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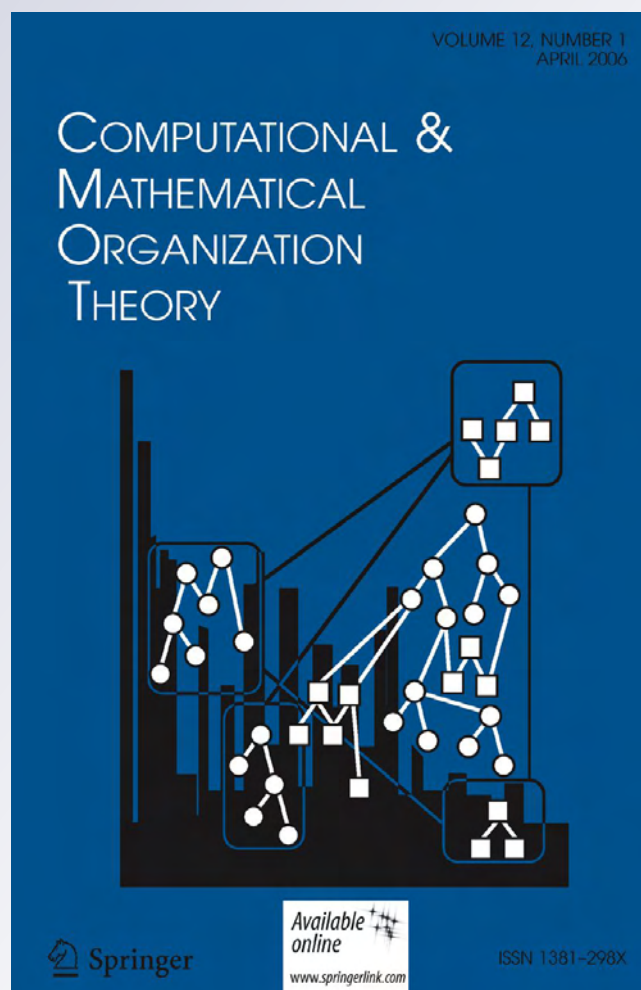
Cultural kinship as a computational system: from bottom-up to top-down forms of social organization

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Cultural kinship as a computational system: from bottom-up to top-down forms of social organization

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Abstract A key change in the evolution of our species from a common ancestor with the chimpanzees was the shift to a field of social interaction no longer dependent upon face-to-face interaction for the maintenance of social coherency. Our hunter-gatherers ancestors made a radical shift to social relations based on a culturally constructed system of kinship relations. Unlike biological kinship that reflects the facts of biological reproduction, cultural kinship is a constructed, computational system that enables symbolic computation of kinship relations that are expressed through the kin terms of a kinship terminology. The system of kin terms is analogous to arithmetic as a computational system for computing quantities with symbols instantiated by the counting numbers. The internal logic of a kinship terminology ensures consistency both in kinship relation computations and translation of kin term computations to the perspective of each person who culturally shares the same kinship terminology. The constraint of internal and external consistency does not lead to a single kinship terminology computational system, hence there are a variety of kinship terminology systems across human societies. In this paper I outline a theory for the generative structure of kinship terminology systems and briefly discuss the implications this for explaining structural differences between kinship terminologies and how structure relates to social organization.

Keywords Cultural evolution · Kinship · Social organization · Primate social systems · Hunter-gatherer social systems · Cultural computational systems

1 Introduction

The evolution of our species, *Homo sapiens*, from our primate ancestors includes the introduction of a number of social and cognitive abilities that distinguish human soci-

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eties from those of the non-human primates. One of the key changes was a shift from societies whose organization and internal coherence derives from intensive, face-to-face interaction to societies with relational based forms of social organization. The field of social interaction in non-human primate societies is typically limited to a largely closed group of individuals interacting with each other on a day-to-day basis. With the appearance of hunter-gatherer societies in the Upper Paleolithic around 25–45,000 BP, a major shift reached fruition in which the field of social interaction was no longer dependent upon face-to-face interaction and instead was predicated upon a system of culturally constructed, as opposed to biologically determined, kin relations (Gamble 2007; Read and van der Leeuw, [Forthcoming](#); Leaf and Read 2012). The social boundary shifted from familiarity gained through face-to-face interaction to a boundary based on cultural kin (Read 2012). With this shift, our ancestral hunter-gatherers had made a radical change from a pragmatic social boundary emergent from day-to-day behavior to a conceptual boundary determined through a system of cultural kin relations.

Unlike biological kinship that reflects the facts of reproduction based on who copulated with whom, cultural kinship expressed through kinship terminologies is a conceptual system that makes possible, among other things, computation of kin relations using the kin terms in a kinship terminology. The kin terms may be instantiated genealogically, but not exclusively so. Kinship computations with kin terms are much like doing addition symbolically through number symbols instantiated by the counting numbers. To be a computational system, a kinship terminology must have an internal logic that both ensures internal consistency in the kin term computations and external agreement when translating kin term computations from the subjective perspective of one person to that of another person. Unlike arithmetic, though, there is no single kinship computational system satisfying the requirement of internal consistency and external agreement, hence we find a variety of kinship terminology systems in human societies.

Kinship terminologies are a top-down form of organization for culturally constructed kinship relations as the structure of a kinship terminology does not derive from behavior or other external factors, but from structural constraints that are part of what is meant by kinship relations such as reciprocity of kin terms. I outline a theory for the generative structure of kinship terminology systems. I briefly discuss the logical basis for differences in kinship terminology systems. I indicate how this addresses the long-standing problem of delineating the relationship between kinship terminology systems and forms of social organization.

2 Traditional view of kinship

Systems of kinship have been viewed, from the time of Lewis Henry Morgan in the mid-19th century, as a system based on reproduction and marriage with kinship relations determined primarily by reproduction and secondarily through marriage. All societies have a kinship terminology consisting of a corpus of kin terms, the words used to refer to one's relatives such as in the English expression "He is my brother." Kin terms have been assumed to refer to categories of kin: "the commonest interpretation" is that kin terms are "used to classify kinsmen" (Kronenfeld 1975,

p. 258). Being kin is said to be determined through reproduction and genealogy: “Where the distributional criteria are genealogical and egocentric, we speak of relations of kinship” (Scheffler and Lounsbury 1971, p. 38). The underlying assumption has been that the meaning of kin terms is determined through their referents in a space of genealogical relations (the referents are referred to as kin types), hence, supposedly, kin terms can be specified and characterized through genealogical dimensions such as sex, generation, lineal/collateral, cross/parallel, and so on. From this, it would seem to follow that the primary definitions of kin terms is through reference to genealogical relations established through the distribution of the terms over a space of genealogical relations. This, however, is not the case.

3 Genealogical space

By a genealogical space we mean the structure of relations determined through recursive tracing of parent/child relations using (in English) the mother, father, son and daughter positions derived from reproduction and the husband and wife positions determined through marriage. Genealogical tracing begins with an individual identified as ego and determines, in accord with cultural conventions regarding who is considered to be a mother, father, son or daughter, a person (technically called alter) who has the mother, father, son or daughter relation to ego (when this step in the tracing is based on reproduction) or the husband or wife relation to ego (when this step in the tracing is based on marriage). When the tracing is continued recursively, the person identified as alter is now taken as ego and a new alter is identified and the above tracing step is repeated. Genealogical relations, in this sense, can be thought of as pathways of positions that indicate how one may go from one person (ego) to another person (alter) through individuals connected either by the cultural interpretation of reproduction or by culturally constructed marriage positions. The genealogical definition of a kin term, K , is determined by the ensemble of ego to alter pathways for which ego may (properly) refer to alter by the kin term K .

There are two major problems that arise with this framework and its assumption that kin relations are first and foremost defined through genealogical pathways. One problem arises with regard to the way individual kin terms are interrelated as a system of concepts and the other with regard to the terminology as a whole. Both problems stem from the genealogical framework not accounting for the way kin terms form, as we will see, a bounded, logically structured set of kinship concepts. The first problem refers to the fact that, in practice, kin relations are often computed without reference to genealogical definitions of kin terms. The second problem derives from the fact that “questions about why kinship structures (i.e., kinship terminologies) took the forms they did were ignored” (D’Andrade 2003, p. 311).

4 Kinship relation calculations

Consider the first problem. Extensive ethnographic evidence shows that kinship relations are computed directly from kin terms without referring to genealogical pathways. For example, for the Kariera, a hunter-gatherer group in western Australia,

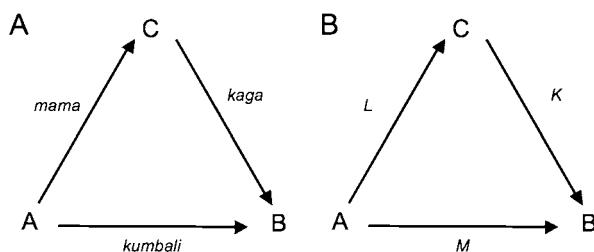


Fig. 1 (A) The kin terms *kaga*, *mama* and *kumbali* are from the Kariera kinship terminology. The product of the kin terms *kaga* and *mama* yields the kin term *kumbali*. (B) For any kinship terminology with *K* the kin term used by individual C to (properly) refer to individual B, *L* the kin term used by individual A to (properly) refer to C, then the product of *K* and *L* is a kin term *M* (if any) used by A to (properly) refer to B: $K \circ L = M$

Alfred Radcliffe-Brown wrote: “The method of determining the relationship of two individuals is extremely simple. Let us suppose . . . that two men, A and B, meet each other for the first time. The man A has relative C who is his *mama*. At the same time, C is the *kaga* of B. It immediately follows that A and B are *kumbali* to each other” (Radcliffe-Brown 1913, pp. 150–151; see Fig. 1A).

The calculation does not immediately make sense to us, of course, since the kin terms *mama* (‘father’), *kaga* (‘maternal uncle’) and *kumbali* (‘male cross-cousin’) are not our kin terms. Nonetheless, we, as English speakers, make similar calculations such as “If I refer to him as uncle and he refers to her as daughter, then I refer to her as cousin.” In both examples, the genealogical positions linking individuals may be unknown as is often the case with adoptions.

In Radcliffe-Brown’s example, individuals A and B can determine their kinship relations to each other just by reference to the kin terms in their kinship terminology (see Fig. 1A). To be able to do this, there must be cultural knowledge that provides connections among the kin terms making up a kinship terminology and in a manner that gives the terminology the form of a logically structured system of kin terms. The form of the structure is terminology specific, hence culture specific, just as the kin terms making up a kinship terminology are culture specific and not universal. Therefore the logic of kin term calculations does not derive from categorization of the genealogical relations making up the genealogical space, but instead must derive from information embedded within the kinship terminology. This brings us to the second problem, namely the conceptual basis for differences in the structure of kinship terminologies.

5 Kin Term Space

The cultural knowledge embedded in the connections among the kin terms making up a kinship terminology form what we will call a Kin Term Space and has structure determined through the products of kin terms from a kinship terminology (see Fig. 1B). More precisely, in any terminology there will be a set, *G*, of primary kin terms with none of the terms in *G* expressible as the product of other kin terms in the kinship terminology. For English speakers, father, mother, son, daughter, husband, and wife

are primary kin terms. English speakers also have the non-sex marked terms parent, child and spouse that form another set of primary kin terms. All kinship terminologies are “ego centric” meaning that the kinship relations expressed through the kin terms are from the perspective of a person identified as speaker. Thus the English expression “He is my brother” identifies that the person in question has the kinship relation of *brother* to the speaker. The concept of *self*, used to refer to speaker, as in English “myself,” is part of the kin term space, whether or not *self* is recognized as a kin term.

We can now identify, recursively, all of the kin terms in the kinship terminology by querying a competent user of a kinship terminology (Leaf 2006; Leaf and Read 2012) in the manner indicated in Fig. 1(B) by starting with a set G of primary kin terms for the terminology. Let T be the set of kin terms that have currently been identified. Initially, $T = G$. Let L be a term in T and K a term in G . The product of K and L (denoted by $K \circ L$) will, as determined from a competent user, either be: (1) a kin term M not in T , in which case we add M to the set T , (2) a kin term M already in T , in which case we make no change to T , or (3) the product does not yield a kin term (e.g. for English speakers there is no kin term corresponding to the product, *father of father-in-law*). In addition, in some terminologies we may obtain a sequence of kin terms that continues indefinitely with a fixed pattern (e.g., for English speakers we obtain the sequence *parent*, *parent* \circ *parent* = *grandparent*, *parent* \circ *grandparent* = *great grandparent*, *parent* \circ *great grandparent* = *great great grandparent*, and so on). This elicitation procedure identifies the kin term space as a conceptually bounded structure, allowing, for some terminologies, for an unending sequence of terms repeated using the same pattern.

Kinship terminologies will differ structurally from each other according to factors such as what constitutes a set of primary kin terms, which of the kin term products yield an already determined kin term and which products do not yield a kin term. The last two possibilities determine structural equations, expressible in the form of kin term products, that characterize the structure of the Kin Term Space. It follows that we can say that a kinship terminology \mathcal{T} consists of a set T of kin terms, a binary product (the kin term product) defined over the members of T , and a set S of structural equations satisfied by the binary product as determined from the elicitation of kin terms. It follows that a kinship terminology inherently has the structure of an abstract algebra. More formally, we can say that a kinship terminology \mathcal{T} is characterized by the ordered triple $\mathcal{T} = \langle T, \circ, S \rangle$, where T is a set of kin terms, \circ is a binary product defined over the members of T , and S is the set of structural equations satisfied by \circ . The Kin Term Space is the structure for this abstract algebra.

The characterization of a kinship terminology as an abstract algebra leaves open both the relationship of the Kin Term Space to the Genealogical Space and the conceptual basis for identifying the primary kin terms from which other kin terms are derived through products of primary kin terms. There is, however, no universal set of primary kin terms, though all terminologies have primary terms structurally comparable to mother and father (or possibly parent) in English and their reciprocal terms, son, daughter and child. Hence there must be a conceptual structure through which the primary kin terms can be determined. We will now identify this conceptual structure. This will also determine the relationship between the Kin Term Space and the Genealogical Space.

What we have identified as a Kin Term Space and a Genealogical Space must each have a predecessor, both from an ontological and an evolutionary perspective. From an evolutionary perspective, it appears that among the non-human primates the macaques can conceptualize something like a mother relation; that is, they can conceptualize an ensemble of behaviors comprising mothering behavior and directed towards an offspring, thereby increasing the likelihood of the survival of an offspring, hence increasing her reproductive fitness. Macaques can, apparently, distinguish mothering behavior from the behavior of a female towards biologically unrelated offspring (Dasser 1988). The precursor of kinship relations in human societies could have begun, evolutionarily speaking, with something like the macaque recognition of a relation based on mothering behaviors. A father relation, though it would not arise in non-human primates due to lack of male parenting behavior (Chapais 2008), would likely arise during the ancestry of *Homo sapiens* when males were incorporated, either directly or indirectly, in the provisioning of offspring, a process that probably started around 300–500,000 BP. Male provisioning of females with meat may have been necessary both for females to cope with secondary altriciality of offspring and as a way to provide the nutritional energy demands linked to increased encephalization. Regular inclusion of meat protein in the diet is shown by changes in the intestine during this time period (Aiello and Wheeler 1995).

Another major change occurred in the social environment of the ancestors of *Homo sapiens* around the time of the Upper Paleolithic when the social field lost its time and place dependency, expanded in size and became more like the social systems we find, for example, in hunter-gatherer societies. The change was to a social field determined through conceptually constructed kinship relations rather than face-to-face interaction (Gamble 2007; Read 2012; Leaf and Read 2012). It is likely that the precursor to marriage as an institution had its beginnings with this last change since marriage, though expressed behaviorally through the sexual relations between males and females, has to do with the conditions recognized by the members of a social group for the offspring of a female to be collectively and publicly recognized as being incorporated within their social field. That is, there was a change that led to offspring being accepted as members of the social field through a system of conceptual relationships instead of being dependent upon direct, face-to-face interaction with the offspring, as is the case in non-human primate societies.

6 Family Space

Altogether, we can assume that motherhood and fatherhood, the reciprocal relations of sonhood and daughterhood, and a culturally constructed concept of marriage that includes the conditions for an offspring of a female to be recognized as a member of a social group, provide the conceptual foundation for the primary elements from which the Genealogical Space and the Kin Term Space are constructed. We will refer to the structure determined through this ensemble of positions and relations as a Family Space (see Fig. 2, left side). We now show how each of the Genealogical Space and the Kin term Space is constructed from the Family Space and in so doing we will also establish the relationship between these two spaces.

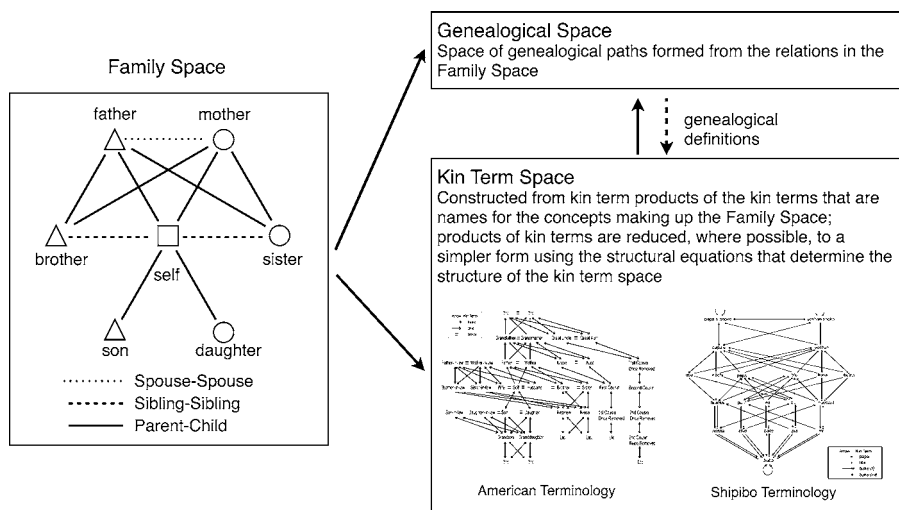


Fig. 2 Decomposition of the Kinship Space of kinship relations into three components: (1) a Family Space based on the concepts of parenthood, childhood, siblinghood and spousehood, (2) a Genealogical Space derived from the Family Space through tracing genealogical paths from one individual to another using a sequence of individuals connected by parent/child or spouse relations, and (3) a Kin Term Space based on kin term products using the primary kin terms and with structure given by structural equations satisfied by the kin term products (see text for additional details). Examples of Kin Term Spaces are shown for the American kinship terminology and the kinship terminology of the Shipibo horticulturalists of Peru

6.1 Construction of the Genealogical Space

The Genealogical Space consists of genealogical paths that are made up of a sequence of father/mother (F/M) and son/daughter (S/D) relations from the Family Space with the constraint that an S or a D relation cannot be followed by an F or an M relation. The constraint restricts genealogical paths to upward paths using the F and/or M relations, downward paths using the S and/or D relations, or upward paths followed by downward paths; that is, to paths connecting individuals through a sequence of relations, either expressed directly with an upward or a downward sequence of relations, or through a common “ancestor” when an upward sequence of relations is followed by a downward sequence of relations. Two genealogical paths may be concatenated to form a single genealogical path except when the first path ends with an S or a D and the second path begins with an F or an M .

A genealogical path $P = P_1 P_2 \dots P_n$, where each P_i is a member of the set $\{F, M, S, D\}$ of relations determined from the positions in the Family Space and the P_i 's are consistent with the constraint on genealogical paths, may, potentially, be recursively instantiated by a sequence of persons from a group G of persons as follows. Let person A_0 in G be the instantiation of the self position in the Family Space and then find person A_1 in G (if any) such that $A_0 P_1 A_1$ (that is, A_1 is at the position specified by the P_1 relation and so A_1 has the P_1 relation to A_0 , hence A_1 is A_0 's P_1 ; e.g., if $P_1 = M$, then A_1 is A_0 's mother). Next, assume recursively that A_1 is at the self position and find person A_2 in G (if any) such that $A_1 P_2 A_2$. Continue recursively in this manner, finding, if possible, a sequence of persons A_i in G for each of

the relations P_i in the sequence of relations forming the genealogical path P . If there is a person A_i in G for each of the relations P_i in P , then the genealogical path P has instantiation in G by the sequence of persons A_0, A_1, \dots, A_n .

For English speakers, and Americans in particular, the mother and father relations with speaker are presumed to carry with them something akin to a genetic relationship, or what Schneider (1968) has referred to as a biogenetic substance. Thus to say “she is my mother” has, for English speakers, the presumption that the women in question gave birth to the speaker. This, however, is not universal and even for English speakers the matter is more complex as the concept of motherhood is not defined by biological criteria alone; e.g., when a child is adopted by a married couple, the adopting parents are considered to be mother and father despite the absence of a genetic connection. This has led to the distinction between *genitor/genetrix* (physical father/physical mother) and *pater/mater* (social mother/social father), but this is not satisfactory as it is not universally the case that a presumed physical relationship determines motherhood/fatherhood. Instead, what constitutes motherhood/fatherhood is culture specific, hence the meaning of the Family Space concepts can, and does, vary from one cultural context to another.

6.2 Construction of the Kin Term Space

Now consider the way in which new kinship concepts are constructed from the concepts making up the Family Space and symbolically represented (in the linguistic/mathematical sense) by linguistic expressions that we will refer to as kin terms. The kin terms will be names for the kinship relation concepts constructed from the concepts making up the Family Space. We will do this in a manner that leads to the kin term product discussed above as a way to express the kinship relations embedded in the kinship terminology through kin terms. In this way the structure of a Kin Term Space will be consistent with the manner in which users of a terminology compute kin relations from the kin terms making up a kinship terminology, as discussed previously. The set of kin terms corresponding to the concepts making up a Kin Term Space form a kinship terminology and a Kin Term Space will have a structure determined by the structural relations among the kin term concepts expressed through kin term products. In this way, a Kin Term Space will be a computational domain within which kin term relations can be computed through kin term products and the structure of a Kin Term Space will represent the way kin term concepts are structurally organized in a particular culture.

We begin by first relating the concepts that constitute the Family Space to a Kin Term Space by taking these concepts and their names to be the primary kin terms in a Kin Term Space; e.g., for English speakers the primary kin terms will be mother, father, parent, son, daughter, child, husband, wife, and spouse, the linguistic expressions used to label the positions that can be occupied by a person satisfying the concept of parenthood, childhood, or spousehood in the Family Space. This usage of concept names in the Family Space as kin terms differs from the usage by English speakers of the same names in the Genealogical Space where the names are used to linguistically identify the relation that holds between speaker and alter, not the concept from which that relation is derived. Thus for English speakers, in the expression,

“she is my mother,” the lexeme *mother* can either be understood as identifying that the female in question satisfies the concept of being a mother, however motherhood may be culturally understood (for example, speaker may be her adopted child), or that the female in question is being identified as the speaker’s mother in a birth sense, hence she is being recognized as satisfying the relation of genealogical mother to speaker. In other words, English does not distinguish between using a lexeme in a conceptual (kin term) versus a relational (genealogical) sense. We will leave it to context as to whether a concept name from the Family Space is being used in a kin term or a genealogical sense; that is, whether the concept name denotes a primary kin term in the Kin Term Space derived from the Family Space or a relation in the Genealogical Space.

Beginning with concepts making up the Family Space, suppose speaker refers to alter_1 by a concept from the Family Space whose name is taken to be the primary kin term L in the Kin Term Space and alter_1 refers to alter_2 by a concept from the Family Space whose name is taken to be the primary kin term K in the Kin Term Space. For example, for English speakers L might be the primary kin term *mother* and K the primary kin term *father* in the Kin Term Space for English speakers. Since speaker refers to alter_1 by the kin term L and alter_1 refers to alter_2 by the kin term K , there is a conceptual relation linking speaker to alter_2 via alter_1 , namely the composition of these two concepts. We will refer to this conceptual relation as the product of the kin term concepts represented by the kin terms L and K , or more simply, by the product of the kin terms L and K , and we will denote the product of K and L by the notation, “ K of L .” To continue our example using English speakers, the kin term product *father* of *mother* identifies the conceptual relation of speaker to alter_2 when speaker refers to alter_1 as *mother* and alter_1 refers to alter_2 as *father*.

When the product of the kin terms K and L is culturally marked with a linguistic label, we will refer to that label as a kin term, hence as an element in the Kin Term Space; thus for English speakers *grandfather* is the kin term label used for the kin term product *father* of *mother* and so *grandfather* is one of the kin terms in the Kin Term Space for English speakers. We continue forming new kin term products with primary kin terms and any new kin term that has been added to the Kin Term Space. Thus for English speakers, since we have added the kin term *grandfather* to the Kin Term Space, we now form the kin term product, *mother* of *grandfather*, which is culturally marked by the lexeme *grandmother*, hence *grandmother* is added as another kin term to the Kin Term Space for English speakers.

The same label may be used for different kin term products; e.g., in English *grandfather* is also the kin term denoting the kin term product *father* of *father*. Some products may not be culturally marked; e.g., there is no kin term for *father* of *father-in-law* in English. This process of constructing new kin terms through kin term products is conceptually bounded since for any product of a kin term in the Kin Term Space with a primary kin term will either (1) yield a product that is not culturally marked as a kin term, (2) yield a product that is marked with a kin term already in the Kin Term Space, or (3) yield a sequence of kin term names with a regular pattern such as *grandparent*, *great grandparent*, *great great grandparent*, ... for English speakers.

The structure of the Kin Term Space will be determined by structural equations that express the relationships among the kinship concepts that are part of the Kin

Term Space. Some equations will embed properties common to all kinship systems, such as reciprocity of kinship relations. For example, for English speakers *parent* and *child* are reciprocal concepts in that when speaker refers to alter as *child*, then alter refers to speaker as *parent*, hence the product *parent* of *child* is the kinship relations of speaker to him(her)self. Since speaker refers to him(her)self as *self*, then *parent* of *child* = *self* is the structural equation defining *parent* and *child* to be reciprocal concepts. Other equations may restrict which kin term products give rise to new kin terms, such as *father* of *father-in-law* is not a kin term for English speakers, or may make kin term products reflexive, such as *parent* of *cousin* is *cousin* for English speakers and so *parent* of *cousin* = *cousin* for English speakers.

Kin Term Spaces, hence terminologies, will differ from one another according to differences in which of the concepts in the Family Space are culturally identified as the primary kin terms of the Kin Term Space; e.g., in English the primary kin terms are *parent* and *spouse*, along with the reciprocal term *child* (Leaf and Read 2012; Read 1984; Read and Behrens 1990), whereas other terminologies may use, for example, the concepts of fatherhood and motherhood as the basis for the primary kin terms in the Kin Term Space. Yet other terminologies may use brotherhood and sisterhood as well as fatherhood and motherhood as the basis for the primary terms in the Kin Term Space (Read 2010; Bennardo and Read 2007; Leaf and Read 2012; Read and Behrens 1990). Other differences will arise in accordance with the particular structural equations that are culturally identified as part of the Kin Term Space (see, for example, Read 2013 for a reconstructed, historical sequence of structural changes among the Polynesian terminologies).

7 Kin term semantics

We can now relate the Genealogical Space to the Kin Term Space by constructing the genealogical definition of kin terms using the structural equations for the Kin Term Space. This contradicts the Received View of kinship in which it has been assumed that there is an ontological sequence going from first defining kin relations as genealogical relations and then kin terms as the names of categories of genealogical relations. Instead, the categories of genealogical relations are determined from the structural equations that give the Kin Term Space its particular structure, along with a genealogical instantiation of the primary kin terms. We will illustrate the way in which the categories of genealogical relations are generated from the properties of the Kin Term Space with the American/English kinship terminology (AKT).

We begin with the primary terms of the AKT, which are *parent* and *spouse*, with reciprocal term *child* for the term *parent* (Leaf and Read 2012; Read 1984; Read and Behrens 1990). For English speakers, the term *parent* is genealogically instantiated by genealogical father (*f*) or genealogical mother (*m*); that is, genealogical father is referred to by speaker as *father*. The reciprocal term *child* is genealogically instantiated by genealogical son (*s*) or genealogical daughter (*d*). *Spouse* is culturally instantiated by genealogical husband (*h*) or genealogical wife (*w*). Next, suppose we want the genealogical category for, say, the kin term *grandfather*. First we express the kin term using products of primary kin terms that reduce, in the Kin Term Space, to

the kin term in question, allowing for disjunctive expressions of products, if need be. For example, *grandfather* = *father* of *mother*, *father* of *father*, *husband* of *mother* of *father* or *husband* of *mother* of *mother*. Then we replace each of the primary terms by its genealogical instantiation as a genealogical relation, the kin term products denoted by “*K* of *L*,” where *K* and *L* are kin terms, by set products and the kin term products making up a disjunctive definition of a kin term by set unions (denoted by the symbol \cup); thus *grandfather* is rewritten as $\{f\}\{m\} \cup \{f\}\{f\} \cup \{h\}\{m\}\{f\} \cup \{h\}\{m\}\{m\} = \{mf\} \cup \{ff\} \cup \{fmh\} \cup \{mmh\} = \{mf, ff, fmh, mmh\} = \{\text{genealogical mother's genealogical father, genealogical father's genealogical father, genealogical father's genealogical mother's husband, genealogical mother's genealogical mother's husband}\}$; more simply, *grandfather* = {mother's father, father's father, father's mother's husband, mother's mother's husband}. (Kin term products are written from right to left to allow for a kin term product such as speaker referring to alter₁ as *mother* and alter₁ referring to alter₂ as *father* so that the product *father* \circ *mother* can be read, *father* of *mother*, whereas concatenation of genealogical relations are written from left to right, which allows for reading a concatenation such as *fm* to be read as genealogical father's genealogical mother, or father's mother for short.) This procedure provides a one-to-many mapping from the Kin Term Space to the Genealogical Space as indicated by the solid arrow on the right side of Fig. 2. The inverse mapping from the Genealogical Space to the Kin Term Space (see dashed arrow, right side of Fig. 2) is constructed by replacing each genealogical relation in a genealogical path by its corresponding primary kin term and then reducing the product of kin terms in the Kin Term Space to its simplest form; e.g., *ffms* is replaced by the kin term product *son* of *mother* of *father* of *father* = *cousin* in the Kin Term Space, hence the genealogical path *ffms* is mapped to the kin term *cousin*.

We can also “read off” the usage of a kin term from a kin term product that reduces to the kin term in question. The kin term *grandfather* for example, is the term properly used by an English speaker for alter when speaker (properly) refers to someone by the kin term *mother* or *father* and that person (properly) refers to alter by the kin term *father*. We can also determine the referential meaning of a kin term from a kin term product. The kin term *grandfather*, for example, refers to the genealogical relations given by speaker's father's father or father's mother. This follows from the fact that *father* of *father* and *father* of *mother* each reduce to the kin term *grandfather* in the Kin Term Space and the kin terms *father* and *mother* refer to the genealogical relations, genealogical father and genealogical mother, respectively.

8 Elicitation of kin terms: kin term map

We can use the kin product in a manner parallel to the way we generate the Kin Term Space from the primary kin terms to elicit the kin terms of a kinship terminology and to display the resulting structural relations among the kin terms with a graph that we will call a kin term map. We will also illustrate this process with the American Kinship Terminology. Begin with *self* as the starting position. We will form the kin term map by drawing an arrow, a distinct style of arrow for each primary term, to indicate the answer obtained when one asks a competent user of the terminology the

result of taking the kin term product of a kin term L with a primary kin term K . The arrow will start at the kin term L and end at the kin term determined through eliciting the kin term (if any) that is the kin term product of K with L . No arrow of the style corresponding to the primary term will be drawn when the kin term product is not culturally marked with a kin term name. Thus for the primary kin term *parent*, the product of *parent* with *self* would elicit the response, *parent*, and so we draw an arrow from *self* to the kin term *parent* in the graph derived from the elicitation process.

We can also use sex-marked kin terms for the result of the kin term product by using, in this case, sex-marked terms when taking a kin term product with the primary kin term *parent*, along with two arrows, each beginning at the initial kin term. One arrow ends at the sex-marked kin term that is the result of taking a kin term product with the primary term *parent* and the other ends at the other sex-marked term corresponding to taking a kin term product with the primary term *parent*. For example, the kin term product, *parent* of *self*, is either the kin term *father* or the kin term *mother* when the sex marking of kin terms is taken into account in the AKT and so one arrow points from *self* to the kin term *father* and the other arrow points from *self* to the kin term *mother*.

Next we take the kin term product of each elicited kin term with each of the primary kin terms. Thus we elicit that the product of *father* with *parent* is either *grandfather* or *grandmother* and include these two terms in the graph along with arrows from *father* to *grandfather* and to *grandmother*. We continue in this manner until we have elicited the result of taking products with all of the currently elicited kin terms with all of the primary terms and no new kin terms are elicited. The resulting graph is a kin term map of the kinship terminology. The kinship map for the AKT determined from the primary kin terms *parent* and *spouse* and the reciprocal term, *child*, of the primary kin term *parent* is shown in Fig. 3.

9 Examples of kin term maps

The kin term map for the Shipibo horticulturalists is shown in Fig. 2 and differs structurally from the AKT. A kin term map that contrasts even more sharply with the AKT kin term map is the one for the Kariera terminology shown in Fig. 4. The Kariera were traditionally a hunter-gatherer group in Western Australia and their terminology has been important in anthropological theorizing about kinship terminologies and forms of social organization. It is immediately apparent that the structures of the AKT and the Kariera terminologies are very different. The differences in the two terminologies illustrates the second problem with the genealogical approach to kinship systems, namely the failure to account for differences in the structural form of kinship terminologies. The genealogical approach took the structure of a terminology as given and did not account for the pronounced structural differences such as we see, for example, between the AKT and the Kariera terminology.

10 Analogy between arithmetic and kinship terminology systems

To address the second problem arising from assuming only a genealogical basis for kinship systems, we will make the following analogy between the Genealogical Space

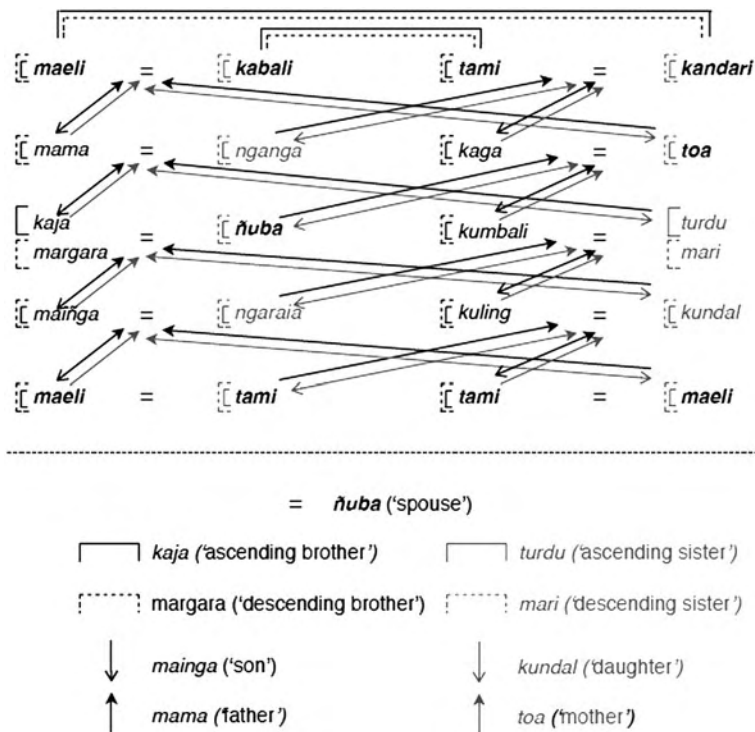


Fig. 4 Kinship map of the Kariera terminology from the perspective of *male self*. The vertical arrows point to the “=” sign only for clarity of the diagram and should be understood as pointing to the kin term matching the sex marking of the arrow. Thus *mama* of *mama* is *maeli*. The vertically oriented sibling symbols to the left of kin terms show that the kin term product of a sibling term with a kin term of the same sex is reflexive and maps that kin term back to itself; e.g. *kaja* of *mama* = *mama* = *margara* of *mama*. The horizontal sibling symbols with heavy lines represent a kin term product with either a male or a female sibling kin term. Thus for the female sibling term, *turdu*, *turdu* of *maeli* is *kandari* and for the male sibling term *kaja*, *kaja* of *kandari* is *maeli*, and similarly for the other kin terms. Black: male marked terms; grey: female marked terms; bold: neutral terms. Modified from Table 1 in Radcliffe-Brown (1913) by including upward arrows showing kin term products with *mama* and *toa*

Both counting numbers and genealogical paths may be combined through composition. The composition (sum) of counting numbers is done through set unions; that is, the sum of a counting number and another counting number is the counting number corresponding to the size of the set formed through set union from the members of a set in the class of sets labeled by one counting number and a set in the class of sets labeled by the other counting number. The composition of genealogical paths is done through concatenation of genealogical paths. This allows us to make an analogy between counting numbers + composition (sums) of counting numbers and genealogical paths + composition (concatenation) of genealogical paths.

We now extend the analogy to arithmetic, a formal system for symbolically determining the sum of counting numbers and to a kin relation system based on the kin term product of kin terms in the kinship terminology that is part of the kin relation system. In the symbolic arithmetic system, the primary, intuitive number concept is

that of the number 1, corresponding to the counting number one. In the kin relation system, the primary concept is that of *parent* (or its sex-marked version), and sometimes *sibling*, from the Family Space. New number concepts are generated in the arithmetic system through the successor number concept: any number, n , has a successor number n^* . The analogous concept in the kin relation systems is that of an successor kin term concept: any kin term concept K has an successor kin term concept K^* . In the arithmetic system, concept generation (that is, formation of a successor number) is done with the binary operation of addition by adding 1 to any number n to form the successor number $n^* = n + 1$. The collection consisting of the number 1 and all successor numbers, $1 + 1 = 2$, $2 + 1 = 3$, ... the *natural number system*. In the kinship relation system, concept generation is done with the binary operation of kin term products by taking the product in the AKT, for example, of the *parent* (or *child*) concept with any kin term K to form the successor kin term K^* . (In the Kari-*era* terminology we would take products with the sex-marked kin term *mama* or with the sex-marked term *nganga*.) In the arithmetic system, structural equations are used to define the addition operation to be associative and commutative. In the kinship relation system, structural equations define the kin term product to be associative (with some limitations) and to introduce other structural properties of a terminology such as reciprocity of kin terms. Now consider how arithmetic forms a symbolic computational system.

10.2 Arithmetic: symbolic computational system

The counting numbers, as discussed above, represent how many objects there are in a collection of objects and all collections of objects having the same size are represented by the same counting number. Suppose we want to add the counting numbers two and three symbolically. We will do this by using addition in the arithmetic system outlined above. First we map the counting numbers two and three to their corresponding natural number symbols, namely 2 and 3, respectively. Then we do the addition using the natural number symbols: $2 + 3 = 5$. Lastly, we map the result of the symbolic computation back to the counting numbers and obtain the counting number five since the natural number symbol, 5, corresponds to the counting number, five. Thus we have determined that the sum of the counting numbers two and three is the counting number five through arithmetic as a symbolic computation system providing a way to form the composition of counting numbers symbolically. The counting number system and the arithmetic system are related to each other through a one-to-one mapping between counting numbers and natural number symbols and the fact that there is a unique arithmetic system with an addition operation that corresponds to the summation operation for counting numbers. Now consider a kinship terminology as a symbolic computational system.

10.3 Kinship terminology: symbolic computational system

Suppose we want to concatenate two genealogical paths symbolically using kin terms. First we map the each genealogical path to its corresponding kin term. Then we do the product of the kin terms in the Kin Term Space. Lastly, we map the result

of doing the kin term product computation in the kinship terminology system back to its corresponding genealogical path(s). For example, suppose we want to concatenate the genealogical path fm with the genealogical path sd . We map $fm \rightarrow mother \circ father = grandmother$ and $sd \rightarrow daughter \circ son = granddaughter$. Then we compute the product $granddaughter \circ grandfather = cousin$. Lastly we map $cousin$ from the Kin Term Space to the category of genealogical relations $\{ffss, ffsd, \dots, f added\}$, which includes the concatenated genealogical path $fmsd$.

This example illustrates the way the relationship between the genealogical system with concatenation and the kin term system with kin term products is analogous to that of the relationship between counting numbers with sums and the natural number system with addition, but differs in two significant ways that accounts for why, on the one hand, there is a single arithmetic system for symbolically doing sums of counting numbers and, on the other hand, there are multiple kinship terminology systems for symbolically doing the concatenation of genealogical paths through kin term products. First, the relationship between terms and genealogical paths is often one-to-many, as shown with the AKT kin term *cousin* above, where the natural numbers have a one-to-one mapping to the counting numbers. Second, whereas the natural numbers have a unique successor operation determined by adding the natural number 1, kin terms may be sex marked, hence there are alternative choices for a primary term to be used to form successor kin term concepts. Third, the sibling concept in the Family Space is, for some terminologies, a compound concept (e.g., *sibling* = *child* \circ *parent* in the AKT), but for other terminologies it is an irreducible concept and is used to generate other kinship relations. As a result, there are multiple kinship terminology systems, each of which provides a “solution” to computing genealogical relations symbolically through kin term products rather than through concatenation of genealogical paths. Consequently, kinship terminologies can vary across different cultural systems even when based on the same, underlying genealogical space simply as a consequence of differences that arise when forming a symbolic system for the computation of kinship relations.

11 Logic of the American kinship terminology

Now we will illustrate how the logic of constructing new kin term concepts through the kin term product leads to generating the structure of a kinship terminology. We will continue to use the AKT to illustrate the argument, but the sequence of steps that are involved appears to be universal. What differs are the primary terms and some of the structural equations.

- Step 1:** Determine the core ascending structure for the terminology (see Fig. 5(A)) and generate an isomorphic ascending structure of kin terms. For the AKT, the core ascending structure is generated using the *self* and *parent* terms from the Family Space (see Fig. 5(B)).
- Step 2:** Generate an isomorphic descending structure of kin terms. For the AKT, the descending structure is generated using the *self* and *child* terms from the Family Space (see Fig. 5(C)).

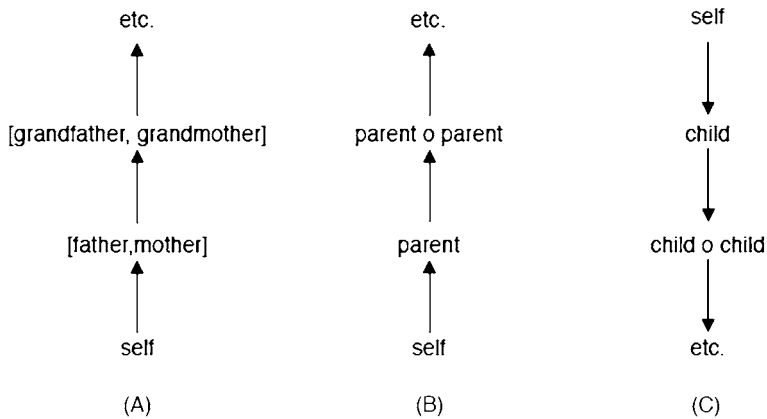


Fig. 5 (A) Simplification of the AKT kin term map (see Fig. 3) to a core ascending structure. (B) Generation of the core ascending structure using *self* and *parent* as the generating terms. (C) Generation of a descending structure isomorphic to the core ascending structure using *self* and *child* as the generating terms

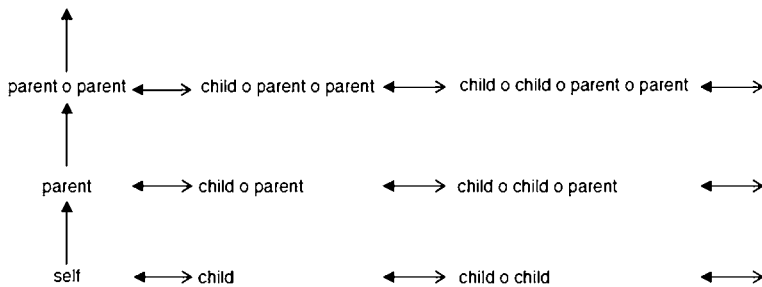


Fig. 6 Structure generated using *self*, *parent* and *child* as the generating terms, along with the equation $\text{parent} \circ \text{child} = \text{self}$ that defines *parent* and *child* to be reciprocal terms. The structure extends to the right and upward, continuing with the same pattern for product of generating terms and arrows connecting nodes

Step 3: Introduce a structural equation that defines the ascending generating term and the descending generating term to be reciprocal kin terms. Determine the structure generated using the generating terms for the ascending and descending structures and the equation making these terms into reciprocal terms. For the AKT, the structural equation defining *parent* and *child* to be reciprocal terms is $\text{parent of child} = \text{self}$, as discussed above. The structure generated using *self*, *parent*, *child* and this structural equation is shown in Fig. 6.

Step 4: Introduce sex marking of kin terms though the concept of maleness and of femaleness. For the AKT, each of the products in Fig. 6 are bifurcated into two products, one marked as a male term and the other as a female term.

Step 5: Introduce an affinal structure by introducing the *spouse* term from the Family Space, structural equations that are part of the *spouse* term (such as *spouse of spouse* is *self*) and equations indicating the way the spouse term relates to the generating terms (such as *spouse of parent* is *parent* and reciprocally, *child of*

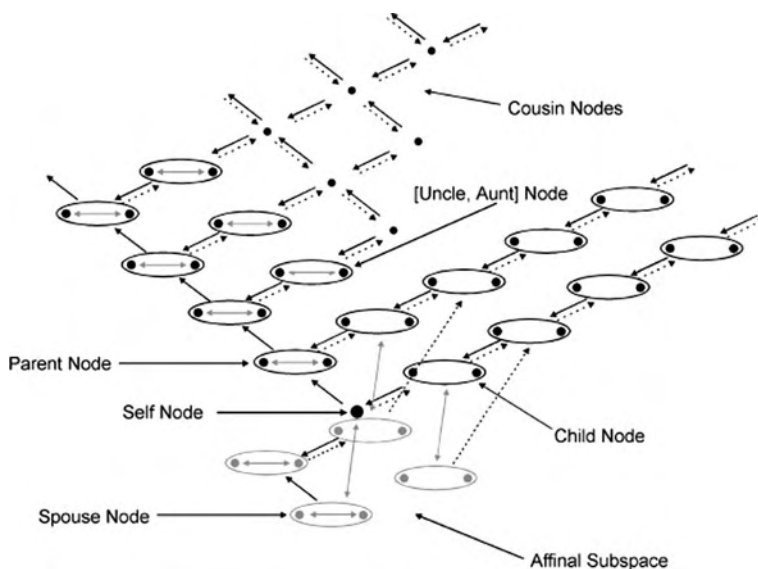


Fig. 7 Structure generated from *self*, *parent*, *child* and *spouse* and the reciprocal equations: $parent \circ child = self$, $spouse \circ spouse = self$; the structural equations: $spouse \circ parent = parent$, $child \circ spouse = child$, $spouse \circ child \circ parent = child \circ parent \circ spouse$; and the structural equations limiting the extent of the affinal structure: $parent \circ parent \circ spouse = 0$, $spouse \circ child \circ child = 0$, $parent \circ spouse \circ child = 0$, where “0” means “not a kin term.” The sex marking of terms (2 nodes circled by an ellipse) is restricted by the rule: A term K is sex marked only if $spouse \circ K$ is a kin term or $spouse \circ K^r$ is a kin term, where K^r is the reciprocal term for K . Gray arrows show products with the spouse term. Nodes in gray correspond to kin terms marked with an “-in-law” suffix

spouse is *child* in the AKT), and equations that limit the extent of the structure determined through the *spouse* concept (such as *parent* of *parent* of *spouse* is not marked as a kin term in the AKT) (see Fig. 7).

Step 6: Introduce rules that may locally modify a portion of the structure (such as a kin term in the AKT remains sex marked only if it or its reciprocal is a kin term when taking a product with the spouse term; e.g., *cousin* is a self-reciprocal terms and *spouse* of *cousin* is not marked as a kin term and so in the American terminology *cousin* is not sex marked).

The result is a predicted terminology based on the properties introduced in Steps 1–6. Next we compare the structure of the predicted terminology to the structure of the kin term map from which it was derived. We find that the predicted terminology and the kin term map are isomorphic (compare Figs. 7 and 3). We have correctly identified the generating terms, the criteria for the sex marking of kin terms, and the structural equations for generating the American Kinship Terminology.

12 Logical implications

We now consider some of the implications of modeling a kinship terminology as a symbolic, computational system in the manner just described. We will briefly con-

sider three kinds of implications: (1) specific properties of a terminology, (2) structural variation among terminologies, including implications extending beyond the target terminology, and (3) aspects going beyond the terminology structure such as the form of social organization for the society with that terminology.

12.1 Terminology properties

We begin with the observation that in the AKT, *spouse* of *uncle* is not *aunt-in-law* and *spouse* of *aunt* is not *uncle-in-law*. This seems to contradict the use of the suffix *-in-law* to denote relations by marriage. We see that *spouse* of *uncle* = *aunt* and *spouse* of *aunt* = *uncle* in the predicted terminology as indicated by the spouse product, shown by a gray arrow, that connects the *aunt* and *uncle* nodes (see Fig. 7, center of figure). This corresponds to *spouse* of *uncle* = *aunt* and *spouse* of *aunt* = *uncle* in the kin term map. Hence there is no anomaly. The use of *aunt* and *uncle* for *spouse* of *uncle* and *spouse* of *aunt*, respectively, is consistent with the underlying logic of the terminology.

12.2 Structural differences

One fundamental structural difference among kinship terminologies is the distinction Lewis Henry Morgan made between what he called descriptive terminologies versus classificatory terminologies. Morgan based the distinction on whether the terminology separates lineal from collateral kinship relations. The distinction has played an important role in theorizing regarding the relations among terminology, prescriptive marriage rules, and forms of social organization. Heretofore there has not been a satisfactory way to account for this structural difference.

The American Kinship Terminology is a descriptive terminology since it distinguishes lineal from collateral kinship relations. In a descriptive terminology, the core, ascending structure (see Fig. 5) is generated using a single, ascending kin term such as *parent* in the AKT.

In a classificatory terminology such as the Kariëra terminology (see Fig. 4) no distinction is made between lineal and collateral relations. Instead, the classificatory terminologies typically equate the ‘father’ term with the ‘brother’ of ‘father’ kin term product and the ‘mother’ term with the ‘sister’ of ‘mother’ kin term product, so the terminology has the kin term product equations, ‘brother’ of ‘father’ = ‘father’ and ‘sister’ of ‘mother’ = ‘mother’. In contrast with descriptive terminologies, the core, ascending structure for a classificatory terminology is generated using both an ascending kin term and a sibling kin term (Read 2007; Bennardo and Read 2007; Leaf and Read 2012; Read and Behrens 1990). Typically, these two terms and the *self* term are initially sex marked (see Read 2007 and Leaf and Read 2012 for more details).

Correspondingly, the core, ascending structure is more complex than the ascending structure for descriptive terminologies. As the construction proceeds when sibling kin terms are used as generating terms, it logically follows that the kin term product ‘brother’ of ‘father’ is the kin term ‘father’ (Read 2007; Bennardo and Read 2007; Leaf and Read 2012; Read and Behrens 1990), which accounts for the structural

difference between descriptive and classificatory terminologies. The use of sibling as a generating, rather than a derivative, concept implies that the sibling relationship should have a central position in societies with classificatory terminologies.

12.2.1 Centrality of the sibling relationship

The centrality of the sibling relation for generating a classificatory terminology is carried over to the way sibling is conceptualized in cultures with a classificatory terminology. This can be seen in the following quotes from ethnographies on societies with classificatory terminologies. Among the Tangu of New Guinea, “siblingship is the determinant that descent might have been expected to be ... descent was probably always calculated from siblingship ... and siblingship rather than descent always provided the definitive norms of social behavior” (Burridge 1959/60, pp. 128, 130). For the Kaluli of New Guinea, “Kaluli ties of sibling relationship are in contradiction to those traced by descent (by genealogical reckoning) and ... the sibling relationship takes precedence over descent whenever the principles are in conflict” (Lindenbaum 1964, p. 56). The Kuma of New Guinea consider that “Cross-sex siblings together constitute ... a complete human being” (Reay 1975–76, p. 80). In the Gilbert Islands “brothers and sisters are alter egos” (Lambert 1981, p. 190).

12.2.2 Kinship grounded society

For kinship based, hunter-gatherer societies in which kinship relations are a prerequisite to social relations, the society size is bounded by the number of persons who can mutually compute that they are kin to each other. The society size will be approximately the number of 2nd order kin; that is, the number of kin relationships calculated through the kin term product. For residence groups in hunter-gatherer societies, the modal size is around 25–30 persons (Kelly 1995) and so there will be around 625–900 1st and 2nd order kin. Data on the population size of hunter-gatherer groups have a bimodal distribution with the anti-mode at 825 persons (Read 2012), approximately the midpoint of the predicted size range for hunter-gatherer societies. This implies that hunter-gatherer societies are bounded in size for internal, structural reasons and not for external, environmental and/or ecological reasons.

12.3 Organizational change

From a kinship viewpoint, one of the main changes in social organization that occurs when going from a hunter-gatherer band society form of organization to a tribal society form of organization involves the introduction of descent groups as primary social units. A descent group is based on genealogically tracing to a reference ancestor (or ancestress) through father (or mother) links, depending on the society with this form of social organization. Descent groups cross-cut the kin-based residence groups of hunter-gatherer societies and incorporate individuals who are distantly related from a kin term perspective, or even persons whose kinship relationship is not

known. The size of a tribal society can be one order to several orders of magnitude larger than a hunter-gatherer society with a band-level form of social organization. The tribal structure form of social organization made it possible to incorporate a far larger group of individuals into a coherent society than is possible with a band society where the society is conceptually bounded by those who are known to be kin related to each other or can compute that they are kin related.

13 Conclusion

The evolution of our species, *Homo sapiens*, from an ancestral species we share with modern-day chimpanzees includes the introduction of a number of social and cognitive abilities that distinguish human societies from those of the non-human primates. One of the key changes was a shift from societies whose organization and internal coherence derives from intensive, face-to-face interaction to societies with relational based forms of social organization. The field of social interaction in non-human primate societies is typically limited to a closed group of individuals interacting with each other on a day-to-day basis. With the development of hunter-gatherer societies in the Upper Paleolithic around 25–45,000 BP, a major shift took place in which the field of social interaction was no longer dependent upon face-to-face interaction and instead was predicated upon a system of culturally constructed (as opposed to biologically determined) kin relations. The social boundary shifted from being based on familiarity gained through face-to-face interaction to one determined by those who were cultural kin to each other. Our hunter-gatherer ancestors put into place a radical shift from a pragmatic social boundary expressed through day-to-day behavior to a conceptual social boundary determined through a culturally constructed system of kin relations.

Unlike biological kinship that simply reflects the facts of reproduction based on who copulated with whom, cultural kinship goes beyond biological kinship. It is by a computational system for symbolically computing conceptually defined kinship relations—expressed through the kin terms in a kinship terminology—that the kinship relation one person has to another is determined, much like arithmetic is a computational system for computing quantities with number symbols instantiated by the counting numbers. As a computational system, a kinship terminology must have an internal logic that both ensures internal consistency in kinship relation computations and external consistency when translating kin term computations to the perspective of each person who culturally shares the same kinship terminology computational system. Unlike arithmetic, though, there is no single kinship computational system satisfying the requirement for internal and external consistency, hence there are a variety of kinship terminology systems across human societies. Kinship terminologies provide, then, a top-down form of organization for the culturally constructed kinship relations that make up a kinship system since their structures do not derive from external conditions but from conceptual constraints such as reciprocity of kinship relations. Terminologies are, therefore, *sui generis* in the sense that Emile Durkheim used this expression in *The Division of Labour in Society* (1933 [1893]) and other publications.

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