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ORIGINAL PAPER

From *Pan* to *Homo sapiens*: evolution from individual based to group based forms of social cognition

Dwight Read[1]

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Abstract

The evolution from pre-human primates to modern *Homo sapiens* is a complex one involving many domains, ranging from the material to the social to the cognitive, both at the individual and the community levels. This article focuses on a critical qualitative transition that took place during this evolution involving both the social and the cognitive domains. For the social domain, the transition is from the face-to-face forms of social interaction and organization that characterize the non-human primates that reached, with *Pan*, a hiatus due to the centripetal effects that highly individualized behavior has on a social system. The transition is to the relation-based forms of social organization that evolved in the hominins ancestral to *Homo sapiens* and are universal in human societies today. For the cognitive domain, this transition involves going from behavior responding mainly to phenomenal level sensory inputs to behavior formed in accordance with the concept of a relation, initially abstracted from behavior patterns, then extending the concept of a relation beyond abstraction from behavior patterns to the concept of a relation generated recursively through constructing the relation of a relation. This extension made possible the construction of systems of relations; initially genealogical systems of relations constructed culturally using the logic of recursion, and subsequently, the symbolic, computational systems of kin term relations referred to by anthropologists as kinship terminologies. The latter are "constructed realities" in the sense this term is used by cultural anthropologists. It follows that the evolution of relation-based systems of social interaction is not adequately accounted for through population model evolutionary accounts such as the Dual Inheritance Theory of human evolution since "constructed realities" constitute collectively and publicly shared cultural knowledge rather than the individually and privately possessed knowledge that is assumed in the population model framework for human evolution.

Keywords Kinship · Kinship terminologies · Human evolution · Cultural evolution · Relation-based social systems · Dual Inheritance Theory

✉ Dwight Read
dread@ss.ucla.edu

[1] Department of Anthropology, Department of Statistics, UCLA, Los Angeles, CA 90095, USA

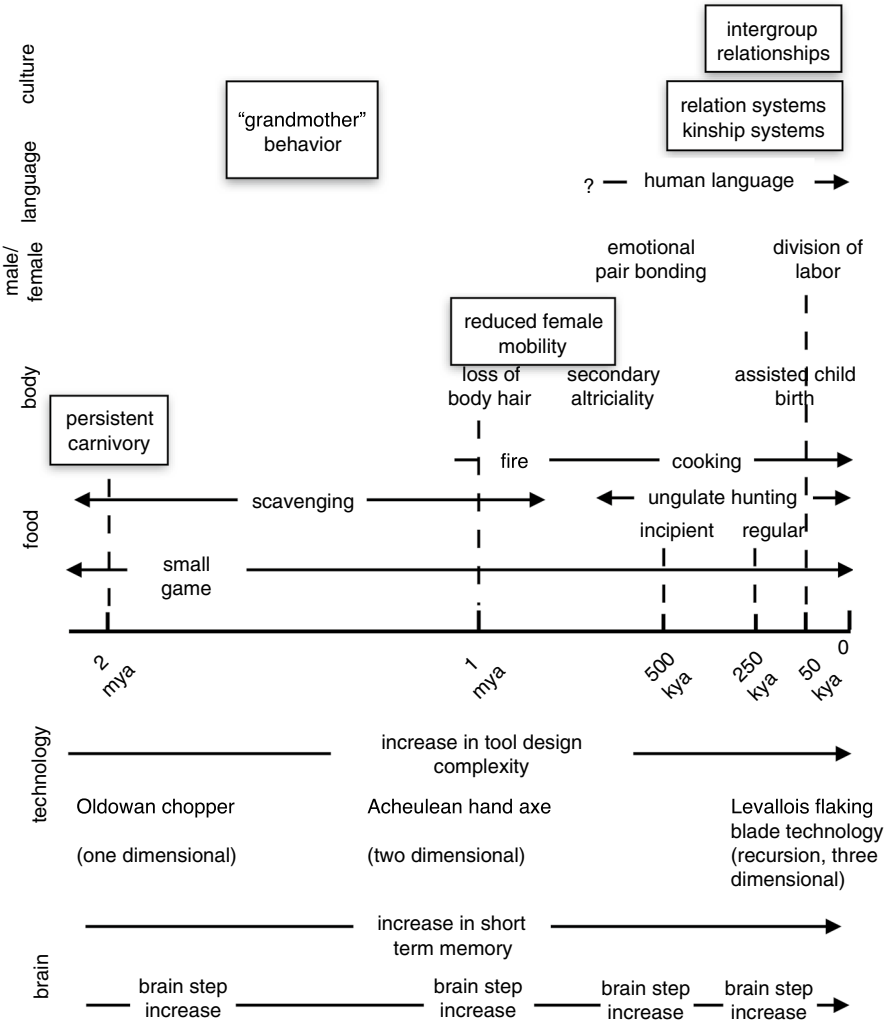

Fig. 1 Evolutionary events from 2 mya to present leading to the relation-based systems of social organization that arose during hominin evolution to *Homo sapiens*. Events are divided into (from bottom to top): brain, technology, food, body (morphology), male/female (relations), language and culture. Rectangular panels identify relevant major behavioral events that occurred during this time period. No change in a single kind of event is a driver for the evolutionary changes in other kinds of events. The interplay among events has been left implicit

1 Introduction

The evolution from pre-human primates to modern *Homo sapiens* through the hominins over the time period from around 10 mya to the time of the Upper Paleolithic is a complex one, involving many domains, both at the individual and the collective levels. As indicated in Fig. 1, these domains include morphological, technical,

social, behavioral, linguistic and cognitive dimensions undergoing change as the evolutionary pathway from the hominins to modern *Homo sapiens* played itself out. Not only are there evolutionary changes along each of these dimensions, in many instances exaptation (see Gould and Vrba 1982) has led to evolutionary changes in one domain also being taken up in a different domain (examples include: language syntax [Fitch 2011], human speech production [MacLarnon 2012], and hominin memory systems [Murray, Wise and Graham 2017]). Rather than a single line of evolution, the evolution of the hominins leading to *Homo sapiens* involves different, but intertwined, evolutionary threads (Foley 2016), with *Homo sapiens* arising as a taxonomically distinct primate species within which are found a suite of traits otherwise distributed individually across different primate species (Chapais 2008).

One of these intertwining evolutionary threads—the focus of this article—relates to a qualitative transformation in the social domain realized during the evolutionary trajectory going from a chimpanzee-like common ancestor of *Pan* and *Homo* to *Homo sapiens.* The transformation is from social relations being worked out individually at the phenomenal level through face-to-face interaction to the construction of relation-based social systems formulated culturally and at the ideational level, thereby enabling social relations to be expressed through language and worked out collectively (Read 2012).

A quintessential example of what is meant here by relation-based systems of social interaction is the universal system of kinship relations found in human societies and expressed and understood through the kin terms making up what anthropologists refer to as kinship terminologies. In general, relation-based social systems universally provide the framework within which social interaction in human societies takes place and contrast sharply with the non-human primate social systems they replaced, which are based on extensive face-to-face interaction. By the latter is meant that an individual works out and develops understanding of the behavior of other group members through face-to-face interaction with those group members, thereby making their individual behavior more predictable, with the latter a pre-requisite for the formation of coherent and stable patterns of social interaction. In contrast, the transformation to relation-based social systems enabled collective, and not just individual, understanding of the expected behavior patterns of group members.

As will be discussed in this article, the evolutionary transition of the hominins from individual to relation-based systems of social interaction resolved the opposition faced by the non-human primates between, on the one hand, maintaining coherent forms of social organization as group size increased and, on the other hand, coping with the increase in social complexity introduced by selection for the individualistic behavior that was part of the phylogenetic transition going from the Old World monkeys to the great apes. Individualistic behavior on the part of group members is the antithesis of coherent social groups:

> The essence of social existence is not to be found in the instincts of isolated individuals but in … the social group … thought of as enormously more significant than the individual; and social behavior and social institutions must be recognized as more permanent than any individual traits. (Judd 1925–1926:154–155).

The tension between individualistic behavior and the coherency of a social unit such as the family can be seen in the observation regarding married couples in the United States that there is a "standing tension between the principle of individualism and the demands of marriage" (Quinn 2018:152). This opposition between individualistic behavior and social behavior was resolved culturally during hominin evolution, it will be argued, by working out a means to accommodate socially the highly individualistic behavior that would also have been a part of the behavioral repertoire of the hominins since highly individualistic behavior characterizes both the extant great apes and humans. The accommodation to individualistic behavior was achieved by developing a cultural framework that, among other things, defines a system of kinship relations linking group members to one another, along with expected positive and supportive behavior on the part of those who are mutual kin according to this system of kinship relations. This led to formation of cultural frameworks that enabled realization of the.

> … cultural goal of controlling, regulating, and where necessary or expedient, suppressing the genetic program so as to allow an otherwise fractious group of individuals to maintain themselves as a functioning sociocultural system … [through] the desired cultural kinship that makes social harmony possible … and [is] maintained over time. (Paul 2018: 65)

The cultural framework that came into play and will be discussed below begins with the cognitive innovation during hominin evolution of the concept of a relation abstracted from patterned behavior, such as the concept of a mother relation abstracted from the mammalian pattern of female mothering behavior directed towards her offspring. The concept of a relation was subsequently extended further through the cognitive innovation of forming a new relation recursively from an already abstracted relation by forming the relation of a relation. This led to forming systems of new relations from already understood relations such as the relations representing the structural organization of a family as a social unit (see Read 2015). Initially, this gave rise to genealogical systems of relations, and subsequently to symbolic, computational systems of relations expressed through the kin terms making up what is referred to by anthropologists as a kinship terminology (Read 2019).

A terminology expresses the kinship relations central to the systems of social organization that replaced face-to-face interaction as the means to work out, within a group, individualistic social relations among group members. Kinship relations are also the means by which an offspring of a female is identified as a group member through groups becoming organized around a conceptual system of relations and expected patterns of behavior. Groups formed in this manner also incorporate collectively the knowledge individuals gain pragmatically through their interactions, both socially and with their physical and ecological environments, with this knowledge transmitted across generations through enculturation (Leaf and Read 2012). In the hunter-gatherer, relation-based systems that came into play during the Upper Paleolithic and are based on resource procurement rather than resource production, the knowledge called upon by individuals in their daily activities expanded from behavior at the phenomenal level to include behavior represented culturally at the ideational level and transmitted to the offspring of group members through

enculturation. The enculturation undergone by a newborn as he or she matures necessarily involves interaction in a social context with other individuals, themselves already enculturated into the cultural milieu of that group. This is analogous to the initial learning of a language since language learning involves daily linguistic interaction with the members of a language community. Neither language learning nor cultural enculturation can be reduced to just being an instance of phenotypic transmission of a phenotype trait from one individual to another through (but not exclusively) imitation. The cultural systems that began to be developed during hominin evolution leading to *Homo sapiens* and transmitted through enculturation are what makes us human and not just a smarter, more social ape (Read 2012).

2 From nature to culture

The transition from the phenomenal level of face-to-face interactions to the ideational level of culturally determined systems of social relations, such as the kinship relations expressed through the kin terms making up kinship terminologies, was a transition from social systems dependent on intensive individual learning regarding social behavior of group members to social systems based on culturally formulated and transmitted knowledge regarding expected behavior by group members. This transition was realized through culturally expressed relation systems that structured social interaction. As expressed by the French anthropologist and philosopher, Claude Lévi-Strauss in his monumental work, *Les Structures Elémentaire de la Parenté* (1949), this transition is made evident by the great apes having reached what was essentially a cognitive barrier insurmountable through biological evolution directed by fitness selection for individually expressed behavior traits. Lévi-Strauss recognized, drawing upon the accounts of the primatologist Robert Yerkes (1927), that the highly individuated behavior among the great apes, or what Tomasello (2014) refers to as individual intentionality, is comparable to what is found in *Homo sapiens* and individuation of behavior, he argued, had the consequence of making behavior less biologically determined. This, he suggested, had a profound, limiting effect on social behavior in the great apes:

> …les grands singes, déjá capables de se dissocier d'un comportement spécifique, ne pouvaient parvenir á rétablir une norme sur un plan nouveau. La conduite instinctive perd la netteté et la précision qu'on lui trouve chez la plupart des mammifères; mais la différence est purement négative, et le domain abandonné par la nature reste territoire inoccupé (1949: 9).
> ("… the great apes, having broken away from a specific pattern of behavior, were unable to reestablish a norm on any new plane. The clear and precise instinctive behavior of most mammals is lost to them, but the difference is purely negative and the field that nature has abandoned remains unoccupied." Translation by J.H. Bell, J.R. von Sturmer and R. Needham.)

In biological terms, individuated behavior is the antithesis of biologically directed behavior since, at the group level, highly individuated behavior leads, across group members, to behavioral variability exceeding genetic trait variability in a group,

hence the highly individuated behaviors of the great apes is not genetically determined. Thus, evolutionary increase in individuated behavior signals a shift from genetic specification of more specific behaviors to specification of less specific, broad behavior capacities.

3 Individuated behavior and social complexity

The degree of individuation in chimpanzee behavior has the consequence that a chimpanzee community composed of 50–100 individuals—more than double the size of Old World Monkey troops—, does not act as a single, coherent social unit (Maryanski 1987 and references therein). Instead, it is composed of largely solitary females comparable to, for example, the asocial female orangutans (Wich, Sterck, and Utami 1999), with males forming what has been characterized as a fission–fusion form of social organization (Nishida 1968). The male social units that form within a chimpanzee community are unstable and small (around a half dozen [Lehmann et al. 2007]) and their coherency is dependent upon working out social relations within a group through face-to-face interaction: "Male chimpanzees use grooming to cultivate and reinforce social bonds with others upon whom they rely for coalitionary support" (Muller and Mitani 2005: 306). Even though conditions such as male philopatry, which enables biological kin selection to be activated (Vigilant et al. 2001), are present, nonetheless biological kin selection has taken on reduced importance for the formation and maintenance of male social units such as coalition dyads and so the latter are not based on biological kin-relatedness (Mitani et al. 2002; Muller and Mitani 2005) but on male face-to-face interaction.

Overall, the community form of social organization of chimpanzees, made up of small reforming, unstable male groups and largely solitary females, is dynamic (Rushmore et al. 2013) and the behavior of group members can lead to changes in their social organization (Strum and Latour 1987). In contrast, the less individuated Old World monkeys conform to a form of social organization constant across species (Di Fiore and Rendall 1994) that transcends individuated behavior my means of social organization built around stable, female dominance hierarchies subject to change only through demographic changes (Fairbanks 2000). The female dominance hierarchies are maintained through the daughter of a female being introduced by her biological mother just below her (the mother) in the dominance hierarchy, with intra-matrigroup social relations worked out through face-to-face interaction (see references in Read 2012). In striking contrast, the male dominance hierarchy in a chimpanzee community is open to challenge by other males, either acting alone or through pairwise coalitions (Muller 2002), hence can be changed through the behavior of males.

Neither the *Pan* communities as a whole nor the small social units of males within these communities are internally cohesive. The driving factor for their lack of cohesiveness, whether at the scale of the community or at the scale of small, male social units, is the social complexity introduced through individuated behavior augmented by the cognitive and behavioral ability of pairs of males to form coalitions, even if just on a temporary basis. Individuation of behavior in combination with pairwise

coalition formation leads to a power-function increase in the social complexity of a social unit with unit size since the number of possible distinct behavior patterns in a social unit with n individuals, each with individuated behavior and able to form pairwise coalitions varies with n^2. The reduction in the size of their social units to 5 or 6 males, in comparison with the larger size of the socially coherent Old World monkey troops, provides an organizational resolution to the social complexity that would characterize larger social units. From a modeling perspective, the empirically observed reduction in size of social units is precisely what is required for the social complexity of chimpanzee social communities to be in accord with the increase in the degree of social complexity implied by the expansion in the neocortex ratio as one goes form the Old World monkeys to the great apes (Read 2012). The neocortex ratio, Dunbar (1992) has argued, measures the extent to which increased social complexity has acted as a driver for increase in cognitive abilities.

4 Coping with social complexity

4.1 Phylogenetic trend 1

The phylogenetic trend in social systems going from the prosimians to the Old World monkeys is one of coping with increased social complexity, measured both through increase in the neocortex ratio and through structural re-organization of prosimian forms of social organization into the troop form of social organization that characterizes the Old World monkeys (see Fig. 2, left side). The latter leads to "marked uniformity in patterns of social organization … among the Old World monkeys" (Di Fiore and Rendall 1994: 9943), with that form of social organization able to subsume individuated behavior (Strum and Latour 1987) arising as part of the social and ecological adaptation of the Old World monkeys.

4.2 Phylogenetic trend 2

The earlier trend towards re-organizing the form of social organization when going phylogenetically from the prosimians to the Old World Monkeys is moderated when continuing phylogenetically towards the great apes (see Fig. 2, right side). Coping with social complexity that otherwise would increase as a power function of the size of social units is achieved by both reducing the size of social units (females become solitary and males form small, unstable social units) and by working out social relations among members of the male social units through mutual grooming by adult males—a grooming pattern that is infrequent in primates other than the great apes (Fedurek and Dunbar 2009). Altogether, the trend is towards smaller, less cohesive social units and increased individuation of behavior, thus requiring chimpanzees to work hard to procure and maintain social units such as male coalitions (Muller and Mitani 2005). The phylogenetic trend from prosimians to the Old World monkeys to the great apes did not lead to larger and more integrated social systems but to a hiatus (see Fig. 3).

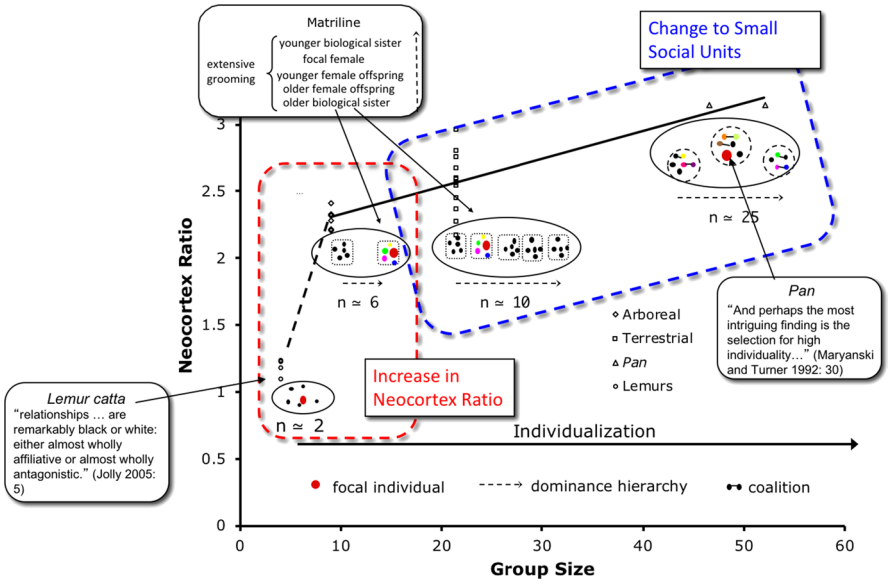

Fig. 2 Responses to increase in social complexity (measured by the number of different behaviors among group members with which a focal individual needs to cope) in primate species due to increase in the individualization of behavior. Response may be by cognitive elaboration measured by increase in the neocortex ratio and/or by reorganization of the structural organization of the primary social units. Prosimians, such as *Lemur catta* (lower left in the figure), have social relationships that are either affiliative or antagonistic, hence have social groups with social complexity $n \sim 2$ different behaviors (affiliative or antagonistic). Change from Prosimians to the Old World monkeys leads to a doubling of the neocortex ratio (see dashed line). Old World monkeys, divided into arboreal and terrestrial, have a more complex social organization than the Prosimians with more individualistic behaviors, females forming stable dominance hierarchies (see comment box, upper left). Social complexity, $n \sim 6$—10, is based on individualistic behavior within a matriline and a stable dominance relation between pairs of matrilines. Increase in social complexity between the Old World monkeys and *Pan* is due to a substantial increase in individualistic behavior and the cognitive ability to form coalitions. Social complexity leads to socially solitaire females. Males only form unstable, small groups (up to 5 or 6 males). The male dominance hierarchy is unstable and cross-cuts male social units. Increase in neocortex ratio is relatively small, implying that coping with social complexity is mainly through major changes in social organization. Absent small social units, the complexity for a male focal individual would be $n \simeq 125$, an order of magnitude more complex than the social complexity of OW monkeys. The social units reduce this possible complexity to $n \simeq 25$, consistent with the change in the neocortex ratio shown by the solid trend line

To put it another way, the adaptive response of the chimpanzees to the increase in social complexity introduced by individuation of behavior did not lead to selection for individuals with equivalently greater social intelligence as a way to cope with increased social complexity but to selection for increase in social intelligence coupled with reduction in the size of social units in order to reduce the social complexity of social units. Although ontogeny need not recapitulate phylogeny, for the ontogeny of chimpanzee development, in comparison to that of humans, a correlation analysis shows that for chimpanzee infants, there is a single factor on which both physical and social-cognitive tasks load, whereas for human infants there are separate factors for physical cognition and social cognition (Herrmann et al. 2010,

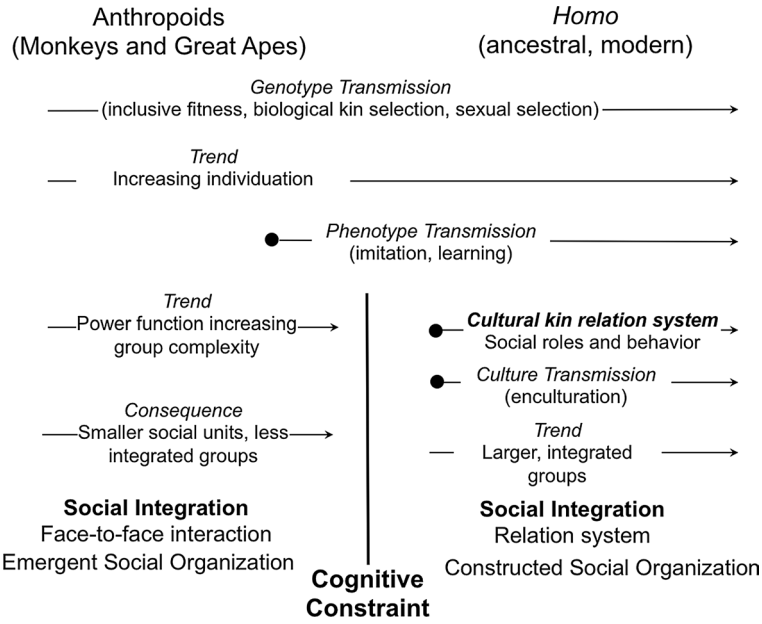

Fig. 3 Cognitive constraint. Solid discs. Start of three new trends. (1) The new trend of phenotypic transmission provides the basis for traditions passed on from one generation to the next and has phylogenetic roots in the great apes and in some of the Old World monkeys. Increasing individuation of behavior leads to a power function increase in social complexity with the chimpanzees. This leads to smaller social units and less integrated groups, thus to a cognitive constraint when face-to-face interaction is the basis for establishing social relations among individuated group members. The cognitive constraint was circumvented non-biologically with the introduction of (2) the new trend of culturally forming social relation systems such as kinship systems. In social relation systems, social organization may be culturally formulated, hence "top down" rather than emergent. (3) The third new trend is the pattern of cultural transmission through enculturation. Redrawn from Fig. 4.5 in Read 2012

referenced in Tomasello 2019). As development continues, human children continue to develop social skills beyond 3 years of age, whereas chimpanzees do not (Wobber et al. 2014).

4.3 The beginning of a new trend: from individual to joint intentionality

It is the hiatus in the development of social cognition skills that Lévi-Strauss addresses when he says that the chimpanzees have "broken away from a specific pattern of behavior." With the appearance of the hominins and subsequent evolution that gives rise to *Homo sapiens* 6 million years later, this hiatus came to an end and *Homo sapiens* became the social species *par excellence*. The trend from hiatus to "social species *par exellence*" is not a continuation of the two trends discussed in the previous section. Instead, the initial hominin ancestors of *Homo sapiens*, would have started out with what Tomasello (2014) characterizes as individual intentionality. For the great apes, Tomasello comments: "they do not possess human-like skills of shared intentionality …. Chimpanzees and bonobos … are and were very clever,

but mainly or only as individuals" (2019: 13). With this as a beginning point, the ecological conditions that led to forming a new phylogenetic line ancestral for *Homo sapiens* and diverging from the ancestral line for *Pan* around 6 mya, also happened to be ecological conditions that favored behaviors leading hominins away from adaptive changes linked mainly to morphological/biological responses. Instead of morphological/biological responses, these conditions lead to adaptive changes that increasingly involved changes in within-group social dynamics that countered the centrifugal effects of highly developed individual behavior on within-group social relations.

Archaeological evidence indicates that technological changes in stone tool production, including expansion of the conceptual framework involved in stone tool production (Read and van der Leeuw 2008), was part of a shift away from fortuitous, occasional hunting of small animals to meat procurement becoming a regular part of the diet by around 2 mya, which opened up selection for group control over access to meat resources large enough to be shared by several individuals. Change in the mode of locomotion to regular bipedalism and the loss of body hair changed the dynamics of females with regard to transportation of newborn offspring. Morphological changes in the pelvis led to constraints on fetal cranial and brain development before birth, hence to secondary altriciality that changed the dynamics of females with regard to food procurement, especially the procurement of meat, which may have led to emotional pair bonding as a means by which females could benefit from the labor of males with regard to resource procurement. These, and other changes in the increasingly more complex adaptations worked out by the hominins ancestral to *Homo sapiens*, would all have led to selection for increased elaboration on within-group social dynamics that counter the centrifugal effect of highly individual behavior. The changes in within-group social dynamics lead to a shift away from individual intentionality to what Tomasello (2014) refers to as joint intentionality: "joint intentionality … comprises two individuals who have a joint goal, structured by joint attention, each of whom has at the same time her own individual role and perspective" (2019: 15). Joint intentionality, it should be noted, is not absent from the chimpanzees. Through face-to-face interaction and through grooming, pairs of males can exhibit joint intentionality at least on a temporary basis by forming, for example, a coalition. Joint intentionality is not, though, the basis for establishing stable social units within which resource procurement and distribution to group members can be engaged in as a group-level trait. For that, more than joint intentionality is required.

4.4 From joint intentionality to the cultural stage

Joint intentionality, by itself, does not restructure group dynamics in a manner that resolves the centrifugal effects of individualized behavior. While a coherent social unit leads to joint intentionality across members of the social unit, the social unit, itself, is not formed through joint intentionality. What is missing is a means by which group members understand that they are interconnected as a group and through which individualized behavior is subsumed at the group level through constructing a

group identity with shared intentionality and identity among group members. Lévi-Strauss identifies this shift from a group dependent on face-to-face interaction for its social cohesion to a cultural basis for group cohesion in his comment that:

> … absence de règles semble apporter le critère le plus sûr qui permette de distinguer un processus naturel d'un processus culturel. …Partou où la règle se manifeste, nous savons avec certitude être à l'étage de la culture (pp. 9, 10) ("… absence of rules seems to provide the surest criterion for distinguishing a natural from a cultural process. …Wherever there are rules we know for certain that the cultural stage has been reached." Translation by J.H. Bell, J.R. von Sturmer and R. Needham.)

By rules, Lévi-Strauss is referring to the ideational level of knowledge shared through the enculturation each individual undergoes by being born and raised in a community, itself identifiable through the cultural knowledge held in common by community members.

5 The cultural stage: cultural rules and culture as a "complex whole"

The rule-based meaning of culture (what Tomasello [2014] refers to as collective intentionality) is, for Lévi-Strauss, an extension of the definition of culture advanced by Edward B. Tylor (Terray 2010). For Tylor, culture is "that complex whole which includes knowledge, beliefs, arts, morals, law, customs, and any other capabilities and habits acquired by man as a member of society" (1871:1). Tylor's notion of culture as a "complex whole" is also expressed by Lévi-Strauss (1983:39) in his observation that:

> Une culture consiste en une muliplicité des traits.… Ces traits s'equilibrent au sein d'un system …. ("A culture consists of multiplicity of traits …. These traits are balanced within a system …." Translated by Joachim Neugroschel and Phoebe Hoss.)

As noted by Emmanuel Terray (2010:25), Lévi-Strauss considers that:

> les éléments constitutifs d'une culture ne sont pas un agrégat sans cohésion résultant du jeu des circonstances: ils forment système; leur association bénéficie ainsi d'une relative stabilité dans le temps. ("… the constituent elements of a culture are not a non-cohesive aggregation that comes about through circumstance. They form a system, and their association benefits from a relative stability in time." Translated by Cadenza Academic Translations.)

In biological terms, Lévi-Strauss's elaboration on Tylor's succinct definition of culture states that culture is not simply an ensemble of traits arising through the Darwinian processes of mutation, replication, inheritance and selection since culture is in the form of coherent system of rules, hence what distinguishes the cultural domain from the biological domain is not the mode of inheritance—Tylor's "habits

acquired by man as a member of society"—but the systemic organization of that domain as a system of rules—Tylor's "complex whole."

6 Dual inheritance theory account of culture

This runs counter to the notion of cultural evolution expressed through Dual Inheritance Theory (DIT) that provides an extension to a Darwinian evolutionary biological account by including phenotypic transmission as the basis for cultural evolution. DIT posits that humans (and to a degree some other species) are shaped by two modes of transmission for traits: genotypic transmission through sexual reproduction and phenotypic transmission through social interaction and imitation. Dual Inheritance Theory—as discussed by Robert Boyd and Peter Richerson (1985)—is not based on Tylor's definition of culture as a "complex whole" but on his statement about the mode of its transmission. For DIT, culture refers to the "habits acquired by man as a member of society," or, in biological terms, has to do with phenotypic rather than genotypic transmission of traits. This distinction allows Boyd and Richerson to extend the population model of Darwinian evolution to phenotypic as well as genotypic traits, but they are able to this only by ignoring that it is the manner in which the elements of culture form a system—stable through time—that is at the heart of what is meant by culture, not the mode of trait transmission. As the biological philosophers William C. Wimsatt and James R. Griesemer (2007:237) comment:

> These thin models for culture [memetics and DIT] … have no purchase on the 'rich' details–or even (more troubling) on the very *existence* of rich details [of culture]. And in failing to do the latter, we argue that they must fall crucially short of an adequate account of the nature and transmission of culture. (emphasis in the original).

What DIT refers to as cultural traits and cultural transmission is more accurately understood as what the sociologist Edward Shils (1981; see also Polyani 1964) refers to as traditions and the transmission of traditions.

Distinguishing culture through the mode of transmission leads to viewing culture as consisting of traits whose functionality is expressed at the individual level, thus making it possible for cultural evolution to be characterized, as is the case for biological evolution, by change in the frequency of traits arising over an appropriately defined population through selection changing the frequency of traits in that population. For biological traits and with sexual reproduction, the population is the largest cohort within which sexual reproduction takes place, namely a biological species (though there are a few exceptions where there is biological transmission beyond species boundaries) and, given that trait transmission is through sexual reproduction, it follows that relative reproductive success is the driver of directionality in evolution within a species. In addition to external conditions affecting relative reproductive success, internal determinants of relative reproductive success include factors relating to the specifics of how sexual reproduction is initiated and plays out.

The shift to phenotypic transmission as the definiendum of a cultural trait allows the same conceptual framework to be applied to cultural traits, but where the

population would be the largest cohort within which phenotypic transmission takes place, such as (but not limited to) a linguistically bounded group, though boundaries for phenotypic transmission are more porous, in general, than boundaries for genotypic transmission. Relative fitness, the measure of evolution directionality in the form of relative reproductive success for biological traits, is also determined for phenotypic traits through the means by which trait transmission takes place. Imitation is a primary means for transmission of a phenotype from one individual to another and in this situation relative fitness for phenotypically transmitted traits is measured by relative success in one's traits being imitated, hence relates to those factors affecting the likelihood of a trait being transmitted through the imitation process. The neurological mechanisms relating to the imitation process are, themselves, subject to biological evolution. As with genotypic traits, the total information content of the phenotypic traits currently distributed across the members of a relevant population can increase through time when directional selection increases the frequency of phenotypic traits modified through mutations (which may be internally, and not just externally, introduced) that introduce new phenotypic traits and/or change the information content of existing phenotypic traits. Accordingly, cultural evolution, as it is defined in the DIT account of cultural evolution, is cumulative just as biological evolution is cumulative.

7 Individual versus group level traits

Culture viewed as a "complex whole"—that is, as a system of ideas (Leaf and Read 2012)—refers not to traits at the level of the individuals making up a group, but to a trait at the level of the group. Consider the system of ideas encapsulated in the well-known adage said to be an old Arabic Proverb (Al-Amily 2003): "A friend of a friend is a friend, a friend of an enemy is an enemy, an enemy of a friend is an enemy and an enemy of an enemy is a friend." The logic of this adage traces back to at least 2250 BC (Cioffi-Revilla 1994) when Khita of Awan in Mesopotamia writes to Naran-sin: "The enemy of Naran-sin is my enemy. The friend of Naran-sin is my friend" (Lai 2001:216).

The adage does not refer to actual behavior, but to the logic of a hypothetical state of affairs since actual behavior involving friends and enemies, however these may be determined, is often inconsistent with the adage. Instead, it presents a cultural meaning for how the concepts "friend" and "enemy" are interrelated through the four statements stating how the concepts of "friend" and "enemy" are interrelated in the form of a (mathematical) relational structure (see discussion in Read 2011) that may then be used computationally in practice. For example, the anthropologist Martin Gusinde notes for the Ona of South America: "A person who has quarreled with someone from another group does not hold back his dislike … he wears his innermost feelings clearly drawn on his face as soon as he meets his enemy *or the latter's friends*" (1931:626, emphasis added). Or, in the terms used by the cultural anthropologist Clifford Geertz (1973), the adage is a model *for* behavior and not a model *of* behavior. In Lévi-Strauss's terms, the adage expresses rules for behavior and thus is part of culture.

8 Culture as a constructed reality

Culture, in this sense, is not directly about the external, phenomenal domain through which we interact with the environment through our senses and need not reflect any or all aspects of the way that that external reality is organized and patterned, but instead is a "constructed reality" (Berger and Luckmann 1966; Spradley and Mann 1975). By this is meant a reality in the sense that culture bearers non-consciously assume the culture milieu into which they have been enculturated is real and objective (Spradley and Mann 1975) and so " beliefs … have become so naturalized that they are not even seen as beliefs" (Strauss 2015:392). Culture is constructed in the sense that the rules expressed in the adage are the creation of the human mind and are not a mapping from external reality to internal representation. Culture, in this sense of a constructed reality, though of necessity located in the minds of individuals, is not composed of individual traits with functionality affecting directly the possessor of that trait regardless of its frequency in a relevant population, as is the case with biological traits. Instead, culture as a constructed reality has functionality at the organizational level of a society and functionality accrues to an individual by being a member of that society (Lane et al. 2009) and being enculturated into the cultural milieu of that society (Read et al. 2009).

8.1 Kinship terms as a constructed reality

This can be seen in the system of kinship relations that are part of the cultural milieu of all societies. Kinship relations are expressed through kin terms (such as mother, father, brother, sister, and so on for English speakers) that are part of a conceptually bounded system of kinship relations (Leaf and Read 2012) and organized structurally (Read 2007) through what anthropologists refer to as a kinship terminology. Kinship terminologies differ from one society to another not only because of language differences, but more importantly because of differences, as expressed by Lewis Henry Morgan in his monumental 1871 publication, *Systems of consanguinity and affinity of the human family*, in the particular concepts upon which kinship relations are based. Morgan initiated the scientific study of kinship terminologies by obtaining world wide lists of kin terms in order to infer what those organizing concepts would be, and in the process founded a scientific American anthropology with focus on cultural aspects of human societies (Trautmann 2001).

8.2 Descriptive versus classificatory terminologies

Through his cross-cultural study of kinship terminologies, Morgan recognized that across world societies there are two, fundamentally different kinds of terminologies, which he referred to as descriptive versus classificatory terminologies, and through which kinship relations are conceptualized and organized. Morgan distinguished descriptive terminologies such as the English-American kinship terminology to be those terminologies that identify kinship relations through kin terms that are

consistent with the distinction between lineal and collateral genealogical relations—a distinction important in English inheritance laws with which Morgan was familiar. In the other terminologies, referred to by him as classificatory terminologies, even the primary kin terms for family kinship relations cross-cut this genealogical distinction.

Contrary to the descriptive terminologies, in which the lineal kin terms such as English mother, father, son, daughter, and so on each have a single, genealogical referent (e.g., genealogical mother is the only genealogical referent of the English kin term mother), in a classificatory terminology the term referring to one's genealogical mother (henceforth mother, for short) also refers to one's mother's mother's daughters, to one's mother's mother's mother's daughter's daughters, and so on, and in a mirror-like way, the term that refers to one's genealogical father also refers to one's father's father's sons, one's father's father's father's son's, sons, and so on. In addition the child of anyone a person refers to by their kin terms that we would translate as 'father' or 'mother' is referred to by their kin terms we would translate as 'brother' or 'sister,' and so on. Whereas the kin terms in descriptive terminologies generally parallel genealogical distinctions that arise through reproduction, Morgan recognized that the same is not true of the classificatory terminologies found in about one half of human societies. While the descriptive terminologies are, at first glance, made up of kin terms that seem to simply reflect biological kinship relations arising from the pattern of sexual reproduction by societal members, Morgan recognized that this was not the case for the classificatory terminologies. The way kin terms in classificatory terminologies cross-cut genealogical relations determined through reproduction made it evident that the structure and organization of classificatory terminologies is neither determined nor constrained by biological relations arising through reproduction, yet the kinship relations expressed in the classificatory terminologies are as real to the users of these terminologies as the relations expressed through the kin terms of a descriptive terminology are to the users of descriptive terminologies.

Morgan, recognized, though he did not express it in these words, that the system of kin terms in societies with classificatory terminologies is a constructed reality. Whereas the descriptive terminologies distinguish siblings from cousins, for example, thus paralleling the biological difference between biological siblings and biological cousins, and whereas these terminologies recognize through kin terms the biological unity of kinds of biological cousins; that is, not distinguishing between cousins who are the child of one's parent's same sex sibling or the child of one's parent's cross-sex siblings, the classificatory terminologies bifurcate the former into persons with whom sexual intercourse is taboo (such as sexual intercourse with siblings), hence cannot be married, and the latter into persons with whom marriage may be prescribed by the group to which one belongs.

8.3 Generative logic for kinship terminologies

Though the descriptive terminologies seem to recognize kinship relations in a manner analogous to biological kin relations determined through sexual reproduction,

recent work on the structural logic of kinship terminologies leads to a different conclusion, namely that no kinship terminology, descriptive or classificatory, is derived from biological relations. Instead, all terminologies have a generative logic for generating the kin terms making up the kinship terminology from the family kinship relations, including terms for the spousal relations defined through the cultural institution of marriage (Read 2007; Leaf and Read 2012; Read, Fischer and Chit Hlaing 2014). Kin terms, then, are not just a way for a group to identify and linguistically name culturally constructed and recognized kinship relations, but are fundamental to the social organization of all societies by providing the conceptual framework for establishing (or denying, in the case of reproduction that is culturally defined as illegitimate) the social identity of a newborn as part of the social domain in which he or she is to be enculturated. In addition, for small scale societies such as the hunter-gatherer societies whose form of social organization traces back to the Upper Paleolithic, identifying kinship relations as they are culturally understood is necessary for social interaction to take place. A hunter-gatherer group consists of all, and only, those individuals who are, or can determine that they are, mutually kin (Bird-David 2017) and being kin to one another is a prerequisite for social interaction to take place. Kinship relations are also the first relation system a newborn learns and the kinship relation system provides a model for learning other relation systems that are part of living in human societies (Leaf and Read 2012). Through enculturation, a child not only learns about kinship relations he or she has to others, but, reciprocally, that these others have a kinship relation to him or her. The child, then is internalizing the kin term system for the group into which he or she is being enculturated, just as a growing child internalizes the language of the group in which he or she is being raised. In addition, kinship terminologies, like a language, have a syntactic structure and this syntactic structure has an underlying logic that enables individuals to compute kin term relations through their cultural knowledge regarding their kinship terminology (Read 2007; Leaf and Read 2012; Read, Fischer and Chit Hlaing 2014).

8.4 Computation of kinship relations from kin terms and the axiom of amity

As has been documented by numerous ethnographers, two individuals who are strangers can determine whether they are mutual kin by determining if there is a third person to whom each has a kin term relationship. As the anthropologist Marshall Sahlins expresses it for the kinship terminology used by the Fiji of the South Pacific:

> [Kin] terms permit comparative strangers to fix kinship rapidly without the necessity of elaborate genealogical reckoning—reckoning that typically would be impossible. With mutual relationship terms all that is required is the discovery of one common relative. Thus, if A is related to B as child to mother, veitanani, while C is related to B as veitacini, sibling of the same sex, then it follows that A is related to C as child to mother although they never before met or knew it. Kin terms are predicable. If two people are each related to a third, then they are related to each other (1962: 155).

More generally, a computation using the kin term L that A uses to refer to B and the kin term K that B uses to refer to C (that is, K is the reciprocal of the term that C uses to refer to B) to determine the kin term M that A uses to refer to C will be summarized by writing the equation, K of L = M (read "the kin term product of K with the kin term L is the kin term M"), and will be referred to as the kin term product of K and L (see Read 1984; Dousset 2008). Two key points that Sahlins notes about the kin term product (and have been observed by numerous other ethnographers; see quotes and references in Read 2007) are: (1) kinship relations expressed through kin terms and the kin term product are not determined through genealogical relations, let alone biological relations, and (2) the terminology is a constructed, symbolic computational system that permits defining and calculating kinship relations in a quasi-mathematical manner using the kin term product.

Kinship systems, it should be noted, are more than just the way group members are interconnected through the system of kin relations expressed through kin terms, but are also include the way kin terms are endowed with what the British social anthropologist Meyer Fortes referred to as the "principle of kinship amity… assumed everywhere to be axiomatically binding" and expressed through the "rule of *prescriptive* altruism" (1969: 232; emphasis added); i.e., those who are culturally recognized as kin to each other are expected and assumed to be altruistic in their behavior simply by virtue of the fact of being kin to one another. For the Mardu, a hunter-gatherer group in western Australia: "the moral universe of the Mardu is populated solely with relatives" (Tonkinson 1991: 57). Expected moral behavior, though, is not simply what individuals are already disposed to do. For the Chón Chuuk of Micronesia: "cultural propositions … define the ranges of deontic powers associated with the different statuses [and] provide reasons for action (i.e., moral reasons) that are *independent of people's inclinations or desires*" (Lowe 2018: 83, emphasis added). Yet, despite cultural prescriptions regarding altruism and morality, and just as the Arabic proverb about friend and enemy may not be followed in practice, kin may, in fact, be mean, nasty and venal towards one another.

9 From individuation to social cohesion via kinship as a constructed reality

The systems of kinship relations developed as part of hominin evolution leading to modern *Homo sapiens* are, then, the cultural means by which a group of individuated persons whose behavior may otherwise lack predictability by other group members is transformed into a cohort of kin with mutually understood relations to one another with the expectation that moral and altruistic behavior will occur simply by virtue of one person being kin to another person. Kinship, as it has been culturally constructed, circumvents, then, the cognitive barrier faced by the great apes and is fundamental to what makes us human and not just a smarter, more social great ape (Read 2012).

9.1 Kinship as an organizational system

Kin terms do not identify individual traits in the same sense that biological traits are individual traits. Whether an individual has a particular genetically specified trait depends on that individual's genome having the requisite genetic information for that trait. Biological traits, in this sense, are not a function of the frequency distribution of the forms of genetic information in a population. Kinship systems are of a different sort than this as they define and organize the domain of kin and express the way members of a group are interrelated to one another through kinship, hence the functionality of kinship is through the way kinship relates to the actions and behaviors of group members as group members and not as individuals. Kinship relations do not exist in a functional sense for individuals in isolation in the way that the functionality of biological traits may still accrue to an individual in isolation. For example, the genetic traits involved in a female giving birth are activated by fertilization of an ovum and this activation and the functionality of the genetic traits called into play during fetal growth leading to birth does not depend on the frequency distribution of these traits in a population of individuals. A female can give birth and then *act* like a mother even in isolation. However, from a kinship perspective, she cannot *be* a mother and thereby benefit from the kinship functionality associated with being a mother in a particular group unless she is recognized as being a mother by group members. The group in which she is socially located can deem her offspring to be illegitimate and thereby deny to her and to her offspring those rights and privileges associated normally with being a group member. In this sense, kin terms are not traits at the level of the individuals making up a population but constitute instead the conceptual framework for what is culturally meant by kinship and through which the functionality associated with kin term relations accrues to individuals by virtue of group membership established through social identity determined by the system of kinship relations expressed through kin terms.

9.2 Transmission through enculturation

The importance of the social group for the functionality of kinship carries over to the mode of its transmission. Kinship systems, and other cultural idea systems, are, like languages, not transmitted phenotypically as a whole through imitation going from one individual to another. For languages, this is evidenced by the fact that linguistic competence on the part of adult native speakers is underdetermined by the linguistic utterances one has heard as a child (Pinker 1989; Bertolo 2001) and so language acquisition involves a complex process going from underdetermination by the linguistic utterances to which an individual has been exposed to adult competence (Eisenbeiss 2009). Similarly, cultural idea systems are transmitted through enculturation as an ongoing, lifelong process through which the social interaction that one individual necessarily has with other individuals from birth onwards triggers a process that is inadequately described by the term imitation. What is involved is more than information transfer in the sense of imitation. Enculturation, like language acquisition, involves transmission of the underlying structure and organization

of information in a manner that allows an individual to generate behavior patterns transcending the specific instances of the information that has been received, yet will be recognized by other culture bearers as being culturally appropriate (Schwartz 1981). Through enculturation, a newborn individual learns to produce, as the cultural anthropologist Ward Goodenough (1964) phrased it, what is considered to be culturally appropriate behavior by those in the group in which he or she is being raised.

9.3 Kinship terminology as a "complex whole"

The functionality accruing to individuals from kinship behavior arises, then, from kinship as an organized system of relations and not simply by virtue of an individual having the concept of each kinship relation as a separate phenotypic trait. Cultural idea systems like kinship systems provide a framework for the social organization of some domain within a society and are not emergent from individual traits (*contra* Smaldino 2014). It is the structural logic of a kinship terminology that makes it a "complex whole" and it is through being a complex whole that its functionality for the social organization of a group tis realized and not through kin terms being transmitted phenotypically rather than genotypically.

10 Evolution of kinship terminologies as computational systems

Non-human primates do not have kinship relations in a conceptual sense; instead, they engage in behavior patterns that may be differentially expressed, via biological kin selection, according to the biological kin relation between agent and recipient of the agent's action. For all mammals, there has been selection for the mothering behavior that a female directs towards her biological offspring and not towards the offspring of other females. In some of the primates, in particular the macaques (Dasser 1988) and the vervet monkeys and baboons (Cheney and Seyfarth 2007), this difference in the behavior pattern of females towards own offspring and the offspring of other females has been shown to be the basis for females categorizing, at a phenomenal level, female/own offspring dyads as a category different from a category based on female/other offspring dyads. In contrast, all human societies recognize a *conceptual* system of kinship relations linguistically marked through what are referred to as kin terms and forming a "complex whole" that anthropologists refer to as a kinship terminology. Thus, there has been an increase in cognitive abilities during hominin evolution leading to *Homo sapiens* that has gone from cognition operating primarily, if not exclusively, at the phenomenal level to cognition that is also capable of operating at the ideational level. While the archaeological record does not provide direct evidence documenting this fundamental change in cognitive abilities and how it played out and led to the evolution of conceptual systems of kinship relations, both indirect evidence and the overall pattern of changes in hominin evolution shown in Fig. 1 make possible informed speculation regarding some of the major events in this trajectory.

10.1 Short term memory size as a cognitive limitation

A key part of the indirect evidence relates to increase in the size of short term working memory in the evolutionary pathway going from a common ancestor of *Pan* and *Homo* to modern *Homo sapiens*. Conservatively, assume the size of short term working memory (STWM) for this common ancestor is the same as that of present-day chimpanzees, which is 2 ± 1 (Read 2008, 2017 *contra* Carruthers 2013; Völter et al. 2019) in contrast with STWM $= 7 \pm 2$ in humans (Miller 1956). The STWM size of *Pan* is illustrated empirically by the fact that the task of cracking a nut by the chimpanzees at Bossou, Guinea through using a flat stone as an anvil, then placing a nut on the anvil and finally hitting the nut on the anvil with another stone to crack it open appears to be at the limit if their cognitive abilities (Parker and McKinney 1999). Chimpanzees do not learn how to do this task before reaching about 4 years of age (Matsuzawa 1994) and those that fail to learn the task either put the nut on the ground and hit it with a stone or place it on the anvil and hit it with a fist. About 20% of the chimpanzees at Bossou never learn to crack nuts this way despite watching repeatedly other chimpanzees crack nuts successfully (Read 2008 and references therein; see Read 2008 for other examples showing that STWM $= 2 \pm 1$ for chimpanzees).

The limited size of the short term working memory of chimpanzees suggests they are not capable of the full range of cognitive reasoning prevalent in humans. This can also be inferred from simulations demonstrating that the STWM size needed to solve optimization problems easily performed by humans is at least 2–5 (Pizlo and Stefanov 2013), hence involves cognitive capacities beyond those of chimpanzees. In addition, non-human primates do not appear to be capable of recursive reasoning in the form of applying the same procedure to the outcome of that procedure (Hauser et al. 2002).

10.2 Abstracting from Behavior to Concept: The Concept of a Mother Relation

Figure 4 shows the relationship between a linear increase in working memory and change in both the encephalization quotient and hominin taxonomic classification during hominin evolution leading to *Homo sapiens*, based on assuming STWM $= 2$ at 6 mya for the divergence of the hominins from a chimpanzee-like ancestor and then having a linear increase in size through time. Given the strong association of STSM size with mental abilities in modern *Homo sapiens* (Alloway and Alloway 2010 and references therein; Cowan et al. 2005; Cowan et al. 2006; Engle 2002; Engle et al. 1999), it follows that increase in STWM size during hominin evolution leading to *Homo sapiens* should be paralleled by the occurrence of more complex behaviors and adaptations derived from an increase in mental and cognitive abilities, first of all in pre-*Homo* hominins and then in the *Homo* genus (Weaver et al. 2001). This pattern is especially apparent in the changes that occurred with stone tool technology (Read and van der Leeuw 2008). In Fig. 4, the increase from STWM $= 2$ to STWM $= 4$ corresponds to the appearance of hominins classified as *Homo habilis*

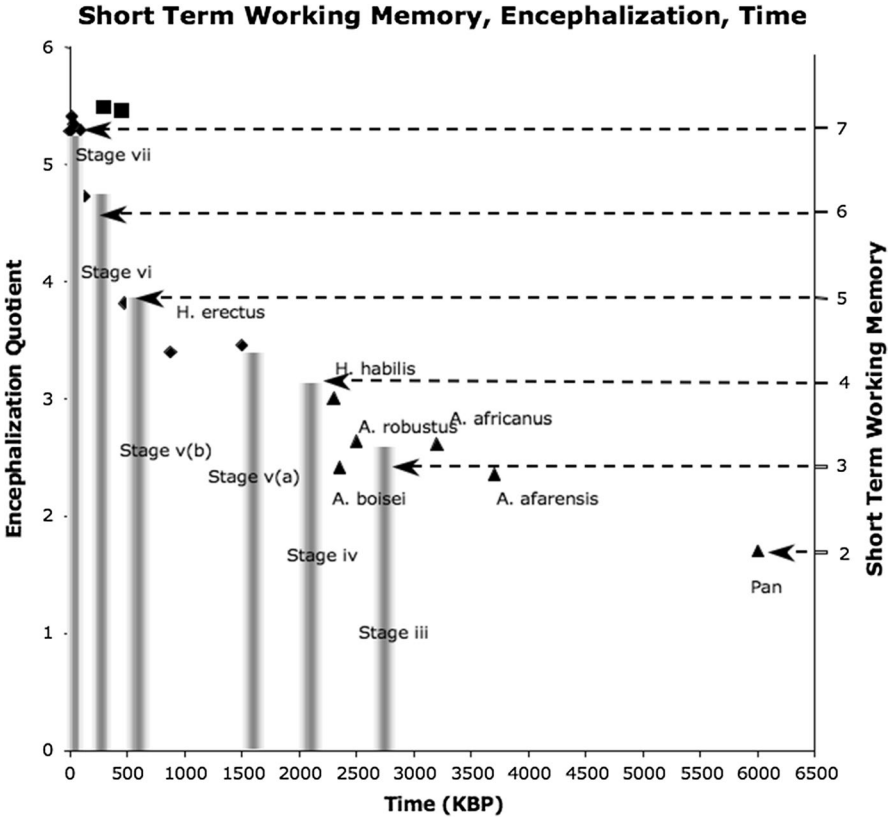

Fig. 4 Graph of encephalization quotient (EQ) estimates based on hominid fossils and *Pan*. Early hominid fossils have been identified by taxon. Each data point is the mean for hominid fossils at that time period. Height of the 'fuzzy' vertical bars is the hominid EQ corresponding to the data for the appearance of the stage represented by the fuzzy bar. Right vertical axis represents STWM. Encephalization data are adapted from the following: filled triangle– Epstein 2002; filled square—Rightmire 2004; filled diamond—Ruff et al. 1997. Phylogenetic groups for the encephalization data are identified except for the data for *Homo* post *H. erectus*. EQ = brain mass/(11.22 body mass0.76). The stages refer to qualitatively different tool forms (see Read and van der Leeuw 2008 for details)

and their associated Oldowan stone tool industry. The subsequent Acheulean stone tool industry is associated with an increase in STWM from 4 to 5 and STWM = 6 corresponds to the technological and conceptual changes in tool making associated with the Middle to Upper Paleolithic time period, while STWM = 7 brings us to modern *Homo sapiens* and the evolutionary elaboration and development of the cognitive capacities and mental abilities associated with our species.

Similar patterns of more elaborated and conceptually more complex adaptations that parallel the increase in STWM occur in other domains as well. Of particular interest here is a major shift in the social relations upon which social organization is grounded. The shift is from social relations being worked out at the phenomenal level of individual behavior through face-to-face interaction to social relations

organized at the ideational level through the relation-based systems of social interaction that underlie the forms of social organizational characterizing human societies today (Read and van der Leeuw 2015).

The restructuring of the social domain is the consequence of changes that occurred in the cognitive domain during evolution from early hominins to modern *Homo sapiens.* In this domain, there was a shift from social relations playing out at the phenomenal level through biologically based propensities guiding face-to-face interaction to social relations playing out at the ideational level through implementation of new "abstract or ideal objects of thought or discourse" (Stjernfelt 2012:53) that made it possible to formulate non-biologically based modes of social interaction and hence of social organization. One of these new "objects of thought," central to the argument being made here, was the formation of the concept of a mother relation between a female and her offspring (and reciprocally of a child relation between an offspring and that female) that then became part of the cognitive repertoire of *Homo*.

The abstraction leading to the mother relation is hypothesized here to have occurred by a process implementing what the philosopher Charles Sanders Peirce calls "hypostatic abstraction.",[12] Hypostatic abstraction, in its mathematical sense, refers to "passing from the existence of different types of connections between entities to forming the concept of 'relation' as a new abstract object" (Stjernfelt 2012: 49). Peirce characterizes hypostatic abstraction linguistically as involving "the transformation of a *concrete predicate* into an abstract noun" (Peirce 1976:160, as quoted in Zeman 1982).

For the context of hominin evolution prior to the appearance of syntactic languages, the linguistic characterization of hypostatic abstraction needs to be taken metaphorically and not literally. In this regard, the innovation leading to the mother relation involves abstraction creating a transition from (1) the phenomenal level of observed behaviors such as (from our analytical perspective) "a female is nurturant, caring and supportive to her offspring," to (2) the ideational level of positing a relation between a female and her offspring such as (again from our analytic perspective) "a female provides nurturance and other forms of support for her offspring," The scare quoted observations in (1) identify nurturant behavior (and other comparable behaviors) as a specific property of a female (Peirce's 'concrete predicate') and this leads to the categorization of a female-offspring dyad either as a female-own offspring dyad or a female-other offspring dyad (as occurs with the macaques). Thus, just as a concrete predicate refers to a property of what it refers to, *nurturant* refers to a behavior property that is part of female. behavior. Next, just as the abstract noun in Peirce's characterization of hypostatic abstraction is the abstracted form of a concrete property, the propensity to providing nurturance is an abstracted form of the nurturant behavior that is a part of female behavior. Thus, the transition

[1] I thank an anonymous reviewer for bringing the relevance of Charles S. Peirce's notion of hypostatic abstraction and the work of F. Stjernfelt on semiotics to my attention.

[2] "Hypostatic abstraction in mathematical logic … is a formal operation that transforms a predicate into a relation; for example 'Honey is sweet' is transformed into 'Honey has sweetness.' … The abstraction of hypostasis takes the concrete physical sense of 'taste' found in 'honey is sweet' and gives it formal metaphysical characteristics in 'honey has sweetness'" (Wikipedia contributors: 2019).

going from the phenomenal level of a property expressed in (1) to the ideational level of a relation that is taken as an abstraction of that property, as expressed in (2), is an instance of Peirce's hypostatic abstraction.[3] The abstraction is not, it should be noted, one of generalization, but of going from what is perceived as being a property of female behavior directed towards her offspring to a relation between a female and that offspring expressed as her propensity to engage in nurturing behavior. The latter can then taken as characterizing the relation of a female to her offspring.

For the concept of a relation introduced by this cognitive innovation to be integrated into a group's cognitive repertoire and not simply just be part of the cognitive phenotype of individuals, it needs to be named, say by "mother." Naming the abstracted relation makes it possible for it to become a symbol held in common by group members. As a symbol, "mother" has the abstracted relation as its semantic content, with activation of this symbol indexed by "provides nurturance." In this sense, saying that this female is a mother to that offspring invokes the semantic content of the "mother" symbol, namely that what makes this female a mother is providing nurturance. This has the implication that the transition from the phenomenal level of concrete nurturant behavior to the ideational level, with the abstracted mother relation of providing nurturance as the meaning of the mother symbol, is also a transition from the phenomenal level of biology to the ideational level of culture. This can be seen by the fact that whereas what constitutes nurturant behavior derives from biology, what constitutes providing nurturance derives from cultural assignment. Thus, what it means to be a mother is culturally, not biologically, determined through what is accepted or defined by a group as to what constitutes providing nurturance.

Abstraction is necessarily involved in this process since formulating the mother relation involves introducing an abstraction that, itself, is not part of the behavior of females toward offspring, whether "own offspring" or not, which fits in with the observation about social systems that "some social models operate with a conceptual structure…that is not derivable from the concepts deployed in behavioral models…" (Maibonn 2007: 572). The relation innovation would need STWM of at least size 4, as it requires keeping in STWM the female in question, the offspring involved, what constitutes nurturance, and the behavior she is engaging in and directed towards those offspring. Thus, abstractions like this going from phenomenal behavior to a relation concept would not have been possible before the size of STWM of hominins had increased to at least 4, around 2 mya (see Fig. 4).

10.3 A relation of a relation is a relation

A second, major innovation was conceptualizing that the relation of a relation is a relation. For the mother relation, the formation of a mother of a mother relation may have a behavioral basis in the behavior discussed in the "grandmother" hypothesis advanced to account for the life span of human females extending well beyond

[3] In predicate form, *nurturant(female)*→*provides(female, nurturance*).

menopause—uniquely among primates (Walker and Herndon 2008) —by arguing that a female's mother increases her fitness if she engages in mothering behavior directed towards the offspring of her biological daughter's offspring after she reaches menopause (Hawkes et al. 1997). This post-menopausal behavior by the biological grandmother would thus be selected for (Lahdenperä et al. 2004 and references therein). The hypothesized "grandmother" behavior provides support for the conceptual innovation that the relation of a relation is a relation—namely, the mother relation of a mother relation is a relation and, reciprocally, the child relation of a child relation is a relation. The "relation of a relation" innovation is critical for the subsequent development of the system of relations that appears to have become part of forming social coherence in the presence of highly individualized behavior for two reasons. First of all, this opens up the possibility of forming, through the logic of recursion, chains of relation connected individuals going from a referent individual to a target individual (and, reciprocally, a chain of relation-connected individuals in the reverse direction), and, secondly, rather than requiring an already selected pattern of behavior between biologically related individuals as the basis for abstracting from the phenomenal to the ideational level in order to conceptualize a new relation, a new relation may now be conceptualized directly through recursive reasoning by forming the relation of a relation as a new relation and without requiring that the individuals in the posited relation actually be biologically related. That is, whereas the mother relation, for example, has its origin through abstraction from mothering behavior occurring between a female and her biological offspring since her mothering behavior must be directed towards her biological offspring in order to increase her relative fitness, this is no longer the case when forming a sequence of relations of relations formed through the logic of recursion. All that is required is that, in the case of the mother relation of a mother relation, for example, the terminal female taken as the mother of the mother of the referent offspring is *believed* to be the mother of the mother of the referent offspring. Thus, a conceptual system of genealogical relations based on recursive reasoning need not be restricted to biologically related individuals: "Genealogies are not accounts of biological relationship but sociological artifacts …" (Barnard and Good 1984:23).

Empirically, the occurrence of the "grandmother" behavior is thought to date to around 1.5 mya (O'Connell et al. 1999). This fits in with a linear increase in the size of STWM to at least 4 by 1.5 mya and to the abstraction leading to the concept of a mother relation possibly occurring as early as 3 mya.[4]

[4] The fact that human language and systems of kinship relations are both syntactically organized linguistic systems raises the question of whether there is a connection between the origin of the one or the other. The simplest genealogical system of kinship relations incorporating both the generation of genealogical relations and the reduction of generated genealogical relations through structural equations would be the mother genealogical relation, its reciprocal child genealogical relation and the genealogical structure formed recursively from mother and/or child genealogical relations, using at most two genealogical relations at a time, and modified, for a female speaker, by the reciprocal genealogical structural equation, child's mother = self. This system would consist of the genealogical relations mother, mother's mother, child, child's child, mother's child and self = child's mother. Implementation of the "grandmother" hypothesis system around 1.5 mya would provide a behavioral basis for the use of recursive logic to go from the mother genealogical relation to the mother of a mother genealogical relation. This suggests that a simple genealogical system of kinship relations could trace back to 1.5 mya, hence before the formation of syntactically structured human languages, and so could be one of the factors leading to embedding recursion as a fundamental feature of human languages.

10.4 Expected behavior and constructed kinship relations

Two other properties are associated with the mother relation (and its reciprocal child relation) and with the relation derived through the relation of a relation. First, abstraction from the pattern of mothering behavior at the phenomenal level to the mother relation at the ideational level implies that the behavior pattern leading to that abstraction would be part of the mother relation concept; that is, the mother relation will include the expectation that the supportive, protective, and emotionally positive behavior associated with mothering behavior would be part of the concept of a mother relation. Second, the behavior pattern associated with a mother relation would empirically carry over to the relation constructed by forming the mother relation of a mother relation as occurs with the "grandmother" hypothesis involving the behavior pattern of mothering behavior being directed from a female to the offspring of her biological daughter, thus suggesting that any positive affect associated with a relation would be carried over to the relation formed recursively as the relation of a relation.

Together, the mother relation (along with its reciprocal child relation), and the concept that the relation of a relation is a relation, are sufficient for generating a system of relations through the logic of recursion. In addition, carrying over the positive, supportive behavior associated with a relation to the relation formed through the relation of relation implies that this system of relations provides a basis for Fortes's Axiom of Amity.

10.5 The father relation

However, a system of conceptual relations based on just the mother relation and its reciprocal child relation, even with forming the relation of a relation as a new relation, will not include males except either as the child of a female where child is the terminal relation in a sequence of relations, or as the initial person in a sequence of relations beginning with the mother relation. The absence of a father relation in early hominin evolution stems from the fact that male parenting behavior is uncommon in the nonhuman primates and does not occur in the chimpanzees (Fernandez-Duque et al. 2009), hence most likely male parenting was not part of early hominin behavior. Male parenting may occur when the time and effort demands of raising an offspring cannot be met by a female alone (Ember and Ember 1979). Conditions like this would likely have become part of hominin evolution by around 500 kya when it appears that the *Homo sapiens* pattern of difficult child births was already in place, a newborn infant was born helpless (often referred to as secondary altriciality) and unable to cling to its biological mother, thus required extensive care and carrying (Dunsworth and Eccleston 2015), hence reducing the biological mother's mobility. A female's reduced mobility would increase her and/or her offspring's risk of being the subject of predation while she forages and/or hunts and scavenges for the meat that had become a regular part of the hominin diet after about 2 mya (Ferraro et al. 2013).

These, and possibly other constraining factors on the various behavioral modalities in which she was engaged, would lead to selection for (emotional) pair bonding

between a male and a female through which a female could bias male behavior towards behaviors that increase her relative fitness (Gavrilets 2012), which, in turn, may have led to male parenting behavior. With the introduction of male parenting into the hominin behavior repertoire, a father relation could also have become part of the conceptual repertoire of hominins.

10.6 Relations introduced through marriage

However, there is a striking asymmetry between a mother relation and a father relation from the perspective of what the members of a community know with regard to who is the mother of whom and who is the father of whom. The biological facts of pregnancy, giving birth and breast feeding are part of mothering behavior that make it publicly evident to group members as to which female is the (biological) mother of which offspring. The same is not true of males. There is no biological property that identifies a male as having impregnated a female, let alone the specific female that he impregnated. This uncertainty in who should be identified as the father of which offspring was resolved through the cultural institution of marriage with its function of identifying for community members the male who will be considered, for social purposes, the (putative) father of the offspring of a female, thereby legitimizing her, from the perspective of the community, as a bearer of children who are then members of that community (Chit Hlaing and Read 2016; see also Malinowski 1913; Gough 1959). Phylogenetic dating for marriage suggests that marriage goes back to at least 50 kya (Walker et al. 2011).

11 Genealogical relations constructed through the logic of recursion

The combination of the concept of a mother relation, a father relation, marriage as a means to identify which male is considered to be the father of the offspring of a female, and forming new relations through using recursion to form the relation of a relation provides the framework for working out genealogical connections among group members and to members of the other groups to which females transferred upon reaching puberty (assuming ancestral chimpanzee male philopatry continued with the hominins). Genealogical relations with associated, expected positive and supportive behavior provides the means to transform social relations away from depending on face-to-face interaction to social relations based on genealogical relations among group members.

12 Cognitive limitation of genealogical relations

Yet building social relations through genealogical relations has a fatal Achilles Heel: the overwhelming cognitive complexity involved for each individual to work out, and keep track of increasingly distant genealogical relations since the number of possible genealogical pathways doubles, at a minimum, with each step taken in a genealogical pathway. In addition, increasing the horizontal breadth of genealogical

relations requires tracing back to distant ancestors through mother and/or father relations and then tracing forward using the reciprocal child relations, hence requires keeping track of genealogical relations involving the dead as well as the living. Adding to this complexity from the perspective of each individual is the difficulty in obtaining agreement across group members regarding how they are linked through genealogical relations since more than one genealogical pathway may connect two individuals and the persons making up a genealogical pathway may be under dispute. Altogether, the scale of these complexities that would arise were social interaction organized through genealogical relations provides the reason no society has a kinship system based solely on genealogical relations. Instead, all societies have a kinship terminology system with around two dozen kin terms organized through a generative logic that enables kin term relations to be computed symbolically from a small set of primary kin terms based on the relations making up conceptually a family unit (see Read 2015, Read et al. 2014 for details). Having a system of kin term relations structured in a manner that makes it possible for individuals to compute symbolically their kin term relations to each other—much like numerical relations among the counting numbers may be computed symbolically using number symbols—resolved the complexity problem associated with genealogical tracing of kin relations (Read 2007; Leaf and Read 2012; Read, Fischer and Chit Hlaing 2014).

13 Outline of the generative logic of kinship terminologies

There is no direct archaeological evidence regarding the origin of the symbolic systems of kin term relations expressed through the kinship terminologies that occur universally in human societies. Indirect evidence consists of inferences made from what is known about the ethnographically established properties of kinship systems found in societies today that can then be linked to kinship inferences based on archaeological evidence (Ensor 2013).

In all terminologies, new kin term relations are generated from the primary kin terms expressing the relations making the conceptual structure underlying family units (Read 2015). The structural form of a generated system of kin term relations is created through incorporating structural equations expressing the cultural kinship ideas that are central to a society's system of kinship relations being expressed through kin terms.

Modeling of the generation of kin term relations proceeds by layers, beginning with the innermost layer of ascending kin terms. These are the terms a newborn first learns through enculturation and the reciprocal terms for these kin terms express the kin term relations of a newborn to already born individuals, such as the reciprocal terms, son and daughter, express the kinship relation of a newborn to those person who are mother and father to the newborn.

Next, the descending kin terms are generated with a structure isomorphic to the structure of the ascending kin terms. The descending terms are the reciprocal kin terms for the ascending kin terms.

Male and female marked kin terms are now introduced. Terms of one sex are already introduced in most terminologies by beginning, for the lineal ascending kin terms, with a sex marked ascending term such as (in Seneca) *hä'-nih* ('father') or *no-yeh'* ('mother'). (The 'father' and 'mother' in single quotes denotes the closest English translation of the Seneca terms *hä'-nih* and *no-yeh',* respectively.) Terms with the opposite sex are now introduced by making an isomorphic version of the already generated ascending and descending terms using terms with sex opposite to that of the already generated structure composed of ascending and descending kin terms. Then the two isomorphic structures, one consisting of male marked terms and the other consisting of female marked terms, are connected together to make a single structure of male marked and female marked kin terms.

For the terminologies where the generation of the terminology begins with a neutral ascending kin term (such as parent in English), the ascending terms and the descending terms are bifurcated into sex marked terms (e.g., the English term parent is bifurcated into father and mother and the child term is bifurcated into son and daughter). This procedure for introducing sex marked terms occurs in many of the western terminologies and in some of the terminologies that occur in other parts of the world.

Affinal kin terms (such as husband and wife in English) that identify kinship relations introduced through marriage are included next, and finally there may be modification of the kinship terminology being generated in order to take into account the way distinctions made in the kinship terminology interface with factors affecting the structure and social organization of a particular society (e.g., the single kin term, *fa'e tangata* ('brother of mother'), that is generated in the Tongan terminology is bifurcated so as to introduce the term *tu'asina* ('younger brother of mother') that relates to their rules regarding inheritance [Bennardo and Read 2007]).

13.1 Generation of ascending kin terms

This overview will now be fleshed out for the English terminology familiar to English speakers, beginning with *parent* as the primary ascending kin term. (*Parent*, rather than *mother* or *father*, will be used as the primary ascending kin term since using *mother* and *father* as the primary ascending kin terms would require introducing ad hoc structural equations to make the terminology being generated match the actual terminology [see Read 2007 for details]). The set $\mathcal{A}$ of generators for the ascending kin terms will be $\mathcal{A} = \{self, parent\}$. The term, *self*, is included as a generating term since *self* refers to "A person's essential being that distinguishes them from others" (Oxford English Dictionary) and linguistically speaker refers to *myself*. New kin terms are generated by repeatedly forming the product of the *parent* term with itself and then identifying which of these products are culturally recognized as defining kin terms by being named, or are not recognized as defining a kin term if not named; e.g., the kin term product, *father* of *father-in-law*, is not named and so this product is not recognized as defining an English kin term. This yields the sequence of kin terms: *parent*, *grandparent* = *parent* of *parent*, *great grandparent* = *parent* of *grandparent*, *great great grandparent* = *parent* of *great grandparent*, and so on. Note

that the English pattern of creating kin term names for all repeated products of *parent* with itself is uncommon among kinship terminologies. More often, the pattern is like that found in the Seneca terminology where the set $\mathcal{A}$ of lineal ascending male generating terms (or, equally, lineal female generating terms) is $\mathcal{A} = \{$*male self*, *hä'-nih* ('father')$\}$. The product of *hä'-nih* with itself is given by *hä'-nih* ('father') of *hä'-nih* ('father') = *hoc'-sote* ('grandparent'). Additional products using *hä'-nih* are all named using *hoc'-sote,* which may be indicated by including the equation *hä'-nih* ('father') of *hoc'-sote* ('grandfather') = *hoc'-sote* ('grandfather') (see discussion by Dwight Read in Matthey 2020 for clarification of the structural implications of using the same kin term name to make the product of *hä'-nih* with *hoc'sote* = *hä'-nih* of *hä'-nih* reflexive through the way this product is named).

13.2 Generation of descending kin terms

The descending kin terms for the English kinship terminology are generated so as to be structurally isomorphic to the ascending kin terms. In place of $\mathcal{A} = \{$*self*, *parent*$\}$, the set $\mathcal{D}$ of descending generating kin terms is $\mathcal{D} = \{$*self*, *child*$\}$ and the repeated products of *child* with itself are named in the English terminology in a manner paralleling the names for the ascending kin terms: *child* of *child* = *grandchild*, *child* of *grandchild* = *great grandchild*, and so on. For the Seneca terminology, however, the naming of the lineal descending terms does not parallel the naming of the lineal ascending terms. The generating set $\mathcal{A}$ for the lineal descending Seneca terms is $\mathcal{D} = \{$*male self*, *ha-ah'-wuk* ('son')$\}$ and the named product of *ha-ah'-wuk* ('son') with itself is *ha-ah'-wuk* ('son') of *ha-ah'-wuk* ('son') = *ha-yä'-da* ('grandson'), and so the form of these kin term names does not parallel the form of the kin term names in the sequence going from *hä'-nih* ('father') to *hoc'-sote* ('grandfather'). The lineal descending terms also include the equation, *ha-ah'-wuk* ('son') of *ha-yä'-da* ('grandson') = *ha-yä'-da* ('grandson'), isomorphic to the analogous equation for the ascending kin terms.

13.3 Reciprocity between ascending and descending terms

The primary lineal ascending term, *parent*, in the case of the English terminology and *hä'-nih,* in the case of the Seneca terminology, and its isomorphic copy, *child* for the English terminology and *ha-ah'-wuk* for the Seneca terminology, are pairs of reciprocal terms. This means that if an English speaker refers to alter by the kin term *child* then alter refers reciprocally to speaker by the kin term *parent*, and if a Seneca male speaker refers to a (male) alter as *ha-ah'-wuk* ('son'), then alter refers reciprocally to speaker by the kin term *hä'-nih* ('father'). The reciprocity for these kin term pairs may be expressed by the equations *parent* of *child* = *self* for English speakers and by *hä'-nih* of *ha-ah'-wuk* = *male self* for male Seneca speakers.

13.4 Two different cultural definitions of sibling

At this point a fundamental division in the generation of terminologies comes to the fore. The division has to do with the difference between the product of *child* and *parent* in the English terminology and of *ha-ah'-wuk* ('child') and *hä'-nih* ('father') in the Seneca terminology. These products, from a logical viewpoint, could either be a new kin term or could be *self* (or *male self*). For English speakers, the primary meaning of *child* of *parent* is a new kin term, namely *sibling*, implying that *sibling*, as a kin term relation, is a derived and not a primary kin term relation, thus *sibling* is not one of the generating terms for the English kinship terminology. For Seneca speakers, the primary meaning of *ha-ah'-wuk* of *hä'-nih* is *male self*, implying for the Seneca term, *ha'je* ('ascending brother'), that *ha'je* ≠ *ha-ah'-wuk* of *hä'-nih*, hence *ha'je* is not a generated term and so it is a primary term. Consequently, the set $\mathcal{A}$ of ascending generating terms for the Seneca terminology must also include the term *ha'je* ('ascending brother') as a generating term: $\mathcal{A} = \{$*male self, ha'je, hä'-nih*$\}$. The ascending terms for Seneca will include all possible products of the generating terms, *ha'je* and *hä'-nih,* subject to a structural equation that distinguishes *ha'je* as a sibling term, namely *ha'je* of *ha'je* = *ha'je*. This difference between the English and the Seneca terminologies — that the English kin term *sibling* is not one of the generating terms for the ascending terms in the English terminology and *ha'je* ('ascending brother') is one of the generating terms for the ascending terms in the Seneca terminology — is the basis for the English terminology matching the definition of a descriptive terminology and the Seneca terminology matching the definition of a classificatory terminology (see Read 2007; Leaf and Read 2012; Read, Fischer and Chit Hlaing 2014 for details).

Analytically identifying whether a sibling term is a derived term or a generating term as the basis for the difference between descriptive and classificatory terminologies requires also turning to ethnographic evidence regarding how the sibling relation is conceptualized. In some cultures such as English, siblings are conceptualized as the children of one's parents other than oneself. Call this Definition 1. For other cultures, siblings are those persons who share the same parents. Call this Definition 2. From a biological viewpoint, the individuals identified by these the two definitions are identical except that the first definition expresses who is a sibling from speaker's viewpoint and the second defines siblings in an absolute sense. Culturally, the two definitions are not equivalent. Cross-cultural ethnographic data show that trying to reduce *sibling* to *child* of *parent* for all terminologies is "unworkable" (Witowski 1972: 171) and so the first definition is not universal. Similarly, a different study using a different methodology also found that both definitions are needed to accommodate differences among terminologies regarding sibling kin terms. The author of this study concluded that groups using the second definition for siblings have classificatory terminologies: "if … Ego prefers to think that he shares … common ascent with his siblings, … [the] terminology will be Bifurcate Merging [i.e., classificatory]" (Dziebel 2007:233).

This raises the fundamental question: *How is it that the two definitions, despite being biologically identical, express the basis for the difference between descriptive and classificatory terminologies?* This question will be answered by showing, to

keep the argument simple and without loss of generality, that the second definition leads, for male marked terms, to the equation 'brother' of 'father' = 'father' used as the marker of a classificatory terminology, where 'brother' and 'father' represent the kin terms in a terminology whose closest English translations are brother and father, respectively.

13.5 Classificatory terminologies are the consequence of definition 2 for siblings

The argument begins by noting that from the perspective of the generative logic of terminologies, the first definition implies that a sibling term is not a primary, generating term whereas the second definition implies that a sibling term is a primary kin term since it is not generated from the'father' term and the 'son' term. This is consistent with the fact that in groups with the second definition of a sibling, the sibling relation is a primary relation. Thus, using the Seneca terminology as an example, the complete ascending generating set $\mathcal{A}$, as noted above, will include the sibling kin term *ha'-je* ('ascending brother'), so the (complete) generating set for the ascending terms of the Seneca terminology is $\mathcal{A}$={*male self*, *hä'-nih* ('father'), *ha'-je* ('ascending brother')}. The generated ascending terms will just be *ha'-je* of *hä'-nih, hoc'-sote, ha'-je* of *hoc'-sote* after products using generating terms are simplified by the following structural equations:

(1) *ha'-je* of *ha'-je*=*ha'-je* (read: " 'ascending brother' of 'ascending brother' = 'ascending brother';" this defines *ha'-je* to be a sibling term),
(2)*hä'-nih* of *ha'-je*=*hä'-nih* (read: " 'father' of 'ascending brother' = 'father';" this is derived from Definition 2),

and

(3) *hä'-nih* of *hoc'-sote*=*hoc'-sote* (read: " 'father' of 'grandfather' = 'grandfather'"; this limits culturally recognized ascending kin terms to the + 1 and + 2 generations).

The naming for the products, *ha'-je* of *hä'-nih,* and *ha'-je of hoc'-sote*, will be deferred until it is first shown how these products are simplified using the generative logic of the Seneca terminology.

The descending terms will have generating set $\mathcal{D}$={*male self*, *ha-ah'-wuk* ('son'), *ha-ga* ('descending brother')} and structural equations isomorphic to Eqs. (1)–(3):

(4) *ha-ga* of *ha-ga*=*ha-ga* (read: " 'descending brother' of 'descending brother' = 'descending brother'"),
(5) *ha-ah'-wuk* of *ha-ga*=*ha-ah'-wuk* (read: " 'son' of 'descending brother' = 'son'"),

and

(6) *ha-ah'-wuk* of *hoc'-sote* = *hoc'-sote* (read: " 'son' of 'grandson' = 'grandson'").

The reason that *ha-ga,* the sibling generating term for the descending kin terms, differs from *ha'-je,* the sibling generating term for the ascending generators, follows from the fact that if *ha'-je* were also the sibling term for the descending generators, then when reciprocity of kin terms is introduced it follows that *ha'-je* of *ha'-je* = *male self* since sibling terms are self-reciprocal. This equation then implies, in combination with Eq. (3), that *ha'-je* = male self, thus contradicting the fact that *ha'-je* is a sibling term. The contradiction is eliminated by the descending term isomorphic to *ha'-je* being a term different from *ha'-je*, namely *ha-ga* ('descending brother'). Consequently, the generative logic also provides the basis for why classificatory terminologies have sibling terms translated as 'ascending brother' ('ascending sister') and 'descending brother' ('descending sister') rather than a single term translated as 'brother' ('sister').

The equations introduced to define the sibling terms as reciprocals to each other are:

(7) *ha'-je* of *ha-ga* = male self = *ha-ga* of *ha'-je*.

Lastly, for closure of the terminology under reciprocity of kin terms, the reciprocal equation for Eq. (5): *ha-ah'-wuk* of *ha-ga* = *ha-ah'-wuk,* will also be an equation for the terminology. The reciprocal equation for Eq. (5) is:

(8) *ha'-je* ('elder brother') of *hä'-nih* ('father') = *hä'-nih* ('father').

Finally, it may be shown that it is also the case that:

(9) *ha-ga* ('younger brother') of *hä'-nih* ('father') = *hä'-nih* ('father') (see Read 2007; Leaf and Read 2012 for details).

The last two equations (along with their analogous versions for female terms) are the defining criteria for a classificatory terminology, hence Definition 2 gives rise to the classificatory terminologies.

This is, to say the least, a remarkable result. The generative logic underlying kinship terminologies implies that the distinction between what are two, radically different kinds of terminologies that have been central to theorizing about differences in the social organization and structure of human societies is the consequence of whether siblings are conceptualized in a descent sense as the children of one's parent other than oneself or in an ascent sense as those persons who share the same parents. The difference between these two definition is conceptual and not biological, thus the difference between descriptive and classificatory terminologies is conceptual and not biological, hence the difference in the two kinds of terminologies is a "constructed reality."

The argument for the difference between the descriptive and the classificatory terminologies has been derived above from, mathematically speaking, a hypothetical

state of affairs, namely Definition 2 and the cultural ideas that are part of kinships system. Hence the argument is mathematical according to the philosopher Charles Peirce's (1956: 1775) definition: "mathematics is the study of what is true of hypothetical states of things." What our ancestors worked out 35,000 years ago, as hypothesized by Leaf and Read (2012), is nothing short of being a monumental achievement. It is no accident that the anthropologist German Dziebel titled his book on kinship terminologies: *The genius of kinship*.

14 Conclusion

The evolutionary transition from a chimpanzee-like ancestral species to *Homo sapiens* is commonly assumed to be quantitative and not qualitative. While it is generally recognized that culture, as it plays out in human societies, sets *Homo sapiens* apart from the non-human primates, differences are seen as one of degree and not of kind. By defining culture as that which is transmitted socially and affects behavior, it follows that there would be a continuous connection, possibly with some parts of the connection having different rates of change, as one traces back from *Homo sapiens* to a primate ancestral species. Since *Homo sapiens* shares phenotype transmission with other primate and non-primate species, the definition of culture through the mode of transmission implies cultural traits are not unique to *Homo sapiens* and, it is argued, what distinguishes *Homo sapiens* is not the fact of culture but the extensive elaboration and cumulative character of cultural traits that is seemingly without limit. In this regard, the advent, first of all, of a spoken language as a mode for transmitting information from one individual to another in the here-and-now, and secondly, the subsequent introduction of writing and reading as a means to record, preserve, transmit and recall information in an analog manner across time and space, and thirdly, the shift from an analog to a digital means to record, preserve, and transmit information have each revolutionized, or are revolutionizing, the degree to which cumulative knowledge has made *Homo sapiens* unlike any other species. But cumulative knowledge is not the whole story. Where we fundamentally differ, in a qualitative sense, is through a change from random and non-teleological source of innovation in traits to the enormous capacity of *Homo sapiens* to innovate and create novelty, purposefully and deliberately, thereby transcending the limitations experienced by other species due to their dependency upon non-teleological innovation initiated through random events (Read et al. 2009): "the distinction between man and animal must be sought … in the growing degree of explicit control …, the ability for an organism to make explicit and control its signs" (Stjernfelt 2012: 49).

Given the scope and range of the changes attributable to the advent of human cultural systems, there must have been more than just an expansion of the mode of evolution by incorporating phenotypic transmission. Small quantitive changes at the biological level can have substantial phenotypic effects when they affect the timing of regulatory events at the beginning of an ontogenetic process (Tomasello 2019). But even more than small quantitative changes leading to large quantitative consequences is the possibility of small quantitative changes having qualitative consequences, such as when the change makes possible circumvention of what previously

was a barrier or constraint. The change in short term memory from the size of STWM = 2 to the size of STWM = 3 (or more) in the first stages of hominin evolution (see Fig. 4) made possible a shift from "A causes B" to "A causes B in context C." A change like this can introduce cognitive shaped behavioral outcomes that otherwise could not be achieved and thus can enable new forms of knowledge to be incorporated when working through behavior that cannot be reduced to just arising from cumulative elaboration arising through mutation and phenotypic transmission. Consider the recursive reasoning that is absent in the nonhuman primates (Hauser et al. 2002) and does not show up archeologically in tool technology until about 250 kya (Hoffecker 2007; also see Fig. 4) after substantial expansion of cognitive abilities as indexed by an increase in working memory to STWM = 6, hence a quantitative change that signals the introduction of a qualitatively new mode of reasoning. The ability to reason recursively is central to the idea that the relation of a relation is a relation and, from this, to the formation of genealogical relations with associated expected patterns of behavior that revolutionized the range and scope of forms of social organization made possible by enabling social interaction between individuals to no longer be constrained by the limits inherent in face-to-face interaction.

Non-human primate social organization depends on a mixture of both genetically specified behaviors and non-genetically established social relations formed through face-to-face interaction. A *sine qua non* of effective and coherent social interaction is for each party to that interaction to be able to act in accordance with what is the likely behavior of the other party under the conditions in which the interaction is taking place. With genetically specified behavior, social interaction depends on the genetically specified behavior of one party being in concordance with the genetically specified behavior of the other party, whereas individualization of behavior makes socially effective and coherent interaction increasingly dependent upon each party being able to work out in real time how to act in accordance with the individualistic behavior of the other party. The phylogenetic trend towards increased dependence on face-to-face interaction and away from genetic specification of behavior has the consequence that the time required for sufficient learning through face-to-face interaction to take place so as to make individualistic behavior sufficiently predictable for there to be constructive and effective social interaction among group members increases with increased individuation. This implies that group cohesion can only be maintained, if at all, with increasing individualization of behavior by reduction in the size of social units, which is what occurred with the chimpanzees (Read 2012).

In contrast, the shift from biologically grounded to culturally grounded systems of social organization based on culturally generated kinship relations established, in an a priori manner, conceptual connections linking one group member to other group members along with expected patterns of social behavior associated with that connection, as expressed in Fortes's Axiom of Amity. In this manner, a qualitative change in how effective and cohesive social interaction can take place was introduced. A kinship system of social relations expressed through a conceptually generated system of kin term defined social relations that includes the expected behavior of one kinsman to another independent of individualistic behavior means each individual is no longer dependent upon extensive face-to-face interaction for there to be mutually coherent social behavior.

In addition, the recursive reasoning underlying genealogical kinship relations requires a STWM size greater than 2. Consider the following goal-directed recursive reasoning: "Outcome C can be obtained from condition B by applying procedure P to condition B and condition B can be realized when it currently is not present by applying procedure P to the currently present condition A to obtain condition B." Nut cracking involves a sequence of steps that reflect this kind of recursive reasoning in that it involves one procedure to be applied to the outcome of another procedure. The first procedure is P: place nut on a flat surface, and the second procedure is P*: hit nut with a stone (see Read and Andersson 2018 for more details). Condition C would be: nut meat is freed from shell, condition B would be: nut is on a hard flat surface. Then, applying procedure P* to condition B yields condition C. Condition A would be: nut has been found, and procedure P would be: put nut on a stone anvil. For nut cracking, procedure P must first be done when condition A occurs in order to create condition B so that procedure P* can now be used to crack the nut and achieve condition C, namely that the nut meat is freed from its shell. A chimpanzee that learns to crack nuts "recognizes" that condition B can be achieved from condition A by first applying procedure P to condition A to obtain condition B, namely by placing the nut that has been found on a flat stone in anticipation of acting on condition B by applying procedure P* to condition B to obtain condition C, namely the nutmeat freed from its shell. Thus, STWM = 3 is necessary since the three elements, NUT, FLAT SURFACE and STONE HAMMER making up the sequence, place NUT on FLAT SURFACE = FLAT STONE and hit with STONE = HAMMER, must all be kept active in mind simultaneously to achieve the final goal of a cracked nut. For those chimpanzees that are only able to either place NUT on GROUND = FLAT SURFACE, hit with STONE HAMMER, or place NUT on FLAT STONE, hit nut with FIST, they are only able to engage in actions that involve just two of the three elements of the sequence required to crack a nut, so their STWM must be equal to 2.

Another critical way that the evolutionary pathway leading to *Homo sapiens* involves more than introducing and elaborating on phenotypic transmission relates to the knowledge needed to circumvent the centripetal social force of the individualization of behavior that had already been selected for as part of the phylogenetic transition from the OW monkeys to the great apes, and acts against social cohesion. The required knowledge for introducing social cohesion in the presence of individualistic behavior is of a different kind than what is obtained through face-to-face interaction. While the latter provides knowledge of how individual members are likely to act, either directly or or indirectly in response to one's own behavior, what is needed for group social cohesion is not individual but collective understanding by community members regarding the likely behavior of community members. The OW monkeys, with a troop structure centered on face-to-face interaction within a matriline and with interaction between matrilines organized through a stable dominance hierarchy, have been able to adapt to virtually every climatic and geographic condition on planet earth without needing to introduce qualitatively new forms of social organization. In contrast, the apes, adapted to tropical forest environments, are virtually as varied in their forms of social organization as the number of ape genera. *Hylobates* has a monogamous form of social organization, *Pongo* lacks social units other than a copulating male and female or a female with her offspring and largely

lives a solitary life, *Gorilla* has a harem form of organization composed of a single adult male and several females, while *Pan* has species with both a multi-male, multi-female community form of social organization within which there are males forming coalitions and small, unstable social units, and a limited female-based form of social organization centered on interactions among largely solitary females. This qualitative variation in forms of social organization in the apes does not have an immediately obvious explanation through adaptation to ecological conditions, hence the variation in forms of social organization may simply be due to each genera arriving at a different way to cope with the centrifugal effect of individualized behavior on social cohesion.

If the variability in forms of social organization in the apes does represent differ-ent ways to cope with the centripetal effects of individualized behavior, it appears that none of the species within each of these genera has been able to find the means to introduce, by biological evolution alone, a centrifugal counterforce positively affecting social cohesion, as noted by Lévi-Strauss. Further, the very fact of selec-tion for individuated behavior in the great ape genera is simultaneously selection for the reduced effect of biological kin selection, often said to be the form of selection leading to prosocial behaviors. In the hominins, rather than by selection for biologi-cally grounded behaviors alone, social cohesion was augmented and extended dur-ing hominid evolution leading to *Homo sapiens* by forming a radically different form of social organization that was no longer dependent on face-to-face interaction. The different form, as evidenced by the social systems of extant hunter-gatherer groups, required, at a minimum, both the expansion of cognitive abilities that made possible the degree of abstraction needed to form the concept of a relation by abstracting from a recurring behavior pattern such as the mothering behavior engaged in by a primate female after giving birth to an offspring, and the expansion of STWM that made it possible to recognize, through the logic of recursion, that the relation of a relation is, itself, a relation. This culminated in forming symbolic systems of kinship relations expressed through kin terms that collectively form what is referred to by anthropologists as a kinship terminology, along with the associated prescription of kinship amity as the presumed basis for relations among those who are kin to one another.

The computational system of kinship relations expressed through kin terms provided the means to work out the kin relation of one individual to another and for the conceptual boundary of group membership to be those who are, or can recognize that they are, kin to one another, regardless of residence location (Read 2012; Bird-David 2017). The boundary is not open-ended and leads to a modal group size of around 600 persons, consistent with empirical evidence for the size of simple hunter-gatherer groups (Read 2012). This is an order of magnitude larger than chimpanzee communities, thus underscoring the fact that the transition to relation-based social systems involved a fundamental change in the social relations of group members to one another from what was possible with face-to-face interaction as the basis for social cohesion. This also made it possible to integrate what otherwise would be social groups isolated in time and space into a meta-social group entity within which what Fortes referred to as "prescribed altruistic behavior" erased biological boundaries for the scope of prosocial behaviors, thus introducing cooperative behavior and

sharing of resources based on cultural rules rather than as a biological trait (Voorhees et al. 2020). Inclusive fitness, in the broad sense of fitness arising from social integration of the behavior of individuals, regardless of their biological affinity, that contributes to the relative fitness of the target individual, is consequently determined (but not exclusively) by cultural rules regarding access to, and sharing of, resources rather than by interaction among individuals whose fitness contribution and biological affinity satisfy Hamilton's rule.

The cognitive innovations involved in the formation of social relations going beyond what is attainable through biological kin selection—part of what Read et al. (2009) refer to as the "innovation innovation" —are also the basis for the cultural knowledge that expresses the social and environmental adaptation for a group organized through relation-based systems of social organization. The latter involves knowledge that is expressed collectively and publicly, rather than individually and privately. The pathway leading from the phenomenal level of categorization based on behavior patters such as, for example, mothering behavior, leads through abstraction to the concept of a relation at the ideational level, then to the recognition that the relation of a relation is again a relation, and from this to a system of relations that were then transformed into symbolic, computational systems of kin term relations. This is also a pathway involving the development and extension of human reasoning and rational thought. From this perspective, the latter does not just reflect cognitive abilities initially introduced at the individual level through mutation, then were fixed in a population through biological selection and exapted as the means for forming systems of social organization but, critically, are cognitive abilities leading to, and developed through, working out a fundamental innovation in how social relations are expressed and organized. This innovation is the basis for how we culturally became humans and not just a smart, highly social ape. For this reason, the development of the reasoning capacity of the human mind is linked to the development of systems of social organization.

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