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Kinship Algebra Expert System (KAES)

A Software Implementation of a Cultural Theory

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The computer program Kinship Algebra Expert System (KAES) provides a graphically based framework for constructing, if possible, a generative algebraic model for the structure of a kinship terminology (the terms used to refer to one's kin). The algebraic modeling is based on a theory of kinship terminologies elaborated through writing the software program. The theory relates the properties and structure of kinship terminologies to an underlying logic that the KAES program helps uncover and model as a generative structure. The program then relates the structural logic of a kinship terminology modeled by the KAES program to a genealogical space based on genealogical tracing of kin relations. The KAES program demonstrates the surprisingly logical character of kinship terminologies and challenges the received view of the primacy of genealogical relations in defining cultural kinship through showing how genealogical definitions of kin terms can be accurately predicted in the terminologies considered to date.

Keywords: *kinship; cultural theory; terminology; algebraic modeling*

The computer program, Kinship Algebra Expert System (KAES), is a graphical user interface application for investigating and modeling the structure of kinship terminologies and the ways in which these are instantiated (for further information and for downloading a copy of the application program, see Read & Fischer, 2005). It is based on a theory of kinship terminology structures elaborated through writing the KAES program. The program is an example of how a theory can be approached and evidence evaluated with respect to that theory to produce results that identify a future research trajectory rather than simply accounting for relations in a body of data. The results of research based on KAES will have far-reaching consequences for many other domains in the social sciences.

The focus on kinship terminologies may strike many readers as a rather specialized and narrow application, especially following more than a decade in which the study of kinship has diminished in the curricula of major anthropology programs, only to be replaced by courses on gender and new reproductive technologies. However, KAES successfully implements a theory of kinship terminology structures that is fundamental to our understanding of the kinship basis through which a newborn person initially obtains social identity crucial throughout his or her life. In addition, by providing a fully worked out theory and model of one culturally constructed symbolic system (symbolic in the linguistic or mathematical and

not the interpretive sense), we gain insights for the critical task of understanding the relationship between culturally constructed symbolic systems and their cultural instantiation.

The program owes its genesis in the 1980s to a problem with communicating the results of algebraic representation of the structure of kinship terminologies to an anthropological audience with little or no mathematical background, especially in the area of algebraic structures. I had just published a paper (Read, 1984) showing how the American kinship terminology (AKT) could be structurally described in the form of what has been called a kin term map (Leaf, 1971) and, more importantly, how the resulting structure could be generated in the form of an algebraic structure known as a semigroup. It became evident that the number of readers in anthropology who could follow the algebraic argument was very limited, and one of my (then) graduate students, Dr. Clifford Behrens, suggested that we develop a software program for doing the structural analysis that would not require a mathematical background on the part of the user. The algebraic part, we decided, could be implemented using Prolog, and we could develop an expert system as a way to provide assistance to a user without background in modeling using algebraic structures. We made the assumption that the algebraic part of the analysis would require, even with the algebraic machinery presented through a user-friendly interface, considerable guidance because the degree to which kinship terminologies had a common, underlying logic was unknown at the time. I had demonstrated that the AKT did have a logic that allowed for the terminology structure displayed in the form of a kin term map to be isomorphically generated from first principles. Additional work on other terminologies made it evident that the same was likely to be true for terminologies very different from the AKT, such as the Trobriand kinship terminology used by the inhabitants of the Trobriand Islands. The Trobriand terminology has been the basis for considerable theoretical work on kinship terminologies using ideas such as rewrite rules borrowed from linguistic analysis (see Lounsbury, 1964) and provided a good test case for determining those features of a kinship terminology that could better be explicated through an algebraic or generative approach grounded in ethnographic observations about the way kin relations are calculated by individuals rather than linguistic methods. Consequently, the program was not simply a translation of an existing theory and application of that theory into a computer idiom. Instead the software program became the idiom through which the theory was developed (see Read & Behrens, 1990).

The advantage of using a computer program as the basis for developing a theory of kinship terminology structures became evident as work progressed. Much of the algebraic analysis related to working out the structure of an algebra once its generating set and structural equations have been specified. This part of the analysis could be programmed in a relatively straightforward manner using Prolog and obviated the need for a theorem-proof written format. With the algebraic machinery developed in Prolog, the analytical and programming effort could then be focused on what precisely was meant by a terminology having a structure that could be generated from first principles and on what were those first principles.

Many of the issues that arose during the writing of the software program had to do with developing the formal, structural equivalent of concepts that were used more intuitively in anthropological theorizing about kinship terminologies, such as reciprocals of kin terms, a key aspect of any kinship terminology. Briefly, the reciprocal of a kin term is the kin term that another person would use to refer to ego when ego refers to a person by that kin term. In the AKT, for example, if I refer to a person as uncle, then that person would refer to me as nephew (because I am a male person). The kin terms *uncle* and *nephew* are said to be reciprocal kin

terms. Although this is a satisfactory notion from an ethnographic viewpoint, a structural analysis requires that the concept of reciprocity be given a structural definition (to be discussed below) for the concept to be implemented in a software program that provides the machinery for modeling the structure of a kinship terminology as a generative, algebraic structure.

An unexpected consequence of simultaneously working out a theory of kinship terminology structures while implementing that theory in the form of an algorithmically based computer program was that the expert system part of the original design for the computer program began to take on less importance as it was discovered that kinship terminology structures are highly logical and have few degrees of freedom in terms of how the structure is generated. Structural properties that are necessary for consistency in calculations with kin terms—such as consistency in sex marking of kin terms used in kin term calculations—and properties of kin terms such as "parent of sibling is parent" in the AKT can be automatically introduced by the algebraic machinery. As the theory became more completely developed, the algebraic analysis performed by KAES almost became a single, large composite algorithm. It cannot truly be a single algorithm as there are different terminology structures that begin with the same generating elements and initial structural equations.

What distinguishes different kinship terminology structures are not differences in the algebraic methods of analysis (which would require expert system assistance for the naïve user) but structural differences in terminologies relevant to the ethnographic level of cultural differences in the specification of what constitutes kinship in a particular society. For example, the Trobriand terminology and the Tongan terminology (used by the inhabitants of the kingdom of Tonga in the Pacific Ocean) have the same initial starting conditions (set of generating elements, structural equations satisfied by these generating elements) but differ at the point where ascending terms (terms used for persons in a generation older than the speaker) are combined with descending terms (terms used for persons in a younger generation) in accordance with structurally alternative ways these two sets of kin terms may be combined together (see Bennardo & Read, n.d.). The structural implications for alternative ways the ascending and descending terms are combined together to form a single structure relate directly to differences in the usages between the two terminologies for terms that otherwise are in similar structural positions in the two terminologies.

The unexpected discovery that terminologies may be modeled almost as a single, composite algorithm has major implications for our understanding of cultural constructs such as kinship terminologies and their relationship to kinship systems in human societies. Rather than providing support for the received view in anthropology that considered terminologies to be a labeling system for categories of kin distinguished for reasons external to the kinship terminology, the KAES program makes it evident that the structural properties of kinship terminologies arise from logical constraints on the generation of structure and differences among terminologies relate to places in the generation of a structure where alternative ways to develop the full terminology structure are logically possible.

The current version of KAES has been implemented in Java with Michael D. Fischer (Read & Fischer, 2005). In the Java version of KAES, the underlying theory has been elaborated further, especially with regard to the relationship between a kinship terminology and genealogy. No attempt was made to translate the Pascal and Prolog code into Java as that code suffered, from a programming viewpoint, from the fact that it was written while developing the theory on which the current computer program is based and was written without having

access to a fully object-oriented programming language. The latter has made possible a much more succinct and more precise representation of the underlying theory.

Overview of the KAES Program

The KAES program has three major components, with menu options including map operations, algebra operations, and operations. The first component (map operations) provides the machinery for entering of kinship terms in the form of a kin term map (see Figure 3) that displays the manner in which kin terms are linked to one another through a kin term product based on ethnographic observations about the ways individuals calculate kinship relations. The kin term map can be represented in the form a table that shows the kin terms that result from taking the product of a kin term with one of the primary kin terms such as mother, father, son, or daughter in the AKT. The kin term map is also presented in the form of a directed graph linked to the table form for displaying the product of kin terms with the primary kin terms. When a kin term is entered by the user, its attributes such as sex marking and whether or not it is a generator kin term are entered by the user. The kin term map displays native knowledge about a kinship system expressed through a kinship terminology and provides the target structure for the algebraic modeling done in the second component (algebra operations) of the program.

The algebraic modeling begins by structurally simplifying the kin term map through user-selected options for simplification of a kin term map. The simplification is run in reverse during the algebraic modeling as one elaborates on an initial algebraic model constructed in accordance with the simplified kin term map. A modified kin term map is defined to be simplified when the modified kin term map has a single, ancestral generating kin term and only consists of ancestral kin terms. The KAES program allows for the user to model a kin term map using user-selected options that activate an ensemble of individual steps composing a stage in the algebraic modeling, such as constructing the descendant structure from the initial, ascendant structure (see Figure 5). Alternatively, the user may sequentially activate the individual steps making a stage in the algebraic modeling. As the modeling proceeds, the KAES program automatically introduces structural equations that are part of the distinctions made regarding kin terms in the kinship terminology.

Each stage in the algebraic modeling of a kinship terminology structure is successful if the algebraic modeling ends up with an algebraic structure isomorphic to the kin term map from the initial simplification of the kin term map corresponding to the current stage in the algebraic modeling. The algebraic construction stops when an algebraic structure that is isomorphic with the kin term map for the complete kinship terminology has been generated.

The algebraic structure may be locally modified by user-selected rules that implement the logic by which a portion of the generated structure may be culturally modified. For example, the generated algebraic model for the AKT has an undifferentiated "cousin space." The cousin space is then modified by a logic applied consistently to kin term products to arrive at the cousin space with the features found in the kinship terminology and expressed through the kin terms of the form "ith cousin j-times removed." Rules are largely terminology specific. Rules for the terminologies considered so far are included in the KAES program. Additional rules will be added to the KAES program as the analysis expands beyond the kinship terminologies considered so far (see Figure 6 for the algebraic model of the AKT generated by the KAES program, including the rule for the cousin terms).

The third component (operations) constructs a genealogical instantiation of the algebraic structure. The instantiation is constructed by first linking the generating elements in the algebraic structure to the genealogical space. In the AKT, for example, the kin terms *parent* and *child* are the primary, generating kin terms. These two kin terms are mapped to the sets of genealogical positions (genealogical mother, genealogical father) and (genealogical son, genealogical daughter), respectively. This mapping, along with the mapping of the identity element to the set (ego), is next extended to other kin terms through set products of the mapping of the generating elements in corresponding to the primary elements in a kin term product. The result of carrying out the genealogical instantiation of kin terms can be displayed in tabular form or in the kind of genealogical diagrams used by anthropologists to show the mapping of kin terms onto a genealogical structure (see Figure 8).

Anthropological Problem: What Constitutes Kinship?

Unraveling what constitutes kinship relations and kinship behavior in human societies has been a central theme in anthropological theorizing ever since the publication by Lewis Henry Morgan of *Systems of Consanguinity and Affinity of the Human Family* in 1870. The centrality of kinship in anthropological theorizing stems from the fact that all human societies are constructed, to one degree or another, around kinship and kinship relations. Although larger scale societies may have developed institutions for societal integration that are not directly based on kinship, such as the notion of citizenship and elected government in state democracies, no society has removed kinship as a fundamental basis for the social identity of individuals. Regardless of other aspects of societal organization, we are born into families that are formed on the basis of kin relations, and from birth onward we are provided, through kinship, with an identity through which we are linked to other individuals, and through these linkages we are provided with a social identity fundamental to our existence as social beings. Our kin-based social identity may coexist with other identities we also hold. In American culture, we are given individual identity at birth through a supposedly unique name—or at least a name unique within the domain of persons known to the parents of the newborn child. The notion of individual identity in American culture is in accord with the concept of a governmental system that also provides citizens with individual rights that recognize the uniqueness of each person as a biological entity. A child also takes on a kinship identity in American culture even though the latter has the opposite effect of constructing a social identity that overrides the biological uniqueness of each person. A newborn child may be a brother or a sister to any other offspring of her or his parents, a nephew or a niece to the siblings of her or his parents, a cousin to the children of the siblings of her or his parents, and so on, simply by virtue of birth and regardless of individual qualities. This kinship identity provides a social identity expressed (in American culture) through terms such as *brother*, *sister*, *son*, *daughter*, and so on and carries with it expected patterns of behavior by virtue of the kind of relationship involved. Americans have shared (though not identical) notions of how children should behave in their status as children or how siblings should interact in their status of siblings, regardless of their biological uniqueness.

In small scale societies, kinship is the basis on which societal boundaries are formed and is a prerequisite to social interaction among individuals. Often the term used to identify the group to which one belongs translates into something like the meaning of the term *ju/'hoansi*, used by a hunter-gatherer group in Botswana to refer to themselves, namely "we, the

real people" (Lee, 2000). Social interaction between individuals does not take place unless they first recognize each other as kin. Nonkin, or strangers, are feared or perhaps considered potentially harmful because those who are not your kin may not share the same set of moral values and modes of behavior as do your kin. Nonkin are not predictable in terms of behavior in contrast to kin, whose behavior is constrained by patterns of behavior associated with the kinds of kin relations. Stranger, in the context of kin-based societies, refers not to those with whom one has not had prior interaction but to individuals outside of the domain of individuals who share the same moral and social values. The world of individuals with a shared set of moral and social values is one's kin. Kin, by virtue of being kin, share a common framework of behavior that is appropriate even if the persons in question have not previously met. With larger scale societies, a domain of kin-like relations that extends many of the properties of shared, expected patterns of behavior among kin to a larger domain of individuals has been added. Tribes, for example, include individuals who may not know their kin relationships but do know their connection to one another through the social groups to which they belong such as lineages and how these social groups are linked via connections derived from kin connections. In state societies, patterns of expected behavior have been extended outside of the domain of kin and kin-like relations through institutions such as citizenship that define for a person the set of rules and laws that are to be obeyed and where infraction of those rules and laws may lead to punishment. But even citizenship has a quasikin basis through the notion that citizenship is passed on from parent to offspring.

We may reasonably assert, then, that kinship is the fundamental concept on which human societies have been formed and constructed. Without understanding what constitutes kinship and how kinship articulates with, and provides the basis for, interaction in all other domains, we only have an incomplete picture of the nature of human societies and social systems. Trying to understand human societies without understanding the underlying kinship system is analogous to trying to understand the chemical properties of matter without understanding the underlying atomic and molecular properties from which those chemical properties derive. The kin relations that connect individuals provide the underlying framework for the interaction of individuals, and without understanding the properties and structural form that kinship relations may take on in a given society, we cannot fully understand how the individuals making up that society become social and not just individual beings and how the society is structured as a social system.

Although the patterns of expected kin behaviors may vary from one society to another, all societies have a means for identifying or labeling some set of relationships between an individual and other individuals that is expressed linguistically through a set of terms known to anthropologists as a kinship terminology. For Americans, the kinship terminology is composed of the terms such as *son*, *daughter*, *brother*, *sister*, *mother*, *father*, *wife*, *husband*, and so on that are used by one individual as a way of referring to the kin relation one has with another individual. It is important to make a distinction between terms of reference (the terms one uses when referring to another individual, such as in the expression from an advertisement for Boys Town in the 1950s: "He ain't heavy—he's my brother.") and terms of address that are used when talking to another individual. The latter is based on the former but may include terms or expressions that relate not simply to the kin relationship between the individuals in question but to patterns of speech that bring into play other aspects of the relationship between the individuals that is being conveyed by the way one person addresses another person, such as the use of honorific forms of speech. In American culture, we have a variety of

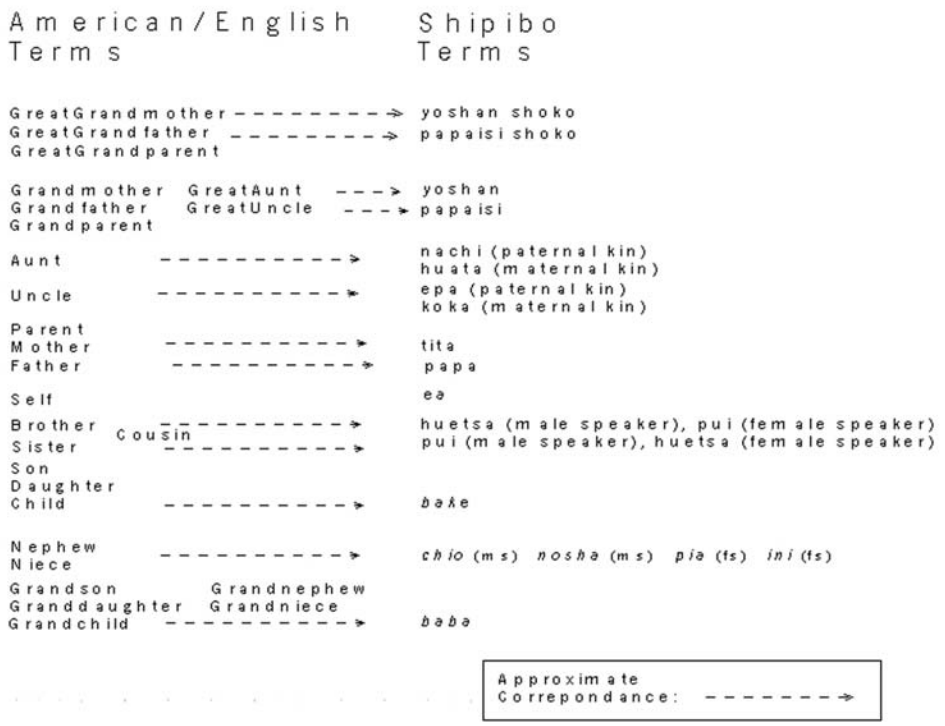
expressions that a child may use when addressing her or his male parent, such as "dad," "pop," "father," "pa," or even the person's first name, with each mode of address having a different connotation. For our purposes here, we will focus on terms of reference only.

Even when we limit ourselves to terms of reference, a complication enters through the fact that we have two distinct ways by which we may refer to someone's kin relationship to speaker. One way is through kin terms, such as the expression, "This is my Aunt Sally." The other is through specification of the genealogical relationship of the person in question to the speaker, as in the expression, "She is my mother's sister." Sometimes both ways of referring to a kin person may occur sequentially, as in the expression, "This is my Aunt Sally—she is my mother's sister," depending on the information that the speaker wants to convey about her or his relationship to the person in question. More generally, corresponding to each kin term, there is one or more genealogical relation for which the kin term may be substituted. For some kin terms, the kin term and the genealogical relations may not be linguistically distinguished. In American culture the expression, "She is my mother," is ambiguous in that the term *mother* can either be the kin term *mother* or the genealogical relation *mother*. Similar comments apply to the American or English kin terms *father*, *brother*, *sister*, *son*, and *daughter*. This correspondence between kin terms and genealogical relations is not true of all terminologies. For many terminologies their term that we would transliterate as mother, for example, does not simply correspond to the genealogical relation mother but may also be properly used for other genealogical relations such as mother's sister (mother's daughter), mother's mother's daughter's daughter, and so on. (A similar comment applies to the term we would transliterate as father.) For terminologies of this kind, the kin term *mother* is similar to kin terms such as *uncle* and *aunt* in the American or English kinship terminology in that the kin term can properly be used to refer to several, different genealogical relations.

Kinship terminologies generally cannot be faithfully translated from one language into another as the relationships that are recognized in one society may not have an exact counterpart among the relationships recognized in another society. Terminologies also vary with respect to the specificity of a kin term with regard to genealogical relations. Whereas the terms *aunt* and *uncle* in American culture do not distinguish whether the relation is through the siblings or spouse of siblings of father versus mother, other terminologies use different terms depending on whether or not the relationship is through one's (genealogical) mother or father as can be seen by comparing the kin term map for the AKT with the kin term map for the kinship terminology used by the Shipibo Indians of Peru (see Figure 1).

The basis for the differences in the kin term relationships that are recognized by different societies has been a source of contention in anthropological theorizing. Equally problematic, though not as systematically addressed, has been identification of the basis for the particular relationships recognized within a given society. At one extreme is the presumption that the relationships linguistically identified through a kinship term are essentially biological in origin and are to be understood as distinctions arising through the process of Darwinian evolution. The biological argument relates the distinctions made within the kinship terminology to reproductive success, taking into account kin selection, inclusive fitness, and so on. A typical kind of argument would be the one advanced for why, in many lineage-based societies, the brother of a sister has a close and authoritative role vis-à-vis his sister's children and lines of inheritance may be from him to his sister's son. The emphasis on sister's brother rather than (putative) genetic father stems, it is argued, arises when paternity is uncertain because of the fact that extramarital affairs are not severely sanctioned. Uncertainty of paternity does not

Figure 1
Comparison of the American Kinship Terminology
With the Shipibo Kinship Terminology



extend to his sister's children (assuming he and his sister are genetic siblings), and so directing his parenting toward his sister's children when paternity uncertainty is sufficiently high increases his reproductive success. More precisely, because his genetic correlation with his genetic children is one half and his genetic correlation with his genetic sister's children is one fourth, then if the certainty of paternity is less than one half, his genetic correlation with his sister's children is greater than his likely correlation with his wife's children (½ × probability of being the genetic father), and so parenting directed toward his sister's children gives him greater reproductive success than does parenting directed toward his wife's children.

A more middle-of-the-ground viewpoint, and one that characterizes most anthropological theorizing about kinship systems, has assumed that the kin terms are based on the biological relationship of reproduction but given cultural expression that may deviate from their biological grounding (Keesing, 1975, p. 13). A distinction is made between genetic father (the man who provides the sperm) and genetic mother (the woman who provides the ovum) and genitor (the man identified as the physical father but who need not be the man who provided the sperm) and genetrix (the woman identified as the physical mother but who need not be the woman who provided the ovum) because knowledge of genetics and its role in reproduction was not known until the work of Gregor Mendel in the mid-1800s. Because of the obvious link between pregnancy and birth, in most societies the woman recognized locally as the genetrix (assuming such an identification is made) is the genetic mother; however, adoption

allows for a woman to be identified as mother even though she is not the genetic mother or the birth mother. In societies such as the Inuit, a woman adopting a child is as real a mother as a woman giving birth to a child, and no distinction is made between a child to whom she has given birth and a child she has adopted. In American culture, we give the adopting woman the kin designation *mother* but recognize that she is not the physical or biological (or birth) mother. The assumption in this perspective is that reproduction and marriage are the basis for kin relations and that the former may have local, cultural constructions that need not match actual genetic linkages. It is assumed that all societies have a notion of genealogy grounded in reproduction and marriage—however, these may be locally constructed—and the genealogical relations are the basis for asserting a kinship connection. Kin terms are viewed as linguistic labels identifying the classification that the members of a society make of a genealogical space grounded in marriage and procreation.

A third perspective, and the one underlying the KAES program, considers kin terms to constitute a system of interconnected concepts expressed through the conceptual connections among the kin terms (Read, 2001). The terminology has a structure in its own right that may be identified without first referring to another domain such as a genealogical space. The structure is based on the manner by which we calculate kin relations using kin terms without first translating kin terms to genealogical representations for the kin terms. In this perspective, the set of kin terms is not just a set of linguistic symbols but also a set of linked symbols that forms the kinship terminology into a structured set of symbols. The structure expressed through the linkages among the kin terms is generative in that the structure can be generated from a few primitive kin terms and structural equations that express the logic underlying the structural form for the terminology. Structural properties arise, in this perspective, through the logic by which the structure is generated from these primitive kin terms. Thus, a kinship terminology is a structured set of symbols that cannot be fully understood without reference to the way the system is generated as a conceptual construct. In this perspective, genealogical tracing, which is the conceptual basis underlying a genealogical space, is also recognized as generating a conceptual system—the genealogical space—distinct from the kin term conceptual system but connected to it through a mapping of the primitive kin terms onto the genealogical relations used in genealogical tracing. Although the previous perspective that posits kin terms to be semantic labels for the classes making up a classification of the genealogical space presumes a conceptual hierarchy going from a genealogical space to a kinship terminology, this third perspective views the genealogical space and the kinship terminology space to be two coexisting conceptual systems, each with a structure determined by the logic of how the space in question—genealogical or terminological—is generated and with a mapping that connects the two spaces but that is necessarily from the kin terminology space onto the genealogical space. The mapping demonstrates that the classification made of the genealogical space and the definition of kin terms using genealogical relations are both the consequence of a more fundamental set of concepts. Hence the definitions of kin terms using genealogical relations and assumed to be primitive concepts in the second perspective are not primitive but instead are derived concepts.

The differences among these three perspectives—biological, genealogical, and cultural—are subject to verification and falsification as each perspective has different implications for what constitutes a kinship terminology. First of all, the biological perspective implies that the kin relations identified through the kin terms making up a kinship terminology should bear a close resemblance to the actual biological relatedness of individuals and differences in termi-

nologies should relate to the pattern of reproductive success in the societies in question in accordance with terminological differences between kin terms and their referents. In this perspective, there should be a close connection between what are effective patterns of social behavior with respect to reproductive success and normative patterns of interaction among kin distinguished through the kinship terminology. In brief, the biological perspective implies that the structure of a kinship terminology and its usage cannot be understood without reference to the biological relatedness of pairs of individuals, their behaviors, and the consequences of those behaviors for reproductive success.

Second, the genealogical perspective implies that a terminology can primarily be understood through the criteria used to classify the possible genealogical relations between pairs of individuals and how different classifications of genealogical relations arise in accordance with linguistic, psychological, and/or ecological constraints. Kin relations in this perspective should be demonstrable as first being conceived genealogically and then given terminological expression according to the definition of kin terms using genealogical relations. The genealogical perspective implies that the structure of a terminology should reflect the criteria and constraints through which a classification of a genealogical space is formulated.

In contrast to both of these perspectives, the cultural perspective implies that the terminology will have a structure whose features can be constructed or generated from a few fundamental concepts along with a general process for the production of the structure of a kinship terminology. A key aspect of this perspective is the logic underlying the structure of the terminology. That logic implies that the kinship terminology should be a logically consistent structure, hence many of its features will be predictable from the logic of how the structure may be generated. In contrast, neither the biological perspective nor the genealogical perspective imply that kinship terminologies should be highly logical in terms of how they constitute a symbolic system. Hence analysis of a kinship terminology with respect to it being constituted in accordance with an underlying logic provides a basis for distinguishing among these three perspectives on what constitutes kinship in human societies.

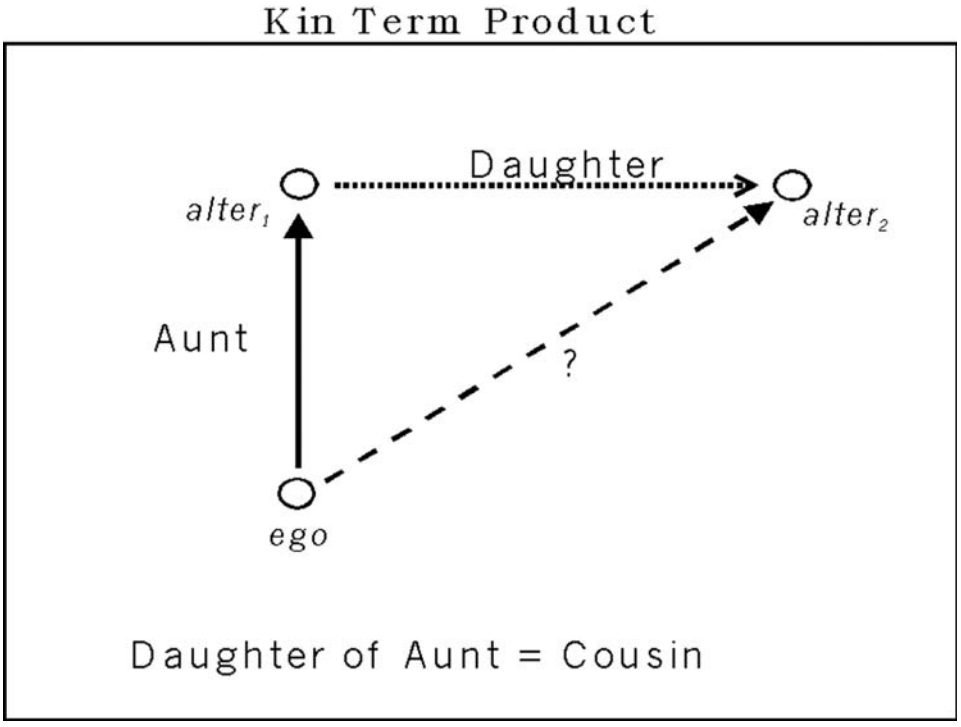
Kinship Terminology Logic

The KAES program is designed to explore the logic underlying the way the kinship terms form a structured system of symbols (with symbols taken in a linguistic and mathematical sense). But more than this, the program is simultaneously an idiom through which a theoretical framework has been developed, a research tool aimed at resolving a fundamental question about a central feature of human societies, and an application program for the analysis of the structural properties of a kinship terminology and its relationship to the genealogical domain. The theoretical framework centers around working out the logic of kinship terminologies based on properties that are based on ethnographic observation. The key ethnographic observation lies in the means by which individuals work out kin relationships.

Kin Term Product

The structural modeling portion of the KAES program is based on the common ethnographic observation that individuals usually do not determine kin relations by identifying their biological pedigree or their genealogical connectedness but by doing computations with kin terms. As the anthropologist Marshall Sahlins (1962) has noted with regard to Moala kinship:

Figure 2
Illustration of a Kin Term Product for the Kin Terms *Aunt* and *Daughter* From the American Kinship Terminology



Note: The product of these kin terms yields the kin term *cousin*.

> [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 predictable. If two people are each related to a third, then they are related to each other.* (p. 155, italics added)

Based on ethnographic observations similar to Sahlins' comment about Moala kinship, we may define a kin term product informally as follows. Suppose one person (ego) properly refers to a second person (alter 1) by the kin term *K*, and alter 1 properly refers to a third person (alter 2) by the kin term *L*. The product of the kin terms *K* and *L* will be the kin term, *M*, if any, that ego properly uses for alter 2. For example and with respect to the American or English kinship terminology, when ego refers to alter 1 by the kin term *aunt* and alter 1 refers to alter 2 by the kin term *daughter*, then ego (properly) uses the kin term *cousin* to refer to alter 2. So the product of the kin terms *daughter* and *mother* is the kin term *cousin* in the AKT (see Figure 2).

We need to make a clear distinction here between *kin types* and *kin type products*, which have to do with genealogical relations, and *kin terms* and *kin term products*, which have to do with the conceptual system we refer to as a kinship terminology and the structure formed from

relations linking kin terms via kin term products. Kin term products express the ways in which the kin terms (viewed as linguistic symbols) form a structured set of symbols. In contrast, kin type products refer to the ways in which a genealogical relation can be constructed through concatenation of pairs of genealogical relations, such as the expression, "Mother's brother's daughter." In the context of genealogy, the words *mother*, *brother*, and *daughter* refer to genealogical tracing based on genitors and genitrixes. Genealogical mother in American culture is the woman who begat ego, and if her identity is unknown, then genealogical tracing through a female parent cannot proceed. This contrasts (in American culture) from kin relations through adoption that are excluded for purposes of genealogical tracing. In both cases, the same kin term, *mother*, may be used for purposes of reference. Thus, if ego has been adopted, then ego has a mother from the perspective of the AKT but not a genealogical mother from the perspective of kin types. Anthropologists have used a technical distinction between social mother, or mater, and physical mother, or genetrix, to distinguish these two situations. The adopted mother, in American culture, is a social mother but not a genetrix. However, this distinction is culturally salient only to the extent that it is a culturally recognized distinction. For some groups such as the Inui mentioned above, no distinction is made between genetrix and mater (or genitor and pater), and so a social mother is also a genetrix for the Inuit.

From the perspective of kin terms, the matter is simpler because either the person in question is one for whom a kin term of reference is appropriate or not according to cultural rules regarding the usage of kin terms. In American culture, the kin term *mother* applies equally to a genetrix or to a social mother. *Mother* (in American culture) is thus a polysemic term that can have the kin type, genealogical mother, as its reference, that can have the social mother as its reference in the case of adoption, or that can be taken as a kin term with linkages to other kin terms through kin term products. When necessary, a distinction between a kin type versus a kin term will be made by capitalizing the kin term and using lower case when referring to a kin type.

For kin terms, the kind of calculation discussed by Sahlins (1962) provides the conceptual basis for viewing kin terms as forming a structured set of symbols. More formally, we define a kin term product as follows:

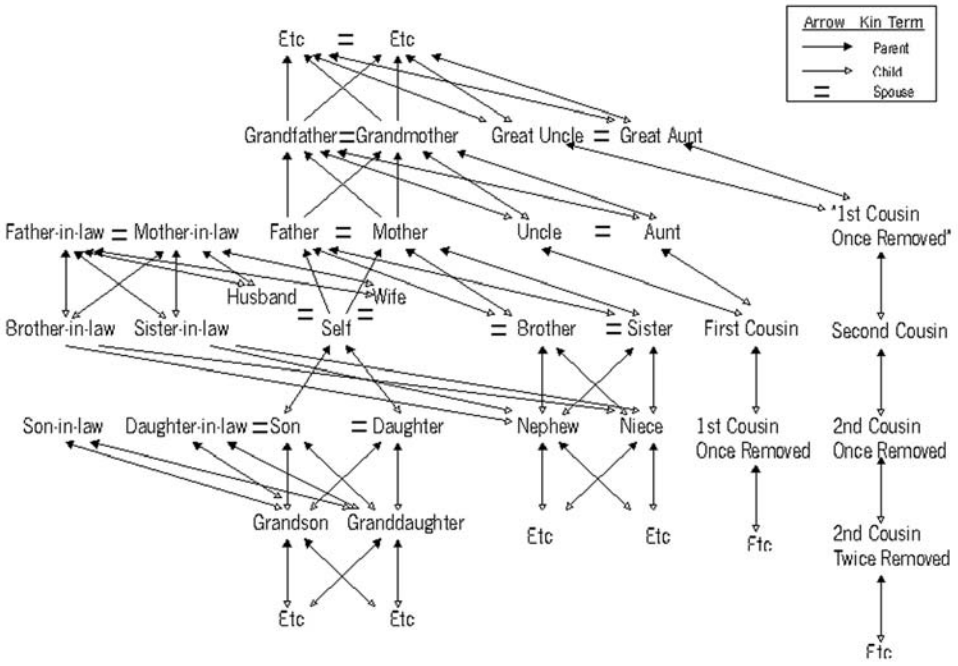
> Definition: Let K and L be kin terms in a given kinship terminology, T. Let ego, alter_1, and alter_2 refer to three arbitrary persons, each of whose cultural repertoire includes the kinship terminology T. The kin term product of K and L, denoted $K \, o \, L$, is a kin term, M, if any, that ego may (properly) use to refer to alter_2 when ego (properly) uses the kin term L to refer to alter_1 and alter_2 (properly) uses the kin term K to refer to alter_2.

Right-to-left product notation will be used as it permits reading the expressing $K \, o \, L$ as "K of L" for a kin term product, and this contrasts with the reading of KL as "K's L" for the genealogical (kin type) product KL of kin types. For example, the symbolic expression $S \, o \, M = A$, where M stands for mother, S for sister, and A for aunt, would be read "sister of mother is aunt," whereas the kin type product *ms* would be read "mother's sister" and *aunt* would be the kin term that can be applied to a person who is one's *ms*.

Kin Term Map

Kin term products are the bases on which the analysis of a kinship terminology structure proceeds. One part of the KAES program deals with representing the structure of a kinship

Figure 3
Kin Term Map for the American Kinship Terminology Based on Taking Products With the Kin Term *Parent* and its Reciprocal Term *Child* and the Kin Term *Spouse*



terminology based on kin term products. A diagram displaying the structure for kin terms based on kin term products is called a kin term map and is the beginning point for the analysis of the structure of a kinship terminology. Figure 3 shows a kin term map for the AKT based on taking products with the kin terms *parent*, *child*, and *spouse*. A variant of this kin term map can be constructed using kin term products with the kin terms *mother*, *father*, *son*, *daughter*, *wife*, and *husband*. In general, more than one kin term map may be possible for the same terminology.

Generating Terms

Although the kin term product is defined for any pair of kin terms, we quickly discover that certain kin terms play central roles in constructing a kin term map. For the AKT, these are terms such as *mother*, *father*, and *parent* and their reciprocals *daughter*, *son*, and *child*. Other kin terms in the AKT can be constructed by taking products of these kin terms. For example, the kin term *grandfather = father o parent* (read, "Grandfather is father of parent," or more completely, "The kin term *grandfather* results from taking the kin term product of the kin term *father* with the kin term *parent*"), where this is a statement about the three symbols, *grandfather*, *father*, and *parent*. The symbol *o* between father and parent indicates that we have a binary product (namely the kin term product) that maps a pair of symbols (in this instance, the father, parent pair) to another symbol (in this instance, the symbol grandfather).

Though this equation may look like a genealogical statement, nothing could be further from the meaning of this equation. The equation states that when ego properly refers to a person as *parent* (and regardless of the actual genealogical connection, if any, between the two persons) and that person properly refers to a third person as *father* (again, regardless of the actual genealogical connection between them, if any), then ego would properly refer to that third person by the kin term *grandfather* (again, regardless of the actual genealogical relationship between them). Some of the persons in question might be adopted and so the actual genealogical relations that are involved are unknown; nonetheless the users of the AKT still know the proper usage of the terminology in cases of adoption by virtue of the conceptual relations that hold among the kin terms.

Criteria for Generating Terms

The kin term map is constructed by first deciding on the kin terms that will serve as the generating terms through which kin terms are linked to one another. The generating terms must account for the closest kin term linkages between a person and another person, and so they will likely be some variant on the kin terms that can be transliterated as *mother*, *father* (and possibly *parent*), and their reciprocals, *daughter*, *son* (and possibly *child*). In addition, terms that can be transliterated as *brother* or *sister* (or possibly *older brother*, *younger brother*, etc.) will be generating terms in some terminologies but not in other terminologies. In the AKT, the analysis of the logic underlying the structural form of the kin term map displayed in Figure 3 establishes that the kin term *brother* is the product of the kin terms *parent* and *son*: *brother* = *son o parent*. In other terminologies, a kin term that can be transliterated as *brother* (or *sister*) or possibly as *older brother* (or *older sister*) is a generating term and not expressible as a kin term product. The distinction between a sibling term taken as a product versus a sibling term taken as a generating term provides the conceptual basis for the distinction between so-called descriptive terminologies versus classificatory terminologies (see below).

Kin Term Map as a Generated Structure

The kin term map, even without any additional analysis, serves as an effective graphical device for displaying the structural differences among kinship terminologies. Each terminology has its own structural form (or variant on a structural form for closely related terminologies) that expresses differences in the ways in which the kin terms of a terminology form a structure.

The kin term map is more than just an effective descriptive means to display the conceptual structure formed by the kin terms in a kinship terminology. An obvious question is whether the map can be generated from a few simple structural properties, and if so, does this account for the features of the terminology (such as the odd way in which the *aunt* and *uncle* terms in the AKT are used both for individuals linked genealogically through parent and child links to ego and for individuals who are linked to ego only through marriage). If the kin term map is the graph of a generative structure, then it follows that a kinship terminology is neither simply a representation of biological kin relations nor a classification of a genealogical space by criteria that lie outside of the kinship terminology. Instead the kinship terminology is a cultural construct, and the meaning of kin terms cannot be fully understood without reference to that construct and the logic underlying how it is generated.

The KAES program is designed to have a number of features aimed at helping construct a kin term map. Kin terms may be entered in any order and at any time. Any kin term that has been entered may be designated as a generating term, and the pattern of arrows that may be drawn showing the kin term product of a kin term with a generating term will be constrained by the features of the generating term such as its sex marking and whether it is an ascending term (i.e., refers to alters in an older generation with respect to ego).

Generating Terms: Descriptive Versus Classificatory Terminologies

One of the key discoveries about terminology structures that has been obtained to date relates to the distinction Morgan (1870) made between what he called descriptive terminologies versus classificatory terminologies. The choice of labels was unfortunate as it led to substantial debate about the validity of the distinction within anthropological theorizing about kinship terminological systems based on the labels *descriptive* versus *classificatory* rather than the structural differences that distinguish the two kinds of terminologies (e.g., Lowie, 1928). At the level of kin terms, some kin terms in a terminology may be descriptive in the sense that the kin term can be given a genealogical definition using a single kin type (such as *mother* is the term used in reference to the kin type mother), and other terms in the same terminology may be classificatory in the sense that a genealogical definition of the kin term will refer to more than a single kin type, such as *uncle* with a genealogical definition: mother's brother, father's brother, mother's sister's husband or father's sister's husband. The distinction Morgan was attempting to identify had to do with structural properties such as whether or not lineal relations traced using either parent kin types only or child kin types only were kept distinct from collateral relations traced using first parent kin types and then child kin types. Thus in the AKT, *parent* is a lineal kin term, whereas *aunt* or *uncle* are collateral kin terms, and the collateral kin types to which the later two kin terms refer are kept distinct from the lineal kin type to which the kin term *parent* refers. In classificatory kinship terminologies that are common in Polynesia and other groups inhabiting islands in the Pacific Ocean, parent and parent's siblings are not kept distinct, and a single kin term, *mother*, refers to mother and mother's sister (and other females on the same generation as mother), and a single kin term, *father*, refers to father and father's brother (and other males on the same generation as father).

Morgan's (1870) structural distinction based on lineal versus collateral only partially identifies the basis on which the lineal-collateral distinction arises. By working out the generative implications of taking a sibling term as a primitive during the process of writing the KAES program, it became evident that the structural distinction Morgan was attempting to identify relates to whether or not the sibling kin terms are generating kin terms or are products of other kin terms. As noted above, in the AKT, the kin term *brother* is constructed via *brother* = *son of parent* (which can also be expressed via the two equations *brother* = *son of father* or *brother* = *son of mother*). The kin term map for the AKT is not consistent with a claim that the sibling terms are generating terms for the terminology, and so the AKT is a descriptive terminology. In contrast, classificatory terminologies such as the Trobriand terminology or the Tongan terminology in the Pacific Ocean area are found to be terminologies for which sibling terms are generating terms. The analysis of the structure of these terminologies demonstrates that the kind of genealogical equations that have been used to define classificatory terminologies, namely $f = fb$ and $m = mz$, are a consequence of the structural implications that arise from including the sibling kin terms among the generating terms for the terminology.

Algebraic Model for a Kin Term Map

The algebra part of KAES refers to the use of algebraic concepts to model the structure of a kinship terminology as displayed through a kin term map. By algebraic structure is meant the structure that is formed by a set of symbols (e.g., the kin terms making up a terminology), a binary product defined for all pairs of symbols in that set (e.g., the kin term product for kin terms), including whether or not the binary product is associative—for example, for the binary operation, +, the sum $a + (b + c)$ is the same as the sum $(a + b) + c$; for kin terms, the product $K\ o\ (L\ o\ M) = (K\ o\ L)\ o\ M$—or commutative (e.g., for the binary number operation, +, $a + b = b + a$; however, commutativity does not hold for most kin term products; e.g., son of father is not the same as father of son), and certain equations that the binary product must satisfy. The equations give an algebra its particular structural form.

For kinship terminologies, we have the following basic algebraic machinery:

1. A set of symbols—the terms making up the kinship terminology.
2. A binary product defined over those symbols—the kin term product, including 0 as a symbol indicating that the product does not yield a kin term; e.g., *father o father-in-law* = 0 in the AKT because there is no kin term representing the product *father o father-in-law.*
3. The binary product is associative—the kin term product is associative, except in certain special cases that are dealt with in the analysis on an individual basis.

An algebraic system satisfying all three of the above is known in the mathematical literature as a semigroup.

The equations that are used when modeling a kinship terminology are used to introduce structural properties that characterize kin terms. The structural equations provide a way to express the structural properties of a kind of kin term with respect to the kin term map and thereby provide a formal definition for what otherwise are informal concepts associated with terminologies. These properties provide definitions for kinds of kin terms such as: (a) a sibling kin term, *S*, is a kin term for which $S\ o\ S = S$ (e.g., in American culture, brother of brother is brother as a kin term product); (b) a spouse kin term, *Sp*, is a kin term for which $Sp\ o\ Sp =$ self (with self a symbol representing the concept of self, a concept fundamental to any kinship system), and so on. The equation $S\ o\ S = S$, for example, follows from the fact that as users of our own terminology, we know what the kin term *brother* means. Among the various meanings associated with the term is the structural property that if ego properly refers to alter 1 as brother and if alter 1 properly refers to alter 2 as brother, then ego properly refers to alter 2 as brother, hence the structural equation $S\ o\ S = S$ becomes the way to structurally define a kin term as a symbol that can be given instantiation with the concept of brother (or equivalently, with the concept of sister because sister of sister is sister). The structural equation does not provide an exhaustive definition of the meaning of, say, the term *brother*, as the instantiation (see below) of an (abstract) symbol may include properties that are not part of the kin terminology structure and bring to bear other cultural aspects associated with cultural constructs relevant to the cultural notion of what constitutes (in this example) brotherhood.

The structural equations also express relations between kin terms such as reciprocity of kin terms. By reciprocity of kin terms is meant that if ego properly uses the kin term *K* to refer to alter, then the kin term *L* that alter properly uses to refer to ego is the reciprocal kin term for *K*. Because of sex marking of kin terms, a kin term need not have a unique reciprocal term. The AKT kin term *mother*, for example, has both *son* and *daughter* as reciprocal kin terms.

The structural property that relates two kin terms *K* and *L* as reciprocal kin terms is either the structural equation, *K o L* = *self or L o K* = self, depending on whether *K* or *L* is the ascending kin term. If *K* is the ascending kin term, then *K o L* = self is the reciprocal equation that defines *L* as a reciprocal kin term for *K*. The notion of reciprocity is almost equivalent to the notion of an inverse element for algebraic structures in that in one direction—first using a descending term and then an ascending term—reciprocity refers back to ego, and self is the concept used by ego to refer to herself or himself. In the other direction, the product does not refer back to ego; otherwise the only kin terms, expressed genealogically, would be lineal kin terms. Thus, for the reciprocal kin terms *father* and *son* in the AKT, father of son is self as a kin term product, but son of father is not self and instead identifies a new kin term, *brother*. The KAES program generates these structural equations that express the structural properties of kin terms automatically as the analysis progresses.

General Model for the Structure of a Kinship Terminology

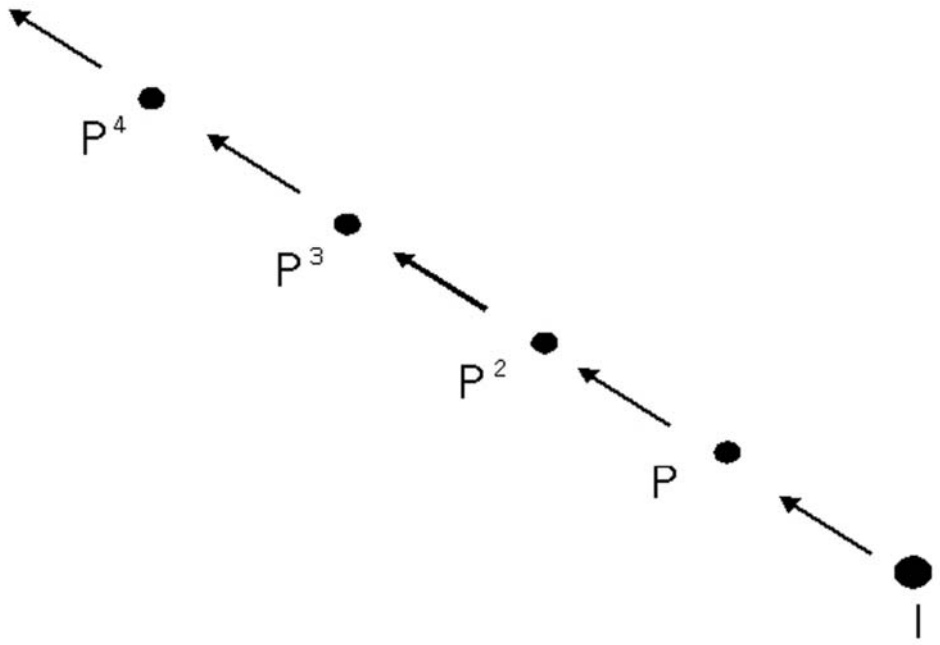
The following is an analytical sequence for generating a kinship terminology that provides the basic framework for the algebraic analysis of a kin term map. The algebraic portion of the KAES program is structured around this analytical sequence.

1. A structure isomorphic to a sequence of ascending kin terms, all with the same sex marking, is constructed based on an ascending generating term such as *mother* if the terms are to be marked female, *father* if the terms are to be marked male, and *parent* if the terms are to be neutral (see Figure 4). Included in this ascending structure is an identity element that can be designated male self, female self, or self, depending on whether the ascending terms are marked male or female or are neutral. By an identity element is meant an algebraic element *I* such that for any element *K*, *K o I* = *I o K* = *K*. The identity element will be designated by the symbol self (with or without a sex marker) on the grounds that a concept of self is both universal and necessary for there to be a kinship terminology; that is, all terminologies must make a distinction between self and other, whether or not there is a linguist symbol representing the concept self in the kinship terminology.

2. A structure of descending kin terms is constructed from the structure of ascending kin terms by making an isomorphic copy of the ascending kin term structure and then a larger algebraic structure made up of both ascending kin terms and descending kin terms, and cross products between ascending and descending kin terms are formed (see Figure 5). Included here is the structural equation that makes an ascending kin term—call it *P*—and its isomorphic kin term—call it *C*—into reciprocal terms, namely *P o C* = *I*.

3. The next step introduces kin terms with the other sex marking or, alternatively, bifurcation of neutral kin terms into male-marked and female-marked kin terms. First, when the kin terms constructed in steps 1 and 2 are already sex marked, then terms of the opposite sex are constructed by taking an isomorphic copy of the structure generated in steps 1 and 2. The isomorphic copy will be a structure of kin terms with the opposite sex. The original structure and this isomorphic structure are combined together, along with appropriate structural equations, to make a new, larger structure consisting of terms marked with both sexes. Second, when the kin terms constructed in steps 1 and 2 are all marked neutral, each kin term is bifurcated into two kin terms marked as male and female terms. Appropriate structural equations that relate male kin term and female kin term products are introduced as appropriate.

Figure 4
An Ascending Structure Based on the Generator, *P*, and the Identity Element, *I*.



Note: The structure will be structurally defined as an ascending structure by the structural properties that the generating term, *P*, will satisfy when an isomorphic copy of this structure becomes the descending structure (see Figure 5).

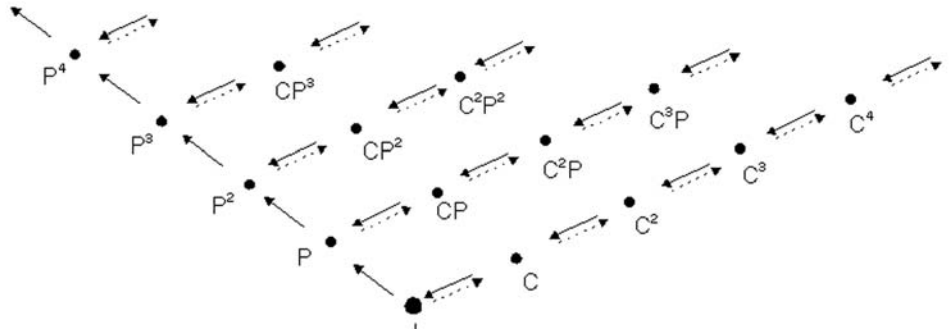
4. Affinal kin terms are introduced next, along with appropriate equations that express the properties of affinal kin terms. (See the double-headed, gray arrows in Figure 6 that represent taking products with the spouse generator. Figure 6 is the structure produced from steps 3 to 5.)

5. Rules are identified that refer to ways that portions of the overall structure are locally modified. For example, in the AKT, not all kin terms are marked as either male terms or female terms according to the sex marking rule: "A kin term, *K*, is marked neutral when the product of *K* with a spouse term is not a kin term." Another rule in the AKT identifies the way in which cousin kin terms may be further distinguished according to properties such as "ith cousin" or "ith cousin j-times removed." These rules relate to ways in which parts of the overall structure are modified for cultural reasons and are not modifications necessary for a terminology to have the structure of a kinship terminology (see the shape of the cousin space in the upper right portion of Figure 6).

Criterion for the Validity of a Structural Model

An algebraic model for a kinship terminology is a valid model for that terminology if and only if the algebraic model is isomorphic to the kin term map representation of the kinship terminology. Not all conceivable kin term maps can be validly represented by an algebraic model. Success in formulating a valid algebraic model for a kinship terminology map identifies the means through which the terminology structure can be logically generated in accordance with the general model for the construction of a kinship terminology. The kin term map

Figure 5
An Isomorphic Copy of the Ascending Structure, With Generating Terms *C* and *I*, is Constructed and Joined to the Ascending Structure, Including Products Between Terms in the Ascending Structure and the Descending Structure



Note: The structural equation, $P \circ C = I$, is introduced to structurally define *P* and *C* as reciprocals. The structural equation also structurally identifies *P* as an ascending generating term and *C* as a descending generating term because an equation defining one term as the reciprocal of another term is of the form, ascending term × descending term = self.

shown in Figure 3 is structurally isomorphic to the algebraic structure shown in Figure 6 (Read & Behrens, 1990), and so the algebraic construction has generated a valid algebraic model for the kin term map of the AKT.

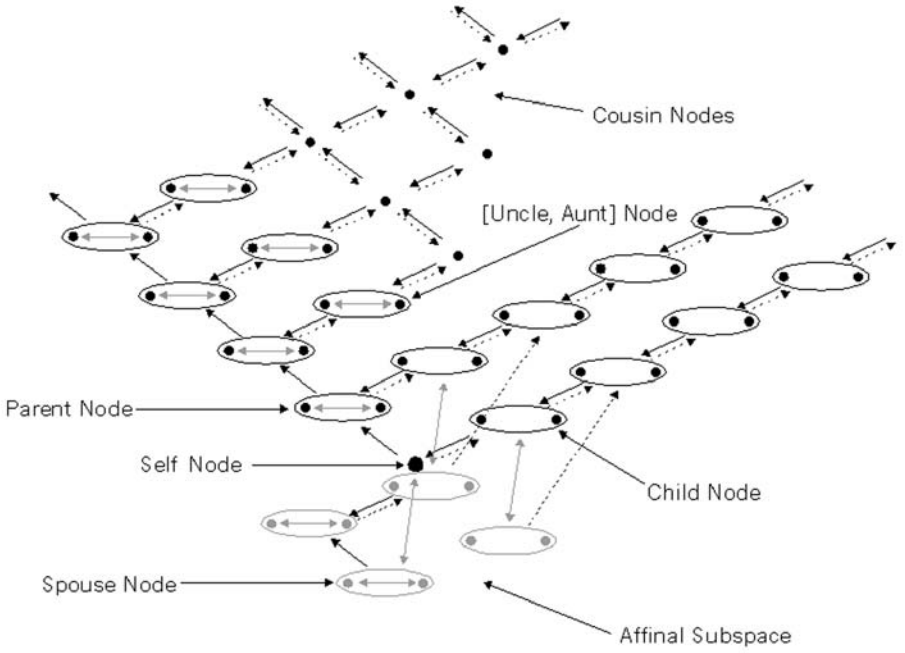
Properties of the algebraic model are properties that arise from the logic of how a kinship terminology can be generated and do not require reference to properties outside of the terminology. For example, the algebraic model that validly represents the AKT has the property, *spouse o aunt = uncle* and *spouse o uncle = aunt*, hence the lack of terms marked with the suffix *-in-law* such as *aunt-in-law* or *uncle-in-law* for these relations by marriage is a consequence of the logic underlying the generation of the AKT as a kinship terminology structure. In Figure 6, the double-headed, gray spouse arrow maps the uncle node onto the aunt node as a consequence of the logic of how the structure displayed in Figure 6 is generated.

Rules that are introduced in step 5 identify structural properties that are not necessary for the structure to have the structural form of a kinship terminology; hence they are properties that may have been introduced for reasons extrinsic to the terminology structure per se. In other words, the analysis distinguishes between properties of the terminological structure that are necessary for the structure to be complete and consistent as a kinship terminology structure and properties that are parts of the terminology but are not necessary for its completeness and consistency and hence are likely to have origin for reasons extrinsic to the generative logic of the kinship terminology structure.

Instantiation of the Symbolic Structure

The algebraic model of a kinship terminology structure consists of abstract symbols and the relations among these symbols as determined by structural equations and other properties guiding the generation of the symbolic structure. These abstract symbols are culturally instantiated (see Figure 7; see Read, 2002, for a discussion of cultural instantiation) with

Figure 6
The Algebraic Structure Generated From the Structure in Figure 5 After Steps 3 to 5 Are Implemented



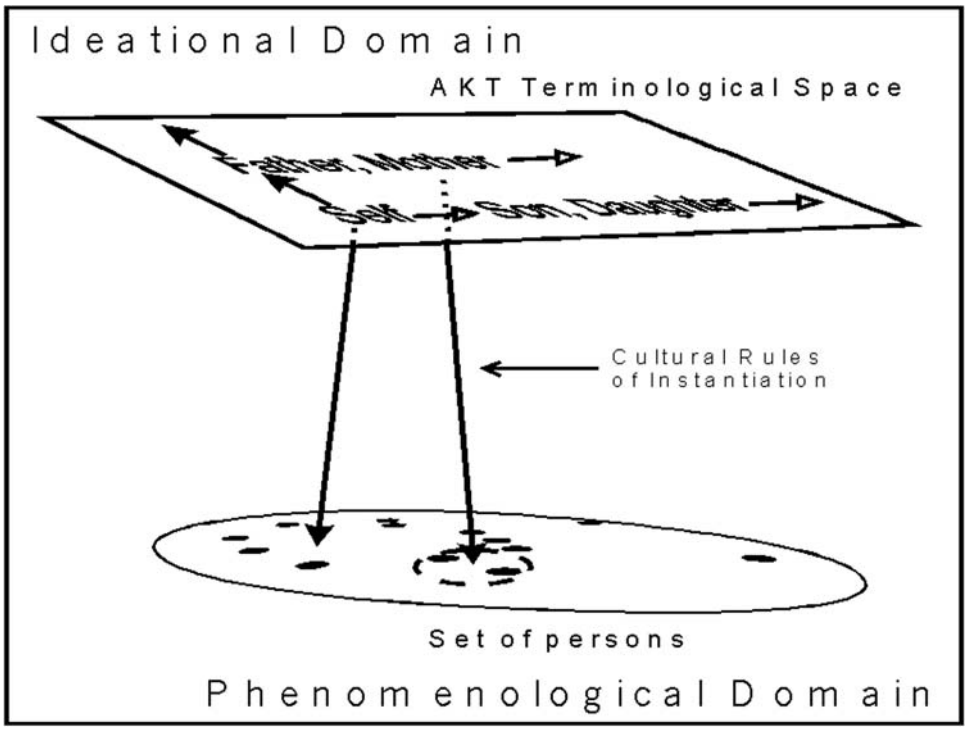
Note: The solid, single-headed arrows show the result of taking a product with the generator, *P*. The dashed, single-headed arrows show the result of taking a product with the reciprocal generator, *C*. The gray, double-headed arrows show the result of taking a product with the spouse generator, *S*. The oval around a pair of nodes indicates a node from the structure produced in step 2 (see Figure 5) that was bifurcated into a pair of sex-marked nodes in step 3. The gray nodes are the affinal (relations by marriage) nodes introduced in step 4 when a spouse-generating element was added to the structure. The gray nodes are labeled either with kin terms having an in-law suffix or are labeled with the spouse terms, *husband* and *wife*, when the algebraic structure is isomorphically mapped onto the kin term map shown in Figure 3.

respect to the individuals for whom the symbols may be properly used as terms of reference when using the kinship terminology to identify kin relationships between individuals. A primary cultural instantiation is through genealogical concepts and is obtained by identifying the instantiation of the generation terms in the algebraic structure with kin types underlying the construction of a genealogical space. A male-marked kin term used in the construction of the ascending structure (e.g., it is instantiated with the kin type, *father*; more precisely, with *genealogical father*). The reciprocal male-marked kin term in the descending structure is instantiated with the kin type *genealogical son* and so on.

Predicted Genealogical Definitions of Kin Terms

Once the generating terms have been instantiated with genealogical kin types, then the instantiation of all other terms can be worked out from the instantiation of the generating kin

Figure 7
Diagram Showing the General Process of Cultural Instantiation of the Algebraic Structure



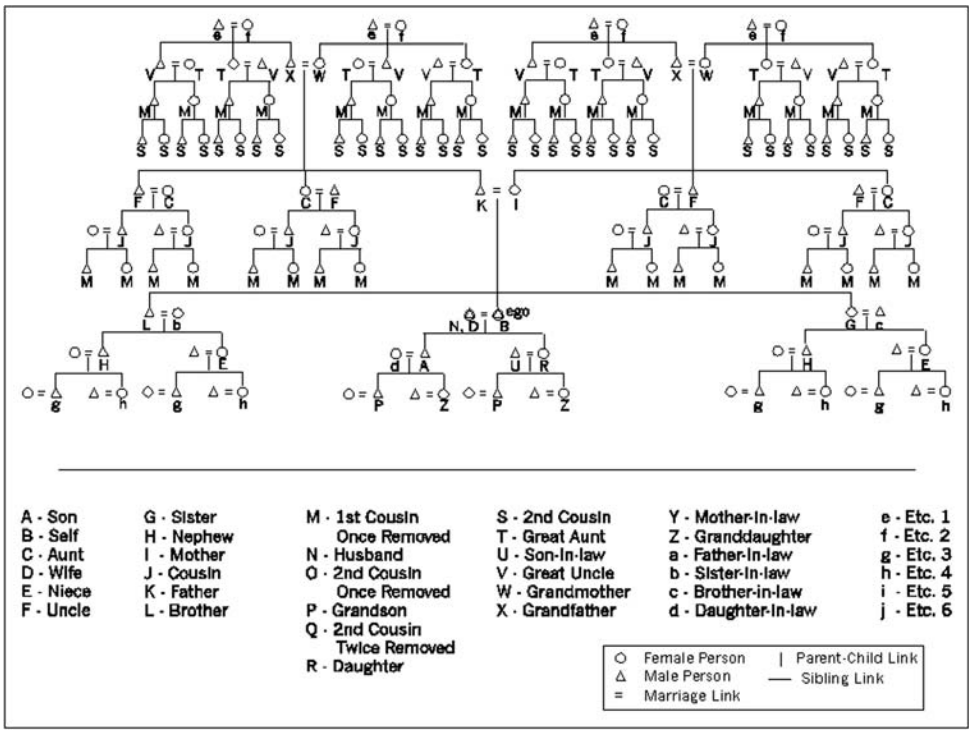
Note: The nodes in the algebraic structure have semantic meaning with respect to the structure in which they are embedded and are then given semantic meaning with regard to individuals to whom the kin terms are applicable through cultural rules of instantiation. One set of rules relates the algebraic structure to a genealogical space by mapping the generating terms for the algebraic structure onto the genealogical space and using the logic of the algebraic structure to determine the mapping of all other nodes in the algebraic structure onto the genealogical space.

terms and the algebraic structure by identifying algebraic products with products of sets of kin types. For example, *grandfather* has the instantiation (*genealogical father*) × (*genealogical father*) = (*genealogical father's father*) because *grandfather* = *father o father* and *father* has the instantiation (*genealogical father*).

This process of instantiation of the generating terms and construction of the instantiation of all other kin terms based on the algebraic structure leads to a predicted set of genealogical definitions of kin terms. For all terminologies considered to date, the predicted genealogical definitions match with 100% accuracy the genealogical definitions elicited by anthropologists (see Figure 8). These genealogical definitions have been assumed to be the primary and irreducible data for the analysis of kinship terminologies. The KAES analysis demonstrates to the contrary that these definitions are predictable from the way in which the terminology is generated as a structure.

Instantiation is not limited to genealogical instantiation. Instead, instantiation depends on cultural rules for mapping abstract symbols to individuals and can be based on other criteria

Figure 8
The Mapping of the American or English Kinship Terminology Kin Terms Onto the Genealogical Space as Predicted From the Algebraic Analysis Performed by the Kinship Algebra Expert System Program



Note: All of the predictions match the genealogical definitions of kin terms for the American or English Kinship Terminology.

such as adoption or other means by which individuals are incorporated within the conceptual structure of a kinship terminology.

Metaphoric Instantiation of Kin Terms

The constraint imposed by the algebraic structure on instantiation lies in the structural properties of a kinship terminology that are mapped onto individuals through the process of instantiation, such as instantiation must be consistent with the reciprocity of kin terms and the generative properties of the kinship terminology structure. The latter implies that kin term products must also map over to individuals under the cultural rules of instantiation. Thus an adopted child is not only a child vis-à-vis the adopting parents, but the adopted child has the appropriate kin term relationship to other individuals in the kinship domain of the adopting parents. This contrasts with instantiation of individual kin terms that does not carry over to other kin terms, such as the use of the kin terms *aunt* and *uncle* by users of the AKT in an honorific sense (e.g., the use of the *uncle* and *aunt* terms for the friends of one's parents). The distinction between the more extended and the more limited forms of instantiation provides a

more formal way to express what has sometimes been referred to as metaphoric usages of kin terms (Scheffler, 1972) and distinguishes when instantiation is metaphoric and not primarily for the usage of the kinship terminology. The genealogical perspective on kin terms assumed, without ethnographic justification, that the primary meaning of kin terms is with respect to kin types, and so any application of kin terms outside of the genealogical domain or where the genealogical definition included noncomparable kin types became metaphorical extension. Classificatory terminologies, in this viewpoint, had kin terms with translation *mother* and *father* whose primary meanings were genealogical mother and genealogical father, respectively, and the usage of the same kin terms for mother's sister and father's brother (and other females and males) was taken to be metaphoric extension of the primary, genealogical meaning of the kin terms. The analysis developed through writing the KAES program constructively shows that the metaphoric extension hypothesis is unnecessary and was devised as a way to accommodate an unwarranted assumption about the nature of kinship terminologies to ethnographic facts that were not in accord with that assumption. There is no need to posit metaphoric extension as there is no need to posit extension from a primary, genealogical meaning of kin terms. The analysis produced by the KAES program constructively demonstrates how the range of kin types included under a kin term arises from the mapping of the generating kin terms to the genealogical domain and the structural equations that determine the structural form for the kinship terminology structure. There is no metaphoric extension as the full range of kin types included under a kin term is generated as part of the logic of the kinship terminology structure and how that structure relates to the genealogical domain.

Conclusion

The KAES program has successfully implemented a theory of kinship terminology structures that makes evident the underlying logic giving a terminology its particular form and accounts for the way the kin terms relate to genealogical relations. Writing the KAES program has been central to working out the logic of kinship terminology structures and, through that logic, the broader implications for what we understand to constitute cultural constructs. The program clarifies the way in which we have two conceptual systems regarding kin relations—the manner in which individuals are connected to one another through genealogical connections and the kin terms that identify the kin relation one individual has to another individual. The biological argument cannot account for the logic modeled through the KAES program; hence it is insufficient to consider kinship, as it occurs in human societies, through biological criterion alone. Human societies are based on what we can call cultural kinship in contrast to biological kinship. This is not to say that biological kinship is irrelevant; cultural kinship has its evolutionary origins in biological kinship but has transformed those origins.

Similarly, the received view in anthropology that has viewed kinship as arising from marriage and reproduction is not so much incorrect as inadequate. Historically, some kind of process of genealogical tracing of connections must have preceded the "invention" of the conceptual structures we refer to as kinship terminologies. One possibility for the evolutionary origin of kinship terminology systems is that they provided a computational device for calculating relations among individuals that was cognitively less demanding than memorizing extensive genealogical linkages. But even if it arose as a computational system, the computational facility enabled the terminology to become the central means by which individuals determine if they have a kinship connection or not as indicated in the quote from Sahlins

(1962) given above. One can calculate kin relations with the kinship terminological system without necessarily referring back to genealogical linkages, and hence the relative importance of genealogical connections versus kin terminology connections has become society specific. Some Australian groups, for example, find it difficult to compute genealogical linkages as it is not a familiar way for determining one's kinship status vis-à-vis another individual (Shapiro, 1982).

The KAES program is a work in progress and will be modified to accommodate features of kinship terminologies not encompassed by the terminologies considered to date as additional terminologies are analyzed. The structure used to implement the algebraic modeling is not likely to be changed. However, if there is a terminology with structure that cannot be accommodated within the structural sequence implemented in the KAES program, then that fact alone will be a striking discovery. The KAES program will also be expanded beyond its current architecture aimed at analyzing and modeling the structure of kin term maps. The instantiation of the algebraic model with respect to genealogical tracing provides the interface needed to embed the structural logic into an agent-based demographic model so as to follow out the logic of kinship terminology structures and their instantiation in terms of a group of individuals undergoing demographic change. Initial work in this direction has highlighted the way in which implementation of an agent-based demographic model raises questions about the constraints on the transmittal of information of kinship relations within a group to progeny. For example, if progeny learned in totality the set of parental kin relations, then the amount of information about kin being transmitted across generations expands at least exponentially and will outstrip memory capacity. Hence the amount of information transmitted must be limited, thereby raising the issue of how kin relations can be calculated for more distant potential kin and answered through the logic modeled by the KAES program. Coupling the KAES program with agent-based demographic simulation should make it possible to examine in more detail the consequences of marriage rules in conjunction with terminologies and how marriage rules and kin terminology structure relate to social organization in kin-based societies.

The logic of terminologies raises questions about human cognition and why terminologies are highly logic. In part it relates to calculation of kin relations in a manner consistent across all individuals sharing the same terminology. In another part, it raises questions about the evolutionary trajectory that leads from behavior centered around biological kin to behavior centered around cultural kin and whether that trajectory can be accommodated in a Darwinian evolutionary framework or whether it signals a change to social organization based on culturally constructed conceptual systems for which the idiom of descent with modification driven by reproductive success is no longer the primary driver for evolutionary change (cf. Read, 2003).

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