity of primate groups, since, in order to trace relationships, one has to move empirically through tracking individuals and the patterns of their interaction over time. Since relationships do not occur in a vacuum, the effect of relationships on one another begins to reflect group structure. In the decades since the SI-Hypothesis kick-off in the 1980s field primatologist have indeed studied long-term non-kin associations, albeit not deliberately addressing Hinde's model as a whole. Field studies in behavioral ecology, when applied so simplistically to long-lived social species, often *collapses* rather than *traverses* levels of social complexity, failing to relate or reconcile proximate and ultimate levels of causality (see Tinbergen's 4 whys, above).

Edwin Hutchins: Seeing cognition in distributed systems. In his theory of Distributed Cognition, or D-Cog, Hutchins (1995) defines cognition as the *process of propagation and transformation of representational states across representational media*. This carefully crafted definition hints at several ways D-Cog breaks the mold of cognitive theories that have confined the locus of cognitive change inside the head of individual subjects. It shifts the emphasis to cognition as a process, the definition of mental representation from a static physical structure to an event, and traces a trajectory that in many cognitive systems crosses the traditional boundarie*s* of the cognitive unit of analysis. Yet even as cognition is thus rendered visible in socio-technical settings, D-Cog can be seen as making an even stronger claim: Regardless of the chosen unit of analysis, at any scale, cognition is inherently a complex distributed process. Thus formulated, D-Cog bridges what is empirically more tractable in socio-technical settings to other cognitive phenomena, a perspective that is steadily gaining ground in cognitive neuroscience.

Conceptually, D-Cog was able to build a solid bridge to classical cognitive science by maintaining perspectives on cognition-as-computation and the significance of representational accounts, even as representational structure leaked across the inside/outside boundaries of individual agents. By recognizing that the cognitive properties of systems may differ from the cognitive properties of the elements from which these systems emerge, Hutchins offers an alternative view of the challenge individual agents may face in complex socio-cognitive settings. The problem-solving individuals engage in may be more about bringing internal resources and external representational structure into coordination, in response to system level regularities.

Rather than repeating the behaviorist fallacy–considering internal mental processes irrelevant to the explanation of stimulus and response behavior–D-Cog builds on more dynamical approaches to intra-psychological processes, and offers empirical guidelines that side-step the analytic necessity of cognitive psychology to hypothesize simple goal-structures against which behavioral data were typically tested. In other words, D-Cog analysis is not beholden to the reductionist correspondences depicted in the representational gambit described earlier. Hutchins is not 'robbing' individual agents of richly intentional behavior, but rather cautioning against misattribution of intentionality to individual agents when it may be more accurately and decentrally located in the organization of the larger system.

Unit of cognitive analysis: Empirically, cognitive systems may be identified by a regularly occurring outcome, extending the boundaries of the unit of analysis around any factor that directly influences the outcome. To understand the cognitive systems that operate on a flight deck of an airplane, for example, one would trace the boundaries of the system around the agents (pilots, co-pilots, air traffic controllers, etc.) and the other structures in their environment (such as charts, instrument panels, communication channels, etc.) that are brought into coordination in the process, say, of a take off or landing procedure. Rather than an exhaustive inclusion of every item, the aim is to capture the factors that are most directly related to the *cognitive* outcome, now allowed to manifest within, between and across individuals and their environment.

Tracing trajectories of representational states. The actual accounting in such cognitive systems is achieved by tracing the way representational structures are brought into coordination, over the course of an unfolding activity. The cognitive system, identified by a regularly occurring outcome, is now studied and traced as a process. The analysis is aimed at capturing system level regularities and tracking the way elements in the system *participate* in this process. By studying regularly observed outcomes and understanding the way they are organized, a researcher constructs an empirical lens it can now turn on other dynamics in the system that have not produced the same outcome, and examine how they differ. In Cognition in the Wild, Hutchins tracks the cognitive system of the fix-cycle – a navigational practice of charting the direction a ship will use to keep track of its course – and once understood, is able to examine how it differed from a near-accident in which the system broke down.

Cognition: beyond representational accounts? D-Cog's most significant contribution to cognitive accounting of behavior was in shifting the emphasis of how certain types of cognitive processes are achieved from happening largely inside the head to happening mostly in embodied coordination in the world. While the representational status of structures in nhp natural environments is difficult to ascertain, cognitive neuroscience has moved itself towards a more embodied view of cognition, finding ways to examine behavior 'closer' to the body (see also Chapter 5 & 6). Embodied coordination between individuals is empirically tractable in nhp, as are system level regularities in polyadic social dynamics – the 'stuff' that SI-Hypothesis proponents were so captivated by at the outset.

Hinde & Hutchins Combined: Social Complexity (Relationships) & Distributed Cognition (Interactions) While Hinde's model shows how tracking relationships provides an effective portal onto social complexity (since tracking relationships requires addressing individuals, interactions, and group structure), Hutchins D-Cog provides the conceptual bridge that makes it possible to track relational dimensions of cognition in social interaction data. The common method of state-space system descriptions and sequential analysis (see next chapter) builds an integrative approach to *socio-cognitive* phenomena. These two frameworks and their complementarity in my thesis project allow a more agnostic articulation of the relationships between social and cognitive dimensions of behavior, hence the emphasis on *socio-cognitive* phenomena and research.

1.5 Thesis Statement: Behavioral Analysis for Socio-Cognitive Research

My thesis hopes to demonstrate that a renewed dialog between field primatology and cognitive science is critical to our understanding of the nature, development and evolution of socio-cognitive behavior. Moreover, it recognizes the original appeal of the SI-Hypothesis as a rallying point for such a dialog, and it is thus structured to resolve the hurdles that blocked the SI-Hypothesis from developing into a successful research program.

1.5.1 From the SI-Hypothesis to Socio-Cognitive Research – 2 questions

As I have argued in the previous sections, the challenges to SI-Hypothesis are both in terms of its status as an evolutionary argument, and in terms of the symmetry in logic between *evolutionary* and *cognitive* explanations of behavior. Darwin's basic notion of biological continuity between species not withstanding, evolutionary theory shows up differentially in behavioral ecology and cognitive science. In field primatology, as I have argued, mainstream behavioral ecology, focused as it is on adaptation of individuals, seems to censor the very behavioral patterns that appealed to SI-Hypothesis proponents at the outset. Complex social dynamics that may be rare, context dependent, and contingent upon relational history and individual experience are not easily linked to stringent accounting of differential reproductive success. In cognitive science, by contrast, evolutionary theory shows up mainly as post hoc speculations that have no bearing on the methods of data collection or analysis. This discrepancy challenges the validity of causal claims made based on behavioral data and clouds the explanatory aspirations of both field primatologists and cognitive scientists.

My two questions are as follows: ***(Q1)*** how can the SI-Hypothesis become a productive behavioral research program by adopting C-Systems Thinking and ***(Q2)*** how can this approach to behavioral analysis be integrated into socio-cognitive research in general.

1.5.2 (Q1) Modified Behavioral Research for the SI-Hypothesis

I propose that no new methods or theories are necessary for the SI-Hypothesis (see section 1.2) to become a comprehensive research program for socio-cognitive phenomena. Given the triple investigative agenda I set out with (see Table 1.1,) I will address, in turn, the impact of each tier on my thesis project.

Tier1 (Paradigm): Implications of C-Systems Thinking. Figures 1.3a and 1.3b depict the core interrelated shifts required in conducting behavioral research in general and socio-cognitive research in particular. The three-axis 'cube' speaks to the relationship between *phenomenological* (X-axis), *empirical* (Y-axis), and *interpretive* (Z-axis) dimensions of doing research (see also Figure 1.1 for reference). Figure 1.3a pertains to a more conceptual structure of research while Figure 1.3b goes further to interpret these shifts as empirical specifications relevant to *social interaction data*. I chose to represent these shifts as cubes to emphasize the interdependency between the axes.

Interpretive axis: Theory / Explanations: The shift represents the main impact of C-Systems Thinking on paradigm in search of singular causal driving mechanism. It requires *releasing constraints* on causal singularity and cause-effect directionality. Mostly by abandoning teleological argument structures. This shift typically means a move from focus on outcome to tracking process. We are not asking–then testing–what we expect if social complexity *drives* cognition, but rather what sort of processes are likely to evidence socio-cognitive links, and how might we track their dynamics

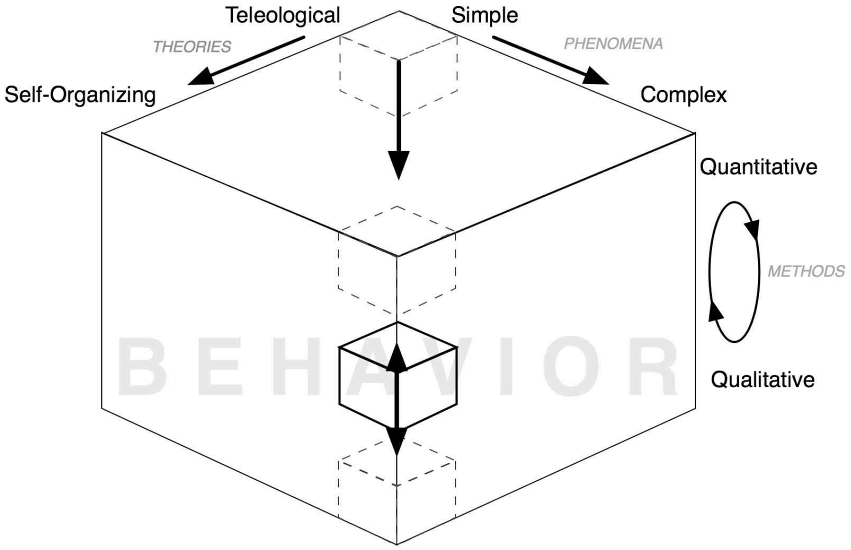
Relaxing constraints of teleological framing in evolutionary and cognitive arguments entails very different challenges to methods of data collection and analysis, even as they are masked by the conceptual and metaphorical symmetry I articulated earlier. It may be relatively straightforward to remain agnostic regarding the direction of causality in evolutionary explanations; cognitive interpretations on the other hand challenge how we use attribution of intentionality in behavioral analysis, which is why I deploy Hutchins' D-Cog framework to the analysis of social interactions.

Phenomenological axis: Phenomena / Data-Structures: C-Systems Thinking teaches us not to expect complex phenomena to be resolved as extrapolations or linear approximations of simple ones. Rather we may need to start with the 'simplest' complex system, or identify key features that would guarantee the relevance of our insights to other complex systems.

I will demonstrate that the failure of the phenotypic and representational gambits will not be resolved by simply increasing our sample size only to deploy the same techniques, or by tweaking analysis techniques on the same data. It calls for reevaluating the very data structures we deploy, requiring, first, revisiting (see Figure 1.1) the phenomenological history–here, of baboon field observations–which I undertake at the outset of Chapter 2. These insights allow me to make more principled choices in reconfiguring the data structures I might use for analysis.

Empirical axis: Methods / Analysis: The history of C-Systems Thinking in general and even Dynamical Systems Theory more specifically speak to how important qualitative turns were in development of computational methods and mathematical breakthroughs, Poincaré Algebraic Topology perhaps the most noted turning point in the history of dynamical systems theory (see Chapter 2). Similarly, post WWII the wide reach of cybernetics in the academic discourse was in no small part helped by the 'soft' (see section 1.4.2) cybernetics championed by Gregory Bateson, Margaret Mead and others. One of the unfortunate lingering trends is the current insulation of 'hard' from 'soft' C-Systems Thinking proponents. I will deploy the formalism of state-space system description to bridge between Hutchins (1995) D-Cog ethnographic methods, and the datasets on baboon social interactions.

1.3a Conceptual



1.3b Empirical

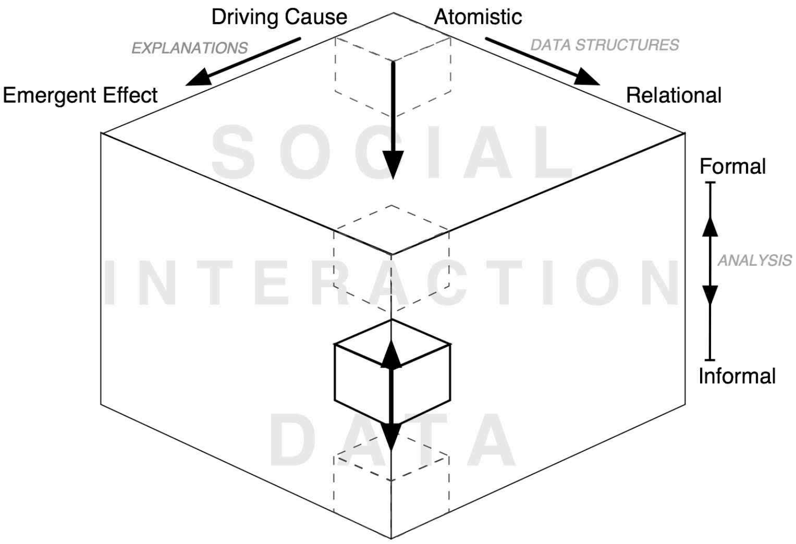


Figure 1.3a-b: The Three-Dimensional Space of Behavioral Analysis. The conceptual space (theory, phenomena, methods,) and more empirically, for social interaction data (explanations, data-structures, analysis) are equally applicable to behavioral explanations of evolutionary patterns, and behavioral explanations of cognitive processes. The arrows represent the shifts proposed in my thesis. Smaller dash-lined cubes represent placement of various current positions in this space. The thicker arrows and thicker-lined cube represent the desired resultant position.

Tier2 (Theory): Implications of The SI-Hypothesis. Focusing on the SI-Hypothesis for my thesis project entails reevaluating the way behavioral ecology interprets Darwinian theory to explain behavior. A C-Systems Thinking perspective on development and evolution, such as Evo-Devo (Oyama, 2000/1985; 2000) is particularly relevant as its discourse addresses the symmetry of explanatory logic (see Figure 1.2) for evolutionary and cognitive explanations of behavior. As noted, the SI-Hypothesis provides a discursive challenge to this explanatory structure in that it attempts to explain the evolution OF cognition.

The failure of the phenotypic and representational gambits (section 1.3.1) present the double challenge of measuring social complexity and seeing cognition in spontaneous behavior. Theories that postulate direct mapping between observable extra-somatic behavior and underlying biological mechanisms will not suffice in addressing complex phenomena in long-lived social species. The theoretical challenge demands a shift in the orientation of functional analyses we might deploy – from asking ‘what is it for?’ to asking ‘how does it work?’.

Tier3 (Methods): Implications of State-Space Approach & Sequential Analysis. I use state space descriptions for both social complexity and cognition. This is relatively easy because the flexibility of State-space system descriptions (see chapter 3) provides a common framing for social complexity (relationship approach) and cognition (D-Cog applied to the Interaction approach). Hutchins (1995) D-Cog theory is already couched in ‘state’- like process formulations. C-Systems Thinking provides an exciting yet critical perspective on the isomorphism across domains afforded by the language of ‘systems’ (Bertalanffy, 1969). The use and abuse of what has become known as ‘information theory’ (Shannon & Weaver, 1949), serves such a cautionary tale (e.g., Deacon, 2007, 2008).

Yet the flexibility of defining system boundaries and of identifying systems states–by theory-driven or more epistemic considerations–makes available a host of well-established computational techniques to examine contingencies (e.g., Wickens, 1989) or sequential structure (e.g. Bakeman & Gottman, 1997/1986; Gottman & Roy, 1990) in social interaction data. When I use Hinde’s relationship approach to examine social complexity in a baboon group, I build what is ordinarily considered ‘context’ of social interactions (proximity and association dynamics) right into the data structures, providing a continuous sequential description of triadic configurations, allowing the techniques of sequential analysis to probe this dataset at Hinde’s 4 levels of social complexity (individuals, interactions, relationships, and group structure). When I examine the dynamics of sexual dynamics in the second dataset, the state-space approach allows me to describe the unfolding dynamics leading to a switch in consort male partners, aka Consort Turnover, as a distributed cognitive systems that tracks each participant’s *Profile of Participation* so that the relationship between individual and systems dynamics can be explored. If video data are available (see Ch4) it is possible to go even further and translate discrete data (units of behavior noted in observations recorded by hand) into continuous representations–in this case head movements relative to body orientation in sexual consort participants–forming data representations that are potentially amenable to the computation techniques for *timeseries data* (ibid.)

1.5.3 (Q2) Integrating Behavioral Analysis with Socio-Cognitive Research

In challenging the reductionist edifice of Darwinian evolutionary theory, as I propose earlier, and accepting the failures of the phenotypic and representational gambits, I reject the certainty with which evolutionary claims are made from behavior-only datasets. Yet by no means does this rejection imply that behavioral data are not relevant to evolutionary questions. The framework I propose to address socio-cognitive dimensions of behavior is easily applicable to other phenomena than those I demonstrate it on later in the dissertation (chapter 3 & 4) and to other species, including humans.

Yet productive comparative research is not the sole solution to viable methodology for evolutionary questions. The effort to disentangle the evolutionary and cognitive arguments is to precisely re-imagine what it means to study the evolution of nonhuman and human primate behavior. The access we have to brains and genomes today forms a very different research landscape than what we have been accustomed to. We need to prepare for and sharpen our explanatory and theoretical apparatus in order to employ the types of data that are fast accumulating and the analytic techniques that have been developing to cope with them. Premack (2007), for example, argues for reconsidering the study of cognition now that microscopic studies of human brains reveal unique features, and Hermann et al. (2007) proposed developing a Primate Cognition Test Battery (PCTB) so that better phenotypic characterizations will be available as the sequencing of complete genomes from more primate species become available for scrutiny.

More specifically to analysis methods in behavioral ecology, Garamszegi et al. (2009) noted the recent developments in ecological statistics and their potential impact on behavioral ecology, especially in applying "…analytical tools that incorporate alternatives to the conventional null hypothesis testing based on significance levels." Rather than the binary thinking that has been typical in behavioral sciences, in which hypotheses are tested mainly in terms of falsification, the shift is toward multiple competing biological hypotheses that are translated to statistical models. Such shifts impact data analysis as well as research design (see further details in chapter 2).

Multiple Data Streams. This thesis illustrates the potential use of multiple data-streams in contemporary behavioral research settings. It is not difficult to find parallel recording of physiological measures such as heart rate, galvanic skin response, eye tracking, motion capture, etc. while subjects are moving around. We are entering a phase of research where data streams from brain, genes, physiology, and behavior will be collected in real time on multiple time scales and in sample sizes that afford powerful computational and data mining techniques.

Rather than observable behavior serving only as an index to 'what may lie below', we can now track behavior in parallel to these other temporal streams. Yet our explanatory frameworks are still geared mainly towards tallying actions and decisions to provide performance measures, and we are still learning how to parse the behavioral stream in meaningful ways that are also feasible and not prohibitively labor intensive.

My claim is that we are theoretically unprepared to bring behavior into the same analytic frame of reference even though unfolding behavior is the stage for this socio-cognitive drama playing out. Gene expression changes at a time scale in which behavioral dynamics are easily tractable. And yet our explanatory apparatus has nowhere to hook up these multiple data-streams. We are thrown back in the sea of levels of description, analysis and organization.

1.6 Next Steps

While Hinde's model of social complexity and Hutchins theory of distributed cognition form a conceptual bridge for the SI-Hypothesis to be influenced more productively by C-Systems Thinking sensibilities, the empirical challenge facing field primatologists attempting to study socio-cognitive phenomena is considerable.

The cognitive ethnography exemplified by D-Cog does not allow the generalizations more quantitative methods may confer, and Hinde's mostly dyadic depictions of interactions and relationships does not address polyadic dynamics or their sequential structure.

Moreover, which data structures to use in the study of social interaction dynamics remains to be worked out, with respect to nonhuman primate spontaneous behavior, as does the empirical link between its social and cognitive dimensions.

The development in SI-Hypothesis related research (section 1.2.2) makes it clear that a deeper reevaluation of how theories, phenomena, and methods are linked is needed in order to establish a more comprehensive approach to socio-cognitive phenomena. In alignment with Figure 1.1, I go back, in Chapter2, to the phenomenological history of baboon field observations, and review the behavioral research methods available to behavioral ecologists. As I keep asserting, no new methods or theories are required for the establishment of a productive research program. Yet, what also becomes clear is that even when methods used by behavioral ecologists embrace Dynamical and C-Systems Thinking, they tend to focus on the idealized cases of system that are not of the organized, evolved and mid-size variety (see 1.4.2) that the SI-Hypothesis is so clearly appealing to.

By the end of Chapter 2 I have a research program fleshed out that I demonstrate by applying it to two data sets from baboon social dynamics. The methodology is inclusive and easily tailored to address a variety of setting and easily adaptable for cross-species comparisons.

CHAPTER 2:

Connecting the Dots: Phenomena & Methods for Socio-Cognitive Behavioral Analysis

> Empiricism no longer appears as the solid bedrock on which to build everything else, but as a very poor rendering of experience. This poverty, however, is not overcome by moving *away* from material experience…but *closer* to the much variegated lives materials have to offer.
>
> (Latour, 2005:111-112)

2.1 Overview: Re-Considering Phenomena & Methods

In the previous chapter I identified the theoretical and empirical challenges that limited the SI-Hypothesis as a behavioral research program. ***Theoretically,*** the failure of the phenotypic and representational gambits (see Section 1.3.1) challenged the simple reductionist underpinnings of evolutionary and cognitive explanations of behavior, revealing complex network dynamics of both brains and genomes. ***What happens to evolutionary and cognitive explanations if they can no longer depend on postulated simple correspondences between behavioral regularities and their underlying biological substrates?***

Empirically, the review of the SI-Hypothesis research landscape (see Section 1.2) reveals the persistent struggle field researchers have with operational measures of social complexity, on the one hand, and in seeing cognition in spontaneous behavior, on the other. These difficulties contributed to the decoupling of behavioral analyses regarding social dynamics from those regarding cognition, making the attempts to directly examine the relations between them more difficult. ***Why did only part of Hinde's model (from interactions to relationships) impact research methods? If field primatologist turned to behavioral ecology what other method for analyzing social interactions are available to them? If SI-Hypothesis proponents ignored C-Systems Thinking does that mean behavioral ecology was equally untouched?***

Even when C-System Thinking approaches to socio-cognitive behavior–***Hinde's model of social complexity*** and ***Hutchins' theory of distributed cognition***–are shown to resolve most of the theoretical challenges, and even as they offer clear empirical guidelines, their applicability to spontaneous behavior of *nonhuman* primates leaves critical elements unanswered. Hinde's model was described mostly for dyadic interactions and relationships, cognition manifesting mostly in preferences and expectations individuals have of each other, not items easily tracked in behavioral studies of nonhuman primates. Hutchins D-Cog framework has been applied mostly in human settings rich in technological artifacts and depicting well-structured cultural practices, where representational structures are readily tractable. Providing an adequate representational account of spontaneous behavior in nhp is difficult if not impossible. How then can D-Cog be productive in the context of spontaneous behavior in nonhuman primates?

These limitations point to a ***poor fit between theory and methods***, not likely to be resolved by using the same analysis on more data, nor by using different analyses on the same data. Rather these links between theory and methods require reevaluation of their fit to the phenomena and research questions under study (see Figure 1.1 and Box 1.1***). If the interactions that inspired SI-Hypothesis could not contribute to addressing links between social complexity and cognition, where can we look for tractable socio-cognitive dynamics? What sorts of methods are available that might be appropriate? What are the appropriate joints at which to carve socio-cognitive phenomena in baboons? How did the current functional units we use to analyze social behavior emerge?***

I set out with this question-set to retrace the steps from phenomena to data-structures in the historical context of baboon field observations (Section 2.2) and review the behavioral analysis techniques adapted from other fields to behavioral ecology and field primatology (Section 2.3). In the course of these examinations I identify the phenomena that are most relevant to socio-cognitive research – polyadic dynamics, and the relevance of state-space descriptions. I propose Sequential Analysis of social interactions techniques, to be integrated into the research program I am advocating.

The material is examined through the two lenses I constructed in Chapter 1. The action-oriented lens (my thesis cube, Section 1.5.2) highlights the links between theory, methods and phenomena, which I reconfigure in the next Chapter. The second lens adds a reflective layer that highlights traces of C-Systems Thinking and examines their influence on theory and methods (see three modes of investigation, Table 1.1).

2.2 From Human-Baboon Phenomenology to Social Interaction Data

Social interaction data are already several steps removed from a human observer's experience in the field. I sketch a brief history of early baboon field observations since they contributed disproportionally to the spirit of the SI-Hypothesis. In reexamining the bridges built between phenomena and data structures, I am looking for ways to reconsider socio-cognitive phenomena.

2.2.1 Baboon Phenomenology: Human Field Observations

Primates observing primates offer a unique experience in the world of animal behavior research, and baboons in particular, since both primate species travel mostly on the ground in relatively open habitat. The significance of humans observing baboons by following on foot, at their pace (Strum, 1987), held potential to reveal the kind of social groupings that may be relevant to the baboons themselves. Yet these groupings present constraints on reliable field recording of social interaction data by humans, the history of which helps explain why reconfiguration of data structures will be necessary for this thesis project.

Baboon field research has figured center stage in the development of the SI-Hypothesis, and is probably the most studied genus of primates in Africa. Occupying a similar niche to macaques in Asia – relatively open and just as often on the ground as arboreal, baboons and macaques are the most successful and wide ranging nonhuman primates. Easy access by human observers played a definite factor in their place in the history of field research (DeVore, 1965; Rowell, 1972; etc.) Their extreme sociality and negotiation skills provided the fodder for many of the SI-Hypothesis ideas. For a long time the main ideas about monkeys came mostly from baboon studies (Strum & Fedigan, 2000). Even as their evolutionary history diverged from humans roughly 30 million years ago, they became of particular interest to human researchers who saw in their postulated shift to open savannah analogous to the ecological pressures early hominids had confronted.

Baboon taxonomy overview: Genus *Papio* comprises five baboon species. The mandrill, drill and gelada monkeys are considered close but are not in the same genus. Amongst the five baboon species the hamadryas stands out from the rest in its social organization (Kummer, 1968; Rowell, 1972). Single-male units (Kummer, 1968) comprise the most rigid level (but see below on socio-ecological clusters in savannah baboons,) in which a single male has reproductive monopoly over several females. Males become 'leaders' by taking over from an older male or starting to form their own harem by kidnapping young females. Several single-male units form a band, in which the males are likely to be closely related, and indeed, more grooming partnerships between males are seen than in other baboon species. Bands come together at sleeping cliffs to form loose troops. Even though the social organization may seem fundamentally different, the patterns show up in varying degrees of intensity in the other baboon species (Ransom, 1971). By transplanting olive baboons into hamadryas group, Kummer also showed that the behaviors that most distinguish hamadryas from other baboons, namely the monopoly of access a unit-leader has to his females, has a strong learning component.

The (other) savannah baboons, which include populations that live in forests (e.g., Uganda, Tanzania), live in multi-male multi-female groups where females typically remain in their natal group throughout their lives. Matrilines and their relative ranks remain fairly stable over generations. Males transfer to another troop several times within their lifetime producing less stable hierarchies reflecting the migration dynamics in the troop. Female give birth after a six-month gestation period and lactate for a year at which point they start weaning (e.g., Altmann, 1980) and resume cycling. A female is sexually receptive for about a week prior to ovulation, during which she participates in sexual consort dynamics. During this period of sexual receptivity, a male will try to monopolize access to a female, while other males follow the consort and attempt to take over (see Chapter 5).

Baboons live in troops that may range in size from 15-150. They live in overlapping home ranges and the size, adult sex ratio and foraging patterns are heavily dependent on the ecological conditions of their habitat (e.g., Ransom 1981).

Day-in-a-Life. Baboons are group oriented so that rarely does one find a lone baboon for any extended length of time. Within a home range a troop will have several sleeping sites. They will sleep on cliffs, rocky outcrops, or trees. Rocky outcrops are safer than trees as a protection from leopards, but choice of sleeping site depends on additional factors such as food resource distribution, other baboon troops, and local wildlife or human presence.

Nevertheless, a typical day constitutes a movement from the sleeping site to travel and forage, until mid afternoon where the troop either heads back or towards another sleeping site. The troop usually arrives at the sleeping site at dusk and often remains at the foot of the rocks/trees for a period of resting and socializing before ascending to settle in for the night. The extent of the daily foraging is heavily dependent on food availability and the presence of constraints just as predators, human and livestock movement, etc.

Baboon Supra- and Sub-Groupings. As field researchers began to follow baboon groups routinely, the patterns of movement began to suggest principles of social organization, although some of the earliest interpretations, such as baboon troops comprising of inbred closed social systems (e.g., Washburn & DeVore, 1961:95) turned out to be inaccurate, especially regarding the central role attributed to males. It was, however, in the movement from and to the sleeping site that the various levels of social clustering began to reveal themselves.

Hans Kummer provided some of the most detailed and systematic field observations of hamadryas baboons. The levels of social organization in hamadryas baboons (Kummer, 1968) were very evident in their daily movement, especially the transition from and to the sleeping cliffs. While 'troops' of as many as 600 individuals may share sleeping cliffs at night, as the baboons set out in the morning for the day's foraging, the most distinct subgroup comprises single-male units. Several one-male units have a relatively coherent pattern of movement, forming a 'band' which Kummer came to realize, was the level most like the savanna baboon troops. Of consistent membership, a given band may split up and come together throughout the day. Thus adult males have two major roles: as a leader of a reproductive unit, and as a member in a band. Once the identity of one-male units is established it is easy for human observers to see that boundary maintained even during clustering of several units into a band, or for many bands into a troop at the sleeping cliffs.

For savannah baboons, Altmann & Altmann (1970: 87-89) describe their own observations as well as reports form Thelma Rowell, Kummer, Zuckerman (1932), Lumsden (1951). Two patterns are identified: *supra-group* clusters- several groups sharing the same sleeping area, like Kummer's hamadryas multi-band troops, perhaps for safety against predators. The second pattern is the *subgroups*.

Lumsden (1951) calculated mean subgroup size of 4.43 even though during the day one sees bands of about 40 individuals. Sleeping parties separate as they head for the sleeping site. Quote from Hall (1962a) summarizing his, and others (Lumsden) observations:

> The baboons in view have been observed mostly huddled in twos and threes, with a few single animals, and usually in the sitting posture, on a ledge vertical to the rock face or crevice…There is however no way of determining whether such sub-grouping has any social significance, or whether it is simply a convenient adaptation to the physical requirements of tree-space or rock-formation, allowing for reasonable warmth, shelter and production from predators.
>
> The possibility remains, as a result of our own observations, that all or most animals in a group sometimes pass the night close together. Thus, in South-West Africa, we observed from a hide the whole of a group of 23 animals emerging at down from a single hallow cave in the cliff-face. Watching C group from below their…sleeping-place, we have several times seen only a few animals emerge before dawn, individually or in twos, from rock-crevices, the majority of the group appearing en masses later from behind the shelter of think buss at the base of the cliffs
>
> (Partial quote in Altmann & Altmann, 1970: 88-89)

By the time Thelma Rowell (1972) writes about the social behavior of monkeys, subgroups are described in several sites. After discussing the differences between hamadryas and other baboon species, she refers to Ransom's (1971) comparison with anubis baboons found at Gombe, Tanzania. Ransom is summarized by Rowell (1972:54) to say: "The troop could be subdivided into a series of subgroups on the basis of frequency of friendly interactions between individuals, and was altogether very far from being the rather amorphous horde of animals suggested by earlier studies." Rowell devotes a subsection of her discussion of grouping behavior to "flexible subgroups" in chimpanzees, blue monkeys, etc., noting that the fluid membership of subgroups nevertheless maintain an identity with a single, identifiable, larger group/band/troop, even when the home ranges of several such groups overlap (1972:58.)

Even though hamadryas baboons come together in much bigger groups during the night, single male units maintain the rigidity that is so visible during daytime, mainly through punitive reinforcement by the male towards straying females (Kummer, 1968). While some of the early observations were later re-calibrated by prolonged observations from other populations (e.g., Hall's statements above, which were based on observations of un-habituated chacma baboons living in small groups), field researchers of different baboon species began noting the relative consistency of individuals that end up sleeping next to one another (e.g., J. Altmann, 1980; Ransom, 1981; Stein, 1984). Aside from protection and warmth, J. Altmann (1980) considers that "…the nighttime relationships, by their static nature, may elucidate pattern that exist during the day but are overlaid with foraging and with general activity levels that produce a more fluid social world."

Altmann goes on to examine in detail patterns of association during the day and concludes for males (1980:74): "Male associates were members of the mother's sleeping subgroup and usually had previous associations with the mother sometimes including mating when the infant was conceived." Similarly for females (1980:119): "Mothers' female associates, like that of male associates, came disproportionately from their sleeping subgroups."

Thus, even as foraging and other ecological factors seem to be the primary factor around which these sub-groupings organize, the membership in them is not arbitrary, nor random. Once field researchers identified individuals and tracked groups for continuous extensive periods of time, the intricate interplay of various social factors such as the relative male and female ranks (Stein, 1984:153-159), as well as more temporary contingencies of daily life. Even if researchers at the time segregated by their focus on either social or ecological factors, reading back through this history as one yarn it is impossible not to consider their interdependence (e.g., Strum 1987).

I look to these early, sketchy, and at time inaccurate, observations, in order to *re-imagine* baboons through a socio-cognitive lens rather than reproduce the history of ideas about social or ecological factors. The socio-ecological sensibility of wild populations, however lacking it was in retrospect, is no longer in question (see below and comments on *social niche construction* in section 1.1.3) and the persistent yet fluid demarcations of three recognizable levels (individuals / groups / subgroups) keep surfacing, alongside identification of specific longer term associations between specific individuals (see below & Chapter 4 introduction).

I therefore apply the term *Socio-Ecological, or SE-Clusters* (Forster & Rodriguez, 2006) to these fluid sub-groupings, even as research questions, including those addressed in this thesis, often attempt to treat the social separate from the ecological dimensions of behavior.

2.2.2 Socio-Ecological (SE) Clusters: The Here-and-Now

Socio-Cognitive Ecology. The stance I promote toward behavior is inherently ecological (see Section 1.1.3) in that behavior is seen as interactions between an organism and its environment, where organism and environment are co-constrained, a sensibility captured by the term *niche-construction*. I invoked Flack et al. (2006) notion of *social niche construction* in referring to social species like primates. Yet in this thesis I let the ecological dimension recede somewhat as I focus on reconfiguring socio-cognitive links in behavioral analysis. More accurately, 'socio' in this term refers to socio-ecological dimensions, and perhaps the most complete description of the relations I am interested in tracing would encompass all three, as in ***socio-cognitive ecology***. The empirical studies I present in the following chapters are conducted within a research project that has its long-term focus on the socio-ecology of baboons (Strum 2001/1987). D-Cog, as well, may be easily considered as tracing a socio-cognitive-ecology of representational structures. In this thesis, however, the short time frame of my studies minimizes the differential impact of ecological factors and therefore largely ignored. The SE-Cluster terminology is chosen so that even when ecology is side-stepped, it is not ignored.

SE-Clusters are the most immediate phenomenological reality for a field-researcher studying baboons. The troop may be spread out or partially obscured by vegetation. Yet if an observer is to focus on any one individual, the most immediate contingencies in behavior are found within these clusters. As one moves with a troop of baboons throughout the day, these clusters form and dissolve with the ebb and flow of life on the savannah. The size of a food patch (e.g. the canopy size of a flowering acacia, or the richness of a corm site), the reproductive state of one or more females, the long-term associations, etc., all play a role. Changing activities also call for a different clustering. For example, as a troop may settle on a food-patch that requires extractive foraging infants and juveniles find challenging, or it may take longer for the adults to get their fill, one may find the formation of play groups among infants and juveniles, which may partially dissolve when the group begins to move again and infants sort by their maternal affiliation, or special relationships with adult males.

A social behavior field researcher encounters SE-Clusters and uses systematic measures to record a subset or perhaps track them as a unit. If one could track a whole SE-Cluster over time, the shifts in the dynamics and/or membership would register the relevant events and the immediate context by which to render individual behavior locally meaningful. This is the *'here-and-now'* of baboon life.

Thus the SE-Cluster traces the smallest unit that has immediate socio-ecological coherence. One would find social factors that extend beyond the SE-Cluster, as well as ecological factors that extend across them. It is also the intuitive level at which observers interpret social behavior. "Why did X do A to Y? Well, he was sitting next to Y when Z attacked W, and then grabbed the food item form…"

Realizing the phenomenological status of SE-Clusters for human observers also provides a guideline for where to return to when a particular data structure does not make sense. Human observers become sensitized to SE-Clusters because it is their relative stability that seems most consistent for the baboons themselves (see the discussion of ‘repeated assembly’ in Caporael, 1997; and see Rowell, 2000a on paying attention to subjects as a guide to the subjects’ targets of attention).

Nexus of Multiple Timescales: The SE-Cluster can read as the moment-by-moment unit of meaningful action. It represents a nexus of social and ecological factors in which multiple time scales intersect: The here-and-now unfolding of events; the developmental trajectory that each individual participating in that moment; and the history of that practice, its evolution. In Hutchins (1995: 372) Figure 9.1 similarly describes a moment of human practice as a 3-D cube through which three axes intersect: the X axis, the thickest, is labeled 'the conduct of the activity'; the Y axis, and thinnest, is labeled as the 'development of the practice'; and the Z axis, intermediate thickness is labeled the 'development of the practitioners'. In behavioral ecology terms we may consider 'the conduct of the activity' to be the same, the Y-axis representing historical or evolutionary time; and the Z-axis is ontogeny. But there are many more timescales that are relevant to social dynamics: the time scale of a single interaction; the time scale of a chain of Interactions (as we will see in the next chapter); the time scale of relationships (patterns of interaction over time) and then time scales of other social structures. The socio-cognitive challenge to individuals, as I will demonstrate in Chapter 5, is navigating the moment-to-moment dynamics while tracking relational dynamics at multiple spatio-temporal scales.

2.2.3 From SE-Clusters to Social Interaction Data

I emphasize the phenomenological reality of SE-Clusters, since it is at this experiential level that field primatologists encounter social behavior, and is likely to resemble the experiential level of the baboons. Seeing 'inside' and 'beyond' the boundaries of SE-Clusters requires systematic monitoring and recording. However, when we encounter data presented in reports of research, the data points are invariably subsets *yanked out* of a SE-Cluster's boundaries.

In the next two chapters I will present data on two types of social systems, each consisting of a *SE-Cluster subset,* and were the studies done in parallel, these two subsets would likely overlap. In the first case (Chapter 4), I look at male-female-infant unbroken chains of interactions as my 'system', while in the second case (Chapter 5) I look at the dynamics of sexual consorts. It is likely that a male following a sexual consort pair, for example, as part of the *consort party* (see Chapter 5), might interact with a female-infant pair as part of the consort dynamics, therefore 'counting' as a member in both the sexual consort system and the male-female-infant system from within the same SE-Cluster.

Socio-Cognitive Mini-Clusters – Polyadic Dynamics: The dramatic dynamics that attracted the attention of field observers and also inspired SI-Hypothesis formulations – such as contests over access to a sexually receptive female during consorts, or the inclusion of an infant as a buffer in male-male disputes, or the negotiation over meat from a recent predation – erupt within SE-Clusters, even if they leak across cluster boundaries as they develop, say in an inter-troop encounter, or prolonged fights. Their fast pace, involves multiple agents (polyadic = three or more) with likely conflicting agendas, and bodily confrontations that exhibit a dance-like quality (see Smuts, 1985 anecdotal narrative, also quoted in Chapter 5). The dynamics are experienced by human observers as an organized chaotic storm that is unfolding on multiple timescales (see above). The here-and-now participants are nevertheless responsive to historical relational contingencies, and by-standers incessantly monitor every move, as confirmed, for example, by playback experiments (Cheney & Seyfarth, 2007). ***I locate the relevant phenomena for this thesis precisely in the overlap between the SE-Cluster features and these temporary polyadic swirls of socio-cognitive drama.*** The complexity of polyadic interaction dynamics, and yet their relative rarity within any particular relationship trajectory, become the placeholder for the modified research program I propose (see Chapters 3 & 6).

Social Interaction Data Collection: The limitations on human observation and recording historically imposed a dyadic structure on interactions and relationships, as Hinde's model suggests. Field primatologists and behavioral ecologists more generally, develop systematic procedures by which sampling of behavioral data takes place (see Altmann, 1974; Martin & Bateson, 1993/1986; Lehner, 1996/1979). Behavioral categories are operationally defined using ethograms, and they tend to be identified descriptively or by their effect / outcome (Hinde, 1976b). During social interactions, the identity of the participants, and often the directionality of a behavioral category are recorded. The directionality of a behavioral gesture often anticipates and/or imposes a dyadic structure on interactions even when it happens in a polyadic configuration, by suggesting a single target or recipient. Categories of short duration may be recorded as a single one-time event, while behavioral states allow for onset/offset markers that provide measures of duration. If recorded over specified time windows, these tallies can provide rates of interaction as well as their frequency.

The degree to which the context of a particular sub-configuration enters the data recording depends on its postulated relevance to the research question and its availability to reliable recording. Even when interactions unfold in the presence of more than two individuals, protocols often identify a primary dyad, and relegate others as context, or not at all. It is not uncommon for focal samples to tally all occurrences of several behavioral categories, while noting at prescribed intervals, simple proximity measures between a focal subject and its nearest neighbors. Such 'point samples' provide an independent measure of proximity as an alternative to the tedious recording of all movements between individuals and the focal subject.

Roughly, then, behavioral data from social interactions reveal the type and quality of the interaction as well as the identity of at least the primary participants, along with contextual variables deemed relevant to the research questions. Even though we construct data-structures not unlike those collected in experimental studies where a task is presented to subjects in controlled settings, it is important to realize that in field studies of spontaneous occurring behavior, study conditions are *extracted* ad hoc from the rich contextual flow of, at the very minimum, larger SE-Clusters. How these data are deployed in analyses is reviewed next.

2.3 Behavioral Analysis of Social Dynamics – Behavioral Ecology & Other Behavioral Sciences

I begin the survey of social interaction data analysis, by recounting the main approach to *individual* performance that has been the inferential bedrock of behavioral ecology and behavioral cognitive science (see also Figure 1.3). As I move through methods of analyzing social dynamics I find a repeated shift to more network and/or dynamical approaches. Newtonian mechanics in its attempt to approximate idealized states of every element in a closed system keeps coming up short against real world data. Instead, a relativistic stance of probabilities and statistical regularities is developed repeatedly, changing the architecture of analytic models. Yet even with these changes, the problems posed by behavioral ecologists remain largely in the realm of simplistic 2-factor models that fall short in the face of complex social interactions in primates.

2.3.1 Individuals – Performance Measures – Optimality & Optimization

As an individual's actions are recorded and tallied, they are evaluated relative to a task, as if the subject were being scored on a test. Even in non-experimental conditions a 'task space' is postulated, offering the functional framing by which to measure the patterns in the accumulating data. In as much as we find regularities and trends across individuals we consider these to reflect the functional tendencies of the population – or the species-typical pattern, the regularity that might reflect the underlying mechanism or rule that governs this behavioral pattern. In as much as differences between individuals are significant, they are considered an indicator of significant differences in the same underlying mechanisms.

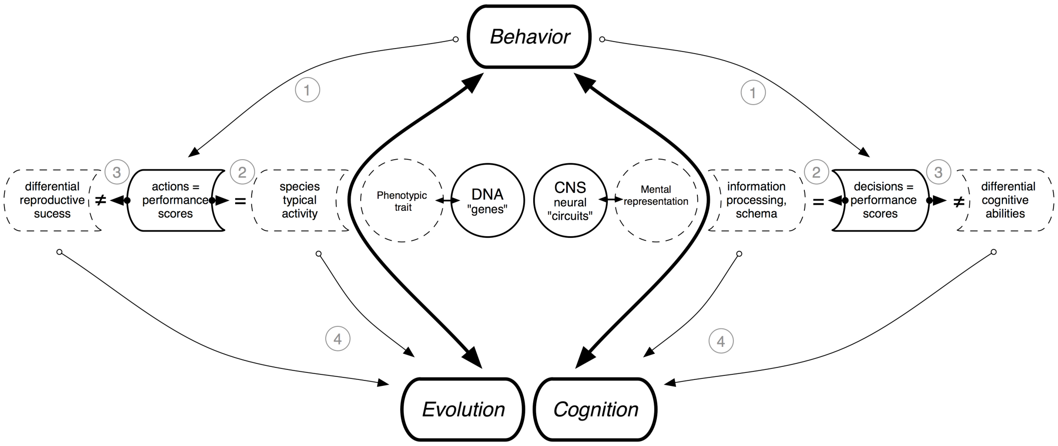


Figure 2.1: **Evolutionary and Cognitive Explanations of Behavior, Revisited.** Shared parallel structure even though the time frame, unit of analysis, and underlying 'substance' (DNA and Central Nervous System, or CNS) are different. In each case the analysis of behavioral patterns depends on a set of postulated correspondences between several layers of explanatory entities. Behavioral research proceeds by (1) data collection on individuals, which are then analyzed for (2) similarities to extract common 'universal' features, and for (3) differences that point to differential abilities supposedly linkable to difference in underlying biological substrate. The patterns of similarities and differences are (4) deployed to explain cognitive and evolutionary factors/processes/ etc.

Figure 2.1 extracted from Fig 1.2, shows the symmetry in explanatory 'logic' of cognitive and evolutionary accounts of *behavioral patterns of individuals*. The most significant link in the hypothetical chain is on the 'inside' where a direct mapping is postulated between a measurable chunk of biological substrate (DNA-genes and CNS-neural circuit) and a functional unit (phenotypic trait for DNA and mental representation for CNS). Behavioral regularities are then assumed to correspond with the logic of these functional units in predictable ways, so that differential performance scores of individuals, corresponding, on the evolution 'side' for example, to genotypic variation, are typically tested against optimality models – maximizing life-time reproductive success, or optimizing information processing.

> Optimality modeling is used in behavioral ecology mostly as a test of whether a particular adaptive argument explains a particular phenomenon. The model is constructed to include the components of the explanation (maximized currencies, constraints, trade-offs, etc.) and often a deliberate minimum of anything else. The next stage is to calculate the optimal behavior given these assumptions. If these predictions match empirical data, one can claim to have a coherent explanation for why that behavior occurs. Sometimes the match occurs only over a restricted range of the model parameter, in which case measuring or varying the corresponding

> characteristics in the real world offers a further empirical test. In the absence of a match, a new or modified explanation must be sought.
>
> …[B]ehavioral ecologists are usually satisfied that they understand the selective value of a behavior if they successfully predict merely the rough qualitative form of the policy or of the resultant patters of behavior.
>
> (Hutchinson & Gigerenzer, 2005a: 109-110)

Optimization can be understood in two ways: One approach is an examination of *outcome-as-optimal-performance*, which can only be assessed with respect to a specified environment, and a known currency (Hutchinson & Gigerenzer, 2005b). Another approach is to assume the subject is in search of *optimum benefit*. In this case the assessment is of the *process*, and various algorithms may be tested numerically against empirical data (ibid). But, researchers may not assume that their algorithms, even if they fit the data, reflect the actual behavior and strategy of their subjects. "Observing non-optimal behavior is no guarantee that the animal is not using optimization. And Observing optimal behavior is no guarantee that the animal is not using simple heuristics." (Hutchins & Gigerenzer, 2005b: 161)

2.3.2 Associations – Sociometry & Social Network Analysis (Graph Theory)

As field researchers were able to identify individual subjects, repeatedly, association patterns made it possible to construct structural models of various groupings, using methods that were developed in sociology and social psychology in the 1930s, starting 'officially' with Jacob Levy Moreno (L. Freeman, 2004:31), who coined *sociometry* for the field of structural explorations in groups, their graphical form known as *sociograms*.

Sociograms (identical mathematically to directed graphs) appear in many of the first descriptions of primate groups under observation (e.g., Carpenter, 1945; Kummer, 1968; see reviews in Hinde, 1970; Haraway, 1989). The graphic visualization of density and directionality of pair-wise associations between individuals or their composite age-sex classes (e.g., adult males, adult females, juveniles, infants, etc.) became part of the typical descriptive tool-kit. Not yet mathematically sophisticated or amenable to inferential analysis, their long standing utility remained questionable. Perhaps, then, to validate the field of *Social Network Analysis* as a normal science, Freeman insists on defining it by the following four features:

> 1. Social network analysis is motivated by a structural intuition based on ties linking social actors, 2. It is grounded in systematic empirical data, 3. It draws heavily on graphic imagery, and *4. It relies on the use of mathematical and/or computational models*.
>
> (Freeman, 2004:3)

Thus Freeman considers 'pre-history', important nonetheless, all the descriptive and graphical attempts, and pinpoints the proper beginning of the field of *social network analysis* to a probabilistic analysis by Paul Lazarsfeld of Moreno's data (Moreno & Jennings, 1938) creating a base-line model for sociometric choice (Freeman, 2004:38). The trend then continued, albeit with chronological gasps, with Kurt Lewin's (1936, 1946) *field analysis*, developed further with his students' translation of structural issues into questions about matrices. First published by Luce and Perry in 1949, they formally defined the notion of "clique" (Freeman, 2004:69). The application of *graph theory* to problems of social structure began with the work of Harary in the 1950s (see references in Freeman, 2004:71), although it was not until the 70s and 80s that the methods became widespread.

Accounting of pair-wise association patterns organized in matrix form, focused, for example, on agonistic encounters, gave rise to the discernment of agonistic *rank lineages* in animal groups under observation (examples in Hinde, 1970, Whitehead, 2008). Whether the characteristics of rank linkages can be attributed to individuals or whether they can be considered an intervening variable (e.g., Hinde & Datta, 1981) or perhaps a genuine group feature (Datta, 1983a, 1983b) influences the causal links drawn into explanatory frameworks (see Strum, 1982, for discussion on the validity of male agonistic dominance rank in baboons).

Recently with the increasing availability of larger datasets and more readily available computational and visualization tools, social network analyses have resurfaced in a wider range of research on both human and nonhuman animals (review of examples and techniques in Whitehead, 2008). Networks can be analyzed as to their features and characteristic organization in various contexts. Features such as path-length, clustering, regional-connectivity (e.g., Supekar et al., 2009) can be extracted and compared. The way connections can spread through networks has also become an important computational field. For example, in the context of studying social learning Hoppitt & Laland (2011) developed Network Based Diffusion Analysis to detect social learning.

Clearly, the inferences drawn from such analyses are dependent on what the *nodes* and *connections* in a described network 'stand' for. There is no social, biological or physical meaning inherent in the computational techniques beyond domain-specific assumptions and constraints. As the relational structural abstractions of phenomena are revealed through the evolving technology of recording and visualization devices, we find network approaches to brains, genomes, languages, diseases, etc., increasingly productive.

Yet network analysis, just as any of the analyses I survey here, lays no ontological claims to a particular phenomenological reality, as much as it provides a *method* of description and explanation (see Latour, 2005, for his discussion on the role of 'network' in Actor-Network Theory). Network analysis is a modeling tool for studying *structural* aspects of complex phenomena. Structural models assume a *structural invariance* of their elements, and of the relations among them, relative to the timescale used to describe their behavior (Allen & Star, 1982:166). Below I will describe other tools, tailored for capturing and modeling their *dynamical* aspects (see Ward, 2002, for clear distinctions between static, structural, and dynamical models in the cognitive sciences.)

2.3.3 Interactions– Strategy – Game Theory

Although the theory of games has a longer history, Game Theory as a field of investigation started with Von Neumann in the late 1920s. Developed originally in economics (von Neumann & Morgenstern, 1944), *Game Theory* models individuals 'playing a game' with specific prescribed payoff structures. One of the first popular examples of Game Theory in economics was the Prisoner's Dilemma (see Figure2.2) in which two accomplices to a crime are given a choice between snitching on their accomplice (Defect) or admitting to the crime (Cooperate), for a differential reward that gave them a lighter punishment only if both admitted to the crime. The prisoners, in their deliberations, supposedly had to exercise the kind of Theory of Mind described earlier to try and second-guess what their partner in crime would do, and then choose the option that would work best to their own advantage. As you can see from the payoff structure in the figure, the order of success goes from highest to lowest when a subject defects on his cooperating partner, lower when both cooperate, even lower when both defect, and worst when a subject cooperates but the partner defects.

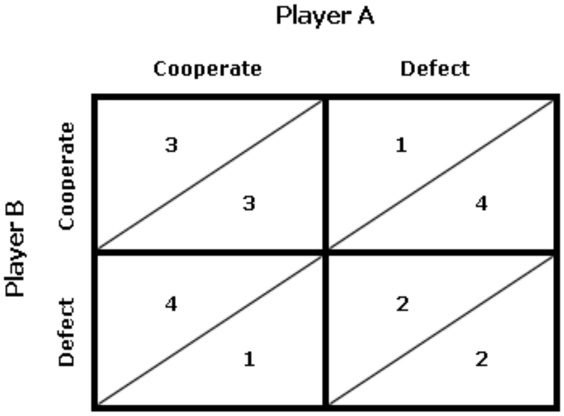


Figure 2.2: Game Theory Accounting – The Prisoner's Dilemma

The classical models assume a game played by *rational* agents who know the rules and the outcomes, as well as the strategy of their opponent. Assuming that in spite of this perfect knowledge agents would not change their own strategy, John Nash (1951) proved mathematically that an equilibrium point would be reached such that the system would be resistant to any new strategy. This *Nash Equilibrium*, the limits of its relevance to human players clearly apparent, nevertheless found an intuitive appeal in behavioral ecology, where the 'perfect knowledge' could be metaphorically offloaded onto natural selection.

The *Nash Equilibrium*, in behavioral ecology terms, was deemed an *Evolutionary Stable Strategy*, or ESS (Maynard Smith & Price, 1973; Maynard Smith, 1974), and was seen more reasonably from the gene's eye view, given that 'gene strategies' did not suffer the same objections to *brain strategies* in not-so-rational human agents. The Prisoner's Dilemma was re-imagined for behavioral ecologists (Axelrod & Hamilton, 1981), and other contexts soon followed (e.g., Hawks & Doves, Cheaters vs. Honest, etc.) It was clear to the researchers that 'strategy' did not imply a conscious cognitive deliberation as was implied in the case of mainstream economic theory at the time.

That the logic of evolutionary game theory could be applied, at least in principle, to complex considerations of the phylogeny of cognition, can be seen in attempts to discern the 'competing' influence of *natural selection* on *survival traits* versus *sexual selection* acting on *fitness indicators*, considered risky and costly to individual survivorship (Bradbury & Vehrencamp, 1998; Miller, 2000.) Miller (2000) proposes human general intelligence, the so called 'g factor', to promote the sexual selection of fitness indicators of human intelligence, and considers public displays of intelligence, humor and creativity, as good candidates. Fitness indicators typically manifest in sexually dimorphic mating displays, and Miller cites "demographic data on the production of costly, difficult, public displays for intelligence, such as painting pictures, writing novels, producing jazz albums and publishing philosophical speculations…with males producing about 10 times more displays than females, and male display rate peaking in early sexual maturity, corresponding to the peak of courtship effort" (Miller, 1997, 2000). How to compute the cost/benefit payoffs and who are the *players* in this game theoretic framing are issues that remain unresolved.

In behavioral ecology in general, though, the mechanism for settling on a *system level equilibrium* was considered an *artifact of individual selection*, similarly to the predator/prey dynamics describe by Lotka-Volterra models (Krebs & Davies, 1984) where predator and prey populations oscillate with the fluctuation of numbers of individuals. What kin-selection (Hamilton, 1964) and reciprocal altruism (Trivers, 1971) seemed to have shown, is that all social behavior can potentially be explained in terms of differential performance of individuals. Behavioral ecology seems to have made social groupings evolutionarily inconsequential as biological structures.

Game theory research has grown in sophistication and nuance across the behavioral sciences with the development of more powerful computational tools, a variety of game configurations and feedback loops, and growing interest in bounded rationality, or even *ecological rationality* defined "…as the performance, in terms of a given currency, of a given heuristic in a given environment" (Hutchinson & Gigerenzer, 2005a: 109).

Researchers also combine methods of game theory with other dynamic and structural models. Dedeo et al., (2010), for example, developed a computational approach they call *Inductive Game Theory (IGT)* to show that pair-wise formalisms, and the immediate ecological context, are inadequate to explain observations of conflict mediation in nonhuman primates.

Dedeo et al. (2010) showcase the growing potential of combining computational methods, as well as deriving individual strategies and their payoffs from time-series data on competitive processes. Curiously, their inspiration for addressing prior knowledge of individual monkeys from the history of interactions actually came from statistical inference methods used in *genetic analysis* developed to address the non-independent nature of data on gene expression profiles. "The goal of Inductive Game Theory is to extract decision making strategies and behavioral time series from known interaction networks". The paper thus uses *graph theory* for the *interaction network analysis*, as well as modeling of 1-setp Markov models (see next section). Their strategy space for the *game theory* aspect of their analysis is a lattice (rather than the typical 2x2 table) that allows for inclusion of multiple players.

Dedeo et al (2010) IGT transformations from "…standard game theory models–a canonical approach to the study of conflict–(where) payoffs are posited, higher order strategic interactions are typically neglected, and data rarely derived from temporally resolved, natural observations of strategic interactions" is promising when it is able to demonstrate the potential validity of intuitions that most primate observers agree on: that memory of past events is more important than the immediate ecological context, and pair-wise considerations do not suffice to explain the patterns of negotiating social conflict in primate groups.

In Chapter 1 I mentioned a type of coalition game model dubbed the ***biological marketplace*** (Noë et al, 1991, Noë & Hammerstein, 1994, 1995) which was developed as an alternative to Priority-of-Access model (Altmann, 1962; Seyfarth, 1977, in order to address asymmetric exchanges where one commodity is fixed while the price paid for it is variable and can depend on 'market forces' such as the balance between the trading classes, or the level of supply. In baboons such a model was adapted by Henzi & Barrett (2002) to consider exchanges between females grooming mothers in order to gain access to their infants. More recently Barrett & Henzi (2002, 2005) began reconsidering cognitive features of social interactions by contrasting these models with relationships studies (but see also Frank & Silk, 2009a-b). I pick up on this thread in Chapter 4 discussion.

2.3.4 Interactions – Communication – Information Theory:

Even as early ethologists described some animal displays as conveying (useful) information to conspecifics (e.g. von Frisch waggle dance in bees) and others as revealing internal state (mating, threat displays), behavioral ecologists in the late 70s criticized the tendency by which "communication is seen as a vehicle of inter-individual cooperation, and its evolution is mutual co-evolution" (Dawkins & Krebs, 1978, cited in Hinde, 1981, but also see Krebs & Dawkins, 1984 comeback).

Armed with a new arsenal of individual adaptation models to explain social behavior, such as kin selection (Hamilton, 1964) reciprocal altruism (Trivers, 1971) and, now, game theory (Maynard Smith, 1974), these researchers still saw communication first and foremost as a social event, but the *meaning* and *function* of signals from the listener's perspective were likely to differ significantly from that of the signaler's (Marler, 1961; Seyfarth & Cheney, 2003). Moreover, Dawkins & Krebs (1978) advocated abandoning the use of the *information transfer* notion altogether (see Seyfarth et al. 2010), as they and others considered the *manipulation hypothesis* (for signalers) and *assessment/management* approach (for receivers) (ibid) more appropriate. For these critics the researchers' use of *information* seemed imbued with all the cognitive entailments we usually attribute to human meaningful use of language, etc. of which they wanted no part. Dawkins & Krebs (1978) are quoted in Hinde (1981) to define communication as follows: "Communication is said to occur when an animal, the actor, does something which appears to be the result of selection to influence the sense organs of another animal, the reactor, so that the reactor's behavior changes to the advantage of the actor." By the time Krebs & Dawkins (1984) respond to Hinde (1981) they have incorporated into their argument a detailed treatment of what became the golden mathematical standard for communication research, aka Information Theory (Shannon, 1948; Shannon & Weaver, 1949).

In the human behavioral sciences the status and quantification of information in the context of communication had a no less confusing history, revolving, similarly around the same technical definition applied to information by Claude Shannon. Working at Bell Laboratories, Shannon published a technical report in 1948, titled *A Mathematical Theory of Communication,* in the context of considering transmission along telephone cables, and their *capacity* to handle signals in a noisy environment. *Information* in this context is considered a measure of uncertainty, or the 'freedom of choice' of a transmitter to choose a signal from a pool of possible messages. The larger the pool, the more uncertainty and the more choice a transmitter has in conveying a message. That *uncertainty* of a transmitter can be linked to more choice and more information challenges our everyday intuition of what it means to be informative.

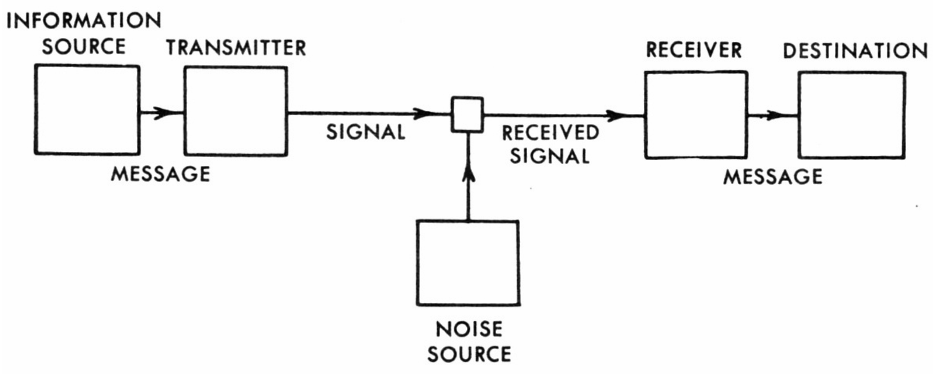


Figure 2.3: Communication Scheme from Shannon & Weaver, 1949

But Shannon clearly describes the problem he confronted (see Fig 4):

> [F]rom the point of view of engineering, a communication system must face the problem of handling *any* message that the source can produce. If it is not possible or practicable to design a system which can handle everything perfectly, then the system should be designed to handle well the jobs it is most likely to be asked to do, and should resign itself to be less efficient for the rare task. This sort of consideration leads at once to the necessity of characterizing the statistical nature of the whole ensemble of messages which a given kind of source can and will produce. And *information*, as used in communication theory, does just this.
>
> (Shannon & Weaver, 1949:103-4)

In treating information capacity *statistically* in a manner analogous to Boltzmann's and others treatment of entropy (read loosely, disorder) in thermodynamic systems, Shannon intentionally ignored the everyday notions of information as reference, as representation, and most of all, as carrying meaning, and noted that "the semantic value of the signal has no bearing on this problem" (Shannon, 1948.) The potential advantages of figuring out the *statistical* constraints on types of signals in types of communication channels *first*, before tackling content, seemed counter intuitive to many behavioral researchers, conforming perhaps to what Sereno (2005) describes as the *semantic urge* in speculations regarding the function and evolution of language (and see discussions in Heji et al, 1997; Deacon, 2007). Yet it turns out that it may be what nervous systems do in certain contexts, as Sereno's (2005) birdsong examples suggest for human language origin on a phylogenetic scale, or, ontogenetically, as when human infants seem to learn (the statistical regularities of) word-boundaries in the language spoken around them long before they tackle word meanings. The framing of communication in terms of engineering and design also found resonance with evolutionary theorists who follow evolution-as-design framing and consider behavioral ecology research mostly as a problem of *reverse engineering* (e.g., Dennett, 1995; Hauser, 1996, but see objections in Wimsatt, 2006a-b).

While the *technical problem* (how accurately can the symbols of communication be transmitted) constituted the focus of Shannon's *Mathematical Theory of Communication*, Weaver contextualized Shannon's 1948 report in their joint book (Shannon & Weaver, 1949) by naming two other levels of investigation that together constituted for him the problem of communication: the *semantic problem* (how precisely do the transmitted symbols convey the desired information) and the *effectiveness problem* (how effectively does the received meaning affect conduct in the desirable way.) Even though Weaver's comments on Shannon's work are rarely referenced, they capture well the kinds of issues that developed in the ensuing decades.

The bulk of Shannon's mathematical contributions came in discerning structural and dynamic contingencies in types of signals (discrete vs. continuous) transmitted through types of communication channels (with and without noise). He used *Markov Models* to test for the order and temporal dependencies in signals (the probability that a current state of the system is contingent upon the previous state, lag-1, or the second to last state, lag-2, etc.), and focused on redundancy in code sequences as revealing their anatomy, an area of expertise Shannon applied to encryption problems during WWII. The power of abstracting features of signal mediums (discrete words on a page, analog sound waves, etc) increased the appeal of applying these principles in a variety of fields.

Most significant, perhaps, was the abstraction of the problem of *communication* as that of *transmission,* to be understood as a common feature of many phenomena, even though for cognition researchers signal transmission was too often confused with *meaning* production (Heji et al., 1997:411).

The notion of transmission nevertheless finds relevance whether addressing circulatory physiological systems, neuronal populations–the area Norbert Weiner preferred to take these computational approaches–gene transfer on individual and evolutionary scale, transmission of disease, of ideas, and of radio signals into space, etc. Yet Heji et al. (1997) argue that this view "starts with an assumption that "something" is transmitted without being modified, and that all transmission channels can be reduced to one channel", ignoring all the interactions and transformations that ensue in real complex systems.

We see specialized fields of inquiry developing around what we may consider the *functional components* of the communication 'system' in that they each can be expressed from within their own functional logic. Note for example, the similarities above in the *effectiveness problem* identified by Weaver, to the *manipulation hypothesis* and to the definition of communication by Dawkins & Krebs (1978). In their later paper Krebs & Dawkins (1984) were even more explicit about communication as manipulation and 'mindreading', yet they treat signals and manipulative communication synonymously, confounding often functionally distinct phenomena (Grafen, 1990:535). This particular functional analysis leads Grafen and others back to game theory for an examination of payoff structures, but other researchers have focused on the *effectiveness problem* from the point of view of the receiver – *signal detection* – where the functional analysis may have to distinguish between intended and unintended recipients – a female mate and a predator bat, respectively, of a male frog's mating call, for example (Akre et. Al., 2011.)

Thus the original formulations by Shannon were subsequently adapted to each context. Early in the days of applying information theory to learning, for example, psychologists Trabasso & Bower (1968) tried to formulate a Markov chain theory for concept learning. Gregg & Simon (1967) recount (see also Ward, 2002) how they had to negotiate moving between more and less formalized descriptions in order to capture important empirical phenomena that were not directly amenable to the mathematical formulations.

> When they recast the informal theory into a formal symbolic language, much like a computer programming language, it captured the concept learning phenomenon quite well while avoiding the inconsistency and imprecision usually associated with informal theory…they could mathematize the formal information-processing theory whenever it was necessary to generate and test quantitative predictions.
>
> (Ward, 2002:58-59)

Some behavioral ecologists interested in cognition see the usefulness of Shannon's information theory as a way to assess *reduction of uncertainty* in the *recipient* "…because it connects communication to learning theory and to research on the mechanisms by which animals associate signals (or cues) with each other or with outcomes of specific behaviors." (Seyfarth et al, 2010).

Others however, like the above critique of *transmission* by Heji et. Al., 1997), objected to simplified interpretations of Shannon's scheme of communication as happening between (only) two actors in what seems like a very linear process (e.g., King, 2004). In many social contexts it is difficult to identify the roles of signaler, receiver, and the communicative act, in any but a very abstract formulation, which often requires leaving out a lot of context (see discussion in Grafen, 1990). The productive application of Shannon's information theory to *social interaction data* had to wait several additional mathematical iterations.

2.3.5 Sequential Analysis of Social Interactions:

Even as Shannon's personal reference point of communication was between a human transmitter and receiver using language where the source and target represent the brains of each (Shannon & Weaver, 1949), it took over two decades for mathematical tools to be developed that can adequately handle what we think of as typical social interactions among primates.

By Gottman and Roy (1990) account of the history of *sequential analysis* as it applies to social interaction data, it was the significant treatment of *change* and *dependent* structure, that made information theory appealing to social psychology, although the "initial interest in these techniques in the social and biological sciences was limited to the study of the patterning of behavior within *single* individuals (Gottman & Roy, 1990:10)".

The developments in sequential analysis techniques are considered an integral part of behavioral ecology methods (e.g., Martin & Batson 1993: 152-154; Lehner, 1996: 455-457), and some of the earliest applications were by primatologists (e.g., S. Altmann 1965, see next chapter) as well as important methodological contributions (Sackett, 1979). They were not picked up by SI-Hypothesis proponents to examine the link between social complexity and cognition, although one of the two researchers who set it off, uses sequential analysis to examine cognitive dimensions of foraging techniques (e.g., Byrne, 1999). I noted his work in Chapter 1 (Section 1.2.2) and will return to discuss the relevance of his research in Chapter 6.

In the next chapter I discuss Sequential Analysis of social interactions, as I will apply in my own analysis (Bakeman & Gottman, 1997; Gottman & Roy, 1990; Bakeman & Robinson, 1994; Bakeman & Quera, 2011),

2.3.6 Dynamical Systems Theory & State-Space

Dynamics: While an adequate introduction to the breadth of research strands associated with *Dynamical Systems Theory* (DST) is way beyond the scope of this document it is important to recognize its foundational role in the development of the methods describe here, and C-System Thinking more broadly. As a branch of mathematics, DST traces back to Newtonian mechanics and the independent development of *calculus* in its geometric (by Newton) and more symbolic (by Leibnitz) forms. While dynamics of moving bodies were described and visualized before this point, the study of (idealized) natural systems began in earnest only once it was possible to calculate *the rate of change* in velocity (i.e. acceleration or deceleration) of a moving object, and then, through the application of a *dynamic rule,* pin-point its position, or at least its velocity vector, at each instant (by differentiation) and, conversely, describe (by integration) its trajectory in space. Indeed, both Newton and Leibnitz placed their mathematical development of calculus within the realm of natural philosophy (Abraham & Shaw, 1992; Capra, 1996). The success of deducing observable planet motion by applying *differential equations* that take into account only mutual gravitational forces between two spherical bodies, held a fantastical promise:

> The technique of formulating physical laws by means of differential equations (whose solutions then give the behavior of the system for all time) was so powerful that it was tempting to think of the entire universe as a giant mechanism ruled by a collection of differential equations based on a small number of simple laws. Since the solutions of a differential equation depend on the starting value assigned to the variables, it would then simply be a matter of specifying the *initial conditions*, e.g., the position and velocities of all the particles in the universe, to then be able to predict with certainty the behavior of every particle.
>
> (Norton, 1995:46)

Qualitative DST: This promise was quickly thwarted by two factors facing the application of differential equations to real systems: First, *sensitivity to initial conditions* in many complex system means that even very small differences in initial conditions may produce dramatically different system behavior. Second, even fairly simple linear equations are difficult to solve mathematically, and nonlinear differential equations, even as they may be easy to write down, are unsolvable *analytically* except for special cases (e.g., Bertalanffy, 1976/1968; Norton, 1995). *Numerical* solutions to nonlinear equations, by trial-and-error, were made more feasible only with increasing computer power post WWII (Capra, 1996).

The futile aspirations for exact mathematical solutions were eventually replaced by more *qualitative* approaches to understanding dynamics of complex systems, lead by Poincaré in the late 1880s when "Rather than seeking a formula for each solution as a function of time, he proposed to study the collection of all solutions…for all time and all initial conditions at once." (Norton, 1995:46). The shift from an exact solution of a particular condition to a 'space' of all possible solutions is analogous to Shannon's approach to quantifying *information capacity* statistically (1949; and see quote above). Poincaré, however, conceived of the 'space' of all possible solutions and all initial conditions, as a *geometric* space, inventing the field of *algebraic topology* in order to address the patterns of change that remain invariant across such collections of solutions. Each instantiation of a system traces a trajectory through this *state*- or *phase space* (see below). This perspective identifies qualitative features, such as stability, or the probability of shifting from one region of space to another in response to a perturbation. What could be imagined in this 'rubber-sheet' geometry, may in turn be formulated as conjectures that could, in principle, be proven mathematically for increasing number of dimensions. We thus see a recurrent theme in development of analytic tools involving spatial geometric shifts in perspective (topology, but also fractal geometry) from specific to probabilistic, and from exact solutions to qualitative patterns of change, usually finite in number (as in, 3 types of attractors, 20 types of bifurcation patterns, x number of network types), changing our ideas about predictability in science, from exact location to patterns of change. In all cases it is the shift in perspective that preceded the mathematical developments.

State Space & System Descriptions: This is how Abraham & Shaw introduce state spaces:

> The strategies of making mathematical models for observed phenomena have been evolving since ancient times. An organism–physical, biological, or social–is observed in different states. This *observed system* is the target of the modeling activity. Its states cannot really be described by only a few observable parameters, but we pretend that they can. This is the first step in the process of 'mathematical idealization' and leads to a geometric model for the set of all idealized states. The relationship between the actual states of the real organism and the points of the geometric model is a fiction maintained for the sake of discussion, theory, thought, and so on: this is known as the 'conventional interpretation.'
>
> (Abraham & Show, 1992:15)

<u>Empirical vs. Theoretical State-Space:</u> The particular introduction above emphasizes DST as an idealized modeling approach, with limited selective correspondence with real phenomena. It also depicts What Ashby (1957) saw as one of two main approaches to deploying state-space descriptions as research tools. Starting from observed phenomena, system boundaries and state definitions are *empirically* driven, and can be considered *epistemic* (in contrast with *ontic* descriptions, Atmanspacher, 2000; Dale & Spivey, 2005). The other method, which Ashby followed, was to consider all the conceivable systems and then reduce the set to a more reasonable size. This *theoretically* driven model, is analyzed, producing predictions that may then be tested empirically. As Bertalanffy (1976/1968) notes in his survey of general systems theory, each has advantages and shortcomings. Bertalanffy called the observation driven approach, with which he associated his own research, *empirico-intuitive*, and claimed 'it remains rather close to reality and can easily be illustrated and even verified by examples take from the individual fields of science" (Bertalanffy, 1976/1968: 95). Yet this approach may lack the deductive strength of a mathematically motivated model. In either case, it makes the point that we are always studying only a portion and abstraction with the hope of capturing relevant aspects to our research questions. The state-space approach I am proposing in this thesis (see Chapter 3) is definitively *epistemic* and *observation-driven*.

<u>Externalist vs. Internalist Descriptions (Bertalanffy, 1976/1968 Apendix):</u> A *system*, then, in its most general definition, refers to a collection of interacting elements that seem the hang together. *Dynamical* systems exhibit system-level changes over time, each recognizable *system-state* defined by *state variables* constituting the dimensions along which change can be measures. *Dynamical Systems*

Theory encompasses the development of mathematical tools that can model such systems and can describe and/or predict their behavior. In the classical case, an *internal description* defines a system by a number of state variables, their change expressed as a *set of simultaneous differential equations*. Geometrically, the change in each state variable is depicted as a *trajectory through state-space*, the abstract space (with as many dimensions as there are state variables) of all possible system states. An *external description* of a dynamical system, on the other hand, depicts it in terms of inputs and outputs, the system itself 'black boxed', and a *transfer function* relating inputs to outputs. This very generalized treatment made DST a productive starting point for the more specialized considerations we have seen in the variety of methods above. The difference between the two approaches to optimization, for example, can now be understood as an externalist model (optimal performance) versus an internalist model (the process of searching for optimum reward) of, potentially, the same observed phenomena.

DST Bottom Line: The advantages of dynamical systems approaches are that (1) while dynamic models can treat static ones as a special case, if one starts with static models as a different kind, it is impossible to consider dynamic change in the same framework (Weinberg, 2001/1975; Abraham & Shaw, 1992). (2) Another advantage is the increased potency of a recursive process that is contingent on recent and local context. (3) Productive probabilistic shift from certainty of position to prediction of types of change, regions of space, likelihood and anticipation. Far from an examination of a truth function it is about recognizing feature clusters and regularities of change. Yet the limitations of these models for real world situations–the limitations of cybernetics and even probability-based models–is that they assume some knowledge of the whole system, a largely unattainable condition not only in primate behavior. Contemporary variations are fast developing to deal with such conditions, for example, POMDP, or *Partially Observable* Markov Decision Process, is a framework used for modeling human interactions with robots (e.g,. Butko, 2010)

2.3.7 Summary – Behavioral Accounting for Cognitive & Evolutionary Arguments

The survey presented here shows that the symmetry of logic between cognitive and evolutionary explanations, pertaining, as I already showed above and in the last chapter, to individual behavior, extends to the methods used for social associations (i.e., network and graph theory) and social interactions (game theory, information theory, and sequential analysis). In fact, Bertalanffy (1976/68), when proposing a General Systems Theory (GST) both advocated for and cautioned against such *isomorphism in science*.

> General systems theory therefore is not a catalogue of well known differential equations and their solutions, but raises new and well defined problems which partly do not appear in physics, but are of basic importance in non-physical fields…[GST] should be methodologically, an important means of controlling and instigating the transfer of principles from one field to another, and it will no longer be necessary to duplicate or triplicate the discovery of the same principles in different fields isolated from each other. At the same time, by formulating exact criteria, [GST] will guard against superficial analogies which are useless in science and harmful in their practical consequences.
>
> (Bertalanffy, 1976/68:80-81)

This trend, then, warrants reconsideration of the intersection between the logic symmetry across domains and the failure of the phenotypic and representational gambits (Section 1.3.1) based on the C-Systems challenge to how brains and genomes participate in behavior. Given the challenge C-Systems Thinking presents to reductionist correspondences between behavior and the biological substrates (CNS, DNA) from which it emerges, it is striking, nevertheless, that *all* the methods I surveyed for the analysis of associations and social interactions are based on, or compatible with, DST.

Even as the phenotypic and representational gambits fail on reductionist grounds, it is not because the arsenal of behavioral ecology, nor that of traditional cognitive science, is lacking in relevant analysis tools. The culprit, as I have alluded to repeatedly, is the *role* extra-somatic behavior of individuals is expected to play in the explanatory structure in these fields. As long as it is considered a simple reductionist index to what lies ‘below’, the gap between data, analysis, and explanations will not be bridged. It is in reconfiguring links between the phenomena, theory and methods, that the thesis project is moved toward a research program that more productively addresses the SI-Hypothesis. The poor fit was largely brought about by the myopic theoretical stance of the adaptionist program behavioral ecology extended even to studies of long-lived social species.

2.4 Towards a Research Program for Socio-Cognitive Behavior

In this chapter I gave brief and selective overviews of two strands from which I hoped to draw on for my thesis: the early days of human field observations of baboons, and the behavioral analysis tools used in behavioral ecology (and other behavioral sciences) on social dynamics. My aim was to reconsider the ***phenomenological*** and ***methodological*** landscapes relevant to SI-Hypothesis research, in search of effective formulations that resonate with the ***theoretical*** links I already made between Hinde's model of social complexity and Hutchins' D-Cog theory.

2.4.1 Phenomena – From SE-Cluster to Polyadic Dynamics:

The *SE-Cluster* trace a coherent unit of the 'here-and-now' of baboon group life, yet folded into it are the contingencies of longer timescales in which relationship develop and ecological conditions change. My focus on socio-cognitive phenomena defines temporary sub-systems of SE-Clusters, their boundaries determined by the double agenda that still challenges the SI-Hypothesis research landscape: measuring social complexity and tracking relational dimensions of cognition.

Baboon Social Niche Construction: The polyadic dynamics that erupt in baboons groups and capture the attention of both human and baboon by-standers serve as the place holder for ***addressing social complexity*** as they organize *individual* behavior and social *interactions*, while reflecting *group* structure as well as *relationship* histories. By the ***cognitive dimensions*** of the same polyadic token, these dynamics define the immediate *cognitive* challenge of negotiating the *here-and-now* of *local face-to-face interactions* or of the *task-at-hand*. Yet these dynamics also organize cognitive resources that monitor, track and integrate *longer-term relational contingencies*, which individuals can bring to bear on, or be constrained by, in future interactions.

2.4.2 Methods –Towards State-Space Framing of Dynamical Systems

The review of behavioral analysis methods through their theoretical and computational underpinnings showcases the underlying common influence of ***Dynamical Systems Theory***, and of the versatility of ***State-Space descriptions.*** While social network analysis (Section 2.3.2) game theory (Section 2.3.3) and even information theory in the classical formulation of sender/receiver (Section 2.3.4) all resonate with some aspect of polyadic dynamics, each of these on their own would not capture the full gamut of social and cognitive dimensions I just articulated. Combining methods, as I showed, is increasingly successful (e.g., Dedeo et al., 2010) and is an important future endeavor. To recognize the collection I reviewed as a ***family of methods*** opens up the research horizons to examine a set of phenomena from multiple perspectives that share a common dynamical network perspective.

The challenge first and foremost, however, is to find a way of ***describing polyadic dynamics that capture both their social and cognitive dimensions.*** The versatility of state-space framing is appealing in the flexibility it affords and the overall sensibility of repeated interactions as *trajectories through state-space*. The language of both Hinde (how relationships emerge from patterning of interactions over time) and Hutchins (cognition as a the propagation and transformation of representational *states)* capture this dynamic sensibility (see Table 1.4 and further development in Chapter 3).

Once in state-space, the challenge turns to examination of temporal structure between and across multiple divergent agents (not all doing the same thing). These are abstract formulations that would have to map, nontrivially, onto the levels of social complexity (Hinde) on the one hand, and onto dynamics of distributed cognitive systems (Hutchins) on the other. In Section 2.3.5 I flagged a set of well-established methods in social science, ***Sequential Analysis of social interactions*****,** which I will expand on as the tool-kit for socio-cognitive behavior

2.4.3 Next Step: Re-configure Phenomena – Methods – Theory

As noted in the last Section 2.3.7 the overview of the behavioral analysis methods showed that the symmetry of logic in cognitive and evolutionary explanations of behavior (Figure 1.3 & 2.1) is not limited to individual performance measures and can be found in any and all of the approaches I presented. In fact, many more parallel domains have found relevant applications of these models in everything form proteins to voting patterns (see examples in the sections above on optimality models, networks, game theory and information theory). This insight has two implications to my thesis: the first is a decoupling of analysis logic from the specific failures of the *phenotypic* and *representational gambits* (see comments in Sections 2.3.7). The abstractions of dynamical methods focus on *types of connections*, and are inherently *relational*, and thus can refer to or stand for ‘anything’. The generic formulation of dynamical systems and state-space can be liberating but it further implies a shift of responsibility (to the specific research design) in identifying valid correspondences between data structures and explanatory variables. Distinctions between data structures that capture *social* vs. *cognitive* dimensions of polyadic dynamics, for example, are important in the datasets I examine in Chapters 4 & 5.

In Chapter 1 I identified Hinde and Hutchins as theoretically relevant to the current challenges with the SI-Hypothesis. Yet neither framework could be directly applied as is to nhp social interaction data in order to address both social and cognitive dimensions of behavior. The clarity regarding the phenomena, the promise of state-space descriptions and the potential for sequential analysis provide the phenomena and method with which I return in the next chapter to integrate with the theoretical sensibilities identified in Hinde and Hutchins's frameworks.

CHAPTER 3:

A Behavioral Research Proposal for Socio-Cognitive Phenomena

In Chapter 1 I introduced Hinde's model of social complexity in primates groups, and Hutchins theory of distributed cognition, or D-Cog, as the theoretical tools appropriate for redressing the SI-Hypothesis, and extended more generally to socio-cognitive research. The kinds of data field studies of spontaneous social behavior produce and the behavioral analysis survey in the last chapter provide the tool-kit from which a modified research program for socio-cognitive phenomena is relatively straightforward to assemble.

3.1 Socio-Cognitive Phenomena, Theory & Methods, Reconfigured

3.1.1 Phenomena – Polyadic Dynamics – Socio-Cognitive mini Clusters

The dramatic dynamics that attracted the attention of field observers and also inspired SI-Hypothesis formulations – such as contests over access to a sexually receptive female during consorts, or the inclusion of an infant as a buffer in male-male disputes, or the negotiation over meat from a recent predation, are the phenomena I place at the center of this research program. Their fast pace involves multiple agents with conflicting agendas, and proceeds in dance-like embodied coordination. The here-and-now participants are, nevertheless, responsive to historical relational contingencies.

The complexity of polyadic interaction dynamics and even their relative rarity within any particular relationship trajectory, serve as the placeholder for socio-cognitive phenomena. Socially, they pull simultaneously to multiple levels of social complexity, reflecting the social web as well as the relationship history between individuals. Cognitively, they register the way multiple participants navigate the moment-to-moment here-and-now while reflecting the longer-term relational contingencies that build up over time. Individual participants are monitoring and integrating these relational dynamics even as they are performing the task-at-hand.

3.1.2 Hinde & Hutchins in State Space

Hinde's original insight into social relationships was recognizing they can be read as *the quality and patterning of interactions over time*.

> We have seen that a relationship between two individuals may involve many types of interaction: in behavioural terms the relationship in fact *is* the nature, quality and patterning of the interactions between them. In practice, of course, it is even more than this, because it involves the perceptions and expectancies that each has of the other: however, these are manifest to an observer primarily through the interactions that occur. Now interactions between two individuals rarely occur in vacuo. Each of the participants interacts also with other individuals, and these interactions affect their mutual interactions and thus their relationships with each other. The study of social behaviour thus inevitably leads to the study of groups. And just as the relationship between two individuals is the nature, quality and patterning of interactions between them, so the structure of the group is the nature, quality and patterning of relationships within it.
>
> (Hinde, 1970:19-20)

The repeated emphasis of patterning of interactions over time to trace relationships, and tracking patterns of relationships within a group to reveal group structure, affords easy 'translation' into the state-space framing introduced in the previous chapter. The abstract nature of state-space framing support the flexibility, along with the responsibility a researcher has, to identify system boundaries and system states that provide a relevant and credible portal into ones research questions. As I have noted in the introduction to Hinde's framework in Chapter 1, the main challenge to his model is the dyadic depiction of interactions and relationships. There is nothing in Hinde's framing that formally *restricts* the dyadic condition, and the methods of sequential analysis (see below) accommodate subjects regardless of there are individual, pair, triad, family, etc.

The flexibility of the boundaries of the unit of analysis in the methods of sequential analysis resonates more readily with Hutchins D-Cog framing. In fact, much of Hutchins formulations are already expressed qualitatively in *state-space* terminology, where *representational states* are being transformed as they propagate across representational media. The challenge for my thesis project is to adapt the process of tracking change in state, to a setting where the representational status of structures is difficult if not impossible to assert. Yet there is a relatively straightforward fit with the notion that much of the activity in D-Cog revolves around *embodied coordination* with system level regularities, dynamics that are indeed discernable in nonverbal behavior of primates.

I can now take advantage of the common framing of state-space for both Hinde's and Hutchins' frameworks

3.1.3 Sequential Analysis of Social Interactions

By Gottman and Roy (1990) account of the history of *sequential analysis* as it applies to social interaction data, it was the significant treatment of *change* and *dependent* structure, that made *information theory* (see Section 2.3.4) appealing to social psychology, although the 'initial interest in these techniques in the social and biological sciences was limited to the study of the patterning of behavior within *single* individuals' (Gottman & Roy, 1990:10)

Fortunately, Gottman & Roy contend,

> …Gregory Bateson was invited to the 1949 Macy Foundation Conference organized by Norbert Weiner and he immediately took the notions of "communication" to imply communication between people, and notions of "system" to imply interacting social systems such as cultures or families. Unfortunately, although Bateson saw the value of these mathematical tools, he could not apply them.
>
> (Gottman & Roy, 1990: 10)

In exploring the history of the Macy Foundation Conferences (Dupuy, 2009/2000; Garnder, 1987; Haraway, 1989) it seems that it was Bateson's insights (collaborating at the time with Margaret Mead) that introduced the ideas of cybernetics and systems thinking to the social sciences (see "soft" C-Systems Thinking in Section 1.4.2), Bateson discussing information, semantically, as '*a difference that makes a difference*.'

Not only can patterning of behavior be studied *between* subjects, where a subject can be an individual, dyad, sub-group, or a political party (Anderson & Goodman, 1957; Bakeman & Gottman, 1997/1986; Gottman & Roy, 1990), behavioral researchers also collect *repeated observations* of interaction sequences. Anderson & Goodman (1957) paper titled *Statistical inference about Markov chains,* is noted by Gottman & Roy (1990:11) to be pivotal in moving beyond examination of a single sequence of states available at the time, providing a generalized approach that can be applied to Markov models of any order, sensitive to increasing numbers of observations, and comparable to other statistics (i.e., chi-squared) testing contingency tables.

Curiously, the application of these methods came earlier to primatology than to psychology. Stuart Altmann (1965) analyzed social communication over grooming among young rhesus monkeys, testing the Markov order by asking how far back in the past one could go to gain information in predicting social behavior. In this detail-rich document, Altmann presents a thorough application of the tools and ideas available at the time. Along with the careful analysis it also painstakingly and honestly reveals the limitations on the type of inferences possible, as the limits on their questionable utility, relative to the complexity of the phenomena observed. This paper bespeaks a certain irony, since the matrix of possible dyadic combinations, once actually printed out on paper, measured 6x9 ft, which, Altmann acknowledged, would make it difficult to publish in print (S. Altmann, 1965:503).

Gottman & Roy observe of such studies:

> Unfortunately, there were serious problems with the *utility* of many of the early sequential analyses, because they relied on the omnibus tests of information theory (e.g., tests of the order or amount of memory in the Markov process). The questions most researchers have, far more specific than these questions of order, concern whether or not *specific* transition frequencies from an antecedent to a consequent state are different than one would expect if the two states were independent. Subsequent tests (such as chi-square tests) of specific cells of a transition matrix are possible, but in the past the problem was one of not usually having enough data to employ the tests with confidence.
>
> (Gottman & Roy, 1990:13)

The tools that become available to ethologists in the 1970s and are first published mainly in journals of animal behavior, begin to influence developmental psychologists who worked with primates, followed by psychologists studying mother-infant or father-infant interactions (see references in Gottman & Roy, 1990:14). Gottman & Roy note in particular three tools: Log-linear and logit analysis, which are essentially methods for handling multiway contingency tables (Wickens, 1989); time-series analysis; and lag sequential analysis. The latter, developed by Gene Sackett (1979) made it possible to estimate sequential connection between two events separated in time, hence ‘lag’, ignoring intermediate events. Not only could one then make inferences about sequences with less data than would be required for a Markov analysis, it also made it "…possible to study the *pattern* of a relationship between two events as a *function* of lag" (Gottman & Roy, 1990:13).

It seems that by the time behavioral ecology displaces ethology as the paradigm adhered to by field primatologists, these techniques fall out of the tool-kits of most researchers (but see Hinde, 1970, for broad and detailed review), for reasons anticipated perhaps by Stuart Altmann in his 1965 paper, noting the lack of insight into semantic aspects of communication on the one hand, and the lack of functional analysis on the other. I quote these comments verbatim since they, and the references Altmann cites, speak directly to the conundrum central to this dissertation: how are we to capture the complexity and nuance of primate social and cognitive lives we see unfolding in front of us, while finding ways to account for the functional and adaptive significance that may have impacted their evolution? Stuart Altmann (1965) notes in closing:

> Nothing has been said about whether variations within any of the behavior patterns resulted in continuous communication or whether any of the messages are semantic, iconic and so forth (see Hockett, 1960). Nor are we any closer, as a result of our stochastic analysis, to depicting the structure of meta-communication (Altmann, 1962b; Bateson, 1955) or of nested contingencies (Chomsky, 1956, 1957). In short, primate communication has many structural and syntactic properties, and many contingencies that are still to be studied.
>
> Beyond that, we have said nothing, in our analysis, of the functions of communication, of its adaptive significance, of its outcome–except in so far as the outcome is the response of another individual. Ultimately, we would like to know how each choice of a particular course of action under specified circumstances affects the individual's chances of surviving and reproducing. The requisite data are extremely difficult to get. Such inadequacies in the stochastic model do not invalidate it. But messages are contingent upon factors other than preceding messages. Much work remains to be done.
>
> (S. Altmann, 1965:521)

The sequential analysis methods proposed by Gottman & Roy (1990) and Bakeman & Gottman (1997/1986) and much of the studies they refer to, are not common fare among field primatologists currently, confirming, perhaps, the shifting emphasis toward the behavioral ecology bias for functional analysis and (individual) adaptionist models. In this thesis I take advantage of the inherent flexibility and agnosticism of these computational techniques with regard to the unit of analysis (subject as individual, dyad, etc.) and the developing sophistication of tools addressing contingency table analysis on the one hand (for categorical data), and timeseries analysis (for continuous data) on the other. In Chapter 4 I will use multiway contingency tables (log-linear analysis) on social interaction data of male-female-infant triadic interactions, while in Chapter 5 I demonstrate the potential of transforming baboon head movement from video data into continuous representations, amenable to timeseries analysis.

3.2 Behavioral Research for Socio-Cognitive Phenomena

3.2.1 Hinde's Two-Step Social Complexity meets Hutchins D-Cog

I am proposing that studying socio-cognitive phenomena requires a double-pronged approach that follows Hinde's routes of generalization from social interaction data (see Figure 3.1, taken from Hinde, 1997). The modification of Hinde's original formulation beyond dyadic interactions and dyadic relationships in this figure is straightforward in sequential analysis techniques. Hinde's relationship approach is thus used to probe the *social complexity* 'side' of the SI-Hypothesis. The *cognition* 'side' of the SI-Hypothesis is probed by applying Hutchins D-Cog framing to analyze social interactions as distributed systems.

Hinde's double-pronged model, overlaid with the phenomenology of SE-Clustered described earlier, brings into sharper relief the complexity of the socio-cognitive challenge – the need to navigate embodied action in the here-and-now of local face-to-face interactions, even while keeping track of relational dynamics with multiple agents over multiple spatio-temporal scales. The promise for the common analytic framing of these dynamics, even as they are tracked independently, is found in the use of well-established techniques for exploring sequential contingencies that can be systematically applied within, between and across levels of social complexity.

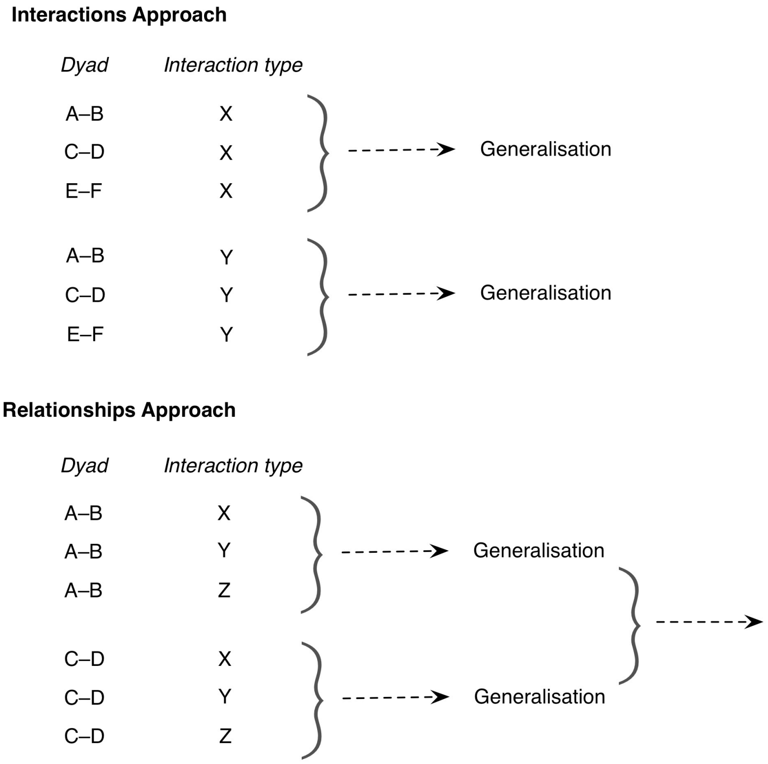


Figure 3.1: Hinde's Routes of Generalization from Social Interaction Data (from Hinde, 1997)

3.2.2 Sequential Analysis & Contextual Design

Sequential analysis, as I described above, became a more effective tool for social scientists only once techniques were developed (e.g., Anderson & Goodman, 1957) that go beyond the examination of a single sequence of events or codes, as originally envisioned by Shannon (1948), the discontent Stuart Altmann expressed over his attempt to run Markov models on sequences of behavior in macaques (see above), a case in point. Most social interaction data, and the kinds of questions we wish to address, would necessitate *repeated observations* of chains of interactions of varying length and composition. Development of tools for probing sequential dependencies gained more traction among researchers as they learned to describe behavioral streams as sequences of *classifiable* (i.e., categories of) events, or states. Moreover, one could now probe how these sequential dependencies vary with specific study designs or relevant explanatory variables. Thus,

> There are two goals to sequential analysis. The first goal of sequential analysis is to discover stochastic (i.e., probabilistic) patterns in the data. The goal is equivalent to 'cracking the code.' …In effect, we want to discover the order and the common

> sequences that characterize the data. The second goal of sequential analysis is to assess the effect of contextual or explanatory variables on sequential structure.
> (Gottman & Roy, 1990:19)

Proponents of sequential analysis for the social sciences (e.g., Bakeman & Gottman, 1997/1986; Gottman & Roy, 1990; Bakeman & Quera, 2011) promote taking this two-step ***Contextual Design*** approach**,** the first to provide the descriptive *summary analysis* of the dataset, while in the second step the study design is brought to bare on patterns revealed in the data. The Hinde-Hutchins framework provides the theoretical grounding for selecting relevant study factors for this thesis (see Next Steps below).

Categorical vs. Continuous Data Behavioral data in general, and event sequences in particular, are usually segregated by non-ordered categories, types of behavioral 'chunks' that defy continuous measures from one category to the next. While two-way contingency tables utilizing the chi-square statistic, for example, are well-established techniques for analyzing categorical data, the t-test for continuous data is considered by some to have more power (but see Wickens, 1989 for critique of this argument). In general, statistical analyses for categorical data have lagged behind development of techniques for continuous data (Wickens, 1989).

Two- vs. Multi-factor Analysis The discrepancy between categorical and continuous data worsens with the shift from two- to multi-factor analyses. While it is common to show preference for analysis of variance over multiple t-tests, an analogous move from two-way to multiway contingency tables (MWCT) analysis is less widespread (ibid.). This discrepancy is due in part to the tradeoff with the amounts of data and computation necessary for even 3 and 4-way tables. I will explore the utility of MWCT analysis in demonstrating Hinde's approach to social complexity, using my baboons data, in the next chapter. I also contrast the typical behavioral data collected currently – *counts of events* that often collapse time (see section 2.2.3) – with event sequences that allow *counts of transitions* between events to show the value of capturing a 'what's next?' sensibility that such transitions represent.

Exploratory Analysis – Generating vs. Testing Hypotheses: Not only is my thesis project exploratory in its demonstration of sequential analysis in the next two chapter, the approach to sequential analysis in the social sciences in general is often geared toward generating hypotheses for further study (e.g., Gottman & Roy, 1990:168). There is a high motivation to discover potential higher-order associations that would be impossible to detect if instead one kept producing a multitude of 2-way contingency tables. Gottman & Roy (1990:32) identify four main approaches to sequential analysis of social interactions:

> **Option1:** Do not pool the data. Compute indices of sequential connection for each subject (dyad, etc…) in the study. Do standard ANOVAS, regressions, etc.
>
> **Option2:** Pool data across subjects. Test timetable's order, stationarity, homogeneity. Then see if the timetable varies with the contextual variables in our experimental design.
>
> **Option3:** Study the timetable for each subject (dyad, etc.) in the study. Useful for exploratory analyses.
>
> **Option4:** Create time series from categorical data.

From these options, the two most relevant to the socio-cognitive research framework I am proposing are Option 2 and Option 4 (see below), although all are useful and promising in the exploratory phase of research.

3.2.3 Next Steps – Proof of Concept with Baboon Field Data

Many challenges remain to be addressed given the rough sketch of the research program I am proposing. From determining the nuts and bolts of each approach in state-space with type of behavioral data typically recorded by field primatologists, to addressing phenomena that are relevant to the SI-Hypothesis in general, and to baboon socio-ecology in particular.

The next two chapters aim at demonstrating the way this approach can be adapted to address relevant questions in two datasets from field observations of a single troop of baboons as part of a long-term project in Laikipia, Kenya. I separate out the two prongs in order to highlight their differences:

First, in **Chapter4,** Hinde's relationship approach is applied to a dataset on male-female-infant triadic interactions over a 6-month period around the birth of the infant. I explore the way interaction dynamics relate to successive levels of social complexity (relationships, group structures), using ***Option2*** since it provides the best opportunity to look at many subjects across levels.

Next, in **Chapter 5,** Hinde's interaction approach is applied using D-cog framing, to a switch in male partners – the most salient event in sexual consort dynamics in baboons. I demonstrate how a complex polyadic event can be re-described as a complex cognitive system, grounded in Hutchins' D-Cog approach. I also show both how state-space diagrams describe system regularities, and how video data of the same kind of event affords an opportunity to use ***Option 4:*** *creating time series form categorical data,* here producing the time series from head movements relative to body orientation of 5 baboons as they participate in the dynamics that lead to a turnover event.

These two demonstration chapters emphasize methodological considerations, highlighting the value of a focus on hypothesis generation, over hypothesis testing in exploratory phases of research.

CHAPTER 4:

Social Complexity AS Context – Sequential Analysis of Male-Female-Infant (MFI) Relations

> This interrelation of behavior patterns is at one and the same time exasperating and delightful to the observer. On one hand it presents him with the frustrating, often impossible task of isolating functional relationships. On the other it constitutes the fabric of the social milieu that is so fascinating.
>
> (Ransom, 1981:107-8)

> …I think the main issue is often one of level or unit of analysis rather than dimensionality. Mapping from demography to social organization and from either of these to individual experience must be done with care. A problem occurs when we use a phenomenon defined at the level of the group to predict one at the individual level…Difficulty also occurs when we relate immediate consequences of behavior, its lifetime consequences, and its intergenerational consequences due to either cultural or genetic transmission. We need to use the appropriate level of analysis rather than add dimensions.
>
> (Jeanne Altmann, 1980:191)

This chapter and the next serve to demonstrate the two-pronged approach to behavioral studies of socio-cognitive phenomena that constitutes my thesis project. They are structured around empirically relevant issues in field primatology while showcasing the methodological principles I am advocating. This chapter focuses on social complexity of male-female-infant relations while the next will focus on distributed cognition of sexual consort turnover events. Here I present a principled investigation into social complexity that is responsive to the challenge captured in the opening comments by Ransom and addresses some of the confusion between levels of analysis and dimensionality depicted in Altmann's statement. The three-tier commentary I set up for this dissertation–of paradigm, theory & methods (See Table 1.1)–continues to provide the subtext throughout.

4.1 Observing Interactions, Tracing Relationships, Revealing Group Structure

4.1.1 Polyadic Interaction Dynamics

Polyadic dynamics (i.e. of three or more) in baboons were pivotal in the formulation of the SI-Hypothesis (see refs in Byrne & Whiten, 1988a, 1988b), and among the more salient to early field primatologists consisted of an adult male carrying an infant in the (sometime agonistic) presence of another male (e.g., Ransom & Ransom, 1971; review in Stein, 1984; also Strum, 1984). The myriad of labels attached to this pattern (godfather, agonistic buffering, paternal care, protection from infanticide, etc.; See Stein 1984:1 for a comprehensive list) attest to the struggle observers had interpreting its function. Another dramatic polyadic context involved the intense negotiations over which male remains closest to–and reproductively active with–a sexually receptive female during mate-guarding, or sexual consort activity (e.g., Altmann, 1980; Ransom, 1981; overview in Smuts, 1985). The periodic switch in male partners–referred to as a sexual *consort turnover (CTO)* event–will be the focus of the next chapter. Individuals may be involved in both patterns simultaneously, as they might in yet other polyadic configurations such as male-male coalitions, when two or more males coordinating their aggressive behavior towards another male(s) (e.g., Noë & Sluijter, 1990), or in inter-troop encounters, etc.

By the phenomenological language I developed in chapter2, these dynamics present possibly overlapping *subsets* of the same *socio-ecological, or SE- Cluster* (akin to the *subgroup* discussions in Stein, 1984:151; Ransom, 1981:178-199). It is not uncommon for the intensity of dynamics to spill over cluster boundaries, as is especially likely in sexual consort dynamics and inter-troop encounters. The multitude of socio-ecological contingencies resonates with Ransom's reflection on the difficulty of parsing the relational web into independent functional units.

And yet, like the membership of SE-Clusters, extended field studies of identified individuals soon revealed the relational configurations in these polyadic interactions to reflect persistent longer-term dynamics. A male who carries an infant might turn out to have a history of association and affiliative behavior with that specific infant starting from the period right after its birth, lasting years. Often these *male-infant special relationships* overlap with a long-term friendship between the male and the infant's mother, as I will explore in more detail in this chapter. Such *male-female friendships* may last more than 6 years in olive baboons (Smuts, 1985:220) enduring through repeated cycles of birth and mating (but see Cheney & Seyfarth, 2007; Silk et al, 2009; for different pattern in chacma baboons). Yet the impact of *male-female friendships* on the types of negotiations that lead to the *CTO events* described above is difficult to evaluate, as multiple males gain serial access to, and copulate with, the female during the narrow window of time in which she is sexually receptive (see Ransom, 1981 & Smuts, 1985, for olive baboons; Nguyen et al., 2009, for yellow baboons; but see e.g., Palombit et al 1997, for a different pattern in chacma baboons). The complexity is such, that most current studies restrict their focus and very *definition* of *friendship* to males with anestrous females (e.g., Palombit et al. 1997; Lemasson et al., 2008; Moscovice et al., 2009; Huchard et al., 2010).

Indeed, as systematic accounting of long-term relationships gradually accumulated, it revealed these dramatic polyadic interactions to represent a relatively small proportion and a rare–or clustered–occurrence in the course of any given relationship trajectory. And yet polyadic dynamics seem decidedly contingent upon the longer-term associations even if in unpredictable ways (e.g., Ransom, 1981; Stein, 1984; Strum, 1983, 1984; Smuts, 1985; etc.). ***To a field observer, then, polyadic interactions speak simultaneously to the relational history of individuals and to the broader context of the social web.*** It was the sense that these complex juxtapositions were routinely and competently exploited by individual primates, that fuelled the flames of the SI-Hypothesis, especially in its Machiavellian form (Byrne & Whiten, 1988a).

Over the last two decades field primatologists settled on three main approaches within behavioral ecology (see overview in Chapter2) linking interactions to relationships or to group structure. Relationships are examined solely for their evolutionary adaptive benefits to *individual* partners or their genetic offspring (see recent examples Silk at al., 2006a, 2006b; Lemasson et al. 2008; Moscovice et al., 2009; Nguyen et al. 2009) while interactions in a group context are increasingly being framed in terms of bargaining commodities in the *biological marketplace* (Noë et al., 1991; Noë & Hammerstein, 1994, 1995; Henzi & Barrett, 2002). Additionally, in the last few years *social network* *analysis* has experienced a revival (see chapter 2) so that group structure is examined through this lens as well (e.g. Lehmann & Dunbar, 2009).

These approaches are still treated independently in the research literature, although the tension between them is receiving more scrutiny as it is beginning to reframe the *socio-cognitive challenge* of primate group living (e.g., Barrett & Henzi, 2002, 2005; Barrett et al., 2003; Barrett et al., 2007; Dedeo et al., 2010; Frank & Silk, 2009a, 2009b; Lehmann & Dunbar, 2009). Here I am offering a re-examination of interactions and relationships in a group context from a more operational *How-Does-It-Work* perspective (see Cummins 2000), proposing a deliberate investigation of social complexity guided by Hinde's model as a starting point.

This perspective invariably trades in common relational dynamics–proximity patterns, and affiliative interactions such as greeting and grooming–leaving the more dramatic polyadic dynamics accounted for only indirectly. I turn my focus on and extend my analysis to such dynamics in the *next* chapter in order to serve the overarching aim of my thesis: to articulate a framework that will allow more direct analytic links between social and cognitive dimensions of primate behavior.

4.1.2 Traversing Hinde's Levels of Social Complexity

I use a dataset on male-female-infant triadic interactions during an ecologically mediated *clustering of births* in the MLK troop of the Uaso Ngiro Baboon Project in Laikipia, Kenya, to examine ***how social interaction dynamics and longer-term relationships may influence one another, and how they, in turn, might influence, and be influenced by, group structure***.

Applying Hinde's *relationship approach* (e.g., Hinde, 1976, 1987, 1997; see previous chapters.) I take advantage of two factors such a *birth cluster* uniquely presents: the enhanced physical proximity between female and infant for the first few months of life, combined with a relatively narrow window of time in which a concentrated pool of newborn infants becomes a salient feature of group structure. I examine male-female-infant (MFI) associations as a *subset* of the relational nexus these conditions juxtapose (see next section).

I address two main question: First, between interactions and relationships, ***Q1: how might a period of enhanced physical proximity between female and infant right after birth be related to the***

development and/or maintenance of male-female friendships and male-infant special relationships? Second, between group structure and interaction dynamics, ***Q2: how might a concentrated 'pool' of newborn infants influence the interaction and association dynamics between males and female-infant pairs in the group?***

I emphasize *Complexity-AS-Context* (see also discussion on *organized* complexity in Ch1) to act as a placeholder for the examination of the *context of social interactions* on multiple spatiotemporal scales, Hinde's social complexity framework motivating the *contextual design* for the analysis.

4.1.3 Phenomena: New Infants, Relational Webs, & Birth Clusters

I took advantage of an *ecologically mediated birth cluster* to explore the factors that may influence the establishment and maintenance of long-term male-female friendships and male-infant special relationships.

Birth & Triadic Interactions: The presence (arrival) of a newborn infant is hard to miss in a baboon troop, not only for its striking black coloration contrasting with the typical gray/olive of its species, to which it transitions over the first 6 months of life (see Figure 4.2), but also for the constant parade of visits/greetings/attention it receives from other troop members. The new mother's limited mobility, but even more so, the physical dependency of the infant on its mother for the first months of its life, set the stage for a heightened intensity and frequency of polyadic interactions

Birth & Relationships: The social hub intensified by the presence of a new infant brings into juxtaposition a number of longer-term non-kin associations that have been the hallmark of describing social complexity in primates. These include friendships between males and females, alliances between adult males, grooming partnerships between non-kin females, preexisting special relationships between males and older infants or juveniles, and new opportunities for male-infant special relationships to develop. The growing use of genetic testing (e.g., Buchan et al., 2003; Charpentier et al., 2008; Moscovice et al., 2009; Nguyen et al., 2009; Huchard et al. 2010) can distinguish biological from 'behavioral' fathers (males who were sexually active with the female during the conception cycle, but were excluded by genetic analysis), as well as father-friends from non-father friends. These studies suggest that male-infant, and even male-juvenile special relationships are not exclusively kin based (see discussion for details).

Ecologically Mediated Birth Cluster: The drought cycle in the study site (see Strum, 2001/1987) is at times severe enough to arrest females' reproductive cycling. When conditions improve, the synchronous resumption of reproductive cycling provides a facultative 'breeding season', followed by a temporal clustering of births. The clustering in the reproductive cycles of females gradually diminishes as the variation in number of cycles to conception and the survivorship of the infants plays out. In this study period, traces of the clustering were still present when the females resumed cycling after the weaning of their infants, about a year after birth. The dataset presented in the next chapter on sexual consort dynamics was collected during this subsequent period.

Such a 'baby boom' brings into sharper relief the shift in social dynamics that usually mark the arrival of a new infant. Not only are there more opportunities for polyadic social interactions, given the physical contact of the infant with its mother, preferences may get a heightened expression, as time and space are constrained by an increase in the simultaneously available pool of new-born infants (see Henzi & Barrett, 2002 for a framing of infants as a commodity in a baboon 'market' in female-female relations; also Frank & Silk, 2009a, 2009b). Although these patterns may be skewed relative to non-drought times, the aim here is to take advantage of these irregular conditions as a 'natural experiment' and as a magnifying lens through which relevant issues of relational dynamics can be articulated for further research.

4.2 Methods: Complexity AS Context FOR Sequential Analysis

Birth Cluster Study Basics: Over a 6-month period, focal samples (Altmann, 1974) of 8 female-infant pairs were collected, following each subject for one hour per week, for a total of 187 hours of observation. During the sampling period all interactions between any of the 8 adult males in the troop and the focal female-infant pair were recorded maintaining sequential structure. Included were association dynamics that depicted movement patterns, visual monitoring, and types of activities. Interactions and dynamics with other troop members were noted in a context column, while maintaining the sequential structure with focal interactions with troop males. The *MFI dataset* constitutes organizing the focal MFI data, sans contextual interactions with other troop members, after categorizing the recorded behavioral codes into hierarchical categories by *type* and triadic *actor-combination* (see Tables 4.3a-b)

4.2.1 MFI Contextual Design

Following Gottman & Roy (1990), sequential analysis generally proceeds in two steps. The first examines sequential structure in the data, and the second explores the effect of contextual/explanatory variables on these patterns. Here, I add non-sequential analysis as the exploratory analysis entry point and build the contextual design to track Hinde's levels of social complexity. Typical examples of study of study factors relevant to the MFI study are summarized in Table 4.1.

Table 4.1: Potential *Study Factors* by Hinde's Levels. *rank is not an intrinsic characteristic of individuals but a relational measure of how they behave with others (Hinde, 1983:47)**.**

Level of Social Complexity	**Study Factors**
Individuals	***Male*** residency/age/size [relative rank*]; ***Female*** age/ reproductive status / [relative rank*]; ***Infant*** age/ gender / [relative rank*]
Interactions	***Types*** of interaction ***Participants*** (actor combinations), ***Structure*** (temporal, spatial, sequential)
Relationships	History and status of: ***Male-female*** friendships ***Male-infants*** special relationships ***Male-male*** alliances ***Female-female*** bonds ***Female-infant*** relationship
Group Structure	***Temporary phenomena*** (e.g. Birth Cluster) ***Age/Sex class*** structure (e.g., adult age/sex ratio) ***Dominance hierarchies*** Relationships between and across individuals Sub-groupings

The distinction between *study data* and *study factors* differentiates *immediate* from *cumulative* context, in that *immediate context* of social interactions is recorded as behavior unfolds, while *cumulative context* gets assembled from systematic monitoring over time (project/demographic records). In observational studies of nonhuman primates the mere identification of individuals, let alone their kin relations, reproductive status, and other demographic variables, are a result of painstaking systematic accounting and calibration. The insights from short-term targeted studies gain explanatory power as they are set against the backdrop of long-term project records, especially when they are assembled in ways that are made specifically relevant to the research questions of the study. I start therefore with the *cumulative context* extracted from the demographic records.

4.2.2 MFI Cumulative Context – Individuals, Relationships, Group Structure

The Subject-Pool Matrix- Figure 4.1a synthesizes the relational status of the study subjects for a 3-month period before, and for a full year after, the six-month study period. The 8 female-infant pairs and 8 males (see Appendix – Tables 4A.1a-b) are arranged in an 8x8 matrix, each cell constituting a *triadic grid* (see Figure 4.1b) summarizing male-female (blue/bottom row) and male-infant (red/top row) relationships. The overall matrix organizes the relational status along three dimensions. Female-Infant pairs produce the columns, in order of their relative rank, while males organize the rows, in order of their relative age. Finally, male-male alliances are shown in connecting lines between male ID codes, the thickness of which is proportional to their status. Male BB disappeared from the group soon after the study ended. Pre-study relational status is available for all the females but only two of the infants (AE and HZ), born by the time the study began.

It is impossible to identify definitive trends in such a small sample, even as patterns seems non-random, since any pattern that holds for two of the males or the female-infant pairs seems disrupted by a third. The two higher-ranking female-infant pairs, for example, have long term relationships with the same males while the lower ranking pairs have more variable and less consistent relations. Similarly, the oldest two males have fewer yet more consistent relations. Interestingly, the two strongest male alliances in which adult male RL is a partner show a divergent pattern of relations with female-infants pairs–"complementary" with the older male (ND) while parallel with the younger male (HK). Although inconclusive this multilayered visualization points to the likely interdependence of these relational dimensions and offers a richer background against which to examine study data.

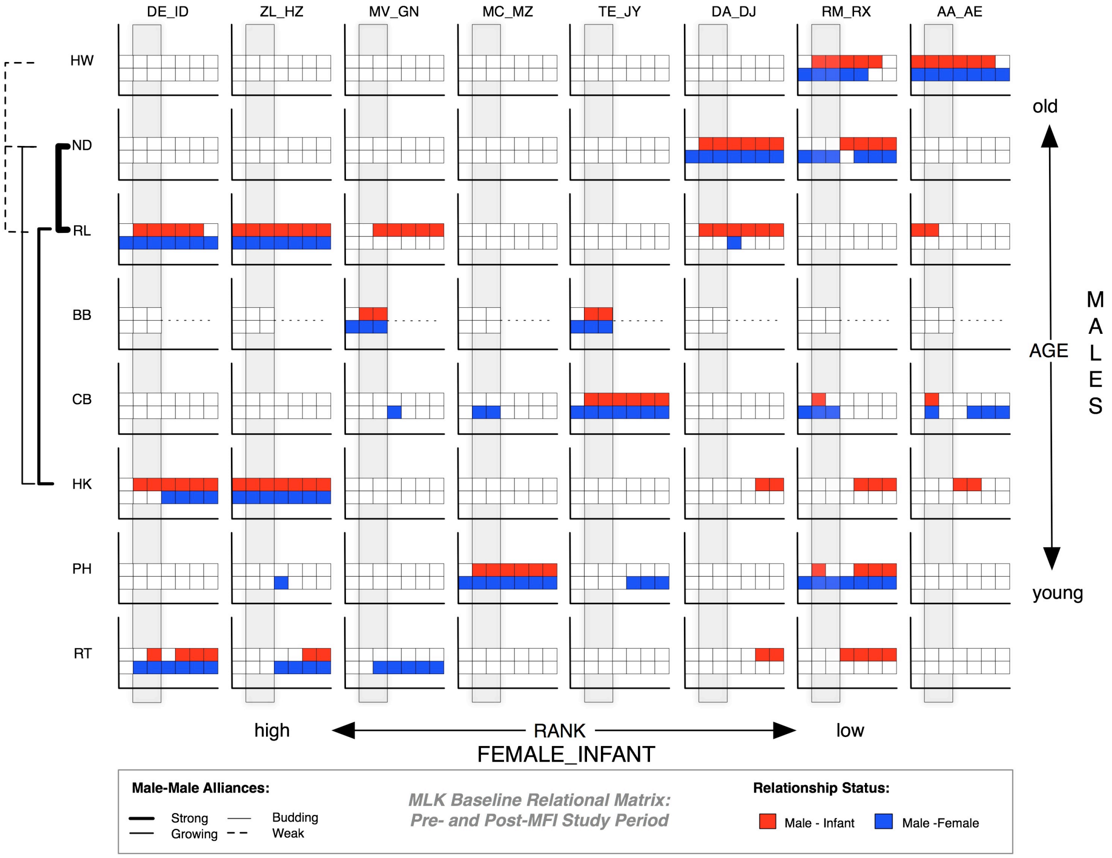


Figure 4.1a: MFI Subject Pool Relational Matrix. The triadic grids (4.2b) of MFI study subjects are arranged in a matrix organized to represent several relational dimensions: Male relative age on the 'Y axis', with annotations on the L-hand axis depicting the strength of male-male alliances during the period covered; female rank on the 'X axis'.

<u>*MFI Triadic Grid:*</u> Figure 4.1b shows the details of one cell in the subject pool matrix, the MFI triad of male PH and Female-Infant pair RM_RX. The assignment of relationships status (presence/absence) for each 3-month grid cell, as noted above: the bottom row, in blue, represents male-female status, and the top row, in red, represents male-infant status. The 3-month status is synthesized from monthly project demographic reports (see below).

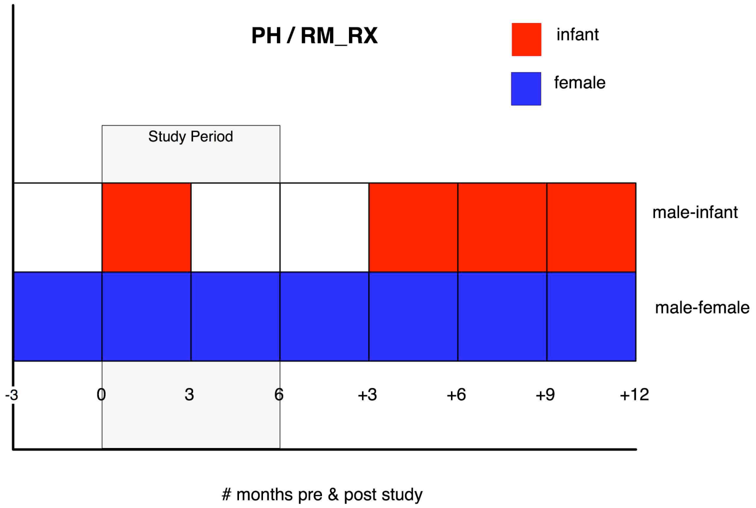


Figure 4.1b MFI Triadic Grid. 3-month blocks before, during and after the MFI study period, in which presence/absence of male-infant (red) and male-female (blue) relationships are noted. Collapsed from monthly project reports (each 3 month block required more than one month to be evaluated as present)

While some triads exhibit *association symmetry* in male-infant and male-female relations, others (e.g. males RL & RT with female-infant MV_GN) show relations only with the infant or with the female, but not both. In addition, while the longest continuous relations demonstrate a *historical consistency* between the study period and after, others (e.g., male RT with ZL_HZ & RM_RX) are less consistent (we will pick up and these distinctions for analysis. See Section 4.3.1).

Friendship & Special Relationship Assignments: In contrast to most relationship studies in which friendships are defined and identified by patterns of proximity and grooming in the study data (e.g. Palombit et al., 1997; Lemasson et al., 2008; Moscovice et al., 2009; Shur, 2008; but see Smuts, 1985 for an attempt to differentiate study data from data contributing to relationship assessment,) I rely on independent demographic reports before, during and after the study period for assessment of male-male alliances, male-female friendships and male-infant special relationships. On an ongoing basis, monthly assessments were reached by consensus of 4-6 field observers at project meetings that summarize field observations for the preceding month. Each study troop was followed for at least 2 full days per week, and is typically covered by 1-2 observers for half-day sessions for a total of 3-6 days per week. Activity scans 2-3 times per hour require observers to note every troop member, while in between scans other data are collected, including social scans, and ad lib notes. Priority is given to recording polyadic interactions thus maximizing the attention observers devote to relational dynamics in the troop. For each male, the report lists all male alliances (and their strength), adult & subadult female friends, and all special relationships males have with juvenile and infants. The consensus on friendships and special relationships requires observation of *special* interactions beyond the proximity and affiliative interactions that typify the relationship routine (see discussion). Special interactions manifest as an expression of possessiveness in the face of third-party involvement, in a male carrying an infant, and/or agonistic intervention or other support in conflicts on behalf of the friend (see discussion on testing solicitude of relationship partners e.g., Palombit et al 1997; Lemasson et al 2008).

Temporary Group Structure – Birth Cluster: An infant baboon's natal coat color starts 'black.' Typically, by around 3 months of age the color begins to change in patches, and the infant is considered 'transitional' until its coat reaches the adult 'brown' coloration by about 6 months. In this study the number of black infants in the group peaked at 7 for about a month and remained at 6-7 infants for almost 3 months (10.5 weeks).

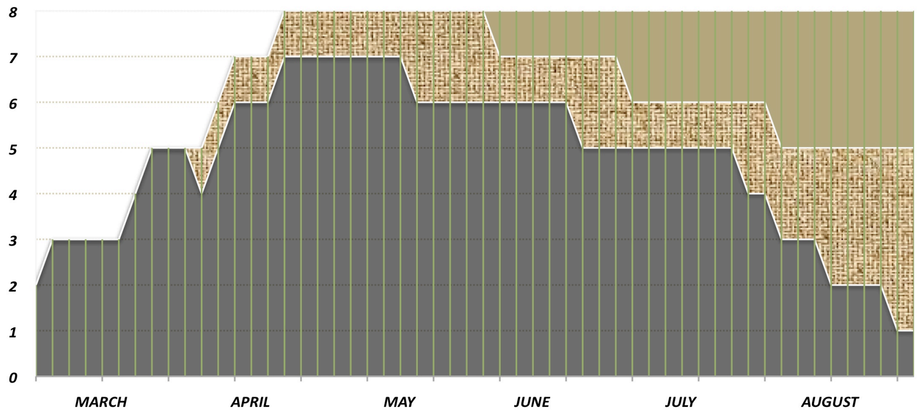


Figure 4.2: Birth Cluster & Infant Coat Color. Number, in half-week increments (droplines), of Black, Transitional and Brown Infants over the course of the study. 2 Black infants were present when the study began.

The attractiveness of young 'black' infants to other troop members is a striking feature in old world monkeys (e.g., Altmann, 1980; Nicholson, 1987; Silk, 1999). Not only was the birth cluster a transient group factor, there may have been an even narrower 'bottleneck' of 'black' infants (see Section 4.3.1)

4.2.3 MFI Immediate Context – Data-Structures

The MFI dataset represents a subset of the data recorded in this field study (see Section 4.2 opening.) The main data structures produced consist of triadic CHAINS (n=1251) of interactions, or STATES (n=2916) during continuous MFI encounters. The sequence of states identify the STATE-TRANSITIONS (n=4107) (see Fig 4.3 for visual scheme, and Appendix – Table 4A.2 for detailed tallies.)

<u>*Data Structure: State – TYPES of interactions*</u>

Table 4.3a presents the state TYPE categories at three different resolutions. For this dataset, the data were coded at the highest (11-TYPE) level, although to achieve adequate counts for analysis lumping to the 4 and 5-TYPE categories was necessary.

Table 4.2a: MFI State TYPE Categories. POSS and SPCL categories are both polyadic interactions in that they involve 3rd party relation**s.** "OTHER" lumps AGON and SPCL for inferential analysis

4 Type	*5 Type*	*11Type*	*Brief Description*
ASOC - ASSOCIATION	***ASOC*** - ASSOCIATION	***as0***	Proximity without visual monitoring
		as1	Proximity with visual monitoring
		as2	Proximity w/visual monitoring & coordinated activities
GRT - GREETING	***GRT*** - GREETING	***gt1***	Greet in passing or w/out physical contact
		gt2	Greet with physical contact
GRM – GROOMING	***GRM*** – GROOMING	***pg***	Present for groom with no response
		gm	Groom or being groomed
OTHER	***AGON*** - AGONISTIC	***ds***	Displacement from food, social partner, or passive
		ag	Threat, chase, and/or contact aggression
	SPCL - SPECIAL	***Ps - Possessive***	Possessive gesture toward an association between others, by targeting an individual or interfering with the association.
		spcl(type)	Polyadic configuration such as Agonistic Buffering, Saving Face, Enlisting for Support, and Agonistic Intervention on behalf of another

In behavioral sampling (e.g., Altman, 1974) proximity dynamics are often recorded using embedded point sampling (ibid) in parallel to continuous tallies of other interaction types. In contrast, by incorporating movement and visual coordination data (ASOC states) sequentially into the behavioral 'stream', along with other interaction types, I produced *continuous* chains as data structures that have association dynamics 'built in'. In doing so I can refrain from using proximity as an added dimension (see Altmann's quote opening the chapter).

Data Structure: State – Triadic ACTOR Combinations

States are also characterized by a particular triadic MFI configuration, as summarized in Table 4.3b below. As with State-TYPE, three levels of resolution (2-ACTOR, 5-ACTOR and 8-ACTOR) allow lumping and splitting as appropriate.

Table 4.2b: MFI Triadic Subjects – Actor Combinations. Three (x8, x5, x2) levels of resolution in focal actor-combination distinctions: configurations determined by finest (x8) resolution, yet most tallies and transitions analyses presented here are at x4 or x2 resolution.

Focal Actor Combinations			***Male in interaction with the focal...***
2-Actor	***X5***	***X8***	
M-F	***m-fml***	***m-fml***	female, before giving birth
	M-F	***m-f***	female on her own
	M-FI	***m-fi***	female-infant in physical contact
		m-f,i	female and infant in close proximity
M-I	***M-IF***	***m-if***	infant, in physical contact with female
		m-i,f	infant in close proximity to female
	M-I	***m-i***	infant on its own
		m-(i)	infant, after being left w/male by female

By identifying triadic subjects I push against the dyadic depiction of social interactions in Hinde's model.

Data Structure – Composite States (TYPE X ACTOR)

Each MFI triadic state is identified simultaneously by its TYPE (Table 4.3a) and by its ACTOR combination (Table 4.3b). If so maintained, analysis of sequential connections between *types* of interaction would remain separate of the examination of sequential connection between *actor* combinations, straining the assessment of interdependence between them. Gottman & Roy (1990) recommend combining features so that sequential connections could be made relevant to both. In such a *composite scheme*, a type of interaction (e.g., greeting "GRT") by one of the actor combinations (e.g., male interacting with female-infant as a unit, "m-fi") is a single composite state, so that a change in either TYPE or ACTOR signifies a transition to a different state. Multiplying the number of actors by state types provides the number of possible composite states in this system. The tradeoff is immediately apparent: 8 actor combinations and 11 state types produce 88 possibilities which would reduce the number of observations in each category. The levels of differentiation for each feature provide alternative composite schemes. In Table 4.2c I show the composite states defined by the second level of differentiation in ACTOR and in TYPE, to produce a 25-state *Lumped Composite Scheme*.

Table 4.2c: MFI Lumped Composite States – Type X Actor. A scheme of composite states was constructed in order to treat each state as factoring both type and actor combination. 5 Types X 5 Actors = 25 States

Lumped SCHEME		*as0*	*as1*	*as2*	*gt1*	*gt2*	*pg*	*gm*	*ds*	*ag*	*ps*	*spcl*
		ASOC			***GRT***		***GRM***		***AGON***		***SPCL***	
fml	***fml***	*L1*			*L2*		*L3*		*L4*		*L5*	
f	***F***	*L6*			*L7*		*L8*		*L9*		*L10*	
fi	***FI***	*L11*			*L12*		*L13*		*L14*		*L15*	
f,i												
if	***IF***	*L16*			*L17*		*L18*		*L19*		*L20*	
i,f												
i	***I***	*L21*			*L22*		*L23*		*L24*		*L25*	
(i)												

Bakeman & Gottman (1997:24) advocate "using coding categories that represent a somewhat more molecular level than the level planned for analysis…" since, among other things, it may end up revealing distinctions not anticipated at the outset of the analysis.

<u>Data Structure: Chains & State-Transitions:</u>

Temporal structure in this dataset is used in two ways: The longer time-scale of weeks and months of study mark infant age and the peak in the birth cluster (Figure 4.2). For the data structures themselves, however, time is used only to mark the sequence of events, not their duration.

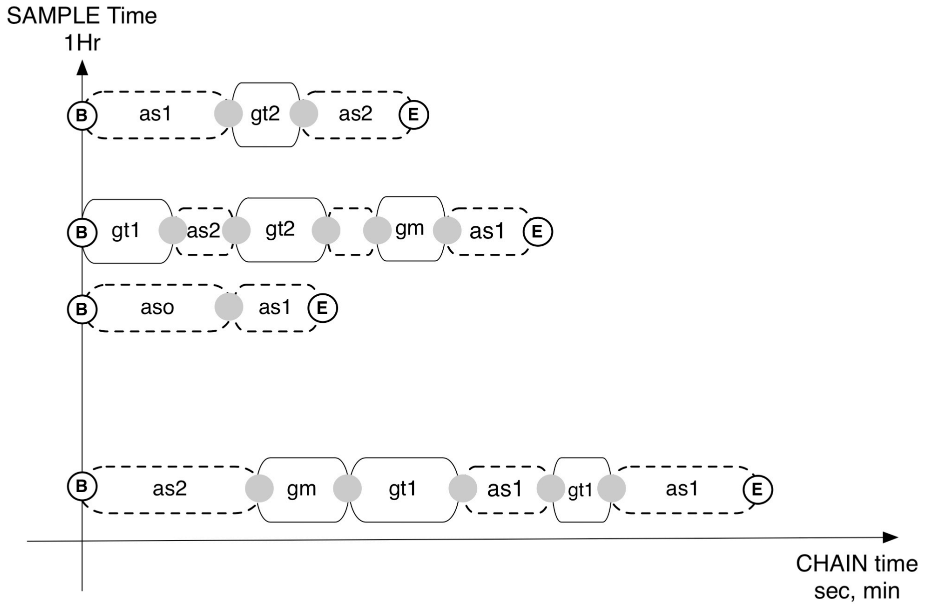


Figure 4.3: MFI Data-Structures – Chains, States & Transitions. Each chain tracked as long as male is in social space with focal subject, gray dots represent the transitions between states. 'B' and 'E' circles represent beginning and end of each chain. For graphic simplicity I label states by TYPE only.

Figure 4.3 shows a schematic of how the chain structure unfolds within each one-hour sample. The gray circles between each pair of states mark the state-transitions. It is customary to add 'begin' and 'end' transitions to mark the boundaries between chains. Beyond the tallies of states and of chains, *tallies of state transitions* can capture possible sequential dependencies not traceable otherwise.

4.2.4 Summary MFI Contextual Design:

Levels of Description, Levels of Analysis & Multiway Contingency Tables

While Table 4.1 presented the potential factors relevant to the MFI study in each of levels of Hinde's model, Table 4.3 below summarizes how and where these factors are represented in this study. It showcases the departure from Hinde's depiction of dyadic interactions and sets the stage for examining *interaction dynamics* in relation to other levels of social complexity. In other words, Table 4.3 attempts to map the *levels of description* available in this study onto the *levels of analysis* (Table 4.1) motivated by Hinde's hierarchical model.

Table 4.3: Complexity AS Context in MFI study. Summary of data structures and cumulative context representations, organized by Hinde's levels to map onto Table 4.1

Hinde's Levels	MFI Context	Representation
Individuals	Triadic subjects: Male, Female, Infant	ACTOR combinations (Table 4.2b)
Interactions	Sequential Chains	STATE types (Table 4.2a) CHAINS & TRANSITIONS (Figure 4.3)
Individuals X Interaction	Composite States as the unit of interaction	ACTOR x TYPE lumped composite scheme (Table 4.2c)
Relationships	Historical Contingency and Association Symmetry: • Male-Female • Male-Infant	Triadic Grid (Figure 4.1b) Relationship Factors (Table 4.5)
Group Structure	Inter-relationship effects: • Female relative rank • Male relative age • Male-male alliances	Subject Pool Matrix (Figure 4.1a)
	Group Context: Birth Cluster	Birth Cluster Infant Coat Color (Figure 4.2)

Multiway Contingency Tables: Sequential analysis proponents (e.g., Bakeman & Gottman, 1997; Gottman & Roy, 1990; Bakeman & Quera, 2011) advocate using *multiway contingency tables (MWCT)* analysis (also known as *log-linear* analysis) to address what they term *cross-referenced events*, where multiple features / factors can be linked to classifiable (i.e., categorical) events or states. Here, every triadic *chain* and every *composite state-transition* within it is cross-referenced by multiple factors, such as its triadic MFI subject, the status assessment of the MFI relations, and marked by when it occurred within the birth-bluster study period.

MWCT analysis is not necessarily a *sequential* technique (see Wickens, 1989) and the shift from the more familiar 2-way to multiway contingency tables (for categorical data) analysis is considered an analog to the shift from multiple t-tests to analysis of variance (for continuous measures, when study factors are categorical). See Wickens (1989: 71-73) for discussion. The evaluation of multiple factors simultaneously in MWCT analysis is similar to the logic of multiple regression analysis-of-variance (where both data measures and the contextual design variables are continuous; see Bakeman & Robinson, 1994). MWCT is thus similar to analysis of variance in that it can identify significant main effects and interactions, or associations, between factors, as well as provide post hoc opportunities to examine standardized residuals of deviant cells.

Exploratory analysis and sample size: These techniques are particularly relevant in exploratory analysis where one of the aims is to *discover* higher-order association effects–between explanatory variables–on patterns in the study data. Not only is the analysis I present exploratory, it is explicitly demonstrative of an *approach to analysis* more than it is a definitive interpretation of comprehensive results. Given the small sample size, especially in the context of multivariate analysis, I am cautious in my interpretation relative to *results* reported in the literature, and rather emphasize the *types of questions* I can ask, and the *type of data-structures* I can deploy in an analysis that attempts to address how interactions, relationships and group structure influence each other.

4.3 MFI Exploratory Analysis

As noted, the goals of sequential analysis (Bakeman & Gottman, 1997; Gottman & Roy, 1990; Bakeman & Robinson, 1994; Bakeman & Quera, 2011) are to examine sequential connection in the data and then assess the effects of contextual variables on these patterns. Yet sequential analysis, considering the added labor entailed in producing such datasets, may not always be the best-suited approach. The exploratory nature of this research–searching for potential contingencies between level of social complexity rather than a targeted testing of specific hypotheses–demands a broader familiarity with general patterns in these data that may help determine if sequential analysis is really necessary, and if so, where might it be directed.

4.3.1 Non-Sequential Analysis: Interaction Rate & Chain Length

(Q1) – Interactions vs. Relationships:

Interaction Rate. Figure 4.4 overlays the interaction rates from study data on the subject pool matrix in Figure 4.1. Interaction rate measures are collapsed into two 3-month blocks matching the time blocks of the subject pool matrix. High, medium, and low interaction rates for female-biased (blue) and infant-bias (red) MFI configurations are shown.

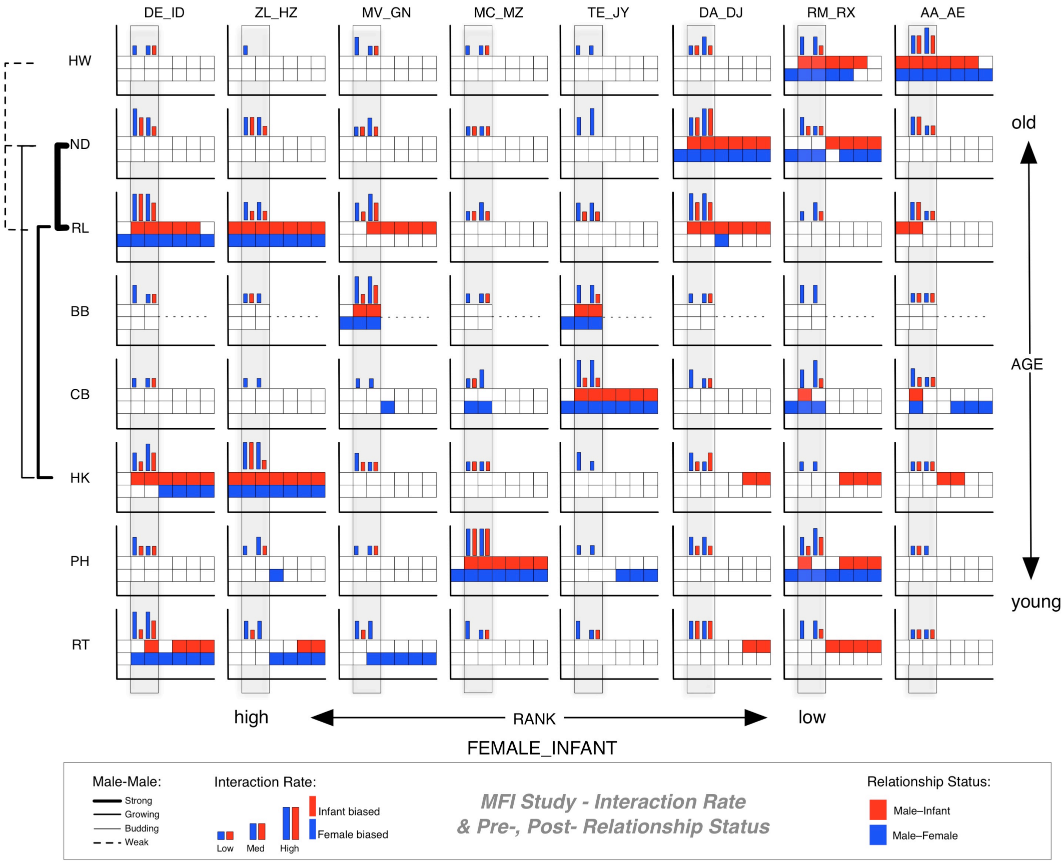


Figure 4.4: MFI Study Triadic Interaction Rates. Rates overlaid on subject pool matrix (Figure 4.1) Female biased and infant biased interaction rates (low, med, high) for two 3-month periods during the study. Even though only 30 of the 64 triads show up in the cumulative context from project record, every triad experienced at least some level of interaction dynamics during the study period.

A quick visual inspection suggests that the intensity of interactions during the 6-month study may indeed match longer-term relationship status assessments. The strongest relationships in terms of their duration and whether they include both male-female and male-infant relations also show a high interaction rate for one or both female- and infant-biased configurations. Yet several triads deviate from this pattern. For example, Male ND shows high interaction rate with both DE_ID and ZL-HZ during the study but not a long-term relationship with either (see more comprehensive comments in Forster & Rodriguez, 2006). Overall, while only 30 MFI triads show relationship assessments, all 64 exhibit at least some level of interaction during the study period. Are there differences in the interaction dynamics during the study that correspond to the longer-term assessments?

Chain Length. Examining overall ***Relations [R]*** status factor (levels: *R=Relations; nR=nonRelations*) shows that the mean chain length for those who have relations is significantly longer than those who do not (*R mean = 2.8, nR mean=1.8, two-sample t-test: t-value = 5.6, p<0.001, df=1154*).

I further distinguish MFI triads who have *Relations (R)* along two dimensions: ***Historical Consistency [H]*** factor (levels: *C=Consistent; iC=inConsistent*) evaluates whether a relationship present *during* a significant portion or all of the study period endured *after* the study ended; ***Association Symmetry [A]*** factor (levels: *S=Symmetric; aS=aSymmetric*) marks parallels between *male-female* friendships and *male-infant* special relationships. Table 4.4 shows the 2-Factor assessment for each of the 30 MFI triads noted as having relations before, during, or in the year after the study period (see Appendix-Table 4A.3 for assignments).

Table 4.4: MFI Relationship Factors – History & Association

***RELATIONSHIP** factors*		***Association [A]***	
	levels	***Symmetric***	***aSymmetric***
History [H]	***Consistent***	*CS*	*CaS*
	inConsistent	*iCS*	*iCaS*

Pair-wise testing reveals that only *CS* (*consistent, symmetric*) relations have significantly longer mean chain lengths than *iCaS* (*inconsistent, asymmetric*) relations (*CS mean=3.25, iCaS mean=2.0, two-sample t=2.98, p~0.003, df=508.*) These measures support the relationship assessments from project records and identify *[R]* and *[H] [A]* as potential *study factors* for MWCT analysis (sections 4.3.3-4).

(Q2) – Interactions vs. Group Structure: Birth Cluster

Interaction Rate. Does the clustering of births (see Figure 4.2) influence the interaction dynamics of MFI triads? Figure 4.5a shows mean interaction rate (per min) for the 8 female-infant pairs collapsed over the whole study. Higher relative-rank seems to correspond to higher interaction rate overall. When spread month-by-month over the study period the stacked graphs in Figure 4.5b show several peaks but no obvious correlation among them. Further Alignment by infant birth-date (Figure

4.5c) suggests an upward (then downward) trend in interaction rate shortly after birth, more clearly seen by pooling these data across subjects (Figure 4.5d). The rise and fall in interaction rate by infant age indicates a peak window between 5 and 15 weeks of age.

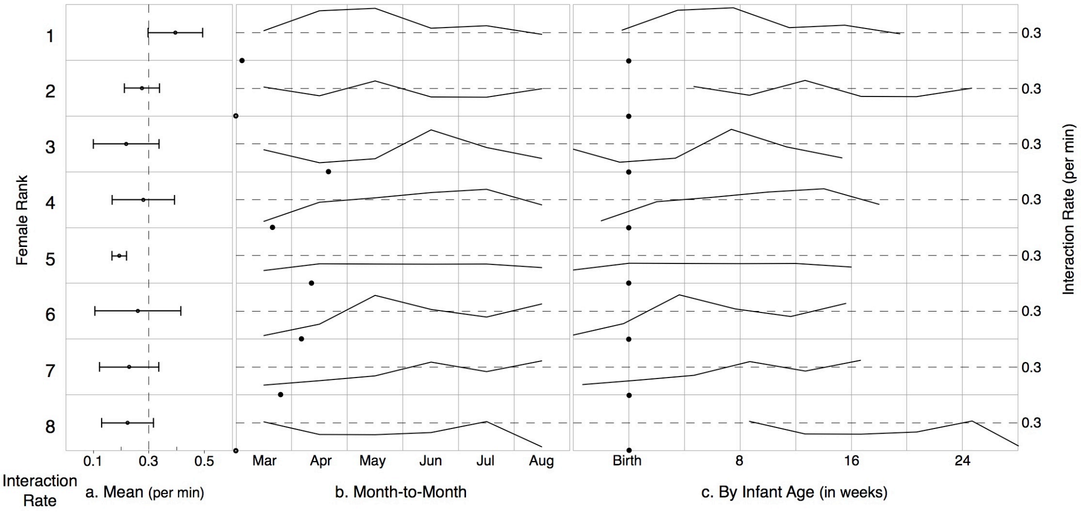


Figure 4.5a-c: MFI Interaction Rate, Female Relative Rank & Infant Age. Triadic interactions (n=2913) over a six-month period (187 hours): 1a. Mean interaction rate (per minute) by female rank (high=1) with one standard deviation error bars. 1b. Stacked line graphs of interaction rate broken down by month – data points placed in middle of each month block; black dots at accurate date-of-birth (infants of females #2 and #8 were present at study outset.) 1c. Study data aligned by infant age (in weeks) (From Forster & Rodriguez, 2006)

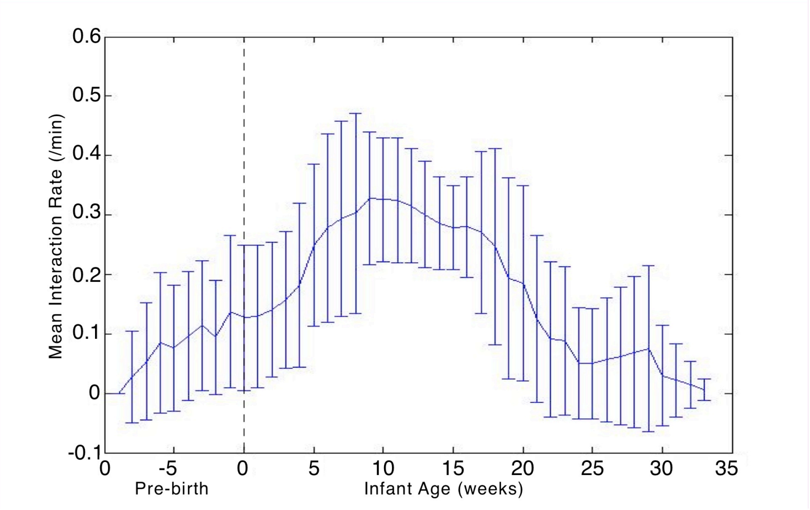


Figure 4.5d: MFI Pooled Interaction Rate by Infant Age (weeks). Mean interaction rate and error bars (one standard deviation) pooled from Fig 4.5c bars by infant age (weeks). Dashed line at 0 weeks of age separates pre-birth data points, from females who gave birth over the first two months of the study.

The age-related pattern represented in Figure 4.5d, however, dovetails the clustering of births in the study period (Figure 4.2). How does the high degree of overlap among infants, growing from two to eight infants in the first 7.5 weeks of the study, affect interaction dynamics?

Figure 4.2 suggest a peak of overlap in ‘black’ infants (n=7) lasting about one month, then staying at n=6 for a total of 10.5 weeks. I identify this period (7, then 6 black infants) as the *Peak (P)* level of the ***Birth Cluster [B]*** factor – and categorize as the *non-Peak (nP)* level all chains when the number of black infants ≤ 5 (the 1.5 weeks of 6 black infants prior to the peak are left out of this analysis).

Chain Length. To examine the maternal ***Relative Dominance [D]*** factor (levels: *Hi=High; Lo=Low*) I assign the 4 top- and 4 low-ranking female-infant pairs, respectively.

Table 4.5: MFI Group Factors – Birth Cluster & Relative Dominance

***Group** factors*		***Dominance [D]***	
	levels	***High***	***Low***
Birth Cluster [B]	***Peak***	*PHi*	*PLo*
	nonPeak	*nPHi*	*nPLo*

Mean chain length did not differ significantly between Peak (P mean=2.4) and non-Peak (nP mean=2.3), nor did it significantly differ between High (Hi) and Low (Lo) relative dominance rank. It is not clear how to interpret the lack of significant difference in chain length between high and low ranking female-infant pairs since it is not a typical measure reported in the literature. Neither is the distinction I am making here within a birth cluster (Peak vs nonPeak). It may be that high-ranking females ‘achieve’ higher *interaction rate* because each encounter is shorter (i.e., shorter chain length). It is also possible that by dividing the female-infant pool in two categories (Hi vs. Lo) rather than using, for instance, two highest ranking vs. two lowest ranking, I am masking the impact rank my have. Similarly, the choice of Peak window (7 then 6 black infants) could be varied. Given the questionable interpretive value of mean chain length, I hesitate to purse many more tests at this point.

From Q1 analysis above we already know that mean chain length is significantly different between MFI triads that had relations (R) and those that did not (nR). Since the Relations *[R]* distinction is a *group* level factor, perhaps it will prove significant between Peak (P) and nonPeak (nP) periods?

Table 4.6: MFI Group Factors – Birth Cluster & Relations

***Group** factors*		***Relations [R]***	
	levels	***relations***	***non-relations***
Birth Cluster [B]	***peak***	*PR*	*PnR*
	nonpeak	*nPR*	*nPnR*

P and nP levels mean chain lengths are not significantly different neither as a main effect, as noted above, nor within *Relations [R]* factor levels (R cases, nR cases). This may be because the birth cluster impact the *types* of interactions or even their *duration* rather than chain length. It may also be because the timeframe chosen masks actual differences in interaction within the study period. The peak of 7 black infants includes samples (n=23 out of 70) of 3-4 infants prior to the 5-week cut-off suggested by Figure 4.5d. Yet it is important to chose a group variable that had somewhat independent relevance, i.e., the visibility of coat color, rather than circularly representing age. Perhaps overarching is the small sample size of this data set and the possibility that individual variation masks any differences between these factors. The exploration of group level study factors is, nevertheless, an important feature of this approach.

<u>Summary Non-Sequential Analysis:</u>

The cursory look at a couple of basic nonsequential measures begins to suggest relevant "explanatory" variables, more clearly in the context of *Relational History [H] & Association Symmetry [A]* than with the impact of the *Birth Cluster [B]*. The visualization of interaction rate overlaid on the subject pool matrix (Fig 4.4), and the line graph of interaction rate vs. infant age (Fig 4.5d) raise intriguing possibilities regarding these study factors that warrant further analyses. Yet so far in this analysis interactions are assumed to be independent of one another. In addition, using only *mean length* of the triadic *Chains* masks the potential impact of their TYPE and/or their ACTOR combination on actual transitions between the *Composite States* that make up these data structures (Section 4.2.3). Might *sequential analysis* reveal additional dependencies?

4.3.2 Sequential Analysis - Study Data: Order/ Independence & State Transitions

Figures 4.6a-b presents two *state-transition diagrams,* visually summarizing the 1st order, or lag-1, transition frequencies of states by *TYPE* (Figure 4.6a) and by *ACTOR* combination (Figure 4.6b). TYPE and ACTOR state transition are diagramed separately since a state-transition diagram of *Composite States* (Table 4.3) would have too many states, some with too few observations, and would be challenging to represent visually. See Appendix Tables 4A.4a-b, Figure 4A.1, Tables 4A.5a-b – for data tables of observations, proportions, and tests of independence on state-TYPE. State-ACTOR would follow identical procedure.

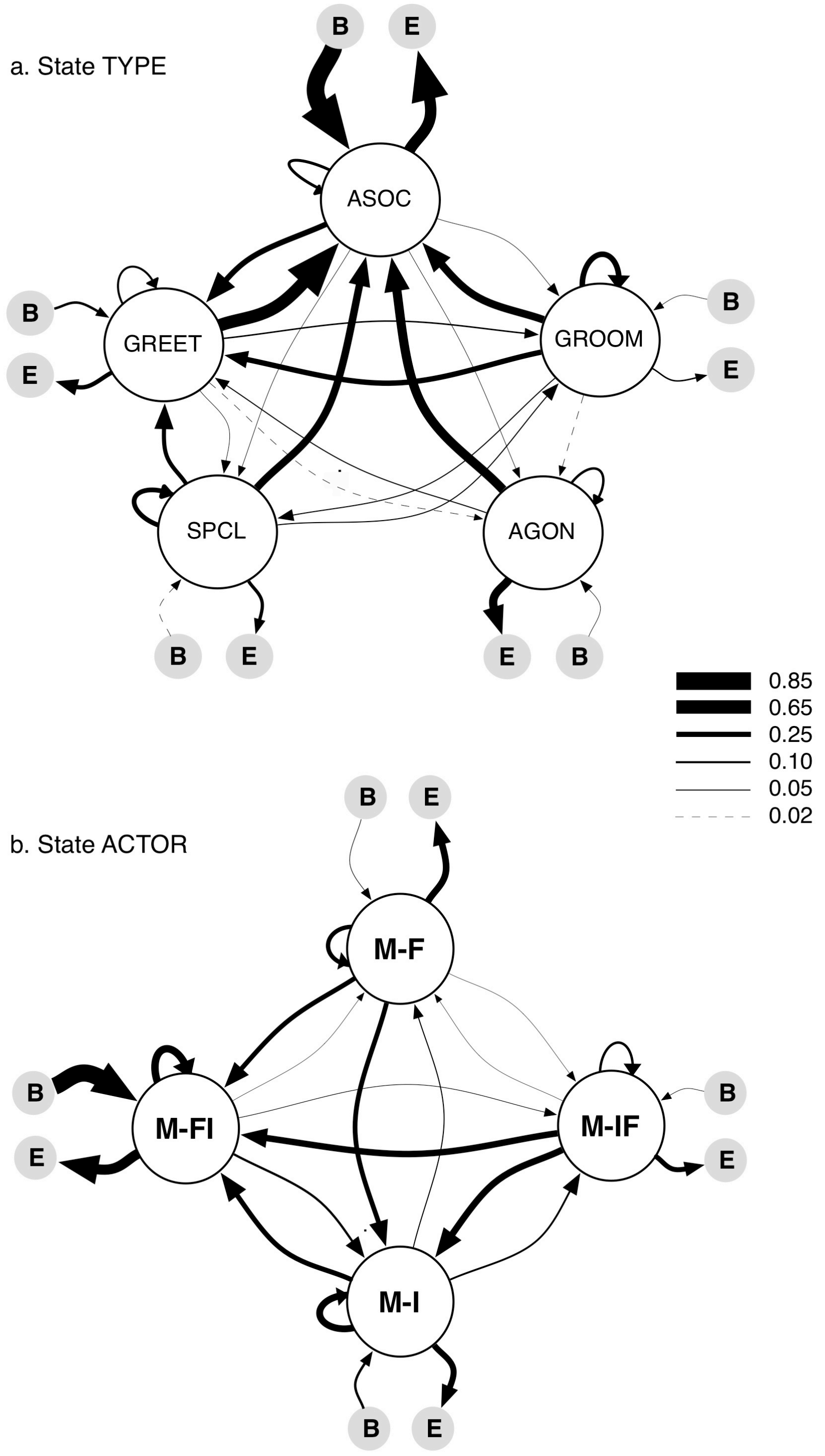


Figure 4.6a-b. MFI TYPE (above) and ACTOR (below) State Transition Diagrams. Proportional transition frequencies are expressed graphically by the thickness of arrows – proportional to their magnitude as specified in the legend.

Independence, or lag-0, is most commonly tested with Pearson chi-square statistic on a 2-way contingency table that tallies observations FROM (previous state) in rows TO (current state) in columns (see Appendix – Table 4A.4a-b). The χ^2 value for both tables is hugely significant, as the visual inspection of the state-diagrams already attests to. If the states were independent of one another we would expect to see line-thickness 'leaving' each state to be more evenly distributed.

Given the significant difference between Lag-0 and Lag-1, interpreted as reducing uncertainty of the next state, higher order dependencies are typically dropped from the analysis since it would be difficult to separate their effect from the already significant impact of Lag-1.

A visual inspection of Figure 4.6a suggests ASOC state as a strong attractor region since it shows the largest proportion (see line thickness) of the transitions from any other TYPE in the state space. In addition, ASOC and GRT have the strongest two-way transitions. Of all the states except for ASOC, GRT has a bigger proportion of chains starting directly with it (from 'begin' to GRT), which means that some of the GRT interactions do not require ASOC as a prelude. Yet once within GRT, the most likely transition is to ASOC, in greater proportion than from other states. Similarly, Figure 4.6b, shows M-FI and M-I ACTOR combinations to "attract" transitions from other ACTOR states in higher proportions and have stronger two-way transitions between them than any other pair. Only four of the 5-ACTOR combination categories are represented since 'fml' chains (from the pre-birth period) could not transition, within themselves, to other ACTOR states.

Given the general thrust of the MFI study, and the expectation that the study period has relevance to the establishment of male-infant special relationships, it may seem surprising that the M-IF ACTOR-state is not being more frequently transitioned to, since it represents interactions in which the male differentially targets the infant on, or in close proximity to, its mother. It is possible, given the definition I used (see Table 4.3a) that the M-FI category masks some of the interactions that are more infant-oriented but are just not discernable as such given the close physical proximity between mother and infant (surprisingly, this issues receives potential clarification in the MWCT analysis, with regard to the Birth Cluster, in Section 4.3.4).

Overall, while these patterns are suggestive, the goal of the analysis is to examine the impact of study factors on the *composite state* transitions. Since the different state-TYPES and state-ACTOR combinations are indicating the same data points, the repetition of further analysis just by TYPE and then just by ACTOR masks the dependencies between them.

4.3.3 Sequential Analysis – Study Factors: Effect on FROM / TO Transitions

The cursory dipping into the two study questions via simple measures such as interaction rate and mean chain length are suggestive enough to raise many more questions that would result in a cascade of 2-way significance tests, or contingency tables–for classification data such as TYPE or ACTOR states or for measures such as CHAIN length, examined by study factors such as [R], [H], [A], [B], [D])–a cascade that very rapidly becomes difficult to interpret. Such a series of 2-way significance testing may miss higher-order interactions or association effects (Wickens, 1989), which this investigation into *levels of social complexity* is particularly interested in. “Even when the data can ultimately be collapsed to a two-way test, the pattern of association should be considered in its fuller form first “ (Wickens, 1989:2-3)

Yet the non-sequential exploration and the lag-1 state transition diagrams provide a critical first pass of the study data that is suggestive in a number of ways: Interaction dynamics during the study period may indeed correspond to the longer term male-infant special relationships and male-female friendships (*Historical Consistency [H]* factor), and even to the differentiation between them (*Association Symmetry [A]* factor).

The impact of the *Birth Cluster [B]* factor is more ambiguous although it is clear that infant age and interaction rate are highly correlated, and that relational status may also be important. Can we find association or interaction effects between *Relations [R]* status (*R vs. nR)* and the *Birth Cluster [B]* periods (*P vs. nP*) in the troop that manifest in the interaction dynamics (i.e., the FROM/TO composite state transitions), which did not show up in mean chain length?

The Lag-1 sequential connections depicted in the state-transition diagrams (Figures 4.6a-b) provide additional insight into the dynamics of interaction, flagging particular state transitions. For *TYPE-states**:** begin-to-ASOC*; *ASOC-to-GRT*; *GRT-to-ASOC*; *ASOC.-to-end.* Transitions of interest for

*ACTOR-states***:** *begin-to-M-FI*; *M-FI-to-M-I*; *M-I-to-M-FI*; *M-FI-to-end.* In the *composite states* of the *Lumped SCHEME* (Table 4.2c) these translates into transitions between states: *0(begin); L10; L11; L21; L22; 26(end)*. Table 4.7 identifies these transitions, subsets of which will appear in the MWCT analysis below.

Table 4.7: Composite Transitions of Interest. ‘*m*’ for “male” is omitted since it is redundant to all cases

FROM	***TO***
begin	*fi-ASOC*
	fi-GRT
	i-ASOC
	i-GRT
fi-ASOC	*fi-ASOC*
	fi-GRT
	i-ASOC
	i-GRT
	end
fi-GRT	*fi-ASOC*
	i-ASOC
	i-GRT
	end
i-ASOC	*fi-ASOC*
	fi-GRT
	i-ASOC
	i-GRT
	end
i-GRT	*fi-ASOC*
	fi-GRT
	i-ASOC
	i-GRT
	end

MWCT, or Log-Linear, Analysis:

Using ILOG3 (Bakeman & Robinson, 1994; Bakeman & Quera, 2011), the cells in the multiway contingency table I used consist of transition counts of lag-1, or FROM [F] /TO [T] factors, from the MFI pooled dataset of composite triadic chains. The contextual design determines how the subset timetables for each multiway factor are constructed. The major concern is with the limited number of transitions counts in each cell once the timetable is divvyed up by particular study factors (see comments on lumping below). The multiple factors, and the multiple levels within each factor, produce a huge number of possible models to test for independence relative to the observed timetable.

Expected Frequencies in MWCT cells are calculated and summarized with a likelihood ratio $\boldsymbol{LRX^2}$ or $\boldsymbol{G^2}$ statistic, produced for each model,

$$G^2 = 2\sum_i (observed)_i \log \frac{(observed)_i}{(\exp ected)_i}$$

The expected counts are calculated using an ***Iterative Proportional Fitting*** (IPF) algorithm (Gottman & Roy, 1990; Bakeman & Rosenblum, 1994). As noted the number of possible models generated is too large to be exhaustively examined, and a separate G^2, degrees of freedom, and significance probability, are calculated for each model. The challenge of a MWCT analysis is to develop a principled approach to selectively examine for models that parsimoniously fit the patterns in the observed data (see recent example .

Model Fitting: Gottman & Roy (1990) note "the goal of model fitting is to find a *simple and interesting model* that fits the data, in other words, that produces a non-significant *chi square* which in not significant because the model provides a good approximation to the table." Gottman & Roy (1990) and Bakeman & Robinson (1994) review several procedures, the most common of which is to evaluate a series of models arranged in a *nested hierarchy*, starting with the observed data (the *saturated model*), deleting terms with each step. When looking at such a nested hierarchy, the difference between the G^2 and degrees of freedom of two adjacent models can provide an assessment of the significance of the deleted term in the fuller model (Gottman & Roy, 1990: 128). The organization of the hierarchy may be theory driven, or it may represent a systematic attempt to examine association between factors by decreasing levels (e.g., in a 4-way table, deleting the 4-way term, then all 3-way terms, then all 2-way terms, etc.). These procedures are particularly advantages in exploratory analysis that aims to *discover* higher-order association effects that may produce testable hypotheses for further research.

Inspection of Deviant Cells (post hoc): In a model that is rejected a cell-by-cell inspection can reveal the cells that are *'ruining the fit'*. This could be because these cells represent outliers, or because they represent the influence of a term that should not be removed from the rejected model if it is to fit the observed data. The cell-by-cell inspection is carried out on the *adjusted residuals* in order to take into account the effects of the cell counts that produced the residual differences. In such an inspection attention to specific transitions may be theoretically motivated, or a result of prior analysis. The 'flagged' lag-1 transitions from the state-transition diagrams (Figure 4.6a-b), summarized in Table 4.7, will be of special interest in the MFI MWCT analysis.

Lumping, Splitting, and Cleaning Model Data: In sparse contingency tables where many cells are empty or have only few observations lumping into grosser categories is in order. The general rule of thumb Bakeman & Gottman (1997) suggest is to aim for 5 times the number of observations than the number of cells in the table. In addition, it is recommended not to allow more than 20% of the cells to have expected counts less than 5. Responding to these constraints requires lumping finer distinctions into fewer categories. Some cells may be valid 'structural zeros' – cells that represent impossible transitions (such as 'from x-to-begin' or 'from end-to-x' or the diagonal cells in a time table that cannot have the same state follow itself). In some cases, where low-count cells cannot be lumped or removed, or when they seem to be outliers, they can be declared as 'structural zeros' and a repeat analysis could determine if this change produced a significantly different G^2.

For the MFI MWCT analysis the clean up involved several steps: removing the pre-birth chains (n= 93; composite states *L1-L5*), and lumping the rare SPCL, AGON and GRM states into a catch all OTHER (*L9*) state. This process leaves ***FROM [F]*** and ***TO [T]*** factors having 9 levels each (*L9, L11, L12, L16, L17, L21, L22*; with *L0* and *L26* as *begin* and *end, respectively.*)

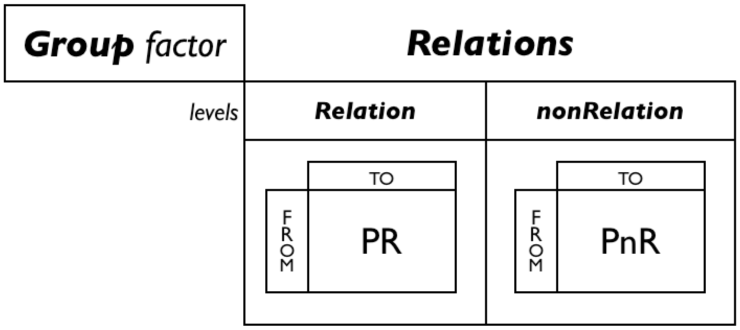
Grooming interactions are of central focus in relationship and interaction studies (but see Cords, 1997, for contrasting view on their significance), and yet they were not common enough in this dataset to include as their own category. An attempt to run a MWCT analysis that included GRM states but lumped across ACTOR (i.e., one category that would include composite states *L8, L13, L18,* and *L23*) still left too many empty cells for the analysis to be of any inferential value. The reasons for the relative rarity of the grooming interactions in this dataset are not clear. It is interesting to consider the impact of the birth cluster on interaction dynamics. If males may be trying to engage more triads (and we see all males engaging all triads at least minimally), they may be trading off the extra time and effort (and familiarity) grooming interactions require. These queries are beyond the specific data set extracted for this analysis.

4.3.4 MWCT Q1: Interactions vs. Relationships.

For this question, I repeat the two-step mean chain length comparison, this time looking at study factors effects on TO/FROM state transitions (see Table 4.8a & Table 4.9a)

Q1A: Relations [R] effect on Composite State transitions FROM [F] TO [T]

Table 4.8a: MWCT scheme for FxTxR (9x9x2) 3-way table



<u>Model Fitting FxTxR (9x9x2):</u> Table 4.8a illustrates the kind of nested hierarchy produced by the ILOG3.0 program when no specific selective direction is provided. The hierarchy removes terms by decreasing level from higher order, saturated model, downward although the order *within* each level (2-way terms, steps 3-5; 1-way terms, steps 6-8) in this case is arbitrary. Step6 to Step8 (from 1-way terms to the empty [0] model) do not make much sense to include. Bakeman & Robinson (1994) recommend choosing a 'base' model that fits the research design and questions, and then search for an accepted model somewhere between the base model and saturated model.

Base Model [FT][R]: In this case the logic of lag-1 transitions represent inherent *FROM [F]*- and *TO [T]* factor dependencies, and would make it difficult to interpret models in which [F] or [T] were separated out or attached differentially to the third factor. It therefore makes sense that a base model would include the joint term [FT] because it has the basic F/T transitions, and includes the [R] factor, which accounts for base rates of R and nR (i.e., total number of transitions) *but not* any other 2-way or 3-way association terms.

Step3 in Table 4.8b supports the notion that [FT] is an important term, since when it is deleted the model is rejected.

Table 4.8b: MWCT Nested Hierarchy of Models for FxTxR (9x9x2) 3-Way Table

Step	*Model*	$G^2\leq$	*df*	*~p*	*Deleted*	$\hat{}G^2\leq$	*^df*	*~p*
1	[FTR]	0.0	0	1.00	--			
2	[FT][TR][FR]	25.3	17	.09	FTR	25.3	17	0.09
3	[TR][FR]	1436	43	<0.01	FT	1410.7	26	<0.01
4	[FR][T]	1624.8	49	<0.01	TR	188.8	6	<0.01
5	[T][F][R]	1715.8	55	<0.01	FR	91	6	<0.01
6	[F][R]	4557.6	62	<0.01	T	2841.8	7	<0.01
7	[R]	6097.4	69	<0.01	F	1539.8	7	<0.01
8	[0]	12381.1	70	<0.01	R	6283.7	1	<0.01

Table 4.8c, therefore, may be a more economical way to represent the relevant model space for FxTxR. Step 2 shows that even when deleting the 3-way term, the model still fits the data (*p~0.09.*) Step3A examine the base model, which is also rejected. Step 3B is just a repeat of Step 3 in Table 4.8b, showing the importance of the [FT] term when it is the first to be deleted from the model in Step 2. Removing the 3-way term [FTR] (Step 2) leaves a model with all 2-way interactions (which includes all simpler terms in it, even if they are not written out.) Step 2 presents a model that is simpler than the saturated model and yet does not differ from it significantly, and so still fits the observed patterns.

Table 4.8c: MWCT Model List by Levels for FxTxR (9x9x2) 3-Way Table

Step	*Model*	$G^2\leq$	*df*	*~p*	*Deleted*	$\hat{}G^2\leq$	*^df*	*~p*
1	[FTR]	0.0	0	1.00	--			
2	[FT][TR][FR]	25.3	17	0.09	FTR	25.3	17	0.09
3A	[FT][R]	109.9	29	<0.01	FR TR	84.6	12	<0.01
3B	[TR][FR]	1436	43	<0.01	FT	1410.7	26	<0.01

In sum, I fail to reject the model in Step 2, [FT][TR][FR], and accept it as the most parsimonious option, although it is difficult to interpret factors [TR] and [FR] in phenomenological terms. Step 3B demonstrated the significance of the [FT] term, and Step 3A examines removal of the other 2-way terms in order to evaluate the base model.

Post-hoc Deviant Cell Inspection of Base Model [FT][R]:

How does this rejected model (Table 4.8c, Step 3A) compare with the models that do fit the observed data? Table 4.8d summarizes the subset of cells with significant *adjusted residuals* (measured at ≥≤ +/- 2.5, or three standard deviations, for $p \leq 0.01$) for the *Relations [R]* factor (R vs. nR levels). The corresponding cells are either significant (in bold) or very close to +/- 2.5 (in parentheses).

Table 4.8d: Adjusted Residuals for Base Model [FT][R]

Line	***FROM***	***TO***	***R***	***nR***
1	*begin*	*fi-ASOC*	(-2.44)	**3.05**
2	*fi-ASOC*	*i-GRT*	**2.47**	**-3.09**
3		*end*	(-2.40)	**3.00**
4	*i-GRT*	*fi-ASOC*	**2.71**	**-3.39**

The adjusted residuals in the rejected model show a consistent reversal of sign between Relations (R) and non-Relations (nR). Where one shows more than expected significant, or near-significant, values, the other shows the reverse, suggesting that this categorization (R & nR) with respect to these transitions may reflect a valid distinction.

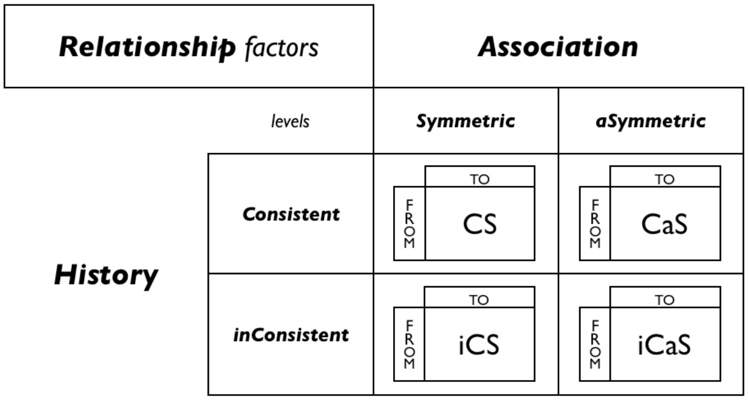
Relations (R) triads are more likely to transition from fi-ASOC to i-GRT (Line2) and from i-GRT to fi-ASOC (Line4) reinforcing the notion of an ASOC-GRT-ASOC loop in Figure 4.6a, especially directed at the infant, while associating with the female-infant together. In contrast, nonRelation (nR) triads are more likely to start chains by associating with the female-infant (Line 1) *and* more likely to end chains from such associations (Line 3) but much less likely to greet the infant on its own (Line 2), or remain in association after greeting (Line 4).

Traditional studies that look at proximity in terms of percentage of time spent within a specified distance, find males who have relations with females and infants also spend more time with them (e.g., Packer, 1980; Altmann, 1980; Smuts, 1985 using Nicholson's 1982 data, etc.). *Percentage of time in proximity*, however, is a different window into interaction dynamics than the *lag-1 transitions* in the analysis presented here. Thus nR triads who are *more* likely to *begin* and *end* chains with fi-ASOC (Line 1 and Line 3) than R triads may actually reflect *less* familiarity with one another. When present together with the reverse pattern in *transitions* from ASOC-to-GRT and GRT-to-ASOC (Line 2 and Line 4) it may reflect more directly the *increased ease* with which triads who have a relational history negotiate affiliative behavior (see Smuts, 2002, for similar argument on greetings between adult male-baboons).

It is important to exercise considerable caution regarding the validity of inferences based on particular deviant cells in a *rejected* model. From the perspective of log-linear analysis one can only say that the terms *missing* from this base model (perhaps association effects between R or nR with [FT]) would have *estimated the observed cell count* better. Yet the fact that R vs. nR adjusted residuals show *consistent* reversal of significant values could motivate generating testable hypotheses for further research, as well as encourage pursuing further MWCT analysis regarding *Historical Consistency [H]* and *Association Symmetry [A]* factors in the 30 MFI triads within the Relations (R) level.

Q1B: Historical Consistency [H] & Association Symmetry [A] effect on Composite State Transitions [F][T]

4.9a: MWCT Scheme for FxTxHxA (9x9x2x2) 4-Way Table



***Relationship** factors*		***Association***	
	levels	***Symmetric***	***aSymmetric***
History	***Consistent***	TO FROM CS	TO FROM CaS
	inConsistent	TO FROM iCS	TO FROM iCaS

<u>*Model Fitting FxTxHxA (9x9x2x2):*</u> The first three steps depicted in Table 4.9b demonstrate that even after removing 4-way terms and all 3-way terms a model of all 2-way terms is much simpler than the saturated model but still fits the observed pattern. In steps 4A-6A and then again in steps 4B-6B I show two sequences of removing three 2-way terms to examine their differential effect on the model in Step3. More specifically, for this analysis, I am interested in association effects *between* Historical Consistency [H] and Association Symmetry [A], and therefore focus on the 2-way term [HA]. As before, I consider the dependency between FROM [F] and TO [T] in the 2-way term [FT]. Deleting [HA] from the model in Step3 suggests that its inclusion is significant, the *difference* in G^2 is 197, and it is significant at $p<0.01$, yet continuing to remove [HF] and then [HT], the models are still rejected, but the *differences* (the 3 right hand columns in Table 4.10a) with adjacent levels are not.

Similarly when I go back to Step 3 and begin (Step 4B) to remove 2-way terms by deleting [FT] – it again suggests it is significant to the model. Does this mean that both [FT] and [HA] are necessary?

Table 4.9b: Nested Hierarchy for FxTxHxA (9x9x2x2) 4-Way Table

Step	*Model*	*$G^2\leq$*	*df*	*~p*	*Deleted*	*^$G^2\leq$*	*^df*	*~p*
1	[FTHA]	0.0	0	1.00	--			
2	[FTA][FTH][FAH][TAH]	0.0	0	1.00	FTAH	0.0	0	1.00
3	[FT][TA][TH][FA][FH][HA]	11.9	15	0.69	FTA FTH TAH FAH	11.9	15	0.69
4A	[FT][TA][TH][FA][FH]	208.9	16	<0.01	HA	197	1	<0.01
5A	[FT][HT][AF][AT]	213.9	20	<0.01	FH	5	4	0.29
6A	[FT][AF][AT][H]	225.3	24	<0.01	TH	11.4	4	0.02
4B	[FH][FA][TH][TA][HA]	693.2	35	<0.01	FT	681.3	20	<0.01
5B	[FH][FA][TH][HA]	770.4	39	<0.01	TA	77.2	4	<0.01
6B	[FA][FH][AH][T]	775.7	43	<0.01	TH	5.3	4	0.26

The model in Step 3 includes all 2-way terms, presenting the most parsimonious option that cannot be rejected.

*Post-hoc Deviant Cell Inspection of base model [FT][H][A]***:**

Analogous to the previous analysis I select a naïve model [FT][H][A] in order to capture the FROM/TO [FT] basic dependency and the presence of [H] and [A] factors, in terms of the total transition counts (C, iC levels) and (S, aS levels), respectively, but not any 2-way or higher order associations between them. This model was rejected (G^2*=336.7, p <0.01, df=32.*)

Table 4.9c: Adjusted Residuals (≥≤ +/-2.5) for Base Model [FT][H][A]

Line	*FROM*	*TO*	*CS*	*CaS*	*iCS*	*iCaS*
1	*begin*	*fi-ASOC*	(1.96)	**-3.3**	**-5.12**	**8.59**
2		*i-ASOC*			(-2.13)	**4.44**
3	*fi-ASOC*	*fi-ASOC*		**-2.58**		
4		*fi-GRT*	**2.6**	**-3.59**		
5		*i-GRT*	(2.34)	**-3.44**		
6		*end*	(2.22)	**-3.00**	**-5.14**	**7.46**
7	*fi-GRT*	*fi-ASOC*	**2.57**	**-3.1**		
8		*end*				**3.01**
9	*i-ASOC*	*end*			(-2.22)	**3.47**
10	*i-GRT*	*fi-ASOC*		(-2.31)		

The significant (and almost significant) adjusted residuals of the rejected naïve model are shown in Table 4.9c. As noted above, these values are not a direct reflection of the actual phenomena, but we could see the consistency within each category in the directionality of the values (either all positive or all negative). Consistent Symmetric (CS) triads are the only ones that show more than expected 'male-fi-GRT to male-fi-ASOC' transitions (Line7) indicating the ASOC-GRT-ASOC loop. Consistent asymmetric (CaS) triads show the opposite directionality suggesting that the difference between then and CS triads may have to do with the symmetry in the association [A], rather than the historical consistency [H]. Inconsistent asymmetric (iCaS) triads show much higher adjusted residuals to beginning and end of chains (Lines 1,2,6,8,9), suggesting they may more accurately "belong" to the nonRelations (nR) level of the [R] factor.

Summary: Q1 Relations [R], Consistency [H] & Symmetry [A]:

The patterns suggested from the non-sequential analysis (interaction rate and chain length) received further support and an additional level of scrutiny / nuance from the MWCT analysis. Even though all 64 MFI triads had some level of interaction during the study period, those who had any relationship status at all showed complementary patterns in the deviant cell inspection of the relevant naïve (base) model. Interaction dynamics during the study period do reflect association effects between *historical consistency [H]* and *association symmetry [A]*. When no association between them is allowed, like in the naïve case, the model is rejected.

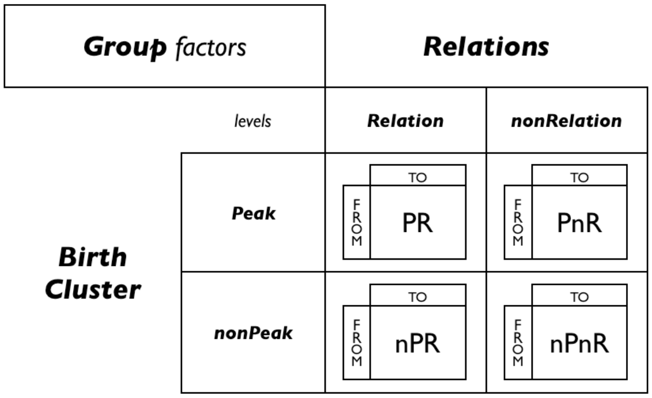
The ASOC-GRT-ASOC loop registers MFI triads in Relations (R), and even within (R) it stands out in consistent/symmetric (CS) triads. Does this pattern suggest that the long-term specificity in relationships might emerge from a simple 'rule-of-thumb' that supports 'sticking around' *after* affiliative behavior? This notion offers the intriguing possibility that lag-1 transitions represent a crude but relatively direct proxy to 'what next?' decision making patterns in establishing and maintaining longer-term relationships (see discussion, and Barrett et al., 2003). Larger sample sizes are needed so that the finer distinction in association dynamics can be made. For example, state-TYPE "as1" which defines association dynamics with visual monitoring compared with "as2" state, which also involves coordinated activity, may be relevant to the association dynamics that differentially contribute to long-term relationships. Nevertheless this analysis showcases the potential of *sequential structure* in revealing higher-order associations between successive levels of social complexity.

4.3.5 MWCT Q2: Interactions & Group Structure –

Birth Cluster [B] & Relations [R] effect on Composite FROM/TO transitions [F][T]

A MWCT analysis of *Birth Cluster [B]* and *Dominance Rank [D]* factors (FxTxBxD) did not produce any significant results. Even though *Relations [R]* factor applied to the *Birth Cluster [B]* factor did not produce significant differences in mean chain length (see section 4.3.1) *[R]* seemed to be an important factor on its own both with regard to mean chain length as well as in its effect on FROM/TO transitions using MWCT analysis (Q1) in the previous section.

Table 4.10a: MWCT Scheme for FxTxBxR (9x9x2x2) 4-Way Table



As noted in the non-sequential analysis, ***Birth Cluster [B]*** factor identified two levels: a *Peak (P)* level of the birth cluster is restricted to the period of the study in which 7 and then 6 black infants were present in the troop. The *nonPeak (nP)* level includes all chains with 5 or less black infants present in the group.

<u>Model fitting: FxTxBxR (9x9x2x2):</u>

Table 4.10b: MWCT Nested Hierarchies for FxTxBxR (9x9x2x2) 4-Way Table

Step	*Model*	*$G^2\leq$*	*df*	*~p*	*Deleted*	*$\hat{}G^2\leq$*	*^df*	*~p*
1	[FTBR]	0	0	1	--			
2	[FTB][FTR][FBR][TBR]	9.7	0	1	FTBR	9.7	0	1
3	[FT][FB][FR][TB][TR] [BR]	50.1	49	0.43	FTB FTR FBR TBR	40.4	49	0.8
4A	[FB][FR][TB][TR][BR]	1198.8	71	<0.01	FT	1148.7	22	<0.01
5A	[FB][FR][TR][BR]	1207	77	<0.01	TB	8.2	6	0.22
4B	[FT][FB][FR][TB][TR]	50.4	50	0.46	BR	0.3	1	0.6

Models that include all 2-way associations are still not significantly different from the saturated model. While the hierarchy in Table 4.10b suggested that further removing [FT] causes the model to be rejected, thereby suggesting that [FT] association effects are important, step 4B suggested that removing [BR] from a model with all the 2-way interactions (step 3) does not significantly change, so that [BR] association effects may not be critical. Yet the base model [FT][B][R] is rejected (G^2=134.5, rejected at p<0.01 with df=70,) suggesting that an inspection of deviant cells may still offer insight into these factors impact on FROM/TO transitions.

Post-hoc Deviant Cell Inspection Base Model [FT][B][R]:

Table 4.10c: MWCT Adjusted Residuals (significant≥≤+/-2.5) **for Base Model [FT][B][R]**

Line	*FROM*	*TO*	*PR*	*PnR*	*nPR*	*nPnR*
1	*begin*	*fi-ASOC*		(2.26)		
2	*fi-ASOC*	*fi-ASOC*			**2.74**	
3		*i-GRT*	(1.86)	**-3.28**		
4		*end*				(1.96)
5	*fi-GRT*	*fi-ASOC*		(-2.21)		
6	*if-ASOC*	*i-GRT*	**2.77**		**-2.64**	
7	*i-GRT*	*fi-ASOC*				(-1.99)
8		*if-ASOC*	(2.10)		(-2.00)	

The significant adjusted residuals (i.e., those contributing the most to the poor fit of this model) in Table 4.10c show that Relations [R] factor may have the most impact, since only within R level of [R] there is a relevant difference in [B]. In other words it helps best to compare PR vs. nPR columns: For (R) triads, it seems, there is a clear shift in pattern between (P) and (nP) periods. While the Peak (P) period is marked by almost significant larger than expected values in ASOC-GRT-ASOC loop (Lines 3,6,8), in the nonpeak (nP) period R triads 'switch' to larger than expected values in the self-transition that remains in association with the female-infant.

Perhaps even more importantly, Line6 represents the *only* case where a non-flagged transition (from male-if-ASOC to male-i-GRT) shows up as significant. In the context of the ACTOR-state transition diagram in Section 4.2, I noted the expectation that M-IF ACTOR-state would be more frequently transitioned to, since it represents interactions in which the male differentially targets the infant on, or in close proximity to, its mother. I suggested that perhaps the M-FI category masks some of the interactions that are more infant-oriented but are just not discernable as such given the close physical proximity between mother and infant. It is intriguing, therefore, that the R triads during the peak P period actually register significantly higher than expected adjusted residual values in a state transition from a male-if-ASOC (Line 6) to a male-i-GRT state, both singling out differential attention to the infant.

The PnR category is also significantly negative (Line 3) in the transition from ASOC to GRT, raising the possibility that during the peak period, there may be a penalty or cost associated with the closer and more intimate dynamics that are involved in greeting. Here too, a larger sample size would make possible an examination of the distinctions (see Table 4.2a) between ‘gt1’ TYPE– greeting without physical contact, and ‘gt2’ TYPE- greeting with physical contact, where one might find some of the nuance regarding the dynamics involved in establishing longer-term relationships.

Summary: Q2 Birth Cluster [B] & Relations [R]:

The results here are less clear than the analysis on *historical consistency [H]* and *association symmetry [A]* relationship factors, although it demonstrates the value of proceeding with the full analysis in such an exploratory phase even when the model fitting is inconclusive. Even though no main association effect between the *Birth Cluster [B]* factor and *Relations [R]* factor were present, the post hoc inspection of the deviant cells in the base model, revealed patterns that resonated with earlier analyses and lent support to the possibility that males do in fact target infants differentially during the peak period, even through these interactions may get diluted or masked by methodological constraints (see above).

Overall, it suggests that relational history plays out significantly in the period after birth. That the relational history is *not* the only factor, is born out, not just by the MWCT analysis, but also by the long-term observed pattern in the subject pool matrix (Figure 4.1) in which several male-infant special relationships were ‘picked up’ only much after the study period, or that male-infant special relationships diverged asymmetrically from male-female friendships, a pattern Smuts (1985) observed as infants matured.

The lack of sufficient grooming (GRM) states for the MWCT analysis is of concern, since grooming has played such an important role in interpreting relational dynamics in baboons. As noted earlier, it may also reflect a valid impact of the birth cluster in that ASOC and GRT are less intimate and less time consuming, so that if males are actually trying to engage multiple female-infant pairs, they may trade 'quality for quantity'.

4.4 Discussion: The Socio-Cognitive Challenge – Interactions, Relationships, Groups & Levels of Investigation

To capitalize on interaction and relationship research in baboons in order to increase their relevance to the socio-cognitive behavior, I proposed and demonstrated two main moves in this chapter: the first was to shift the explanatory bias in relationship studies to a more operational How-Does-it-Work perspective in place of the What-is-it-For tradition in behavioral ecology (see bellow). The second move was to integrate into a single study questions that relate interaction dynamics to long-term relationships, on the one hand, and to group structure, on the other. I used data on male-female-infant relations during an ecologically mediated birth cluster to examine *(Q1)* how interaction dynamics during the study period are related to assessments of long-term relationships and *(Q2)* how the clustering of births in the group relates to these interaction dynamics. Addressing these questions was accomplished by a more deliberate and systematic tracking of Hinde's social complexity model, and by forming one kind of data structure (triadic CHAINS of Composite States) that had spatial, temporal and relational context of interaction dynamics built-in.

To briefly summarize, even though all 64 MFI triads in the study showed some level of association and interaction dynamics during the study period, there were systematic differences between triads that had long-term relations (R) and those that did not (nR). Both historical consistency [H] and association symmetry [A] factors in longer-term relationships seem to reflect these differences (models that do not allow association between these factors were rejected). These differences showed up in two important patterns in the composite state transitions: nonRelation triads, and the inconsistent asymmetric (iCaS) triads from the Relations (R) level seem to require ASOC states at the beginning and end of chains, while consistent symmetric (CS) triads trace a ASOC-GRT-ASOC loop. Most important, it suggests the tendency to remain in association (ASOC state) *after* greeting (GRT), a distinction that could not have been detected in non-sequential data.

The impact of the Birth Cluster [B] on interaction dynamics was less clear, but the Peak (P) period did point to one interesting pattern, with regard to MFI triads that had Relations (R) compared with those who did not (nR): R triads during the Paek (P) period may be more likely to target infants when they are on their mother (M-IF state-ACTOR combination) or on their own (M-I). In nonPeak (nP) periods, R triads switch from this pattern to remaining in ASOC states in much higher than expected rates than nonRelation (nR) triads.

These patterns suggest that the period right after birth serves a critical period for establishing and/or strengthening longer-term relations and that proximity between individuals is important not just in sheer proportion, but in the *sequencing* of association between and around affiliative interactions. Even though long-term relations reflect significant patterns right after birth, *all* MFI triads were actively engaged during that period, suggesting that variations on these trends (see Figure 4.1 and Figure 4.4) reflect other factors, such as patterns of male-male alliances, to be relevant as well.

In what follows I highlight some implications of the departure my proposal represents from current studies on baboons.

4.4.1 Q1: Interaction Dynamics & MFI Relations

Although Smuts (1985: *Sex and Friendship in Baboons*)–the now classic reference point to male-female-infant relationship studies–set out deliberately (1985:7-8) to address both *theory driven* evolutionary questions and *observation driven* insights into cognitive and emotional inner life of her study subjects, cognition all but fell out of the relationship studies that followed. So did social complexity. A cluster of recent reports on male-infant/juvenile and male-female-infant relationship studies in yellow (Kenya: Buchan et al., 2003; Charpentier et al., 2008; Nguyen et al., 2009), olive (Kenya: Lemasson et al., 2008; Shur, 2008) and chacma (Botswana: Palombit, 2009; Lemasson et al., 2008; Namibia: Huchard et al., 2010) baboons showcases the progress in mixed methods alongside the theoretical stasis in the field of primate relationships research since then. Table 4.11 summarizes the dimensions of these studies.

Table 4.11: **Recent Relationship Studies in Yellow, Olive & Chacma Baboons.** Each of the 8 column headers consists of first author initials and year of publication. Entries in the cells signify ‘Y’=item tested & confirmed; ‘y’ = weak confirmation; ‘N’=tested & rejected; ‘n’=weak rejection

<u>Studies:</u>
Yellow baboons, Kenya (Amboseli)
    JB: Buchan et al (2003)
    MC: Charpentier et al (2008)
    NN: Nguyen et al. (2009)
Chacma baboons, Botswana (Moremi)
    RP: Palombit (1997)
    LM: Moscovice et al (2009)
Chacma baboons, Namibia (Tasobis)
    EH: Huchard et al (2010)
Olive baboons, Kenya (Laikipia–Segera)
    AL: Lemasson et al (2008)
    DS: Shur (2008)

	Baboon species: Location	Yellow: Kenya			Chacma: Namibia, Botswana			Olive: Kenya	
Category	**Item**	**JB 2003**	**MC 2008**	**NN 2009**	**RP 1997**	**LM 2009**	**EH 2010**	**AL 2008**	**DS 2008**
Subjects	**M**ale **F**emale **I**nfant **J**uvenile	M-J	Offspring	M-FI	M-FI	M-J	M-FI	M-FI	M-F
Female Advantage Hypotheses	Anti-Infanticide				Y		y		
	Infanticidal Risk			N					
	Anti-Harassment			Y	y			Y	Y
	Future Care			Y	y	Y		n	
Male Advantage Hypotheses	Parenting Effort	Y	Y	Y		y	Y		Y
	Future Mating Effort			N					n
	Social Tool Advantage								
Evidence	Behavioral Observation	Y	--	Y	Y	Y	Y	Y	Y
	Demographic Records	Y	Y	Y	Y	Y	Y		
	Playback Experiments				Y	Y		Y	
	Genetics	Y	Y	Y		Y	Y		
	Hormones								Y
Relationship Identification & Evaluation Measures	Nearest Neighbor only			Y		Y			
	Tolerated Approaches					Y			
	Prox. – C-Score				Y		Y	Y	Y
	Prox. – Hinde's Index				Y		Y	Y	Y
	Allogrooming			Y	Y		Y	Y	
	Infant Handling			Y	Y		Y	Y	
	Agonism				Y			Y	
	Paternity – Genetics	Y	Y	Y		Y	Y		
	Paternity – Behavioral	Y		Y		Y			
	Father Co-residency		Y						
	Solicitude				Y	Y		Y	
Benefit Fitness Measures	Infant survival			Y	Y				
	Offspring age at maturity		Y						
	Support in conflicts	Y			Y	Y		Y	
	Future mating success			Y					
	Number of friends							Y	
	Harass / stress reduction			Y	Y			Y	Y

These reports most importantly demonstrate the accrued benefits of maintaining long-term field sites, producing detailed demographic records that span generations and multiple groups within study populations, offering a detailed background against which specific queries are examined. For example, male support of juvenile offspring covering 75 juveniles with known paternity from 5 groups (Buchan et al, 2003) suggests that males showed preferential support to their genetic offspring but also support their 'unrelated' offspring (infants who's mother had a friendship with the male when she was lactating, yet were not the *genetic* offspring of the male). Or, co-residency patterns of males and their offspring over a 30-year period (Charpentier et al. 2008) demonstrated that both sons and daughters gained fitness benefits (in terms of age at sexual maturation) the longer their father remained in the troop after they were born. The advantage of increasingly less invasive methods for acquiring both genetic (e.g., Huchard et al, 2010) and hormonal (e.g., Engh et al, 2006; Shur, 2008) assays, adds a portal into kinship and stress physiology. These records are crucial in evaluating patterns of social behavior for their functionality and both their short- and long-term impact.

While Table 4.11 compares these studies in terms of hypotheses tested, sources of evidence, measures used for the identification and evaluation of friendships, and the measures of fitness benefits used, here I want to focus on the differences in framing between these studies and the framework I demonstrated in this chapter, and examine the impact of these differences on methods of data collection and analysis.

Framework – Male-Female-Infant Relations: In multimale animal societies, where more than one male copulates with the female during the days that lead to conception, paternity is most likely uncertain. In such social species males are expected to show little or no parental care, and are expected to 'invest' in females only in as much as it will increase their future mating success. Yet male baboons show direct support and differential attachment to particular infants, and these attachments most often coincide with year-round friendships with those youngsters' mothers. The central evolutionary question in both cases is the same *'what are these relationships for?'*

The hypotheses all revolve around kin-selection (via kin recognition) for male-infant relations, and around survival and mating for male-female friendships. Thus from the female's perspective, her consistent investment in male friends has been proposed as a strategy to avoid exposure to infanticidal males (Hrdy, 1979; Smuts, 1985; Palombit et al., 1997), as a strategy to protect herself from harassment by other adult males and females (Altmann, 1980; etc.), and as a strategy to promote future parental care for her offspring (e.g., Altmann, 1980; Smuts 1985.) What is a relationship for in terms of male advantage? Parental care, if he is the father of the female's offspring; Future mating effort, if his friendship with the lactating female translated into better access to the female when she resumes cycling (see Nguyen et al., 2009); and the more vague hypothesis about the advantage a male gains from being able to use the infant or the mother as buffers during conflicts with other males (Stein, 1984; Strum, 1983, 1984; Palombit et al 1997).

Researchers mostly agree that these hypotheses are not necessarily mutually exclusive, and that some may be impossible to verify. For example, low rates of infanticide reported in some populations may reflect the *success* of anti-infanticidal strategies (Palombit, 2003; Nguyen et al., 2009,) making for a rather un-falsifiable hypothesis.

Impact on methods: The thrust of this framing and narrow hypothesis space translated into a very stable methodological approach: identify relationships and evaluate their status, on the one hand, while, on the other, define and measure fitness benefits to individual partners. In other words, the measures one is looking for are outcomes – effects of a theoretically driven causal relationship (see Cummins, 2000, for the difference between explaining 'effects' and explaining 'capacities'). One then looks for correlations or more causally driven relations between these measures, and behavioral tracking is narrowly geared towards this double challenge. The orthodoxy of the individual (relative to the population mean) as the only unit of selection dismisses as irrelevant fitness advantages of other relational units (e.g., showing that friendships with particular individual characteristics last longer, or that groups fare better when certain types of relationships are present or absent.)

Bottom line: In the decades since Smuts (1985) attempted to integrate evolutionary and cognitive explanations of behavior into an understanding of baboon male-female-infant relations, both cognition and social complexity receded from the research paradigm, emphasizing outcome over process in methodology, even as discussion comments lament the critical role such information would play in satisfying explanations (e.g., Charpentier et al, 2008)

Identification and evaluation of friendships: Except for three studies that looked only at male-offspring relations (Buchan et al 2003; Charpentier et al 2008; Moscovice et al., 2009) identification and evaluation of male-female friendships references Smuts (1985) classic study on sex and friendships in olive baboons. Smuts showed that even though friendships may last years and span multiple mating and birth cycles, behavior of male and female friends shifts dramatically during periods of sexual activity (these patterns are different in chacma baboons, see below).

All the more recent studies build on these differences to restrict their definition of friendships to anestrous period in the in the reproductive cycle, most often limited to lactating females. More over, the link between males and infants is assumed always to involve the infant's mother, again in deference to Smuts findings that after the first 16 weeks, the independence of male-infant and male-female relationships is more visible (Smuts, 1985:114). As the subject pool matrix in the MFI study (Figure 4.1) suggests, males may differentially form friendships with the mother or the infant.

Smuts used proximity point samples (Altmann, 1974) to produce a C-Score that weighted the number of point samples giving higher value the closer the subjects were to one another (e.g., within 1m, 2-3m, 5m) These proximity scores, when comparing males to a particular female usually show a large discontinuity between 1-3 males with high scores and all the other males. Another measure to evaluate who is responsible for maintaining proximity was developed by Hinde and is called the "Hinde index," which evaluated the relative contribution (percentage) of each partner to 'approaches' and 'leaves'.

While Smuts attempted to draw the grooming profiles from separate sources of data than the interaction data she used for analysis, more recent studies do not bother to separate, or they draw on data from project records.

Two departures form Smuts C-Score and Hinde's index emerged. Nguyen et al. (2009) uses a composite index (following Silk et al. 2003, building on Sapolsky et al. 1997). The other departure involves experimental testing for 'willingness' to support a friend in distress. The use of playback experiments to test for solicitude of a male in response to distress calls recorded from the male's female friend and /or from her infant, is a more direct expression, perhaps of relationship value, and, in fact, resonates more deeply with the observer-consensus method I relied upon in extracting relationship assessments from the long-term demographic records.

4.4.2 Q2: Interaction Dynamics & Group Structure

Framing – Biological Markets: The alternatives to kin-selection (Hamilton, 1964) in explaining cooperative social interaction patterns first came in the form of reciprocal altruism (Trivers, 1971) and game theory versions of The Prisoner's Dilemma (Axelrod & Hamilton, 1981; see chapter2). But these situations all dealt with equal partners and reciprocal symmetric relationships, or with single partners. Stuart Altmann (1962) identified the notion of *Priority of Access* (PoA) in the context of male dominance hierarchy and mating opportunities: If only one female was receptive, the highest-ranking male would monopolize access to her; if two females are receptive access to them will be monopolized by the two highest-ranking males, and so on. Strum (1982) tested the predictions of *male dominance* as the key factor in *PoA* to estrous females and meat, and proposed an alternative *male residency* hypothesis. Seyfarth (1977) applied the *PoA* model in the context of female-female grooming partners and their relative dominance ranks (see Sambrook et al. 1995 testing and offering alternatives). The *biological market* (Noë et al, 1991; Noë and Hammerstein, 1994, etc.) builds on this effort to deal with asymmetric trading classes where one group has a fixed commodity and the other can vary the price they pay. These models have been explored mostly with grooming between females and/or with exchanging infant handling for grooming (Henzi & Barrett, 2002; Frank & Silk, 2009a, 2009b).

Hypotheses: The hypotheses in the biological market frameworks have to do with the increase or decrease in supply (number of infants, or number of potential partners) and predictions about price change, the ability of the trader class that has the commodity (mothers of young infants) to extract a higher price (longer grooming by others) when the supply is low (Henzi & Barrett, 2002). Given a particular supply and demand structure, hypotheses revolve around the impact of dominance both within and between the trading classes.

Impact on Methods: The framing of biological markets in the paradigm of coalition games (Noë & Hammerstein, 1994) requires a simplistic identification of what would constitute a commodity and price in baboon interactions, which forces a narrowing of the behavioral lens onto one or two different 'trading' classes – two age/sex classes such as adult males and adult sexually receptive females or females with young infants and females without. The exchange market is over one fixed commodity, such as mating opportunity, or access to infants. This framing biases short term horizon of behavioral contingencies, and neglects the variety and context of behavioral exchanges. The perspective of long-term relationships is often neglected, although the interpretation of behavior in more cognitive and decision-making oriented terms is a refreshing shift from the relationship studies described above (see Henzi & Barrett, 2002 for chacma baboons, and alternative patterns (in olive baboons) and interpretations by Frank & Silk, 2009a, 2009b.)

***A Note on Social network Analysis**:* Lehmann & Dunbar (2009) offer a recent example of the increase use of techniques that describe social networks to address the interplay between interactions and group level relational patterns, although, here, as in the biological market literature, the focus is on grooming networks among adult females, neglecting the variety of meanings and contexts in which grooming behavior is expressed. These techniques however are much more promising as description of social complexity that begins to compare and contrast features between and across taxa.

4.4.3 Complexity AS Context: Sequential Analysis & MWCT

In contrast with these frameworks I was able to maintain a more consistent separation between levels of analysis, in this case, Hinde's levels of social complexity. I accomplished this separation by (1) keeping study factors, of relationships and of group structure, separate from study data and (2) constructing a single kind of data structure from the study data that had spatial, temporal and relational dimensions of behavior built-in.

Specifically, the use of association dynamics (ASOC, Table 4.2a) as a state-TYPE and its integration with state-ACTOR (Table 4.2b) into a Composite States Scheme (Table 4.2c) allowed me to refrain from using proximity patterns as an additional dimension (see Altmann's opening quote), as is the case in the relationship studies described above.

Most importantly, perhaps, these moves allowed me to use the same data-structures (FROM/TO timetable) to respond to both study questions, examining the relations between interaction dynamics and relationships and between interaction dynamics and group level factors. The multivariate analysis using MWCT provided a refreshing alternative to the cascade of two-way significance tests I would otherwise have to struggle with, and which are so prevalent in the literature (e.g., Nguyen et al., 2009)

How Does it Work: More generally, the approach I present here departs strategically from current behavioral ecology paradigms in that it asks of social complexity 'How-Does-it-Work?' rather than 'What is it for?' I build on the expectation that multiple 'what is it for?' will be relevant in any complex system, and that focusing on outcome may not tell us much about the process of reaching that outcome. The hypothesis space for relationship studies described above is a case in point. The predictions are all about effects and outcomes, rather than proximate mechanisms or process. The authors readily concede the likelihood of more than one of these hypotheses being 'served' by male-female friendships, yet how this may come about may be less obvious. The under-specificity of function is an inherent feature of *organized complexity* (see Chapter1).

Some of the questions about proximate mechanisms are increasingly being addressed by physiology and genomics. For example, Shur (2008) testosterone and glucocorticoid analysis in male and female baboons lends more direct support to the consideration of *solicitude* as an important factor in male-female friendship (see also Engh et al. 2006; and then Donaldson & Young, 2008 for recent non-primate example).

The suggestion that staying in association *after* affiliative behavior (the ASOC-GRT-ASOC loop) may be the key 'predictor' of both *historical consistency [H]* and *association symmetry [A]* in longer-term relationships provides *additional* behavioral 'building blocks' for an evolutionary scenario of friendships. In answering 'how does it work' of a complex system we may actually learn more about 'how it came to be?' which is 'behind' the 'what is it for?' question in the first place. Tracking *the way behavior is organized* may serve socio-cognitive research by considering behavior *its own level of analysis* rather than 'just' a faithful indicator to what lies "below" or "above" (see Section 1.3). This challenge demands additional data representations and analysis of behavior that *correspond* to complementary genomic, physiological and neural data streams. Extending Senjowski & Churchland's (1990) *levels of (brain) investigation* by adding, *extra-somatically,* Hinde's levels of social complexity, captures the gist of my thesis objective. See Chapter1 and Chapter 6 for discussion.

4.4.4 What About Cognition, then?

Smuts (1985) kept separate evolutionary and cognitive questions about male-female friendships, and used subjective interpretation of anecdotal observations to address her insights into the psychology and 'underlying' emotions of her subjects. Cognition all but fell out of the studies summarized in Table 4.11 even as studies today adhere to (e.g., Palombit et al, 1997; Lemasson et al, 2008; Shur, 2008) or deliberately depart from (Nguyen et al, 2009) Smuts methods of identifying and evaluating Friendships. Cognition is hinted at in these studies only indirectly – in discussion of paternity recognition, and in the context of playback experiments to test solicitude of partners. In both cases, cognition is not treated as a variable to be measured or considered for analysis, in that it may show individual variation. All baboons seem to have 'it', similar to the assumption that all baboons are competent groomers, so variation between individuals reflects choice and preference rather than competence.

Barrett & Henzi (2002, 2005) and Barrett et al (2007) began to reexamine issues regarding cognitive dimensions of social behavior in the context of the biological market framing, proposing that the relationship researchers have tended to assume that friendships and strategies may also refer cognitively, but the biological market paradigm shows that it is possible to generate these patterns by shorter-term contingencies. Frank & Silk (2009a, b) in testing biological marketplace predictions on another population of baboons argue that grooming transactions among females suggest that they keep track and manage reciprocity on longer timescales.

Nevertheless, the distinction between short and longer-term contingencies has been a productive contribution to revitalizing the cognitive debate. Barrett, Henzi and Dunbar (2003), for example, re-consider the social brain hypothesis as a reflection of the *social* marketplace. They propose that the difference between monkeys and great apes is akin to shifting from a cognition that revolves around "what now?" to an ability to consider future scenarios in the form of "what if.

The sequential analysis I presented in this chapter dealt with lag-1 contingencies. It is tempting to consider these 1st order state transitions as pertaining to the 'what now?' or 'what next?' state, and, as such, we can begin to relate moment-to-moment decision making to wider contexts and longer timescales over which baboons engage with one another. The socio-cognitive challenge is thus framed by a tension between longer-term relationships and navigating the immediacy of specific interactions. The challenge is to combine these perspectives into integrated analytic frameworks, in order to understand relational negotiation at these spatio-temporal scales.

Dedeo et al. (2010) provides a recent example of combining long timeseries of individual conflicts with social network analysis, tested in the context of *iterative game theory*, to argue that immediate context has less of an impact on conflict negotiation in macaques than relational history, and that these conflict dynamics cannot be explained in dyadic terms alone, lending support to the primacy of polyadic dynamics.

Return to those dramatic Polyadic Dynamics. I opened this chapter with a description of the kind of polyadic dynamics that fuelled the SI-Hypothesis proponents, although most recent relationships and interaction studies in baboons end up focusing on the more common (proximity, greeting), or easily traceable (grooming) dynamics. The sensibility remains, however, that these polyadic dynamics are key to understanding the socio-cognitive challenge facing baboons. It is in these settings that individuals bring to bear, so it seems, their skills in navigating interactions, combined with longer-term cognitive processes that monitor, evaluate, and integrate the historical context in their relational webs (see Chapter1 comments on *'social niche construction'* in Flack et al. 2006). Can these polyadic dynamics be understood as socio-cognitive systems? The next chapter takes on precisely this question, extending the same framing of sequential analysis, but this time via Hutchins' theory of distributed cognition.

4.5 Appendix

Table 4A.1a: MFI Dataset – Female-Infant Study Subjects: ordered by rank (high=1) and infant's date of birth (DOB). Age in weeks at start and end of the study.

Female-infant	***Relative Rank***	***DOB***	***i age start***	***i age end***	***# of samples***
DE_ID	***1***	2 Mar 89	0wks	25wks	24
ZL_HZ	***2***	22 Jan 89	5wks	30wks	21
MV_GN	***3***	20 Apr 89	(-7)wks	18wks	24
MC_MZ	***4***	19 Mar 89	(-3)wks	22wks	23
TE_JY	***5***	11 Apr 89	(-6)wks	19wks	25
DA_DJ	***6***	6 Apr 89	(-5)wks	20wks	25
RM_RX	***7***	23 Mar 89	(-4)wks	22wks	25
AA_AE	***8***	25 Dec 88	9wks	34wks	20

Table 4A.1b: MFI Dataset – Male Study Subjects: ordered by age from very old through very young. Date of Entry (DOE) notes month/year of each male's entry to the troop and their residency at the beginning and the end of the study period. All considered adults at this stage. Although residency is usually significant in context of behavior, all the younger males are also the new comers (a male is considered a long-term resident after the first 2 years in the troop)

Male	***Relative Age***	***DOE***	***Residency (begin / end) of study (year.month)***	
HW	*very old*	9/1987	1.6	2.0
ND	*old*	7/1986	2.8	3.2
RL	*old*	8/1986	2.7	3.1
BB	*mature*			
CB	*young adult*	6/1988	.9	1.3
HK	*young adult*	10/1987	1.5	1.11
PH	*young adult*	11/1987	1.4	1.10
RT	*very young*	10/1987	1.5	1.11

Table 4A.2: MFI Dataset – Data Structures Counts
^ Included one empty sample.
* One state is counted in two chains (1 SML state).
** Two states are counted in two chains (2 SML states)

Data Structures		**DEID**	**ZLHZ**	**MVG^**	**MCM^**	**TEJY^**	**DADJ^**	**RMRX**	**AAAE**	**Total**
Samples	**TOTAL**	**24**	**21**	**24**	**23**	**25**	**25**	**25**	**20**	**187**
	Pre-birth	0	0	8	3	5	6	5	0	**27**
	Peak ii	9	8	10	8	9	9	8	9	**70**
Chains	**TOTAL**	**205**	**140**	**153**	**166**	**137**	**184**	**147**	**119**	**1251**
	Pre birth	0	0	36	8	22	13	14	0	**93**
	Peak ii	84	65	72	73	58	73	55	48	**528**
States	**TOTAL**	**575***	**349**	**312**	**385****	**295***	**394****	**343**	**266**	**2919**
	Pre birth	0	0	86	10	35	16	25	0	**172**
	Peak ii	274	135	142	169	113	184	124	102	**1243**
Transitions	**TOTAL**	**780**	**489**	**465**	**551**	**432**	**578**	**490**	**385**	**4170**
	Pre birth	0	0	122	18	57	29	39	0	**265**
	Peak ii	358	200	214	242	171	258	179	150	**1772**

Table 4A.3: MFI Triadic Relationships – Historical Consistency & Association Symmetry (* refers to a couple of cases where an unusual pattern is present – see original subject matrix)

	DEID	ZLHZ	MVGN	MCMZ	TEJY	DADJ	RMRX	AAAE	
HW							C S	C S	HW
ND						C S	C* S		ND
RL	C S	C S	C aS			C aS		iC aS*	RL
BB									BB
CB			*	iC aS	C S		iC S	iC aS	CB
HK	iC S	C S				iC aS	iC aS	iC aS	HK
PH		*		C S	iC aS		C* S		PH
RT	C S	iC S	C aS			iC aS	iC aS		RT
	DEID	ZLHZ	MVGN	MCMZ	TEJY	DADJ	RMRX	AAAE	

State Transitions – TYPE Categories:

Table 4A.4a-b: MFI TYPE State-Transition Matrix. All the first set includes all sample chains while the second set includes only post-birth chains. Where cell counts and frequencies differ the cell background is darkened in the post-birth set. PRIOR and END used to identify the boundaries of chains.

			TO					
	Counts	**END**	**ASOC**	**GRT**	**GRM**	**AGON**	**SPCL**	**Total**
	PRIOR		1063	156	10	16	6	1251
FROM	**ASOC**	1050	260	520	21	20	23	1894
	GRT	165	486	78	58	1	12	800
	GRM	10	46	33	34	1	2	126
	AGON	17	19	2	0	5	0	43
	SPCL	9	20	11	3	0	13	56
								4170

			TO					
	Proportion	**END**	**ASOC**	**GRT**	**GRM**	**AGON**	**SPCL**	**Total**
	PRIOR		0.85	0.12	0.01	0.01	0	1.0
FROM	**ASOC**	0.55	0.14	0.27	0.01	0.01	0.01	1.0
	GRT	0.21	0.61	0.10	0.07	0	0.02	1.0
	GRM	0.08	0.37	0.26	0.27	0.01	0.02	1.0
	AGON	0.40	0.44	0.05	0	0.12	0	1.0
	SPCL	0.16	0.36	0.20	0.05	0	0.23	1.0

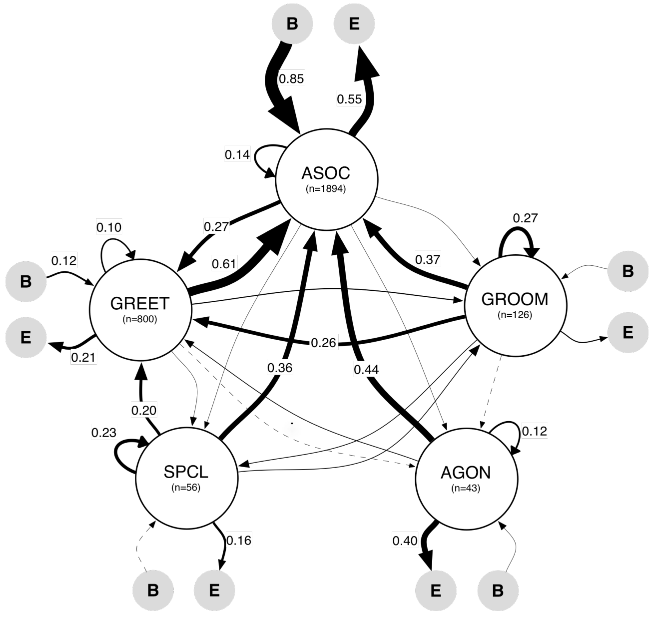


Figure 4A.1: MFI TYPE State Transition Diagram with Numbers. Transition Proportions expressed graphically. Thickness of arrows proportional to the magnitude.

The most common contingency test is between the observed tallies and tallies expected if each type of previous state would transition with equal probability to each of the current states. The test statistic is the Chi-Square

$$X^2 = \sum_{cells} \frac{(observed - \text{exp}ected)^2}{\text{exp}ected}$$

The degrees of freedom = (rows –1) x (columns – 1) = 25

$$Expected\ Frequency\ = \frac{(row\ \ total)(column\ \ total)}{total\ \ number\ \ of\ \ observations}$$

Table 4A.5a-b: MFI TYPE State – Observed vs. Expected

			TO					
	obs	**END**	**ASOC**	**GRT**	**GRM**	**AGON**	**SPCL**	**Total**
	PRIOR		1063	156	10	16	6	**1251**
FROM	**ASOC**	1050	260	520	21	20	23	**1894**
	GRT	165	486	78	58	1	12	**800**
	GRM	10	46	33	34	1	2	**126**
	AGON	17	19	2	0	5	0	**43**
	SPCL	9	20	11	3	0	13	**56**
	Total	**1251**	**1894**	**800**	**126**	**43**	**56**	**4170**

			TO					
	exp	**END**	**ASOC**	**GRT**	**GRM**	**AGON**	**SPCL**	**Total**
	PRIOR	375.30	568.20	240.00	37.80	12.90	16.80	**1251**
FROM	**ASOC**	568.20	860.25	363.36	57.23	19.53	25.44	**1894**
	GRT	240.00	363.36	153.48	24.17	8.25	10.74	**800**
	GRM	37.80	57.23	24.17	3.81	1.30	1.69	**126**
	AGON	12.90	19.53	8.25	1.30	0.44	0.58	**43**
	SPCL	16.80	25.44	10.74	1.69	0.58	0.75	**56**
	Total	**1251**	**1894**	**800**	**126**	**43**	**56**	**4170**

CHAPTER 5:

Distributed Cognition AS Process – Temporal Dynamics of Sexual Consort Turnovers (CTO) Events

Following on the heels of the previous chapter, which focused primarily on social complexity and Hinde's relationship approach, this chapter serves to demonstrate the application of Hutchins' Distributed Cognition (D-Cog) to Hinde's *interaction approach* to demonstrate the second prong of the modified behavioral research program I proposed for socio-cognitive phenomena. While addressing social complexity in the previous chapter was a challenge of *analysis*–in tracking and examining the relations between Hinde's levels of social complexity–in this chapter 'seeing' cognition is primarily a challenge of framing and behavioral *data representation*. It showcases the versatility of state-space framing, and extends the use of temporal dynamics on multiple timescales. Its focus is on *behavioral* data structures and data representations that better serve to track socio-cognitive processes.

5.1 Observing Interactions, Tracking Cognition

5.1.1 What & Where is Cognition in Social Behavior?

Polyadic Dynamics – In the previous chapter, the *social dimensions* of polyadic interactions led to a systematic examination of social complexity, in that they speak simultaneously to the baboon relational web (group structure, in Hinde's model) and to the relational history of individuals (relationships). Yet the polyadic dynamics themselves were largely absent given their relative rarity from the perspective of any one individual or relationship trajectory. Nevertheless, it is in the context of these dramatic polyadic interactions that the social and cognitive dimensions of behavior revealed themselves to inspire the SI-Hypothesis. When I described *SE-Clusters* in Chapter2 as the unit of meaningful behavior I labeled these dynamics as ***'the here-and-now of local face-to-face interactions'***. In this chapter I return to confront polyadic interactions during sexual consorts in baboons in order to demonstrate how the sequential analysis framework can be extended to examine their *cognitive dimensions*.

Polyadic Anecdotes *of Tactical Deception for the SI-Hypothesis***:** In *Sex and Friendship in Baboons,* Smuts (1985) struggled with the methodological discrepancy between her *theory driven* evolutionary query (what is the adaptive significance of male-female friendships) and her *observation* *driven* subjective insights into "psychological components of male competitive tactics" (1985:151) and "emotions underlying sex and friendship" (1985:230). Methodologically distinct, her quantitatively sound behavioral ecology recipe for identifying and evaluating relationships, as I showed in the last chapter, became a central reference point for relationship research in field primatology (e.g., Palombit et al, 1997; Lemasson et al., 2008; Shur, 2008; Huchard et al., 2010). Her insights regarding cognition, however, peppered with anecdotal observations reported from her field notes, were difficult to reconcile as a methodology (Haraway, 1989), and completely receded from baboon relationship research since then (see last chapter).

Yet, at the time, the anecdotes Smuts provided to support speculations regarding the rich inner lives of her study subjects, joined a groundswell of such reporting, most noted perhaps de Waal's (1982) *Chimpanzee Politics,* reading as vividly as any human soap opera. The publication of Smuts' book coincided with the first effort by Byrne and Whiten (1985) to develop a systematic reporting standard for cases of 'tactical deception' (see Chapter1).

Byrne & Whiten solicited carefully structured standardized reports from field researchers that might, against Bernstein's (1988) better judgment, present as equally reputable the plural of "anecdote" and "datum". It was this corpus that gave weight to the official kick-off of the SI-Hypothesis, in its Machiavellian form (see discussion in Chaper1). Riddled with interpretations of intentionality and Theory of Mind, however, this effort dropped out of behavioral ecology research as well. Nevertheless Byrne & Whiten's (1990) attempt at a systematic accounting of anecdotal reports inspired similar analysis by Caro & Hauser (1992), on whether there is teaching in nonhuman animals. Rather than soliciting a survey, they chose to look for published cases in the literature across many taxa. Caro & Hauser were careful to provide an intentionality-neutral operational definition of teaching, avoiding thorny debates. The practice of synthesizing single-case anecdotal reports is repeated from time to time as published studied accumulate and search engines improve. Bates & Byrne (2007) review this historical thread in an attempt at a revival of systematic reporting to address creativity in African Elephants.

Anecdotes of Psychological & Emotional Factors *of Sex & Friendship* **–** Anecdotal reports of cognitive phenomena are telling, often as much about the conceptual framework of the *reporter* as the psychological prowess of the narrative's protagonists. Regardless, these evocative accounts resonate with a rich sensibility regarding the complexity of baboon life. Consider the following example Smuts (1985) presents in a section on *psychological components of tactics* used by males in competition for mates:

> *Early in the morning, Dante is in consort with Andromeda. Three older males, Alex, Sherlock, and Zim, are following and harassing Dante. Their movements are so perfectly synchronized that they take on an almost dance-like quality. Sherlock and Zim stand side by side facing Dante and, in unison, they rapidly and repeatedly threaten Dante with raised brows and then glance at Alex, 20 m away, soliciting his aid. Alex lopes over to them, places one arm around Sherlock's shoulder, and all three pant-grunt at Dante in an antiphonal chorus. In one smooth motion Zim lip-smacks, touches Alex's rear, looks at him, grunts at Sherlock, and then circles around to the other side of Dante. When he is opposite Alex and Sherlock, he resumes threatening Dante and, at precisely the same instant, they do the same. Alex embraces Sherlock and, together, they circle Dante and join Zim. All three stand in contact and swivel as a unit to face Dante, who avoids them. Dante appears increasingly tense. He repeatedly interposes his body between Andromeda and the other males and then herds her away by shoving her from behind. Each time he pushes her, Andromeda squeaks in protest. She too seems tense, glancing back and forth between Dante and the other three males. A few minutes later, a fifth male, Boz, appears on the hillside above the consort pair. Alex, Sherlock, and Zim immediately solicit Boz's aid against Dante. Boz runs towards them, and at the same time the other three once again move toward Dante. Dante and Andromeda break away from each other and run in opposite directions. Zim and Sherlock chase Dante while Boz and Alex run after Andromeda. Alex reaches her first, and she stops running and lets him copulate with her. A new consortship is formed*
>
> *(focal consorts sample, 2 July 1983)*
>
> (italics in the original, Smuts, 1985:153-4)

This narrative serves Smuts as the backdrop for a discussion of *individual* baboons as psychological beings motivated by highly nuanced goals and emotions. The complex dance of bodily coordination is transformed into an argument about confidence, tension, frustration, and the ability of a male baboon to manipulate the emotions of others (Smuts 1985: 154-155). One aim of this chapter is to show that it is the *embodied dynamics* in such a narrative that most reliably reflect cognitive dimensions, *not* in terms of Smuts' inferences about internal mental states, but rather by directly tracing *embodied attention* relative to the overall activity.

When Smuts further examines the benefits of friendship to the female partner she relates several more anecdotes, this time recounting what at first seemed to her like cases of unprovoked male aggression towards females. Yet as she spends more time in the troop, and conducts more extensive several-day follows of specific individuals she begins to see social contingencies play out on longer time scales –

> I concluded that some–perhaps most–of these ‘unprovoked’ attacks are just the opposite. They are attacks in response to specific acts by the victim that the attacker observed and remembered; *it is the observer who does not know the reason for the male’s behavior, not the baboons.* It is indeed possible that baboons remember such incidents and act on the basis of these memories not only over periods of 10 minutes…or even hours…but for days, weeks, or even longer. If I am correct that many ‘unprovoked’ attacks do represent delayed punishment for aggression shown toward a Fried of the male attacker, then defense of Friends is a far more important context for male aggression, and particularly for intense aggression…
>
> (italics, mine)
> (Smuts, 1985:96)

I read Smuts’ observations and inferences as pointing to ***two main scales*** at which socially relevant cognition plays out in the baboons: *(1) the immediate dance-like polyadic negotiation* over the consortship, on the one hand, and *(2) the longer-term relational contingencies,* that contextualize a seemingly unprovoked act of aggression, on the other. These two dimensions become the central focus of this chapter (and see Figure 6.1).

Testing Social Knowledge *with Playback Experiments* **–** Smuts had to observe or rely on other observers witnessing all component incidents to confirm an unusual behavior as historically and relationally contingent. Contrast that with Cheney & Seyfarth’s extension of Marler’s vocalization playback experimental paradigm, which provided a reliable and nuanced testing framework (first with vervet monkeys, then chacma baboons) for precisely such contingencies. From the differential response to individual predator alarm calls in vervet monkeys (Cheney & Seyfarth, 1990), knowledge of third party relations, and the nuanced monitoring (Cheney & Seyfarth, 2007) these field tests opened a portal into the kind of knowledge monkeys regularly and meaningful acted upon.

In the discussion of relationship studies in the last chapter, I noted the use of playback experiments to test for solicitude in male-female friendships (Palombit et al, 1997; Lemasson et al.,

2008) and male-juvenile relationships (Moscovice et al., 2009). These test reveal how *long-term* relationships can impact local action. More dramatically, perhaps, were the indications that baboons are monitoring and updating their assessments continuously in ways that also impact their behavior. Wittig et al., (2007) showed that females respond to reconciliation grunts by the relative of a recent aggressor, as if it were directed at them and related to the recent conflict. Even in more transient relations such as sexual consortships, males are shown to respond differentially to vocalizations simulating an exchange between a consort male and female if the identity of the callers is incongruent with the current consortship status (Crockford et al. 2007).

Progress & Limitations: As impressive as this portal into the exquisite sensitivity of baboons' social knowledge, the playback experiments so far have been used mainly to discern presence or absence of a capacity, or an item of social knowledge, rather than a *measure* that is able to reflect individual differences, relative competence, or other aspects that can begin to integrate cognitive features into the behavioral ecology framework these researchers use to examine the adaptive significance of relationships e.g., Cheney & Seyfarth collaboration with Joan Silk (Silk et al., 2009). Thus for both Smuts (1985) and Cheney & Seyfarth (2007) their commentary on evolutionary significance of social relationships remains somewhat disjointed from their commentary on baboon social cognition. Cognitive assessments within the framework of behavioral ecology requires for these capacities to be measured differentially (relative to a population mean), their developmental trajectories revealed, and the impact of experience on competence tracked (see discussion on Tinbergen 4 Whys in Chapter1).

Non-Cognitive Performance Measures: Scores are readily calculated for male consort performance (e.g., Strum, 1982; Smuts, 1985) and recently more complex formulas for sociality indexes have emerged (e.g., Sapolsky et al., 1997). These scores however make no direct claim regarding their reflection of cognitive abilities. Strum (1982), for example, was evaluating a male's access to resources, and Smuts (1985) was trying to evaluate the adaptive significance of friendships to the male's reproductive success. Ultimately the aim is to develop life history measures that would be relevant in behavioral ecology (recall the logic symmetry in evolutionary and cognitive explanations, Figure 1.3, 2.1).

Animal Social Learning: Linking social cognition to evolution is being done more successfully when looked at across many taxa, for the evolutionary scenarios are often best addressed when comparing species, rather than individualized in long-lived social species. Animal social learning research has had a long and successful trajectory in behavioral ecology (e.g., Leland et al., 1993), less attended to by primatologists in the 1980s and 1990s, not least because the species studied were mostly rodents and birds. A recent convergence of this strand with the band of researchers that were founders of the SI-Hypothesis (e.g., Whiten, Byrne, Dunbar) is beginning to show promising integration of ideas around innovation, creativity and tool use. The integration of these strands is best seen in a meeting titled *Culture Evolves* (June, 2010), organized by Whiten, Hinde, Stringer and Laland (Whiten et al., 2011:938) the proceedings of which were published in a dedicated issue of Philosophical Transactions of the Royal Society B. vol. 366.

Human Social Cognition: While much of experimental psychology is task-performance oriented, paralleling the non-cognitive performance measures above, there are growing attempts to give individuals *social* tasks (e.g., response to faces with different emotional states, etc.) The human social sciences, on the other hand, to which Hinde himself shifted his focus (e.g. Hinde, 1976, 1997), have tended towards describing cognitive processes as occurring between and across individuals, the development of skills dependent on interpersonal dynamics before they become intrapersonal (e.g., Vygotsky, 1978; Gregory Bateson. 1972, 1979; Rogoff, 1990; Hutchins, 1995; Cole, 1996; etc.). Embodied cognition has also been studied in the context of language behavior, examining the co-production of speech and gesture (e.g., McNeill, 2005 and reference therein), as well as in preverbal humans.

Curiously, the growing acceptance of porous boundaries for cognitive phenomena is due mostly to developments in cognitive neuroscience, which is rapidly converging on the notion of ***Extended-Embodied Cognition***, of which mirror neurons research (e.g., Iacoboni, 2008) is perhaps the most popularly noted (but see also section on the social brain in Chapter1). One can regard the general thrust as extending cognition ***beyond the surface of the skull*** in two directions simultaneously: ***<u>'outward'</u>*** to include the physical and social environment**,** and ***<u>'downward'</u>*** <u>(in bipedal humans)</u> to include the body**.** In this chapter I apply Hutchins D-Cog theory in search of behavioral traces in both directions.

5.1.2 From Outcome to Process with Hutchins' D-Cog

I use a hand-coded dataset and a video recording of the type of event depicted in Smuts' anecdote, which recurs with relative regularity during sexual consortships in baboons, in order to examine the *cognitive dimensions* of polyadic interactions. Specifically, the dimensions identified earlier as (1) the moment-to-moment coordinated negotiation of multiple agents in a fast-paced unfolding event, and (2) the relational contingencies that are brought to bear on these dynamics, as well as their build up over time. Analogous to the way *social dimensions* of polyadic interactions in the previous chapter pulled simultaneously toward group structure and relationships, the *cognitive dimensions* of polyadic interactions trace the way individuals negotiate the moment-to-moment 'task at hand' while at the same time monitoring, integrating, and 'constructing' longer term relational webs.

While Hinde's *relationship approach* in the previous chapter led to a focus on the more common association and interaction dynamics (i.e., ASOC, GRT states) that make up the lion's share of relationships, here I focus directly on how the more complex polyadic interactions are organized. More specifically, ***I am looking for <u>behavioral research tools</u> that will <u>extend to cognition</u> the framing I used to address social complexity.***

Using Hutchins' theory of Distributed Cognition, or D-Cog, I take advantage of the regularity and unequivocal outcome of sexual consort turnover, or CTO, events, namely the switch in male consort partners. I examine CTO events as a distributed socio-cognitive system that can be described as definitively resolving the issue 'who will be the next consort male partner?' This framing renders these systems amenable to rigorous tracking and analysis regardless of an observer's ability to infer goals/motives/beliefs of individual participants at the outset.

D-Cog theory in no way disregards cognitive properties of individual participants. Rather it relocates their *behavioral traces* in the process of embodied negotiation and coordination with system level regularities. I therefore assume that the cognitive ‘work’ of individuals will be traceable, not by reference to postulated goals relative to performance outcome, but rather by tracing participation profiles in reference to observable system level regularities.

Specifically I am asking ***what sort of data structures and data representation will allow us to extend the state-space framing and sequential analysis to these polyadic interactions in order to***: ***(Q1) examine the impact of longer-term relational contingencies on participation profiles in CTO events, and (Q2) examine how multiple agents negotiate moment-to-moment unfolding of CTO events in relation to each other and to the ‘task at hand’***.

I continue to follow the proponents of sequential analysis of social interactions (e.g., Bakeman & Gottman, 1997; Gottman & Roy, 1990; Bakeman & Quera, 2011) in this context as well. For one, they advocate flexible identification of study ‘subjects’ at a suitable unit of analysis – agnostic to whether the subject is an individual, dyad, conversation, etc. Here I will demonstrate the versatility of this approach by shifting the boundary and state-space definitions I used in the MFI study in order to better serve the CTO system and the study questions. In addition, as I specified in Chapter3 Gottman & Roy (1990:32) advocate (option iv) exploring opportunities to translate categorical codes to timeseries representations in order to take advantage of well-established timeseries analysis techniques. I will explore such data representations (sans carrying out a full data analysis) in response to Q2.

5.1.3 Phenomena: Female Reproductive Cycle, Sexual Consort Dynamics, & Consort Turnover Events

Human field observers of baboons easily note the impact of sexually receptive females as it reverberates through the troop. Even in baboon populations in which sexual consorts with the alpha male go unchallenged (Cheney & Seyfarth, 2007) troop males have been shown to monitor activities very closely (see below). Except perhaps for inter-troop encounters, the polyadic dynamics surrounding sexual activity are the most dramatic. As with the birth cluster in the last chapter, this setting is a nexus of longer-term associations and conflicting relational agendas, brought into periodically unusual proximity.

Female reproductive cycle: Female baboons' menstrual cycle averages 35-40 days (e.g. descriptions in Ransom, 1981; Smuts, 1985, etc.) and 5-7 days prior to ovulation (the follicular phase) are characterized by sexually activity. Females reach menarche around 4 years of age, followed by a couple of years of erratic cycles, until their first pregnancy when they are around 6-7 years old. After a 6-month gestation, and a yearlong lactation period (if the infant survives), a female resumes cycling and may take 2-4 cycles to conceive again. These parameters are greatly influences by local ecology, yet they point to the *widely spaced clustering of sexual activity* in any one female's life experience. All phases of the reproductive cycle have very visible signs (e.g., Ransom, 1981:108-9) as are their changes with age (Strum & Western, 1982), and are thus easy to track and examine in references to behavioral patterns. The follicular phase carries additional olfactory cues of which male baboons are particularly astute readers.

Sexual Consort Pair: For about a week prior to ovulation, a male baboon tries to monopolize access to a sexually receptive female, considered as *mate-guarding* episodes, or *sexual consortships* (e.g., Seyfarth, 1978a; Ransom, 1981; Smuts, 1985; Bercovitch, 1987 etc.). Ransom (1981:141) notes: 'The behavior of the consort pair is fairly simple and straightforward. The male follows the estrous female, copulating with her periodically, and frequently grooming her between copulations. The female rarely reciprocates this grooming and spends most of the time feeding or interacting with other members of the troop.'

From Consort Pair to Consort Party: For some phases in the day or during the whole mate-guarding period, the consort-pair may remain a short distance from the troop, or experience little interference in their activities by other troop members. Often, however, and more intensely as the day of ovulation approaches, other males follow the consort pair, synchronizing their own activity with that of them, and may engage with consort male on its own, or by forming an alliance with other follower males (see consort turnover below). Other troop members are often part of this extended cluster – young sub-adult males monitoring and coordinating their activity without any further engagement, the consort female's offspring and / or her grooming partners, or infant friends of the consort male, juveniles harassing copulations, etc. Not unlike the relational nexus that forms around a new infant (see previous chapter), the unusual and guarded proximity between the male and female in consort, as well as the shift in activity patterns, turn the consort pair into an attentional vortex where polyadic interactions and conflicting relational agendas intersect.

Sexual Consort Turnover (CTO) Events: For many reasons, only one of which is that both consort partners are adult animals that can move on their own, the volatility of consort dynamics is much higher than found in the context of newborn infants. The disruptions to the consort pair synchrony (initiated from outside or even from within the pair) are such that opportunities arise for a different male to gain access to the female and form a new consortship with her, hence the term 'turnover'. The sources of disruption are as varied as a juvenile harassing a copulation, a consort female showing clear preference for one of the male followers, a consort male making a side greeting to one of the follower males, or having to intervene in a conflict involving a female friend, etc.

The effect on troop dynamics: The pace ebbs and flows throughout the day. Big shifts provide more opportunities for disruption and re-negotiation, such as when a troop leaves the sleeping site in the morning or when it returns to a sleeping site for the night. Troop movement is often affected especially if the consort party members are prominent in the negotiation of troop movement, or if many male followers are involved in consort party dynamics. When no visibly dramatic activity is taking place, other troop members are still monitoring and vigilant of sexual consort dynamics (see above section on testing social knowledge.)

5.2 Methodological Strategy: Cognition AS Process

Sexual Consort Study Basics: an11-months extensive study (1413 hours of observation) of sexual consorts was carried out in the same MLK troop of the Birth Cluster study in the previous chapter. Data collection involved several types of focal sampling, social scans, and ad lib notes: On each day of consort activity the consort female and her male partner were focal subjects for 30 minutes of continuous sampling 6 times–once in each 2-hour block–in a 12-hour field day. In between consort focals I also collected 1-hour focal samples per week on adult females who were not cycling, and when a consort male lost the female to another male, I followed loser males for 30 minutes. This intense data collection routine gave me a lot of continuous coverage of the baboons.

CTO Events Dataset (Macro): Scouring ALL these sources, I was able to extract information on 292 CTO events, 180 cases of which I had nearly complete direct observation of the steps that lead to the switch in male partners. A database of these events coded a variety of features on each CTO, the CTO party participants, visibility and ecological context. I was also able to report a crude blow-by-blow account, as detailed as possible given observation conditions and the limitations of hand coding direct observations.

CTO Events on Video (Micro): Two years after the original study I captured 5 CTO events on tape during a single consortship phase of one of the adult females in the MLK troop. For each of these events, I selected one continuous segment that included the CTO event itself, which I subjected to extensive hand coding. One of these events is presented to demonstrate the representational potential of such data.

5.2.1 CTO Events in Epistemic State Space

Table 5.1 provides the definitions of the system level regularities, the definitions of which emerged in the course of conducting the field study, *independent of the ethogram codes I was using in the sampling routine*. They captured a general sense I first identified as ‘tempo’, and later operationalized into mutually exclusive categories that could reliably label behavioral observations of the consort system at any given moment. It is in this observation-driven context that I choose the term ***epistemic state-space*** to distinguish it from the more *theoretically* driven approaches that propose state-space models as ‘complete’ descriptions. The observation-driven nature of this definition process ensures it will evolve as observations and analyses improve the understanding of the way these systems are organized.

Table 5.1: 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 sub-states are recognized. See text for details (modified from Forster & Rodriguez, 2006)

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*. The state may be initiated by either consort partner 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 paced than STA
NEW	***New Configuration***	A new male in contact with the consort female and/or 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, which may take some time to achieve.

The consort pair can be seen metaphorically as the nucleus of a cell, similarly to how the mother-infant pair was the nucleus of the MFI triadic interaction chains. The trajectories through state-space in both cases track the relations within and between the nucleus and the surrounding cell. In observation-driven state-space it is important for *system* level descriptions to maintain independent definitions in every level of social complexity. For example, many activity sequences move the system into a disrupted (DIS) state, yet the defining criteria–the change in proximity or synchrony of activity *between the consort pair*–inside the nucleus–is a reliable operational criteria to apply across categories. Examples of DIS sub-states are summarized in Table 5.2

Table 5.2: CTO System State Disruption (DIS) – Sub-State Examples. This list exemplifies both the rich yet finite set of variations of sub-state categories. The sub-state can be divided in other meaningful ways relevant to the study questions. For example, disruptions could be categorized by their *ecological* relevance.

Initiated by:	***Some Examples of DIS – Disruptions in CTO events***
Consort Male	• Side-trip to greet a male follower • Hyper vigilance of followers to distraction from grooming and copulating with consort female • Divergent foraging choices • Monitoring social dynamics outside the consort party • Responding to out-of-sight relevant vocalization
Consort Female	• Wanders away – divergent foraging • Distal greet and soliciting of follower male(s) • Responds to grooming solicitation by female friend / offspring / • Responds to being threatened by higher ranking female • Exaggerated run-away at end of copulation • Refuses copulation attempts
Follower Male	• Wanders in between consort male and female • Distal greeting of consort female • Solo challenge of consort male • Incite other follower males • Allies with other males for coordinated challenge • Harass copulations
Other Troop Members	• Juvenile (kin or non-kin) harassing copulations • Female grooming partner • High ranking female aggression • Infant or older offspring come to engage • Consort male's infant friend
OTHER	• Inter-troop encounter • Ecological factors: predators, human or domestic livestock, etc.

5.2.2 Data-Structures – Macro: CTO Events as Trajectories in State Space

CTO paper dataset: the detailed coding scheme I used to record behavioral data preserved the sequential structure of interactions imposing a blow-by-blow account that was still limited in how much detail it could capture during a fast pace dance or chase with 3-5 individuals, as described in Smuts' anecdote above. Nevertheless it was relatively straightforward to map the interaction sequences I extracted fairly easily onto the state space defined in Table 5.1. A few examples of the summary table I used to identify the CTO event state-sequence are shown in Table 5.2.

Table 5.3: CTO Events Translated into State-Space. Three examples are given. The states in the sequence are numbered in the correct temporal order. Case2 and Case3 are spread over 2 rows. Two letter codes are individual IDs the content if for illustrative purposes only.

Case	*State-Space Sequence*	*STA*	*DIS*	*NEG*	*NEW*
1	*STA–DIS–NEG–NEW*	1. RT_DE: RT nervous checking on followers	2. DE wanders/ RT ignores	3. HK agg2 RT (even though closest to DE)	4. HW_DE (HW run-in and pickup)
2	*STA–DIS–NEG–DIS–NEG–NEW*	1. CB_NV	2. NV agg1 JY	3. MS sup JY/NV; CB sup NV/MS; DE sup MS/NV	
			4. NV ran	5. CB follow/NV avoid ND approach, get in between	6. ND_NV in consort
3	*STA–DIS–NGT–DIS–NEW*	1. HK_DE RL, ND, CB – followers	2. RL enlist ND	3. HK aggression RL,ND; CB follow and watch;	
			4. HK chase ND		5. RL takeover. RL_DE

From the database of 180 CTO events, I ended up with as many chains of states slightly different from the triadic chains in the previous chapter. While the MFI triadic chains traced an *unbroken triadic encounter* marking the types of interactions and association dynamics the triad engaged in, the CTO event chains, or trajectories, are identified by the *phase in a process*.

By choosing completed CTO events, identified by a clear outcome (switch in male consort partners), as a subset of all the sexual consort systems I was interested in (e.g., unsuccessful challenges), I could reliably characterize these events without having to deliberate *a priori* over the intentional motivational characteristics of any individual participant.

5.2.3 Data-Structures – Micro: From Categorical to Timeseries Representation

CTO video: In each CTO event captured on video I selected the last continuous sequence that included the CTO events itself and analyzed it at a resolution of 0.1sec =3frames. I used 3-frame units since frame-by-frame judgments achieved poor inter-observer reliability with a research assistant. Table 5.4 lists the broad categories of classifications that were made. The items in each category were operationally defined in much greater detail, with clear criteria for exclusion. Each category was coded *independently* by reviewing the same video segment repeatedly at varying speeds for maximum accuracy. Coding reliability is much higher when body segments are isolated for each pass through the video. Because observers tend to see holistic whole body activity patterns, it is difficult to reach operational criteria and inter-observer reliability. Yet defining criteria for a limb, or just the head, make coding more accurate.

Table 5.4: CTO Video Coding Categories

#	*CATEGORY*	*Example items*
1	**MOVEMENT**	Walk; Run; Climb
2	**STATIONARY**	Stand; Bipedal; Sit, Lay
3	**SOLITARY**	Feed; Self-groom; Self-sex
4	**RELATIONAL**	Groomer/Groomee; Sex; Aggression; Play; Greeting
5	**VISUAL ATTENTION**	Look at; Look away; Glance; Track; Watch; 'Eyes in Back of Head'
6	**Prefix for trajectory**	b=Begin; c=Continue; e=End
7	**Visibility**	Not-Visible; Obstructed; Off Screen
8	**Body Parts**	Face; Lower/Upper Limbs (L/R); Tail; Genitals;

Visual Attention: The codes for Visual Attention (Category 5) were made independently from other activity codes primarily because they can shift divergently, and in parallel, during an activity. For example 'glance' or 'look away' can occur while grooming or moving. Visual attention is a critical cognitive marker, although inferences based on these patterns are difficult to verify. In many situations, both in human and nonhuman primates, gaze-aversion is as typical a response as gaze-direction. In polyadic dynamics, nevertheless, the fast pace dynamics and the multiple agents require rapid shifts of attention, that are more traceable, and it is these ***shifts in attention*** that I wanted to capture in detail, anticipating their dynamics would be relevant to the distributed 'task-at-hand'.

Head Movements Relative to Body Orientation (HMBO): The VISUAL ATTENTION Category (5 in Table 5.4), however, achieved the poorest inter-observer reliability scores, and was the most difficult to assess accurately especially given the video quality under field conditions. Evaluating the *target* of visual attention reliably was all but impossible.

The search for clear operational criteria moved the coding scheme *closer to the body*, since it was difficult to make judgments of distance or orientation relative to other reference points. The baboons' unique dog-like head shape, the tip of the nose in particular, finally emerged as the most reliably visible feature, not in reference to any external factor, but rather in reference to *their own body* *orientation*. Realizing that the head is *always* at a relative orientation to body made it possible to consider head movements as a *continuous representation* of *divided attention* during movement. Undivided attention would just mean the head was in the same orientation as the body (HA in Table 5.5). When individuals are stationary it is possible for shifts in attention to occur with little visible trace. But as embodied coordination and negotiation intensifies the maneuvering of attention becomes visible on the surface. This is particularly the case when considering relative movement rather than absolute trajectories. Scheglloff (1998), for example, considers the composite *body torque* a signature of embodied attention as it is reflected in differential orientation of body segments *in the course of an activity.* These orientations have little significance on their own or yanked out of a specific context. The strength of this coding is in the ability to look at the signatures of multiple participants in parallel. I will return to this thread in the discussion.

Table 5.5 and Figure 5.1 show the categories of movement that allowed me to create a timeseries representation of Head Movements Relative to Body Orientation (Figure 5.2).

Table 5.5: Head Movement Relative to Body Orientation Categories

	HA Head Ahead		
315-360	**HAL** Ahead-Left	**HAR** Ahead-Right	0-45
270-315	**HLA** Left - Ahead	**HRA** Right-Ahead	45-90
Head turned L 90 degrees	**HL** Left	**HR** Right	Head turned R 90 degrees
225-270	**HLB** Left-Back	**HRB** Right-Back	90-135
180-225	**HBL** Back-Left	**HBR** Back-Right	135-180
	HB Head Back		

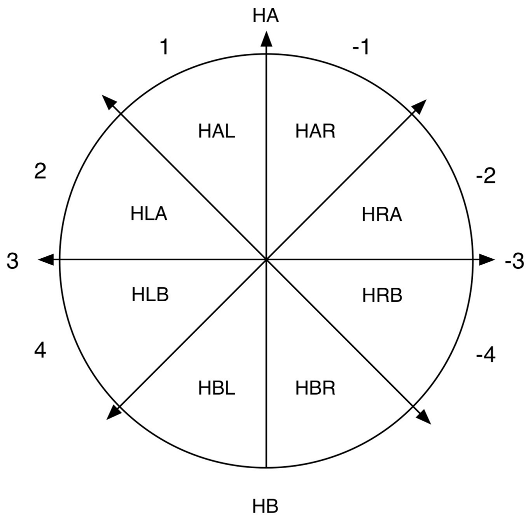


Figure 5.1: HMBO 'Compass Rose'

The 'logic': The head aligns with the body in movement if the movement is directed toward the target of attention. When body movement differs in its orientation from relative head direction, it may indicate divided attention, and, indeed, once the HMBO coding scheme achieved reliability, it also picked up the previous categorical coding I used for visual attention (look, glance, watch, etc.). Moreover, this coding scheme provided a *continuous trajectory* along a circle (Figure 5.1), which easily maps onto a number value that signified the distance from HA (Head Ahead).

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time/frame	vhs frame	HMBO time-step	HMBO Value	HEAD MOVEMENTS	BODY MOVEMENTS
21		344	0		
24		345	0		
27		346	0	b HA-L	
12		361	2	HLA	
15		362	2		
18		363	2		
21		364	2		
24		365	2		
27		366	2		
0:37	1:03	367	2		
3		368	2		
6		369	2	b HLA-R	
18		373	-2	HRA	
21		374	-2		
24		375	-2	b HRA-L	B b HRA-R
12		381	-1	HAR	HAR
15		382	-1	b HAR-R	
18		383	-3	HR	
21		384	-3		
24		385	-3	b HR-L	
				HA	

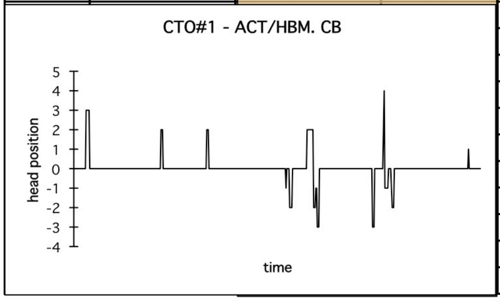


Figure 5.2 HMBO: From Categories to Timeseries Representation. Partial spreadsheet for one follower male participant in a CTO event, with the two highlighted columns showing the mapping of directional codes (Fig 5.1) to numerical values, which produced the timeseries chart on the lower left hand corner. In the chart time is along the X-axis so that points in the timeseries *above* the line signify head turns to the Left, relative to body orientation, and data points *below* the line signify head turns to the Right.

5.2.4 Macro vs. Micro Data Collection & Data Representation

The Macro (direct observations) and Micro (video footage) sources of data are very different and represent a common tradeoff in behavioral research. Direct observations recorded by hand are at a coarser resolution yet can achieve reasonable sample sizes for statistical analysis of broad patterns. Video data may be easy to amass large quantities of, but processing and coding video for meaningful analysis is prohibitively labor intensive. And yet the increased temporal resolution has the potential to reveal dynamics not captured in direct observation. Moreover the repeated viewing at variable speeds assures a refining of data coding, achieving reliability, and returning to the same data source with different coding and analyses. Here the juxtaposition of Macro and Micro offers an opportunity to examine the effectiveness of my effort to re-cast consort dynamics through a D-Cog lens, defining a CTO event as a distributed cognitive system.

5.3 CTO Preliminary Analysis

Toward Inferential Analysis: The main challenge in this chapter is to re-conceive how behavioral research can trace cognitive dimensions of polyadic interactions on two different scales: The 'Macro' scale of the relational web and its impact on 'the here-and-now of local face-to-face interactions'; and the 'Micro' dynamics of fast-paced coordination, negotiation and monitoring of multiple participants. Although these two scales can be treated separately only in abstraction, as they are two side of the same polyadic coin, they are rarely addressed together and even less likely to be studied directly in relation to one another. Although no new methods are presented here I am able to demonstrate how tracking polyadic dynamics can extends to cognition the sequential analysis framework I proposed for addressing social complexity in the previous chapter. The emphasis is thus on demonstrating the relevance of the state-space framing of CTO events (Table 5.1) on which I could 'hang' a particular macro data structure (Section 5.2.2) and micro data representation (Section 5.2.3) that allow socio-cognitive questions to be addressed within a single explanatory framework (see Chapter1). It would be possible then to deploy the type of analysis I demonstrated in the previous chapter (MWCT, or log-linear analysis) and the well-established tools of timeseries analysis (e.g., Bakeman & Gottman, 1997 and reference therein).

5.3.1 From Performance Measures to Profiles of Participation

Male Consort Performance Scores:

The outcome of CTO events can easily identify the roles of males in the dynamics: winner, loser, challenger or follower. Typically cumulative scores may be given to males over the course of a specific study period, a phase in the lifecycle or tenure in the observed group. These are valid and important assessment to explore, but their relevance to moment-to-moment socio-cognitive engagement so far remains unspecified.

Table 5.6 compares 3 self-contained (just within this dataset) measures by relative age class of the males. The scores incorporate the different roles the males performed in each CTO event: winner, loser, challenger (but not winner), or follower (but not challenger or winner), and may not have participated in every case (see Total column).

Table 5.6: Male Roles & Scores in CTO Events. CTO (n=180) roles were designated winner, loser, challenger (but not winner) or follower (but not winner or challenger). Three calculated scores: Score1= win/loss; Score2= win/challenge; Score3= win/total participated. *Each of the two sub-adult males gained and lost temporary access to a single consort female without settling into stable consort dynamics (see Table 5.2)

Male	*Win*	*Lose*	*Challenge*	*Follow*	*Total*	*Score1*	*Score2*	*Score3*	*Age*
HW	7	3	5	8	23	2.33	1.40	0.30	*very old*
ND	34	31	24	9	98	1.10	1.42	0.35	*old*
RL	29	25	25	5	84	1.16	1.16	0.35	*old*
HK	41	36	39	10	126	1.14	1.05	0.33	*mature*
CB	22	26	6	7	61	0.85	3.67	0.36	*mature*
PH	21	24	16	4	65	0.88	1.31	0.32	*young*
RT	25	34	10	2	71	0.74	2.50	0.35	*young*
SQ	0.5*	0.5*	3	16	20	1.00	0.17	0.03	*sub-adult*
GR	0.5*	0.5*	1	2	4	1.00	0.50	0.03	*sub-adult*

Table 5.6 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 (=2.33) than the other males. In absolute numbers, 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. Male HK looks more like the adjacent older age category, although his 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, male HK had an occluded (and visibly swollen) penis sheath which prevented him from achieving intromission when attempting to copulate. 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.

The type of scores in Table 5.6 become interesting reference points to the alternative descriptions I develop next (and see discussion)

CTO Events as Trajectories Through State-Space

While in the last chapter each MFI encounter represented a trajectory through state-space, the boundary of the system was around a specific MFI triad. Here, the system boundaries are the phases of a social encounter leading to a CTO event. The membership in this system is fluid by comparison. While the ‘nucleus’ of the CTO system contains a single male-female pair, the defining event is in fact a *switch in male partners*. The boundaries of the larger cluster, the *consort party*, are also more porous. Yet the sequential structure of ‘chains’ is similar, and the same descriptive and inferential analyses easily map on in spite of the differences.

CTO State-Transitions Diagram

The examination of state transitions is familiar from the previous chapter. FROM/TO state transitions are tallied (Table 5.7a) and their proportions (Table 5.7b) which can then be produced in graphic form (Figure 5.3), the thickness of the line reflecting the proportion of a particular transition relative to all others *leaving* that state.

Table 5.7a-b: CTO State-Transition Matrix. (a) Transition Counts (b) Proportions. See Chapter 4 text and Appendix for parallel examples in the MFI study.

		TO					
	Counts	***STA***	***DIS***	***NEG***	***NEW***	***END***	**Total**
FROM	***STA***	0	187	0	0	0	187
	DIS	3	2	124	38	0	167
	NEG	2	42	6	115	25	190
	NEW	0	5	44	0	154	203
							747

		TO					
	Proportion	***STA***	***DIS***	***NEG***	***NEW***	***END***	**Total**
FROM	***STA***	0.00	1.00	0.00	0.00	0.00	1.00
	DIS	0.02	0.01	0.74	0.23	0.00	1.00
	NEG	0.01	0.22	0.03	0.61	0.13	1.00
	NEW	0.00	0.02	0.22	0.00	0.76	1.00

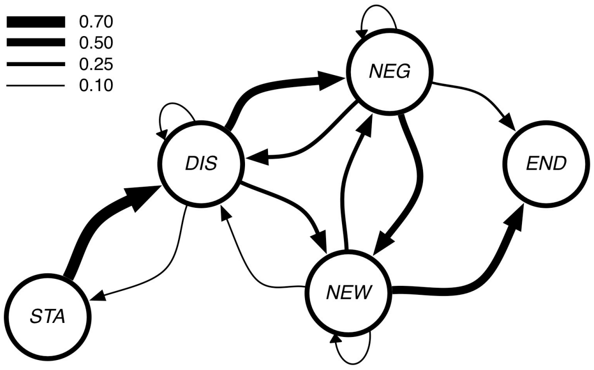


Figure 5.3: CTO State-Transition Diagram

Profiles of Participation: The characterization of system level dynamics to this extent opens up an analytic arena inclusive of *each and every participant*. It offers a richer description of participation than a single score, and can be applied also when no score can be given. In Table 5.2 some of the disruptions (DIS state) occur because juvenile harass copulations. The state-space categorization means that it is possible to characterize how individuals participate in CTO events, as they 'return' to them in different roles throughout their lifecycle.

Further analysis of these cases would require identifying sub-categories for richer descriptions (e.g., Table 5.2 for DIS state), as well as the *cumulative context* of relational factors, similar to the study factors I presented in the previous chapter (see Section 4.2). FROM/TO, or Lag-1 transitions, in the CTO state-space, as in the MFI triadic chains, can be read as reflecting 'what next?' choices and examined in MWCT analysis against relational study factors (see Section 4.3). Both the cumulative context, from which study factors would be identified, as well as the finer discernments of sub-states are beyond the scope of this dataset (extracted from the sexual consort study data as described at the beginning of this section). I pick up on these issues in the discussion.

5.3.2 Micro-Dynamics: Head Movements Relative to Body Orientation

Micro Meet Macro: The procedure I described in Section 5.2.3 (see Figure 5.2) was repeated of the five CTO event participants. The timeseries were then stacked (Figure 5.4a) and placed parallel to a Systems level State-Space time series (at 1sec resolution) that is synchronized in time.

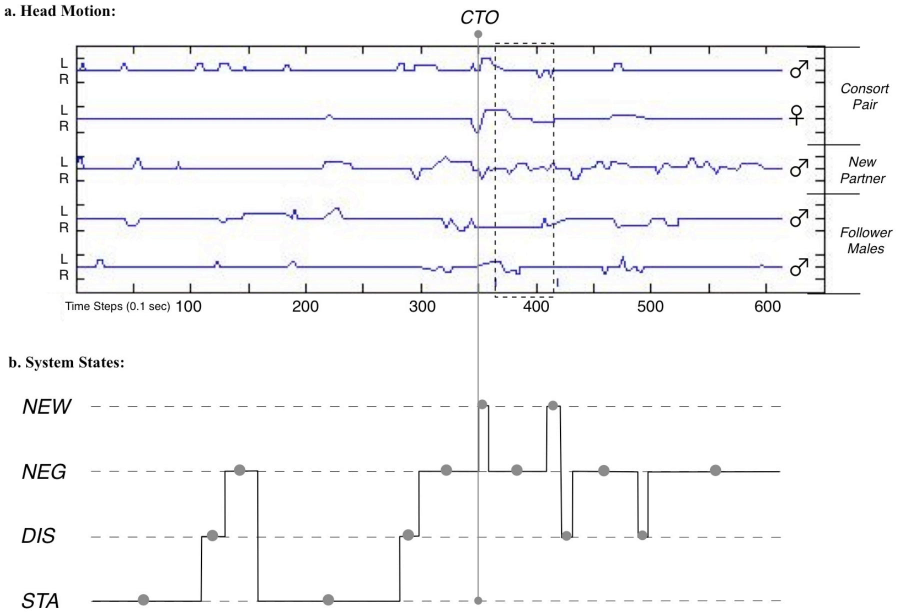


Figure 5.4a-b: CTO Head Motion & Systems States. Video analysis of a 1 minute (at 0.1 sec resolution) capturing a CTO event at time-step 350. (5.4a) Head motion relative to body orientation of 5 consort party participants (consort pair plus 3 males followers). Time series represents head movement to 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 with her new partner. 5.4b. System state (see Table 5.1) transitions.

Consort Pair: The top two stacked timeseries represent the HMBO pattern for the consort male (top) and female for about 35sec before and roughly 25 sec after the actual switch (vertical line, marked CTO) in male partners. Comparing the two time series the female's completely flat line in the pre-switch phase is typical of an experienced and confident female who has a 'loyal' following, and is consistently following her nose, literally. *For analysis purposes,* however, I would label the pattern *flat* to avoid inferences biased by my familiarity with her. A younger or lower ranking female would probably show more divergent visual monitoring, the observers characterize as nervous or anxious. Contrast with her male partner glancing to the left of where he is moving (following the female, as is clear in the video). The curious Left bias may reflect a movement habit positioning himself relative to the female, or relative to the area of concern in his visual field. Spatial information is completely absent from this representation although it is not difficult to imagine an annotation scheme that would add information about, relative distance to the consort female, for example, or might identify (with vertically lines) visible coordination between participants. Soon after the switch, the female HMBO profiles goes *flat* again and already by the end of the copulation, she returns to a straight "Head Ahead" HMBO trajectory. Further validation of her state would be possible by adding the coded layer of her solitary and relational activities (categories 3 & 4 in Table 5.4) in parallel. For clarity and emphasis on HMBO profiles, these other layers were left out.

The CTO Moment: The only moment where all five participants show active HMBO profiles occurs right around the actual switch. The video footage shows the consort male getting drawn into a tense confrontation with one of the followers (the second from the bottom) at which point the new consort partner simply steps in, putting his arm over the consort female's back following her away from the erupting aggressive chase between the other followers and the loser male. The continuous trajectories of timeseries data representations are particularly helpful in seeing patterns of nuanced coordination (the whole time window represents 1 minute of activity) that would be missed in real time watching, not only because it is impossible to keep track of five animals in parallel, but also due to the temporally rapid shifts. Analyzing video footage at a 0.1sec resolution can capture temporal asynchronies that would be impossible to record from direct observation. They may be important signatures in revealing leader/follower dynamics, or the kind of patterns that are likely to precede a system level state transition.

New male partner: copulates with the consort female (dotted box) right after the transition to NEW. Note that for the duration of the copulation his HMBO profile is very active and remains so for the rest of the time window. From the actual video footage it is obvious that he is visually monitoring the aftermath aggression between the loser male and one of the followers, who is a budding ally of the new partner. This is an example of how a male baboon, even while performing the 'task at hand', is clearly not acting as if his only 'goal' is gaining access to the consort female. Instead he devotes a considerable effort to ***monitoring the relational dynamics,*** the fabric of which he is very much a part (see Chapter 6 on delineating Task-Space and Social-Space in polyadic interactions). ***It is the most direct indication that baboons are engaged in complex coordination not only of their bodies in space, but also in monitoring the relational dynamics of others which will likely impact future actions.***

Other video CTO events: 5 CTO events were captured on video, all with the same cast of characters, within a few days, in a single cycle of female MC. She had the a similar profile in the other events when moving, and even when sitting or grooming as she did in the other clips, her head movements were not divergent from her activities. In one of the events MC herself brought about the CTO moment by walking in between two follower males and turning her body and head towards one of them, (showing a clear "preference"?) The male to whom she oriented her rump and head took over, copulating immediately, with a similar pattern of head movements monitoring the aftermath chase of the loser after the other follower males. In two of the clips the post CTO copulation was obscured from the camera view, and in another it occurred among rocks that obscured the view for the new consort male. It is thus difficult to make any generalizations across these events.

Macro/Micro & Everything in Between: Although for visual simplicity I only show two levels of coding (5 HMBO profiles – Figure 5.4a; Systems States– Figure 5.4b), other levels of coding (Table 5.4) are easy to incorporate, as are annotation schemes that would add relevant spatial or ecological information. Since all these data streams are synchronized in time, it is an ideal multilayered representation for exploratory analysis in which discovery of new patterns is likely.

Video footage of selected cases allows ***micro-dynamics of embodied attention*** that is defined in task-specific terms (here, the CTO system states, but in foraging for example, codes might specify hand-eye coordination categories). These sorts of representation reveal nuances of state-space distinctions that were not recognized in the original epistemic state space definition. The coordination of HMBO profiles just before a dramatic state transitions revealed, for example, which male follower the consort female showed a subtle "preference" for, or how two follower males were negotiating their proximity, on the order of 500 msec., relative to the consort pair.

Timeseries coding and analysis. HMBO was hand-coded at 0.1sec resolution, a prohibitively labor intensive effort to consider doing routinely on large sample sizes. That does not mean the end of timeseries analysis nor capturing embodied attention. It might be the sparser sampling regimes are relevant, or that the time series could reflect a different measure that is easier to capture reliably. Timeseries may reflect any coding that can be given a rank order (see examples in Bakeman & Gottman, 1997). In captive setting, motion capture, sensor rich environments may facilitate automated processing.

5.4 Discussion: D-Cog of Baboon Social Niche Construction

In order to bring the socio-cognitive richness of polyadic interactions into the state-space and sequential analysis framework I proposed for social complexity in the previous chapter I had to make two main moves: the first was to shift the explanatory bias from Cognition-in-the-Head-Only to Distributed-Extended-Embodied-Cognition. D-Cog allowed extending cognition in two directions: Outward to include multiple participants in a distributed cognitive system (CTO state-space) that resolves the issue 'who will be the next consort male?' And spreading to the body to track *body torque* (HMBO) as a signature of *embodied attention*.

The second move was is to provide the framing that allows these cognitive dimensions of polyadic dynamics to be examined ***as an extension of the framework I developed for social complexity in the previous chapter.*** Even though polyadic dynamics defined the agenda for investigating social complexity (by pulling at once for group and relationships), the polyadic dynamics themselves are not common enough from the perspective of any one relationship. Here I took on the more complex polyadics directly.

While polyadic dynamics are ‘difficult’ arenas for cognition-in-the-head framing (tracking multiple agents with divergent and conflicting agendas), they are ideal for D-Cog analysis because the negotiation of agendas and coordination of attention are *externalized* into social space and spread onto the body surface in ways that can be tracked reliably.

This recasting of where to locate socio-cognitive dimensions of polyadic dynamics is a departure from how cognition is explicitly addressed in field primatology today, although it captures more successfully the sensibilities of field primatologists describing the events from which their attributions of psychological states and motivations in their subjects originate (e.g., Smuts, 1985 anecdotes)

Briefly, I used a hand-coded dataset and a video segment of CTO events to investigate the types of data structures and data representations that would make tracking behavior of both individual and system level regularities of polyadic interactions reliable and ultimately relevant to two main queries: (Q1) How might relational contingencies impact the participation profile of individuals in polyadic dynamics and (Q2) how do multiple participants negotiate moment to moment unfolding in a particular task space. The same system level regularities (Table 5.1) are made relevant to both.

5.4.1 Field Primatology: From Non-Cognitive Performance Scores to Sociality Index

The CTO scores I assigned to males by the roles they performed in each event (Table 5.6) are a variation on the performance scores used in the context of sexual consorts in baboons, in order to evaluate reproductive success. Many factors go into assessing ‘success’ especially when paternity is ultimately uncertain. For example, one correspondence that needs to be addressed is the link between sexual consorts and copulations (but see curious case of HK, in Section 5.3.1). Another issue is the difference between cycles in which females conceive and which they do not (e.g., Strum, 1982) and whether males are sensitive to the fertility level of the females. Smuts (1985) for example gave each female 1 point for each half-day she was in active consortships and then divided those points evenly between the number of males who were in consort with that female for any half-day period. In all these cases there is some attempt to measure performance in a way that would make it relevant to a proxy of reproductive success. See also the composite proximity scores for assessing male-female friendships in Smuts (1985) and in the cluster of relationship studies I reviewed in Chapter 4.

Sapolsky et al. (1997) wanted a measure of social connectedness and social isolation in male baboons in order to correlate with hypercorticolism. They ended up with a set of 8 social measurements such as rated of affiliative interactions with adult females per hour, number of reciprocal grooming relationships, number of agonistic interactions, etc. A cumulative measurement of 'social connectedness' reflected the subject's deviation from the median for each of the 8 measures. Silk et al. (2003) modified this composite sociality index several times with varying numbers of measures to evaluate female bonds.

While none of these studies make any references to cognitive abilities these measures might reflect, and neither would I, I still would find these empirical findings valid points of reference in the context of the *cognitive* dimensions of polyadic activity I am articulating here. As study sites accumulate long-term demographics and are able to not only look at long term patterns but also assess genetic relatedness (see Chapter 4 discussion) and collect hormonal assays, there are more nuanced ways of evaluating lifetime fitness. To examine these performance measures and sociality indexes against profiles of participation in polyadic interactions would begin to realize the original vision of the SI-Hypothesis – and the goal of a socio-cognitive research program.

5.4.2 (Q1) Relational Contingencies Impact on Polyadic Dynamics – Study Factors & Profiles of Participation – Future Analysis

Relational contingencies point to the generalization Hinde intended for the interaction approach, namely to examine interaction types across levels of social complexity (see Chapter 3). Participation profiles provide the yardstick in that impact of individual characteristics, relationship history, and elements of group structure (sett Table 4.1) can be brought to bear on these profiles or particular segments of them. How do negotiation patterns, or reactions to particular disruptions (examples in Table 5.6) change as a male integrates in a troop in the first 2 years of his residency? How do new friendships with females, and/or their infants impact his negotiation profile? How do drought cycles in this population impact the CTO profiles? Do changes in the adult sex/age ratio leave traces in profiles of participation? Does the Birth Cluster I studied in the same troop a year earlier make a difference? Etc

This family of questions is the same as those I asked in the previous chapter, examining the impact between levels of social complexity. I am looking for study factors against which these profiles would be examined. The actual analysis would require the sort of cumulative context I provided relative to the MFI dataset as well as splitting into sub-states the CTO states I describe in Table 5.1. Both would require additional processing beyond the scope of this particular dataset. For example, Table 5.6 shows the categories of DIS state that show up in the larger study. Even though this dataset comprises 180 events, the translation into state-space was done at the least detailed level, making testing for distinction on this dataset ineffective. In addition, the number of CTO states (other than NEW), for example the DIS states (see Table 5.2), are much higher in the *study data* since not all of those states ended up in a switch in male partner. Now that the CTO system is established it is easier to go into the study data and find partial systems.

The ***Profiles of Participation*** that are traceable through State-Space descriptions of CTO events make it possible to link shorter-term targeted studies (like the Consortship study, or like the Birth Cluster study in the previous chapter) with cumulative context (see previous chapter) that provides relevant study factors to explore longer-term contingencies (e.g., using MWCT analysis for categorical data). The sample size required to make MWCT analysis relevant requires extensive data collection, but once a state-space description is defined reliably, it is relatively easy to amass coarse grain coding from direct observation. Importantly, it is likely to re-code existing shorthand data codes usually used in ad lib notes (Altmann, 1974).

Study Factors & Other Polyadic Contexts: The detailed demographic records in long-term field sites are opening up new arenas for questioning, providing study factors (for MWCT analysis) for many types of polyadic interactions other than CTO events. Predations events, Troop Movement, Inter-troop Encounters, Agonistic Buffering, etc. are examples of well studied polyadic situations that are amenable to state-space descriptions.

5.4.3 Hinde's Interaction Approach through Hutchins D-Cog Lens

CTO as System Outcome: The significance of identifying a *regularly occurring outcome* in studying complex systems cannot be overemphasized. For Hutchins (1995) in the context of navy ship navigation, the *fix cycle* – the set of prescribed activities that can be described as "computing then next navigation point." In understanding how the fix-cycle works *under typical conditions*, Hutchins was able to identify what went wrong in a near accident that occurred as the ship navigated in the San Diego Harbor. The sensitivity to local and initial conditions challenges an observer's ability to predict the next move or an outcome of a process. It was the poor predictability of 'who will be the next consort male' in any particular case, which drove the search for an alternative description. Not unlike the motivation in the previous chapter, this description represents a shift from WHO-Will-Win to How-Does-it-Work-That-Someone-Wins. Challenges are not always successful. In my data I labeled events that did not end up in a new consortship *Attempt Turnover (ATO) events.* These are interesting questions, but only when the CTO system is well understood can we also look at partial trajectories to understand the variations in their organization.

Even though the system traced here is different in its organization from the state space I traced in the previous chapter, the techniques I demonstrated there (MWCT analysis) would be equally relevant here. The STA-DIS-NEG-NEW is at this gross level generic enough to apply to almost any cognitive process. It provides a benchmark to look at other domains, or contexts, and other resources. Recovering from disruptions is a central focus of cognition research. Most importantly, being able to use the SAME state-space description as the backdrop for Embodied Attention ensures that more phenomena can be subject to more direct comparisons.

5.4.4 Polyadic Interactions: Social & Cognitive Dimensions

The simultaneous pull polyadic interactions have on each side of the socio-cognitive 'equation' (towards group structure and relationship on the social side; and toward 'the-here-and-now' or 'the task at hand' and longer term relational contingencies on the cognitive 'side') make them the central phenomenological site for socio-cognitive investigations.

Baboons participate in polyadic interactions throughout their lives and come back to them repeatedly in different roles. Consider the experience of being carried, or carrying someone on one's ventrum. From the moment an infant is born, through such embodied coordination with its mother, perhaps siblings, male friend, and then as an adult female carrying one's offspring, or as a male carrying an infant friend. The D-Cog framework allows these basic coordinated experiences to provide familiar structure to baboons throughout their life even if they possess differing degrees of agency in each life-stage. If baboons learn the system level regularities in which they participate, their challenge is very often not one of learning a completely new skill, but rather shifting the actions that are required to get into coordination with these familiar configurations.

In polyadic interactions, the 'problem space' is also the 'solution space' (Hutchins, personal comm.) – this type of circularity is inherent in socio-cognitive systems and it may also be how they evolve. Van Schaik & Burkart (2011) note as part of the cultural intelligence hypothesis that "improved social learning also improves social learning" thereby improving individual learning abilities.

In the previous chapter, I suggested that the Lag-1 FROM/TO transition, which became the basic unit of interaction analysis, had a cognitive appeal in that it can be read as 'what next?' and therefore reflect some aspects of relational decision making. Discovering cognitive aspects in the sequential analysis aimed at social complexity was an unanticipated bonus. In this chapter the focus on Distributed Cognition has continually referenced the framework developed in the previous chapter, and it is to a more explicit integration between them I turn to in the final chapter.

CHAPTER 6:

The Socio-Cognitive Challenge – Multiple Relational Levels of Investigation

6.1 Overview: The Three-Tier Journey, Revisited

I set up the dissertation around a three-tier investigative agenda (Tables 1.1 & 6.1) that examined how C-Systems Thinking sensibilities and a State-Space framing can transform the SI-Hypothesis into a more comprehensive behavioral research program for Socio-Cognitive phenomena in nonhuman primates.

Table 6.1: Three-Tier Investigative Agenda, Revisited. Table 1.1 identified the issues that were at stake in each tier. Here the main insights from each mode of investigation in the course of carrying out my thesis project are briefly summarized. See text for details

Mode of investigation	Focus	Main insights
Paradigm	*Complex Systems Thinking*	• Dynamical Systems in methods of Behavioral Analysis • Organized Complexity & Levels of Investigation • Behavior as its own level of biological organization
Theory	*Social Intelligence Hypothesis*	• From SI-Hypothesis to Socio-Cognitive Phenomena • Phenotypic & Representational Gambits • From What-is-it-For to How-Does-it-Work
Method	*Dynamical Systems, State-Space & Sequential Analysis*	***Complexity AS Context*** – Hinde's Social Complexity • Data Structures w/ context built in • Multiway Contingency Tables Analysis ***Cognition AS Process*** – Hutchins' Distributed Cognition • From performance measures to Profiles of Participation • Categorical to timeseries representations • HMBO as Embodied Distributed Attention

The review of the SI-Hypothesis landscape in **Chapter 1** left the impression that the agenda set by Byrne & Whiten (1988a) never cohered into a productive research program. The flurry of crosstalk with cognitive scientists receded as field primatologists aligned more strictly with behavioral ecology orthodoxy. This shift, while improving methodological rigor, biased researchers away from contextual factors and relational dimensions that hampered behavioral accounting of individual fitness. In so doing the challenges of the SI-Hypothesis–how to measure social complexity and how to link it to cognitive dimensions of behavior in naturalistic settings–remained far from resolution and mostly left out of the research agenda. The failure of the phenotypic and representational gambits did not seem to impact the explanatory logic or methodology of field-primatologists-turned-behavioral-ecologists. Nor did the full C-Systems Thinking implications of Hinde's model. Yet both Hinde's hierarchical model of social complexity and Hutchins' D-Cog addressed the rich nexus of social and cognitive dimensions of (mostly human) behavior by tracing multiple levels of description and analysis – the requisite empirical devices in systems of *organized* complexity.

The fragmentation in the SI-Hypothesis research landscape, and the challenges of applying Hinde & Hutchins frameworks to nonhuman primates' spontaneous behavior drove me in **Chapter 2** to re-examine the *phenomena* that had so inspired SI-Hypothesis proponents as well as the range of *methods* behavioral ecologists used analyze social dynamics. The primacy of socio-ecological factors in the way baboons organized to move by day, and to settle for the night, was reaffirmed by re-tracing the early days of field observations. Identifying *SE-Clusters* as the minimum unit of meaningful contingencies, or 'the here-and-now' of baboon group life, helped locate the dramatic *polyadic dynamics* that fed the flames of the SI-Hypothesis in consistently *more complex* and *larger units* (see Figure 6.1) than the subsets primatologists typically extract and isolate, as social interaction data, for evolutionary functional analyses.

Nevertheless, C-Systems Thinking and its computational underpinning in Dynamical Systems Theory show up as relevant to behavioral ecology analyses of individual performance (optimality & optimization) social networks (graph theory), strategic interactions (game theory) and communication (information theory), in approaches that have easily transferred between and across behavioral disciplines. Toy-like as the applications of these tools have been relative to the rich complexity of primate social dynamics, the flexibility and generic abstraction of State-Space framing is intuitive and appealing. As such, it puts the onus of meaningful and valid application on the specifics of research design. Many of these analytic techniques that primatologists were among the first to deploy are experiencing a resurgence supported by recent developments of appropriate computational tools.

Reframing of Hinde & Hutchins in State-Space, in **Chapter 3**, was not a far stretch from their original sensibilities. Neither was applying the contextual design logic of Sequential Analysis for social interactions (Bakeman & Gottman, 1997; Gottman & Roy, 1990; Bakeman & Robinson, 1994;

Bakeman & Quera, 2011). These moves structured my proposal for a ***behavioral research program for socio-cognitive phenomena***: A two-pronged approach, first applies Hinde's *relationship approach* to examine social complexity, and then applies Hinde's *interaction approach* through Hutchins' *D-Cog lens*. The state-space framing and tools of sequential analysis provide the shared arena by which it is possible to examine links between social complexity and cognition.

A dataset of male-female-infant relations around a clustering of births, in **Chapter 4,** provided the first proof-of-concept: systematically addressing social complexity through a focus on context. By building immediate context into the social interaction data-structures and testing for sequential dependencies, I was able to examine the same interaction dynamics against study factors (= cumulative context) from both long-term relationships and group structure, levels of social complexity that are typically examined in isolation. MWCT analysis, in contrast to multiple t-tests and/or two-way contingencies, provides opportunities to discover higher-order associations between factors and to generate hypotheses for further research. Most importantly, shifting the explanatory emphasis in relationship and interactions studies to a more operational How-Does-it-Work perspective opens up the black box of social complexity for systematic examination between levels, a sharp departure from the restrictive accounting of individual fitness.

A dataset on sexual consort turnover events, in **Chapter 5**, completed the proof-of-concept of my research program by taking on polyadic dynamics that typically drop out of relationship studies given their relative rarity. Showing how the framework that applied to social complexity could be extended to address cognitive dimensions of polyadic interactions required a second explanatory shift to a *process description* of Extended-Embodied-Distributed-Cognition. It opens up the black box of in-the-head cognition by capturing the cognitive traces the leak out into the physical and social environment, and that spread to the whole body. The state-space framing in this case is modified to describe a polyadic dynamics (with a clear outcome) as a distributed socio-cognitive system, allowing all individuals in the system to trace *Profiles of Participation*, a richer description of individuals than a single performance measure. The Micro-dynamics scale of video footage allows tracing participation profiles of any element in the system on multiple time scales, in a continuous representation, making timeseries analysis an added option in the sequential analysis tool kit. These types of behavioral tracking provide the arena in which to examine the two scales of socio-cognitive effort that captured the imagination of SI-Hypothesis proponents: the dynamic dance of multiple agents navigating moment-to-moment embodied coordination in a complex 'task-at-hand', and the relational contingencies that are monitored, integrated, and brought to bear on future interactions (see right hand side of Figure 6.1).

The real potency of the two types of studies is in their integration into a single research program that is able to link between the systematic examination of social AND the tracking of distributed cognition of polyadic interactions.

6.2 Social Complexity & Cognition, Re-Integrated: Phenomena, Methods & Theory

6.2.1 Polyadic Phenomena: Carving Baboon Life at its Socio-Cognitive Joints

In the first figure in the dissertation (Figure 1.1) I arranged the products and activities of doing science in quadrants around their phenomenological center, to indicate that it could, and perhaps should, be revisited in every phase, but especially when our explanations falter. The phenomena in the center of this thesis project turned out to be the kinds of *polyadic dynamics* I identified in Chapter 2 and described at the outset of Chapter 4, one type of which, CTO events, I looked at in more detail in Chapter 5. I turned to them historically because they were of the type of behavioral patterns that inspired SI-Hypothesis proponents to consider a causal evolutionary scenario for the juxtaposition of the incessant sociality in primate groups with their idiosyncratic and creative problem solving.

I remained tethered, however, to the kind of dramatic polyadics that occur within and across boundaries of SE-Clusters (see Chapter 2), because they successfully carve the baboon world at its socio-cognitive joints, raising the *appropriate questions*, and therefore serving the best placeholder for this project. In relationship studies that follow longitudinal trajectories, polyadic interactions are relatively rare and yet it is in the polyadic interaction that the double pull to both relationships and group structure is strongest. This was the case when the special polyadic dynamics in the opening paragraphs of Chapter 4, such as agonistic buffering, themselves dropped out of the analysis in the MFI dataset, due to their relative rarity within any individual relationship trajectory. For a socio-cognitive program to be successful, there are two implications given the rarity of polyadic interactions in relationship trajectories: The first is not to abandon the query of multiple levels of social complexity. The second implication is to go back and figure out how to study those polyadic dynamics as distributed socio-cognitive systems, so that links between social complexity and cognition can be examined.

In this dissertation, I used Hinde's *relationship approach* and his *interactions approach* on different phenomena (relationship approach on the MFI dataset and interaction approach on the CTO dataset). However these datasets came from studies that represent a *full investigation* that would allow each to receive the 'full' socio-cognitive treatment. See Table 6.2

Table 6.2: Birth Cluster & Sexual Consorts – Interaction, Relationships & Group Structure. The two studies from which I extracted datasets (MFI & CTO) used in this thesis, their relevant relationships and types of interactions. The items that organized the analysis in each case are in italicized bold font.

Study	**Birth Cluster**	**Sexual Consorts**
Dataset	***MFI chains (N=1251)***	***CTO events (N=180)***
Interactions	Association Greeting Grooming Aggression Special	***CTO – Consort Turnover*** ATO – Attempt Turnover Copulations Grooming Coalition formation Male-male side greetings
Relationships	***Male-Female*** ***Male-Infant*** Mother-Infant Male-Male Female-Female	Male-Female Male-Male Female-Female Male-Infant Female-kin
Group Structure	# of overlapping black infants	# of overlapping consorts
	Adult age/sex ratio Male residency pattern Dominance Hierarchies	

The Social & Cognitive Dimensions of polyadic as they are relevant to this thesis, are captured in Figure 6.1. It can be thought of as the space of ***socio-cognitive niche construction*** to build on Flack et al. (2006) depiction of social niche construction (see also Section 2.1.4).

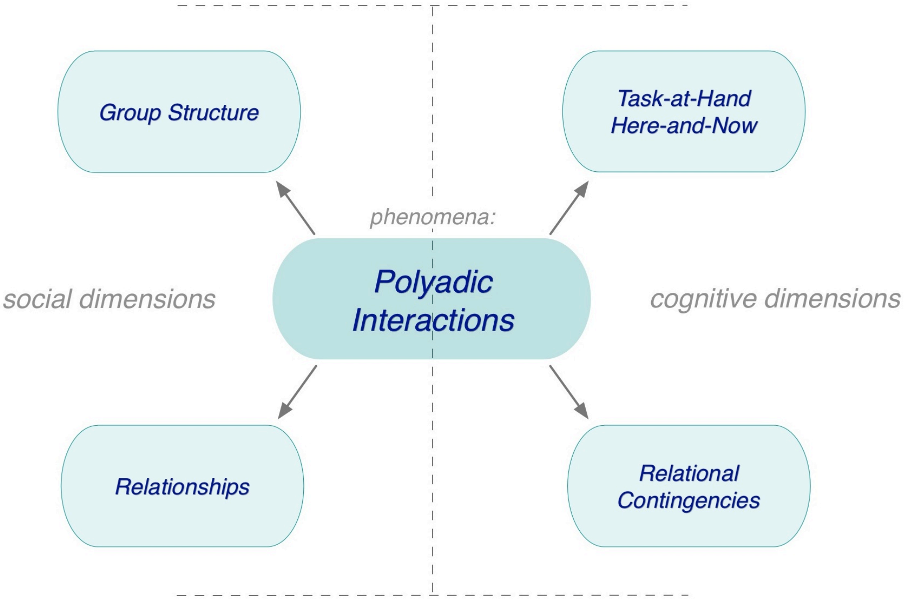


Figure 6.1: Phenomena Gestalt – Social & Cognitive Dimensions of Polyadic Interactions. Polyadic dynamics pull simultaneously to consider relationships and group structure (social dimensions). The same dynamics also pull simultaneously to the moment-to-moment unfolding of embodied coordination of the 'task-at-hand' as well as the monitoring and integration of longer-term relational contingencies (cognitive dimensions)

The quote at the beginning of Chapter 4 is worth repeating:

> This interrelation of behavior patterns is at one and the same time exasperating and delightful to the observer. On one hand it presents him with the frustrating, often impossible task of isolating functional relationships. On the other it constitutes the fabric of the social milieu that is so fascinating.
>
> (Ransom, 1981:107-8)

As the quote suggests, field observers of baboons are constantly alternating between seeing the social network or web, and trying to isolate functional relationships within it. Similarly, the examination of the anecdotes and reflections of Smuts (1985) at the outset of Chapter 5, revealed a two-scale pull: One toward the immediate negotiation of the unfolding interaction, and the other to the relational contingencies that impact behavior, which would otherwise be rendered unreasonable (e.g., the unprovoked acts of aggression Smuts observed).

Primatologists turned behavioral ecologists were taken with these polyadic interactions (see Chapter 1, 2, 5) and articulated much of the sensibilities that drive the framework I am presenting here. As I noted in relation to Smuts' CTO anecdote (Chapter 5) her narrative recounts embodied coordination yet her interpretive text that followed attempted to couch these behavioral traces in terms of internal psychological and emotional states, only. While it is less controversial now to link embodiment to cognition, the expectations about cognition-in-the-head impacted what constituted reliable cognitive evidence in behavioral observations.

The response to the challenge Ransom articulates in the quote above focused on isolating functional relationships from the social tapestry that presents itself to human observers. Functional questions are often easier to address in that they may offer specific testable hypotheses. See Cords, 1997, comments on the difference between Hinde's (1976) descriptive approach to relationships compared with Kummer (1978) functional 'what is it for?' approach and the appeal that had for behavioral ecology.

Field researchers got busy then, carving out functional relations which could have a performance and fitness 'price tag' such as male-female attachment relative to mating success or survival of offspring, female-female bonds and grooming networks, exchange of grooming in the biological market place etc. With each type of relationship came a separate adaptationist characterization. I suggest based on the material presented here that the problem with 'isolating functional relationships' is not with the functional relationships pre se, but with the *isolation,* which makes these frameworks and their hypotheses insulated and difficult to reconcile. The cluster of relationship studies I review in Chapter 4 (Table 4.11) is an example of a seven-fold hypothesis space (what are male-female and male-infant relationships for) that is unresolved even as studies keep organizing conceptually and methodologically around them.

Grooming networks, and female-female bonds are now scientific realities in the research literature and they have been productive constructs. It is impossible to study all the relations and all the connections at once, so my proposal is not a rejection of this approach. The question turns on where does one return to in order to tell a socio-cognitive story? What is the framework on which to hang this or that particular story? How does a researcher return to view the social web *with* the new insights of this or that functional piece?

The research program perspective I proposed is beginning to demonstrate how to get at elements of social complexity that were assumed or underspecified but have yet to be systematically revealed. It also points to a reassembling the whole from its parts, without which a discussion of socio-cognitive challenges remains wanting.

6.2.2 Methods: State-Space & Beyond

The reframing of social interactions in (distributed) state-space opened up the tool-kit of sequential analysis techniques. State-space framing and sequential analysis are not new methods to behavioral ecology or to primatology (see Chapter 2 & Chapter 3). Their effectiveness in the framework I presented is in their flexibility of defining their boundaries as well as the temporal spatial and relational scales at which they capture data. In Chapter 5 I was also able to demonstrate the effectiveness of moving between discrete and continuous representations by translating visual attention categories into a timeseries representation of head movements relative to body orientation (HMBO) Table 6.3 compares these items from the two datasets.

Table 6.3: MFI & CTO Datasets – State-Space & Sequential Analysis, Compared.

Dataset	MFI	CTO
System	Male-Female-Infant Relations Nucleus: Female-Infant pair	Consort Party Nucleus: Male-Female Consort pair.
State-Space	TYPE x ACTOR Composite States	CTO phases: STA-DIS-NEG-NEW
Data-Structure	Triadic MFI chain = one continuous encounter	CTO event chain Until switch in male partner. From stability to new configuration
Sequential Analysis	State-Transition Diagrams, MWCT (log-linear) Analysis	State-Transition Diagrams, Categorical to Timeseries representations
Analysis Levels	**Relationships** Historical Consistency & Association Symmetry	**Relational Contingencies:** Profiles of Participation
	Group Structure Peak Cluster & Relational Status	**Embodied Attention and multiple timescale**: HMBO; Social States; System States
Conceptual Shift	• From What-is-it-For to How-Does-it-Work • Same data structure to examine both relationships and group structure • Systematic Social Complexity Inquiry	• From Performance Measures to Profiles of Participation And embodied attention • Same state-space across multiple spatio temporal time scales
Cross Over	To cognition: Lag-1: ‘what next?’	To Relational Dynamics: Task Space vs. Relational Space

As Section 2.3 demonstrates, sequential analysis is a member in a family of analytic tools that can be used in combination to address different aspects of social dynamics. Social network analysis captures association and can describe group structure is ways that can pick out important relational features not otherwise detected (e.g., Lehmann & Dunbar, 2009). I also described Dedeo et al. (2010) study that combined social network analysis with timeseries data to apply in a modeling approach the authors called inductive game theory. They used this hybrid to look at real and simulated data of conflict management in captive macaques. Timeseries data also allow examination of longer contingencies that I showed in Chapter 5. A graphical visualization of recurrence plots can be used to examine recurrence of themes in an interaction sequences etc. (see Bakeman & Quera, 2011). Social network analysis, and recurrence plots are two additional techniques that would be appealing to employ on such datasets. Both would require larger sample sizes.

6.2.3 Theory From the SI-Hypothesis to the Socio-Cognitive Challenge

The impact of C-Systems Thinking extended to the theoretical investigation of the SI-Hypothesis shifted the emphasis from insisting on a directionality of causality to a more agnostic investigation on the links between social and cognitive dimensions of behavior. The failure of the phenotypic and representational gambits required that the explanatory apparatus from behavior to cognition and from behavior to evolution be re-examined.

What happens to Evolutionary Theory? The most productive sources of evolutionary insight seem to come from cross-species and cross-taxa comparisons; from genetic testing; and from long-term demographic records. In the investigations I offer in this thesis I reject the stronghold behavioral ecology has on the accounting of social behavior in primates, not because I reject evolutionary theory, but because the particular flavor of behavioral ecology applied to social behavior of primates leaves crucial data out of the socio-cognitive picture. It is more a question of *resolution* at which we can account for inclusive fitness in an individual primate's lifetime. The cluster of studies I reviewed in Chapter 4 provides several impressive cases where ***long-term demographic records*** are able to detail benefits to survivorship and reproductive maturation in offspring of male baboons over a 30-year span (Charpentier et al., 2008, and see Chapter 4). This accounting is on a different scale than the accounting I presented, for example in Chapter 4 on male-female-infant triadic relations in which the dynamics of interaction over a 6-month period were tested against longer-term assessments of the *Historical* C*onsistency* and *Association symmetry* in male-female and male-infant relationships. The dynamics captured in the data-structures were Lag-1 transitions–FROM previous state TO current state–providing a 'what's next?' sensibility that tallies or rates of interaction per unit time do not. In this particular case the analysis suggests that remaining in association *after* greeting is a significant feature that maps onto both consistency and symmetry of longer-term relationships. Looking for underlying mechanisms that may relate to a rate of interactions per unit time is a much more abstract and potentially irrelevant query. Yet considering the factors that would influence whether a male would hang around right after greeting has immediate speculative associations regarding physiological state, that may be empirically investigated, similarly to the hormonal profiles Shur (2008) collected from male and female baboons to consider male friends as primed for solicitude. See Donaldson & Young (2008) for an example of evaluating monogamous vs. promiscuous voles.

In long-lived social species understanding ***how behavior works*** is a more reasonable 'job description' for behavioral analysis than trying to grab limited abstracted chunks that would indicate inclusive fitness or reproductive success. Arguing for this or that evolutionary hypothesis that isolates only one supposedly functional relationship, and then repeating that process independently for others does not make sense since that is not how organisms 'present themselves for natural selection'. In the studies I reviewed in Chapter 4, and indeed, in much of behavioral ecology before genetic testing, evolution was mostly in the theory, not the data. Now that alternative portals to evolutionary factors are opening (i.e., genetic testing, and long-term demographic records) up we can reconsider what role behavioral analysis will play most effectively in behavioral ecology.

What happens to Cognition? The main shift in the theoretical perspective on cognition that I look to in this thesis is to a distributed cognition extended in two 'directions': out to the physical and social environment, and spreading from the head to include the body. The shift in human cognitive neuroscience toward extended embodied cognition has been very refreshing to behavioral cognitive scientists who already engage in distributed cognitive ethnography (e.g., Hutchins, 1995; Cole, 1996; etc.). These developments have also been refreshing for researchers of nonhuman animals since they were a priori set across the divide from access to mental representations, speech, text etc. even though they are adept at tracking nonverbal behavior. The importance of embodied cognition for instance showed that the coordination and shifting of attention registers in the *whole body*, not just in eye gaze, and the more complex the social environment the more these negotiations are made visitible. For example, in The Primary Triangle, Fivaz-Depeursinge & Croboz-Warnery (1999) track human mother-father-infant interactions by coding the relative orientation of head, shoulders, torso and pelvis, of each participant, a differential segmentation that was easy to correlate with patterns of healthy and dysfunctional relating in these families. Schegloff (1998) considers the composite of differential orientation of body segments as relevant to social interactions in humans. I deployed a similar logic in the CTO video analysis of HMBO.

A key factor in these explorations is the growing recognition of the relevance of embodied behavior to what I have been calling 'the task-a-hand' or the 'here-and-now.' Not an absolute abstract orientation, but the way behavior is organized in the immediate environment, in accord, or discord with other physical and social features. What was once considered a hard problem (reading cognitive processes in complex setting with multiple agents) become a much more tractable one, as shift of attention, and divergent orientations, point more precisely to where the cognitive 'work' is located.

What happens to Socio-Cognitive Behavior? The socio-cognitive challenge is reframed through the polyadic phenomena (see Figure 6.1) as ***social niche construction*** (Flack et al. 2006; see Section 6.1.1 above, and also Sections 1.1.3 & 2.4.1) The social and cognitive dimensions of behavior intersect in the simultaneous negotiation of the here-and-now or an unfolding interaction while monitoring, integrating and responding to relational contingencies that make up the social web.

Locating and making traceable links between social and cognitive dimensions of behavior makes the investigation of the way *social complexity* and *cognition* are related more amenable to direct investigation, as an alternative and added reference point to black-boxing into abstract measures of group size and brain size (Strum et al., 1997.) Socio-cognitive dynamics, rendered visible across contexts, becomes a common yardstick by which to look in places where only discontinuities were noted before, such as the presence/absence of material culture in human/nonhuman animals. Strum & Forster (2001) argued that while material artifacts may be absent from nonhuman primate life, the socio-cognitive activities of coordination, negotiation, and constructing *nonmaterial* artifacts (e.g., friendships, alliances) that, nevertheless, leave traces in the social environment (i.e., change the shape of the social niche) are common in both.

Evolution: Van Schaik & Burkart (2011) note that social learning improves social learning, in the sense that one is both learning to be social and learning to learn in social settings. It may also improve individual learning and problem solving skills, as suggested by Vygotskian psychology. In species that have a high degree of social learning, also non-social skills are learned in a social context. Tracing socio-cognitive dynamics developmentally and across species would contribute to the recent convergence in the evolution of social learning research (see Chapter 1)

6. 3 Future Directions - Baboons

The reframing of socio-cognitive phenomena I propose here offers opportunities to integrate disparate threads of investigation as well as generate new ones. The key to this effort is in recognizing what Hinde considered the dialectics of levels of social complexity, on the one hand, and the ability to trace cognitive dimensions of social behavior in D-Cog fashion, on the other. It suggests reorganizing a research program around a group or population level socio-ecological phenomena, or around a lifecycle achievement of individuals, of relationships, etc.

GROUP: At its broadest, this framework suggests a re-organization of studies around group level socio-ecological phenomena in order to evaluate how social complexity reverberates through the whole structure. The group may be the smallest viable unit of social complexity in primates. By focusing on the birth cluster in Chapter 4, I was able to examine how it leaves traces on multiple levels of social complexity. Yet the proof-of-concept I demonstrated was just a first step. One would want to see how the study period differed from periods in which births were more spaced out in time, as well as compare the impact of a birth cluster in groups of different sizes. Other temporary phenomena are generally notes as contextually important, but are not necessarily examined systematically across successive levels of social complexity. Periods of drought, troop fission, and other unusual ecological factors offer other such natural experiments.

INTERACTIONS: The cognitive dimensions of polyadic interactions have brought to the fore a reconsideration of where socio-cognitive development can be tracked. More over it demonstrated the advantage of complex polyadics in externalizing and locating where cognitive work gets done. What is social about cognitive processes in primates? And what is cognitive about social interactions? The video analysis in particular offered opportunities to address such questions by mapping interactions such that they discern ‘task-space’ from ‘relational-space’. In the CTO analysis, noting embodied behavior relative to the system level task (i.e. ‘deciding who will be the next consort male’) begins to provide a measure of how these threads weave through socio-cognitive space. Such a characterization, in turn, provides a yardstick by which to track changes over time that capture the impact of experience, learning, maturation, etc. The notion of 'task' is decoupled from intentional in-the-head goals, objectives, etc., and should be thought of more crudely as a 'null hypothesis' for the sake of analysis. With respect to the CTO analysis, for example, if we consider the task as noted above (i.e., deciding who will be the next consort male), than task-deviant behavior (e.g., tracking distant dynamics between males by new consort male, see Chapter 5) jumps out of the data as a reliable 'signal' worthy of analysis. ***PROFILES of PARTICIPATION:*** can be compared across individuals; across lifecycle transitions to evaluate development and learning; across contexts to evaluate domain specificity.

INDIVIDUALS: this framework also proposes a different explanatory structure to questions of lifecycle socio-cognitive achievements. The life-history patterns of male baboons in choices of social strategies over aggression (Strum, 1994) can be traced to a set of relationships, and an individual's profile of participation in polyadic interactions, two strands of investigation that are not always examined in relation to one another.

INTERACTIONS VS. REALTIONSHIPS: The research program I propose for socio-cognitive research captures the main challenge facing individuals: how to navigate *interactions* while building, monitoring and taking advantage of *relationships*. We do not yet look at a particular cognitive landmark achievement and track the differential impact/contribution of a type of interactions over a relational trajectory. This is the kind of question that is particularly relevant to socio-cognitive development in humans in educational settings. While teachers express the significant of building relationships with and between students, most socio-cognitive research focuses on a particular type of interaction.

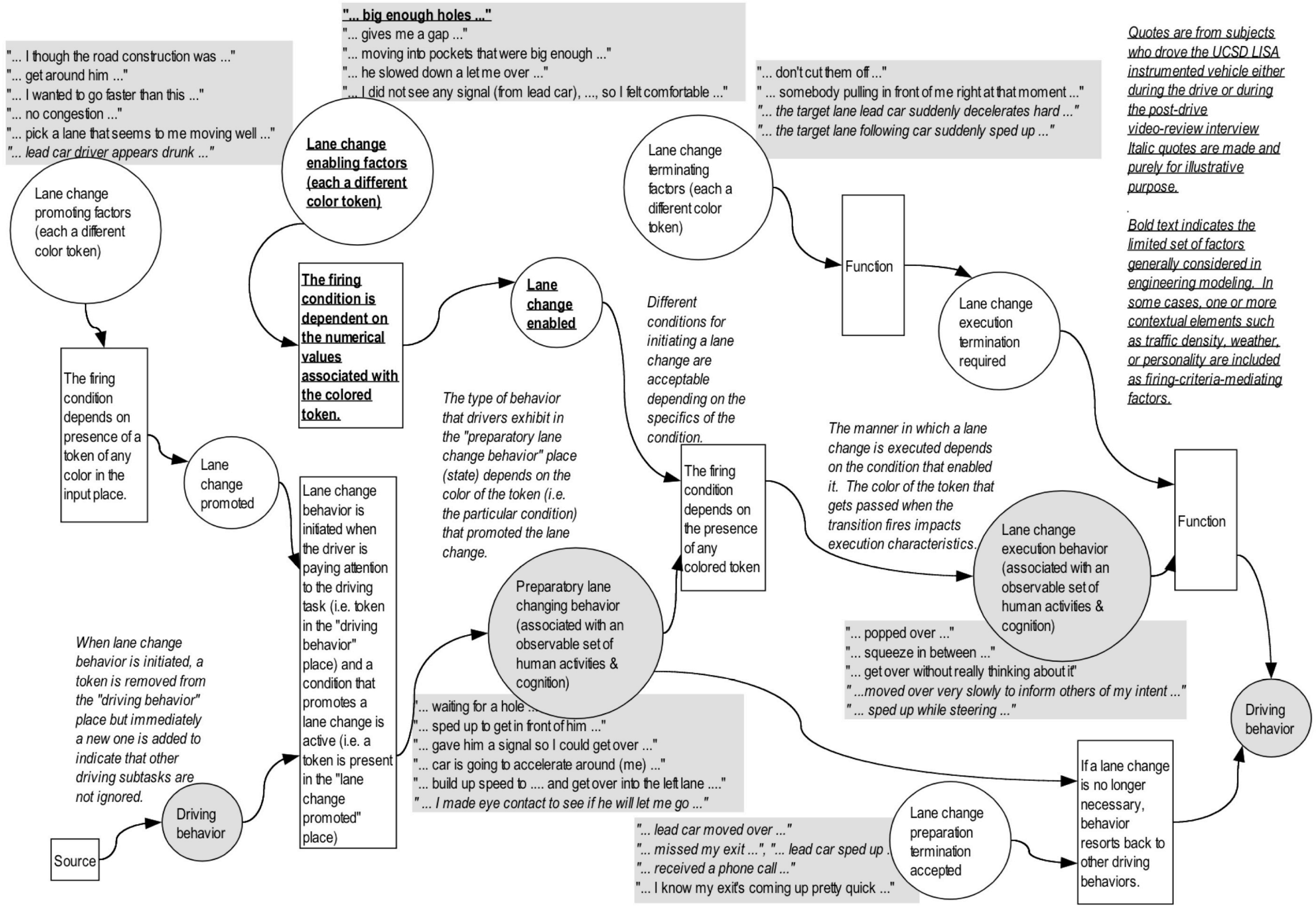
6.4 Back-to-the-Future: From CTO events to Lane Changing to Maternal Bids

The critical move in D-Cog analysis is the reliable identification of a socio-cognitive system, tracing its boundaries such that description of elements participating in the system and coordinating with system level regularities reveal the embodied and relational dimensions of the cognitive work involved. My approach to the sexual consorts study (see Table 6.2) was to begin by studying the CTO event as a distributed socio-cognitive system, since the switch in male consort partners is reliably recorded. The study should not stop there, yet it is a crucial step in a researcher's ability to remain agnostic regarding internal mental states as a pre-requisite for analysis. Here I briefly describe two other contexts in which this device proved a productive entry into a complex arena that remained opaque otherwise. The first is examination of lane changing behavior in the context of designing Intelligence Driver Support Systems. The second is the examination of a bid to switch toys in a mother-infant longitudinal study that aimed at understanding the socio-cognitive achievement that occurs in the first year or life, by which infant-mother-object interactions transform into a well-coordinated 'dance'.

6.4.1 Intelligent Driver Support Systems: State-space of Lane Changing

During a three-year multi-disciplinary research effort into the design of Intelligent Driver Support Systems (IDSS), the HCI-D-Cog lab at UCSD took on a behavioral component of doing field ethnography on driving with the focus on lane changing, since it is a leading cause of vehicle accidents. Here I will briefly describe the shift in perspective on how to study lane-changing behavior and the impact it had on the automotive engineering contingency of the project. The perspective of automotive engineering is to detect a driver's intent to take an action and support the driver to make it safe and successful. The framing of the question was therefore around detecting driver intent. Yet when watching the behavior of drivers during test sessions and in auto-confrontation interviews to elicit further reflections from subjects, it turned out the lane changing may happen in the context of other driving pattern (e.g., getting off the freeway,) and often do not stand out in the self-reported accounts. Instead of trying to identify when drivers intend to change lanes and look to see 'how well they carried out their intention' we examined the corpus of driving sequences on ~30 drivers, and labeled lane changes in the video, to form our initial dataset. These flagged events were studied them as driving systems (including the driver, vehicle, road, traffic, etc., regardless of identifying driver intent to begin with. Our test route intentionally included several stretches of road where multiple lane changes were necessary, as well as long stretches where they were not. The speech during the drive and in the post-drive auto-confrontation interviews provided a first entry point into understanding the way lane-changing systems got organized. This characterization was amenable to a variety of state-space descriptions known as Petri Nets.

Figure 6.2: **A Petri Net Representation of Lane Changing Behavior.** Circles are *place nodes* (behavioral states). Rectangular boxes are *transition nodes* (behavioral transitions). The quoted phrases in shaded boxes are actual comments made by drivers during their drive; they were used as one of the data sources to organize observed behavior. They are associated with the place node that partly overlaps the shaded text box. The bold underlined text refers to the often-adopted lane change view in engineering analysis (From Boer et al., 2005)


"... I though the road construction was ..."
"... get around him ..."
"... I wanted to go faster than this ..."
"... no congestion ..."
"... pick a lane that seems to me moving well ..."
"... lead car driver appears drunk ..."
Lane change promoting factors (each a different color token)
The firing condition depends on presence of a token of any color in the input place.
Lane change promoted
"... big enough holes ..."
"... gives me a gap ..."
"... moving into pockets that were big enough ..."
"... he slowed down a let me over ..."
"... I did not see any signal (from lead car), ..., so I felt comfortable ..."
Lane change enabling factors (each a different color token)
The firing condition is dependent on the numerical values associated with the colored token.
Lane change enabled
Lane change behavior is initiated when the driver is paying attention to the driving task (i.e. token in the "driving behavior" place) and a condition that promotes a lane change is active (i.e. a token is present in the "lane change promoted" place)
When lane change behavior is initiated, a token is removed from the "driving behavior" place but immediately a new one is added to indicate that other driving subtasks are not ignored.
Source
Driving behavior
The type of behavior that drivers exhibit in the "preparatory lane change behavior" place (state) depends on the color of the token (i.e. the particular condition) that promoted the lane change.
Preparatory lane changing behavior (associated with an observable set of human activities & cognition)
"... waiting for a hole ..."
"... sped up to get in front of him ..."
"... gave him a signal so I could get over ..."
"... car is going to accelerate around (me) ..."
"... build up speed to .... and get over into the left lane ...."
"... I made eye contact to see if he will let me go ..."
Different conditions for initiating a lane change are acceptable depending on the specifics of the condition.
The firing condition depends on the presence of any colored token
"... don't cut them off ..."
"... somebody pulling in front of me right at that moment ..."
"... the target lane lead car suddenly decelerates hard ..."
"... the target lane following car suddenly sped up ..."
Lane change terminating factors (each a different color token)
Function
Lane change execution termination required
The manner in which a lane change is executed depends on the condition that enabled it. The color of the token that gets passed when the transition fires impacts execution characteristics.
Lane change execution behavior (associated with an observable set of human activities & cognition)
"... popped over ..."
"... squeeze in between ..."
"... get over without really thinking about it"
"...moved over very slowly to inform others of my intent ..."
"... sped up while steering ..."
Function
Driving behavior
"... lead car moved over ..."
"... missed my exit ...", "... lead car sped up ..."
"... received a phone call ..."
"... I know my exit's coming up pretty quick ..."
Lane change preparation termination accepted
If a lane change is no longer necessary, behavior resorts back to other driving behaviors.
Quotes are from subjects who drove the UCSD LISA instrumented vehicle either during the drive or during the post-drive video-review interview
Italic quotes are made and purely for illustrative purpose.
Bold text indicates the limited set of factors generally considered in engineering modeling. In some cases, one or more contextual elements such as traffic density, weather, or personality are included as firing-criteria-mediating factors.

Lane changing System as Petri-net: Through a unique collaboration between automotive engineers and UCSD ethnographers, Boer & Forster et al. (2005) employed a common graphical state-space based modeling language called Petri nets that enables annotated case studies to be represented in a computational framework that can be used in standard engineering practices. The ethnographer's goal was to explain and quantify the importance of context on driver behavior such that the engineers would be better able to design useful human-centered support systems and to assess whether those necessarily practically constrained support systems will most likely function as expected across a wide range of situations. The Petri Net framework revealed shared cognitive models among subjects (e.g., drivers looked for and evaluated the size and trajectory of 'holes' in the stream of traffic rather than measure distance between cars,) but it was not yet a measurement that was directly relevant to the other streams of data available to engineers from the multitude of sensors embedded in the test vehicle.

Lane Changing in Time Series: Test-bed vehicles make all the automated signals available for study. Most are recorded as parallel tracks of timeseries representations (e.g., steering angle, time-headway to nearest vehicle, gas/break pedal contact, etc., for over 50 sensors). As the ethnographic research continued we discovered several behavioral patterns that were not detected by these signals and which seemed relevant to lane changing behavior. For example, *shifting* hand position on the wheel was more important signal for a change in driver state than where the hands rested in absolute terms, since drivers varied in their wheel grasping habits.

The ethnographers were in search for opportunities to derive behavioral signals that could be translated into timeseries representation, similar to how I translated visual attention into a signal of head movements relative to body orientation (HMBO).

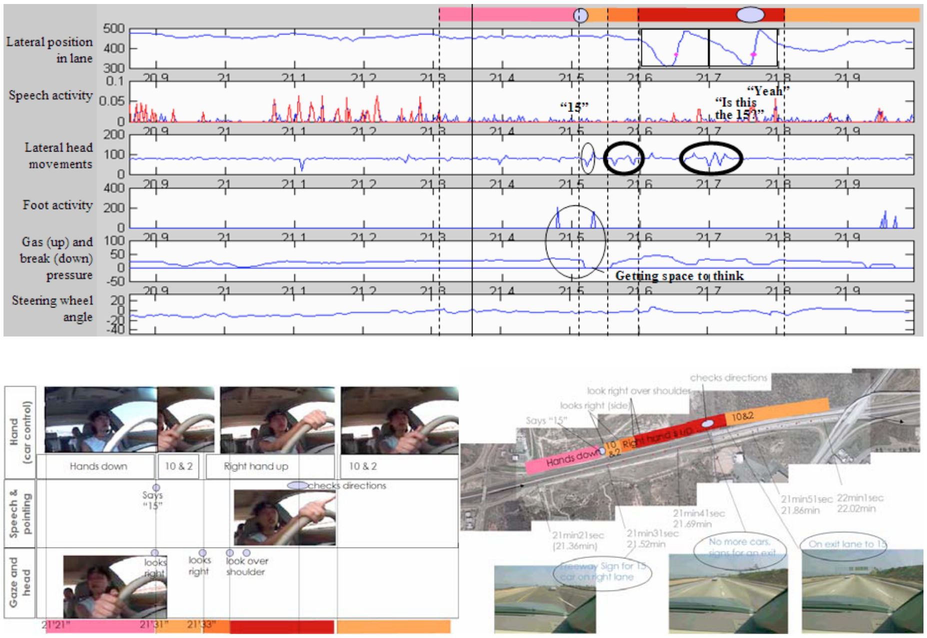


Figure 6.3a-c: Lane Changing System – Three Analysis Views. The system phases are color coded (pink, orange, etc.) and are the shared timeline for all three figures. Top figure: video signals and vehicle sensors. Bottom Left: Driver behavior (hands on wheel and gaze). Bottom Right: contextual mapping of the lane change location. Areal map and three views out the front windshield.

The figure shows a composite of signals that are derived automatically from the vehicle's sensors (can-bus) and timeseries derived from video based on the translation into timeseries representations of foot movement.

Automated detection of foot position: Ethnographic study of driver behavior revealed that states of indecision and hesitation are not recorded by the vehicle sensors since they are built into the gas and break pedal. Drivers exhibited and talked about 'hovering' over the gas or break pedal when they are in a state of increase vigilance, and at times also 'wag' between the gas and break pedal without contacting either. By automatically processing video images from a camera places on the floor of the car (see top left in Figure 6.4), it was possible to distinguish hovering over the gas or break. When the signal oscillated between hovering over the gas and the break, it could be labeled automatically as 'wagging'. The signal from this processing was tracked in parallel to the signal from the gas and break pedal to validate the automated processing of physical contact with either pedal.

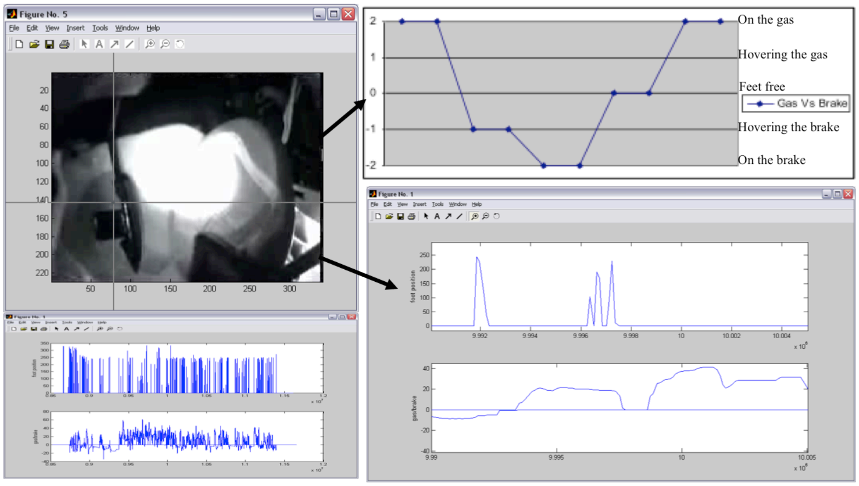


Figure 6.4: Driving Feet – From Ethnographic Categories to Timeseries Representation – Ethnographic codes for foot positions (top right) are translated to time series parallel to the automated signals from the vehicle sensors on the gas and break pedals (bottom right). Top left shows the camera view on the gas and break with the outline of the foot – the view from which automated processing was developed to produce the 5 relevant categories (on gas; hovering over gas; free; hovering over break; on break)

Since system engineers were interested in predicting lane change behavior, and additional signals, such as the states of hovering and wagging, provided a richer understanding of driver behavior relative to the 'system task' of lane changing.

6.4.2 Triadic Interactions Maternal Bids for Novel Toy

In de Barbaro's (2012) thesis the third chapter is devoted to examining what is considered the 12 month social "revolution" in humans, that of *triadic engagement* which de Barbaro et al (2012:chapater3) defines as follows:

> …triadic engagement refers to interactions between two partners that are mutually constrained both by each other and a shared focus of attention. In infant-parent dyads, these episodes provide an opportunity for the infant to access and participate in the practices of the parent (Lave & Wenger, 1991). In this regard triadic attention is the original learning environment.
>
> (de Barbaro et al., 2012)

The shift to triadic engagement is considered to be the birth of *secondary intersubjectivity* (Trevarthen & Hubley, 1978), in that an infant learns to appreciate the subjective experience of others. The shift is attributed to an underlying representational mechanism internal to the nervous system, leaving traces in behavior only in the differential outcome 'before and after'. De Barbaro and colleagues decided to look longitudinally at mother-infant free play videotaped sessions between 4 to 12 months of age with the aim to track the shift as it unfolds. The expression of this achievement is recognized in the type of imitation and games exhibited by mother-infant-object interactions. Identifying episodes of imitation may be difficult to operationalize, but it is even more difficult to identify the behaviors that may form the precursors for such engagement patterns.

The study settings, free-play sessions in the home of the subjects, were prescribed only by suggesting to the parent that of 3 toys available only one toy should be in the center surface between the parent and infant at any given time. This meant that if a novel toy were introduced, the current toy would need to be removed. These ‘toy switches’ became the ideal reliably identified outcome around which to trace a socio-cognitive system on which to focus, since they occurred throughout the developmental trajectory. Thus switching toys in mother-infant play sessions, switching lanes while driving, and switching consort male partners, become the focal entry point into the study of these complex phenomena.

Like the CTO study, the challenge was to find which elements in the ‘system’ to track that would reveal the cognitive work involved. The ‘task-at-hand’ in de Barbaro’s study was the response to *maternal bids* for a novel toy to become the focal object in triadic engagement with the infant. The elements that were tacked in the micro dynamics available from the video data included the attentional modalities available to the subjects: gaze and hands of the parent, and gaze, hands, and mouth of the infant. Figure 6.5 depicts some of the timeseries representations that capture the attentional modalities around *maternal bid* events.

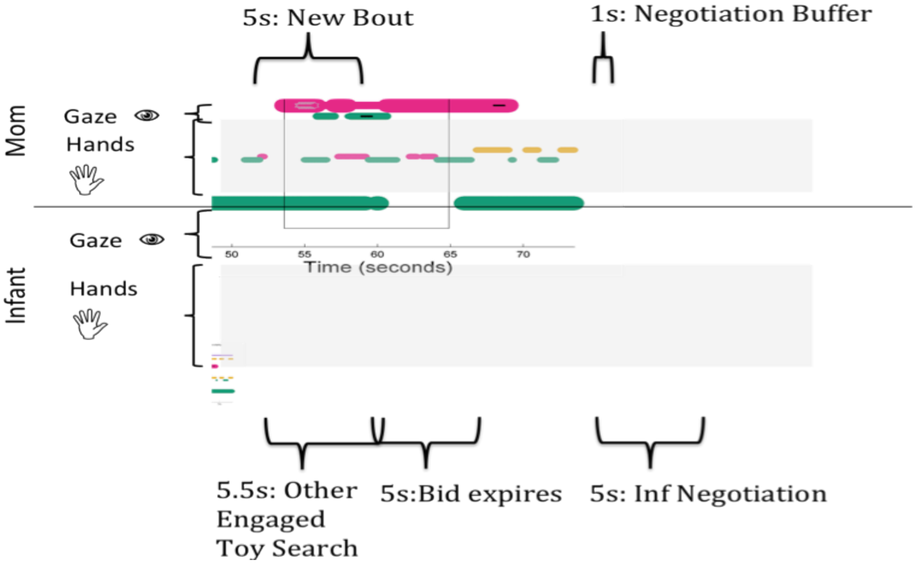


Figure 6.5: **Maternal Bids – Identification Parameters**. Represents approximately 30 seconds of interaction between mother infant and toys in order to illustrate the parameters used in identifying bids and their start and stop times. X-axis represents time in the interaction. Areas on the y-axis correspond to sensory-motor modalities of attending, presence of a colored bar at a given time represents contact between given sensory motor modality and a specific target. The yellow target represents the partner (mother or infant), the remaining colors represent different toys...The square shaped box indicates the start and stop boundaries for the maternal bid to the pink toy, beginning approximately at 54 seconds and ending at approximately 65 seconds.
(de Barbaro, 2012)

6. 5 Behavior as a Biological Level of Organization in Socio-Cognitive Research

Ever since Darwin behavior was looked to not only as a biological trait in its own right, but also as a portal into processes that Darwin himself was only able to postulate theoretically (i.e., a unit of heredity that would be amenable to natural selection, long before 'genes' were re-discovered). Darwin himself searched for not-only-human universals in body and facial expression of emotion, and early ethologist set out to capture the units of behavior that would be amenable to natural selection. From instinct to fixed-action-patterns, innate-releasing-mechanisms, the *phenotypic gambit* is an expression of this pillar of evolutionary perspectives on behavior. If there is a chunk of behavior that could stand in for a *functional* chunk of 'what lied beneath', than carefully studying behavior is a good proxy to studying the mechanism of evolution.

And so we have a tradition of asking of behavior to be a stand-in for evolution. In fact, behavioral ecologist began to hone in on this correspondence and realized that a whole lot of behavior, relative to its job description as an evolutionary proxy, might be irrelevant in the final accounting (of individual inclusive fitness). Search for central trends (linear dominance, proximity score as index for friendships) in a reductionist framework all too often doubles for identification of a driving cause, or underlying mechanism (see Section 1.3 discussion of teleology and the challenges to SI-Hypothesis from 'below'). The phenotypic and representational gambits (Figures 1.2 & 2.1) point precisely to the parallel burden placed on behavioral regularities: as a simple correspondence measure to a functional 'unit' of the relevant biological substrate (genomes and brains).

The SI-Hypothesis presented an added recursive challenge in that its explanatory framework was geared to the evolution OF cognition. As researchers observed behaving primates how were they to pull all these layers out of the behavioral data? Hence the fierce debates over interpretation of behavior in terms of intentionality and theory of mind. Research methods are fast relieving behavioral researchers from these demands (e.g., Altmann & Altmann, 2003 on updated field methods, and the Cluster of studies I review in Chapter 4.) The ease with which we can collect DNA, assay stress hormones etc. begins to segregate the 'work space' for behavioral data.

For example, when collecting fecal matter from known individuals before and after a dramatic social encounter, we no longer ask of behavior to indicate whether the animals was stressed (through the nuanced observation skills of long-time monkey watchers) – rather we allow the hormonal assay to indicate the stress level. What we ask then is *how is the behavior* of animal with a particular stress level *organized*? ***Behavior is relegated its own level of biological organization*** and becomes the very subject of study rather than an poor indicator of something else.

On Levels of Description / Analysis / Investigation**:** As became increasingly apparent in this dissertation, the central epistemological entailment of C-Systems Thinking is in the need to confront phenomena at multiple spatiotemporal scales to be tracked at multiple levels of description and analysis, remaining ontologically agnostic as long as necessary with regard to valid levels of organization. In a chapter titled "Brain and Cognition" Senjowski & Churchland (1990) proposed a framework for *Levels of Investigation* in which they first distinguished between *Levels of Analysis* and *Levels of Organization,* mostly to point to the difficulty in mapping between them. They offer, as first step, seven *Structural Levels* (see Figure 6.6) and comment:

> Accordingly, which structures really constitute a level of organization in the nervous system is an empirical, not an a priori matter. We cannot tell in advance of studying the nervous system how many levels there are nor what is the nature of the structural and functional features of any given level.
>
> …seven general categories of structural organization are discussed (figure 8.1). The count is imprecise for several reasons. Further research may lead do the subdivision of some categories, such as 'systems' into finer-grained categories, and some categories may be profoundly misdrawn and may need to be completely reconfigured. As we come to understand more about the brain and how it works, new levels of organization may be postulated. This is especially likely at higher levels where much less is knows than at the lower levels.
>
> (Senjowski & Churchland, 1990:305)

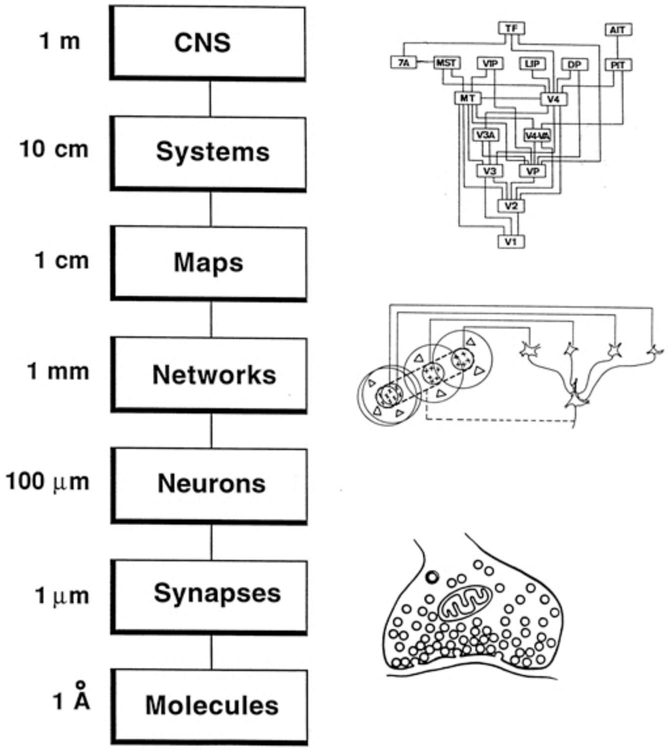


Figure 6.6: Structural Levels of Investigation in the Nervous Systems (modified version of Figure 8.1 in Senjowski & Churchland, 1990)

Extra-somatically, Hinde's (1976, 1987, 1997) hierarchical model of social complexity in primate groups distinguishes at least four *levels of description* (Individuals-Interactions-Relationships-Group), discernable by human observers of primate groups over extended periods–allowing identification of individuals and systematic accumulation of social interaction data. We thus have candidate points of departure for multi-level empirical investigations that may begin to capture socio-cognitive dimensions of behavior. Analogous hierarchies in genomes from nucleotides to chromosomes are not uncommon.

Hinde's own Levels of Social Complexity has gone through various graphical re-iterations in the course of his writing. The one I find most relevant in this context if form his 1987 book Individuals, Relationships and Culture (see Figure 6.7). I chose this figure because it acknowledges the intra-somatic processes (the left most items 'nervous endocrine etc. systems').

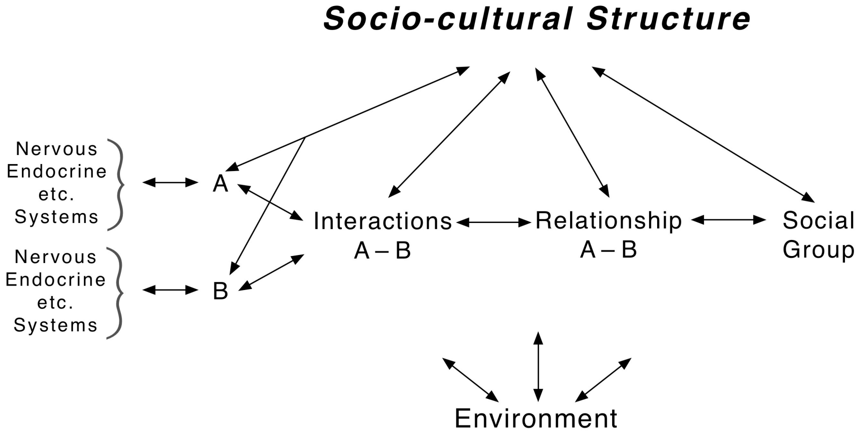


Figure 6.7: Hinde's Dialectics Between Successive Levels of Social Complexity (Figure 1 from Hinde, 1987)

I take graphical license to re-imagine their integration: If I rotate Hinde's figure 90 degrees counterclockwise and conjoin it with Senjowski & Churchland I can demonstrate the continuity in principles of investigation I see between intra- and extra-somatic structural levels of organization.

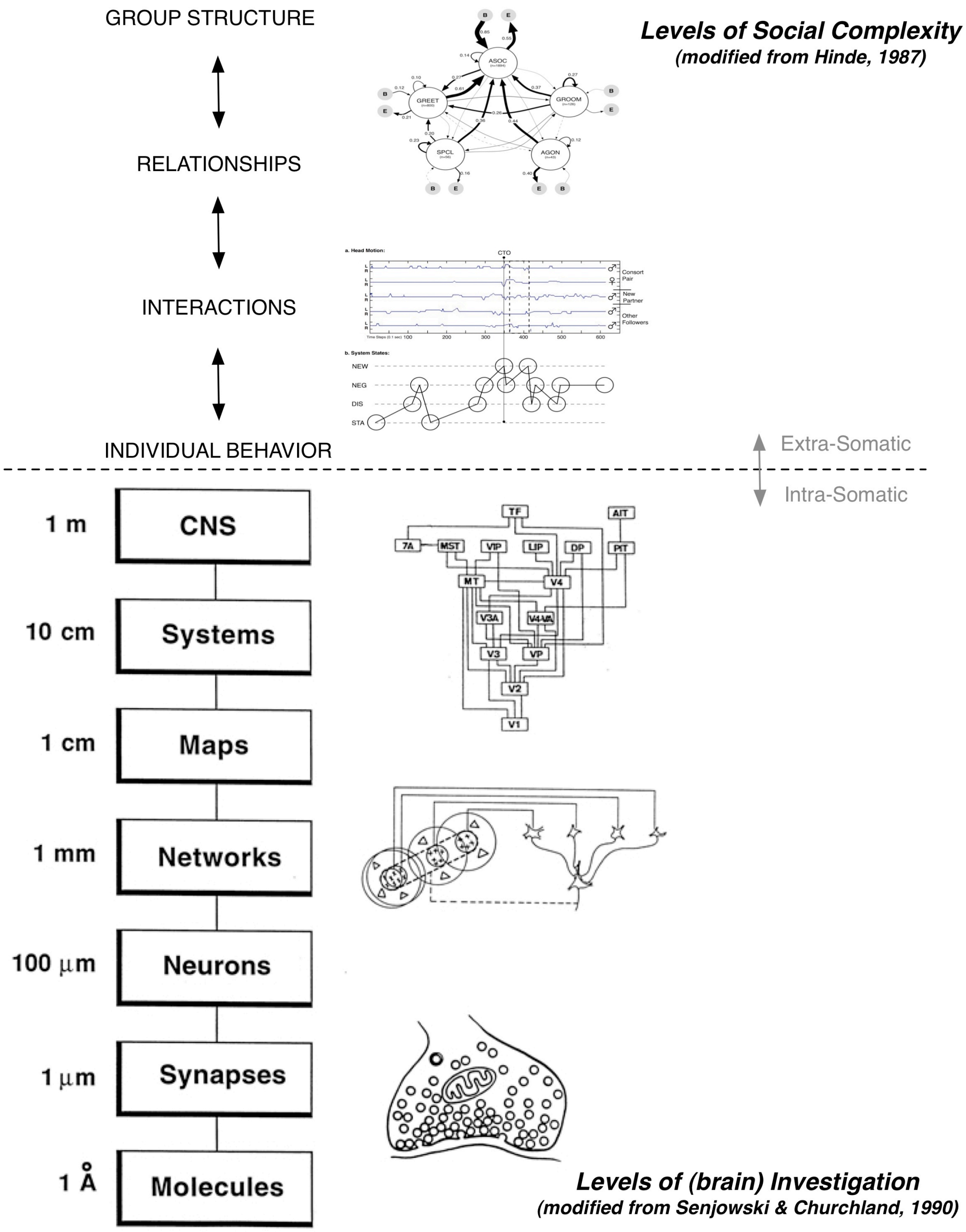


Figure 6.8: Intra- and Extra-Somatic levels of investigation. Combined Hinde's (1987) levels of social complexity with Senjowski & Churchland levels of brain investiagation. The graphics on the uper right are from the analysis presented in this thesis for illustrative purposes only**.**

6. 6 Last Word

The dissertation revolved around the role of behavioral analysis in cognitive and evolutionary explanations, in particular those arguments that link social and cognitive dimensions. Table 6.1 summarizes the conceptual and methodological transformation achieved in the course of developing my thesis project. It required weaving the three strands of paradigm, theory and methods continuously throughout the project since all three interact with one another but in different combinations at different points along the way. For example, while C-Systems thinking was left out of the SI-Hypothesis landscape it continued to impact the behavioral analysis techniques used in behavioral ecology (see Chapter 2.) The formulations of these analyses, however, were still too simplistic to be relevant to the kind of organized complexity, which the SI-Hypothesis was inspired by in its original formulation. Methods such as sociograms and sequential analysis that were tried out in the early days of primatology could not be made relevant to the research agenda.

The only way to make sense of this richly complex landscape was to settle on a phenomenological depiction that would become the center of investigation to which I could return to from any phase of the process (see Figure 1.1) to measure the effectiveness of the conceptual and methodological reconfigurations I proposed. The choice of phenomena was made relatively straightforward by revisiting the early formulations of the SI-Hypothesis (Chapter 1) and then mapping them onto the early observations of baboons (Chapter 2) from which social groupings emerged as relevant research constructs. SE-Clusters, and the dramatic polyadic interactions that erupt in their midst provided such an anchor, even when the phenomena themselves receded from the analysis of social relationships (see Chapter 4).

These phenomena, dramatic polyadic dynamics, are considered difficult to study in either evolutionary or cognitive framing. Yet in the context of the modified research program for socio-cognitive phenomena, they are the most desirable since they externalize the social and cognitive processes that are at the center of our query. The challenge for studies of organized complexity is to find a ‘simple’ enough complex phenomena to which the principles of analysis – multiple levels of investigation of multiple agents on multiple spatio-temporal scales – can be reliably applied.

Far from a set of principles that can be made relevant to every single study design, the proposal I developed and demonstrated in this thesis provides the framing of a ***research program***. It is a research program not only for new research, but also where previous research and evidence from other paradigms can be made relevant to the explanatory aspirations of the original SI-Hypothesis dialog – understanding the nature, development and evolution of social and cognitive dimensions of behavior and how they might be linked. Factors that were considered causal drivers in more simple reductionist framing, such as dominance rank, infanticide (see chapter 4), etc., can be seen as emergent effects of underlying multiple asynchronously nonlinear processes, which our empirical apparatus is increasingly more successful in tracking. Assigning to observable behavior the status of an independent level of investigation rather than imposing on it multi-tasking as a proxy for underlying genetic and neural mechanisms is the most effective device to reach such an understanding.

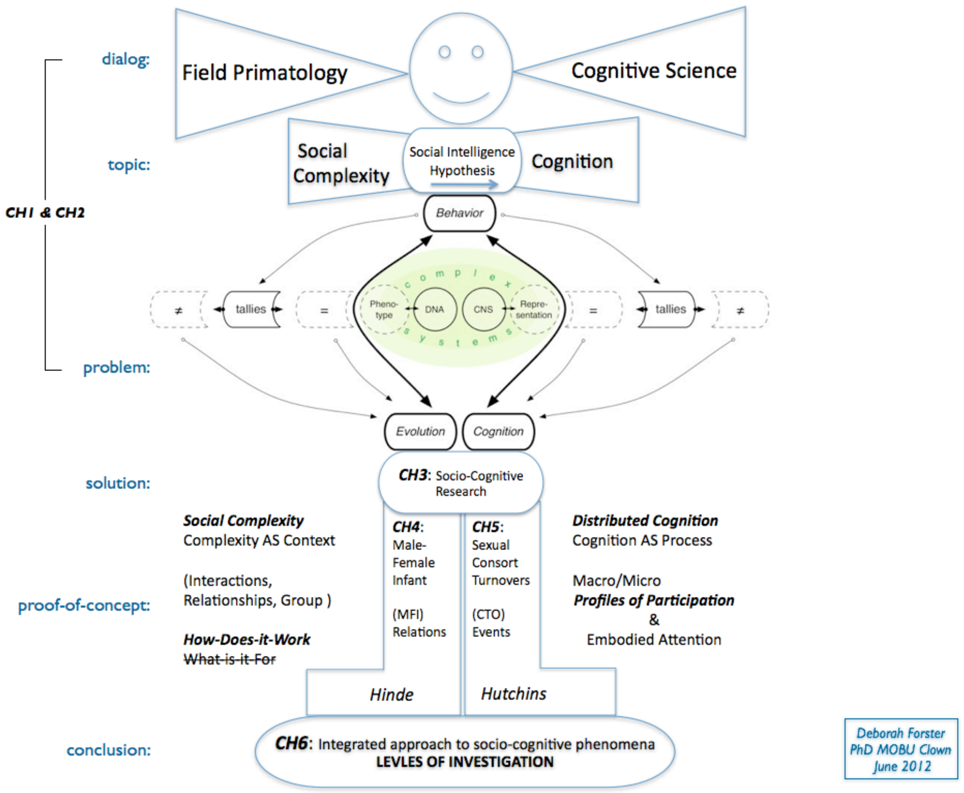


Figure 6.9: Dissertation Structure, Embodied

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