Mathematical Modeling and Anthropology: Its Rationale, Past Successes and Future Directions

Dwight Read, Organizer

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Abstract

When anthropologists talk about their discipline as a holistic study of human societies, particularly non-western societies, mathematics and mathematical modeling does not immediately come to mind, either to persons outside of anthropology and even to most anthropologists. What does mathematics have to do with the study of religious beliefs, ideologies, rituals, kinship and the like? Or more generally, What does mathematical modeling have to do with culture? The application of statistical methods usually makes sense to the questioner when it is explained that these methods relate to the study of human societies through examining patterns in empirical data on how people behave. What is less evident, though, is how mathematical thinking can be part of the way anthropologists reason about human societies and attempt to make sense of not just behavioral patterns, but the underlying cultural framework within which these behaviors are embedded. What is not widely recognized is the way theory in cultural anthropology and mathematical theory have been brought together, thereby constructing a dynamic interplay that helps elucidate what is meant by culture, its relationship to behavior and how the notion of culture relates to concepts and theories developed not only in anthropology but in related disciplines. The interplay is complex and its justification stems from the kind of logical inquiry that is the basis of mathematical reasoning. Linking of mathematical theory with cultural theory, we argue, is not only appropriate but may very well be necessary for more effective development of theory aimed at providing a holistic understanding of human behavior.

In this panel each of the panelists will present a short (5 minute) statement that addresses some of all of a series of questions circulated in advance. After the short statements the panelists will then begin discussion regarding the questions and areas of agreement and disagreement. Participation from the audience will be encouraged and the goal is to develop a dialogue among all of the participants regarding the role of mathematical theorizing and formal modeling in developing theories in cultural anthropology, specifically, and in anthropology, more generally.

Panelists:
Paul Ballonoff, USA
Irina Ezhkova, International Institute of Applied Technology, Belgium
Michael D. Fischer, University of Kent at Canterbury, UK
Paul Jorion, USA
David Kronenfeld, University of California, Riverside, USA
Murray Leaf, University of Texas, Dallas, USA
F. K. Lehman, University of Illinois, Urbana, USA
Dwight Read, University of California, Los Angeles, USA (Organizer)
Sander van der Leeuw, University of Paris, France
Douglas R. White, University of California, Irvine, USA

Set of Questions to Addressed by Panelists:

(No panelist is expected to address all of the questions; rather, each panelist will address those question(s) of interest to her/him)

(1) What does mathematics and formal modeling have to do with the study of religious beliefs, ideologies, rituals, kinship and the like?
(2) What does mathematical and formal modeling have to do with culture?
(3) What are some of the major papers that have helped to frame the application of mathematical theory and formal models to culture theory?
(4) What are some of the past successes of mathematical anthropology; that is, what significant issues in cultural anthropology have been effectively addressed through application of mathematical theory and methods?
(5) What are or should be the goals of mathematical anthropology and/or formal modeling?
(6) What are some of the basic issues confronting theories about culture and how can mathematical theories and formal models relate to these issues?
(7) What are the research questions you have been addressing and in what ways have mathematical theory and/or formal models been relevant to your research?
(8) What are possible directions or research topics that particularly amenable to mathematical theory and formal methods?
(9) Does the application of mathematical theory and formal methods help to refine our understanding and definition of basic concepts relevant to cultural anthropology?
(10) Is cultural evolution a topic that could be effectively addressed by mathematical theory and and/or formal methods and if so, in what way?
(11) How does mathematical theory and formal modeling as applied to cultural anthropology relate to the current interest in agent-based modeling, especially since the latter is often seen as a way to overcome inherent limitations of mathematical modeling?

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Notes on the Progress of Cultural Theory

DISCUSSION PAPER FOR THE PANEL
"MATHEMATICAL ANTHROPOLOGY AND CULTURAL THEORY"
CULTURAL SYSTEMS SESSION, EMCSR 2002
VIENNA, AUSTRIA APRIL 2002

BY

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Mathematical Anthropology is, and should be, an essential tool that makes cultural theory into a predictive science. In this way, it differs little from the role that mathematical physics plays for physical theory. Physical theory became mathematical not simply because the mathematics allows quantification, which is a commonly stated reason for the use of mathematics in social sciences. Instead, mathematics has proven to be a tool that allows thinkers about physical theorists to express their ideas, and to study the consequences of their vision of how the universe is constructed. In doing this, mathematics has allowed physical theory to derive specific testable consequences from postulating particular claims about the nature of the physical world, and to verify from evidence whether these predictions are correct. Often in physical theory, the predictions, even quantified ones, result from structural descriptions of reality, and indeed, much of modern physical theory predicts consequences from increasingly subtle and complex structural visions of reality, by the use of mathematics.

One important implication of the vision above is that use of mathematics is not a goal or end in itself. Instead, the subject is cultural theory, which the study of the description and implications of description of the existence of particular cultures. Mathematics becomes a tool of this study, so long as it can contribute to the effort. The purpose is not simply to create "mathematical models" for their own sake. Thus, unlike traditional (general) systems theory, the purpose is also not to find techniques from other sciences and apply them by analogy. Instead, the mathematics used, if any, must be derived from the properties of cultures and reflect the structure of the theories and descriptions.

This approach has been applied in my own research, with increasingly productive results, while also exploring some less productive paths. My initial work[2] focused on a very traditional descriptive aspect of social anthropology: symbolic description of marriage rules. The work created both logical and graphic (symbolic graphs) description of rules, to show that the operation of such rules has certain "minimal" descriptions, and that these correspond to the commonly used representations of marriage rules and marriage systems found in many ethnographies. The work showed that these rules have relationships to demographic measures, and speculated that this relationship might be better represented by use of

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[2] Doctoral Dissertation of Paul Ballonoff, UCLA Department of Anthropology, 1970. The introduction and philosophical parts were rewritten and published as the preface and first chapter of Ballonoff *A Mathematical Theory of Culture*, Monograph of the Austrian Society for Cybernetic Studies, 1987.

techniques from quantum mechanics. That speculation has guided both successful and less successful explorations of cultural theory of marriage rules.

What turned out to be less successful was an effort to literally represent the system using quantum mathematical formalisms, in particular, "dirac" notation. It proved possible to use a dirac notation, on vector spaces of objects (populations) whose relationships are described by operators, but the substantive content of these representations proved to be their structural content, not their analogy to quantum mathematics using similar symbols. The resulting mathematical structure however proved a useful way to simultaneously represent the logical, graph theoretic and visual graphical representations of these relationships in a single notational system.[3] The operators used in that work also proved similar to ones derived in other mathematical anthropological literature and shown to have group theoretical properties.[4]

This however was not yet a representation of the essential cultural insight to which the initial work was directed: the idea that marriage rules have a particular unique minimal representation, and that the properties of this representation could be used to predict testable properties of a culture using that rule. Two essential steps in this direction occurred while working on a new version of the logical representation of rules. The paper "Theory of Minimal Structures"[5] derived a precise logic and set theory representation of the graphs of minimal structures, and for demonstrating that a particular structure was minimal. At the same period, practical applications on ethnographic data led to the empirical discovery that use of statistics derived from the Stirling Number of the Second Kind allowed successful computation of population statistic predictions, from the claim of the existence of a rule.[6] By 1987 I had realized that these two results are intimately related: the formal structure of the Theory of Minimal Structures implied that the inter-generational operator (mapping) was a surjection; as a result theorems of combinatorial mathematics, the combinatorial properties of that are given by the Stirling Number of the Second Kind.[7] But the combinatorial properties of that surjection,relate numbers of families to numbers of offspring, and are therefore predictions of the demography of the system!

This development had a parallel in quantum theory, though it was not quite the one I first thought to look for. Classical mechanics, and thus also, classical general systems theory, uses statistics based on the Stirling Number of the First Kind. But quantum theory uses statistics with a different combinatorial foundation. Thus, the proper intuition to follow from quantum theory was not so much to imitate the operators, but to look more closely as the mathematical structure of the theory and its combinatorial (density function) consequences over state spaces. Indeed, the same lesson could be drawn from classical statistical mechanics. Were it not for the excessive emphasis by social and general systems theorists on the final result of statistical mechanics, that certain distributions seemed universal, it would have been easier to recognize that statistical mechanics derives simply from a possibility density function with certain properties. That is all that is done by the relationship of the Theory of Minimal Structures to the

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[3] See Duchamp, T. and P. Ballonoff "Matrix Methods in the Theory of Marriage Networks", pages 53 – 62 in Ballonoff (ed.) *Genealogical Mathematics*, Mouton, Paris, 1974; and Duchamp, T. and P Ballonoff, Chapter 3 of P. Ballonoff *Mathematical Foundations of Social Anthropology*, Mouton, Paris, 1975.

[4] See H. White *An Anatomy of Kinship*, Prentice Hall, 19??; and the Appendix to that work by Andre Weil

[5] Written 1971 but published in 1987 as Appendix 1 in Ballonoff 1987, per footnote 2.

[6] See examples cited in P. Ballonoff "Notes Toward a Mathematical Theory of Culture", *in Mathematical Anthropology and Cultural Theory, an International Journal*, .Vol. 1 No. 1 November 2000, <www.SBBay.org/MACT>

[7] See D. Schadach, "A Classification of Mappings", reprinted in relevant part as Appendix 2 of Ballonoff 1987.

Stirling Number of the Second Kind. The logic is essentially the same.

Of equal importance to the claim (proven successful as verified by empirical examples cited in the papers referenced in this Note) that minimal structures relate to population measures, was the claim that the minimal structure of a rule was unique. Related to this was the intuition that because of this uniqueness, the population statistics computable from a rule relate to a population of any size using that rule, not just to the minimally sized population. It turns out that these intuitions are also provable using theorems of mathematics. The proof however did not depend on the combinatorial properties. Instead, they related to the fact that these rules can also be represented as operators of logical or graphical systems, with group theoretical properties, and that the critical operators of these rules (the marriage matrix) always has a trace equal to zero. The mathematics known as the theory of group representations shows that in such cases, the operator is always a reducible to a unique minimal representation.[8] While other literature had observed other group theoretical properties of these operators, none had previously sought inferences from the mathematical theory of group representations. It would not be surprising if additional quite useful inferences for cultural theory can be found in that body of mathematics.

Thus, the essential aspects of the fundamental intuition about cultural theory, that minimal representations were unique and predictive of population statistics, were proven by the use of mathematics. That mathematics also has additional properties, of both theoretical and practical use. In 1980 and 1982 two papers constructed a theory using aspects of more traditional mathematical analysis, to show that cultural change has computable effects on change in population measures. This in turn allowed successfully to compute the population path of the 1000 year "demographic transition" of Western Europe, from a knowledge of change in cultural rules alone.[9]

This conclusion shows also that mathematical theory of culture can and does relate to understanding cultural evolution. The 1982 papers show that cultural theory can be used to retrodict cultural history, and thus also implies that cultural theory can be an effective theory for future prediction. That is, cultural theory can be in some ways a predictive forward looking theory of history.

Two other aspects of the Theory of Minimal Structures also demonstrate this. One is that the concept of a minimal size for existence of a particular rule, does not mean the population will always be at that size if the rule exists. Just the opposite, a culture at the minimal size population using a given rule almost never exists; it is called minimal because it is a threshold beneath which the cultural system fails to reproduce. (Thus also, The Theory of Minimal Structures is not a theory of small systems, it is a theory of structural properties of rules, for systems of any size, as also demonstrated by the above cited mathematical properties of the theory of group representations.) The second aspect showing that cultural theory relates to predicting cultural evolution (indeed, to general biological evolution) follows from recognition that the Theory of Minimal Structures is also a biological theory, relating to both genetic and cognitive properties of cultural systems. This viewpoint was explored in several papers published between 1974 and 2000[10]. The fact, found in the most recent of those papers, that the Theory of Minimal

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[8] See P. Ballonoff "More on the Mathematics of Rule-Bound Systems", pages 129-132. *Cybernetics and Systems: An International Journal*, Volume 26, 1995

[9] See P Ballonoff "Mathematical Demography of Social Systems" pages 101- 112 in R. Trappl, (ed*.) Progress in Cybernetics and Systems Research Vol. X*, Hemisphere Publishing 1982, and "Mathematical Demography of Social Demography II", pages 555- 560 in R. Trappl, (ed.) Cybernetics and Systems Research, North Holland, 1982. which are the Proceedings of EMCSR for 1980 and 1982, respectively.

[10] See P. Ballonoff "Structural Model of the Demographic Transition" pages 164 – 195 in P. Ballonoff (ed.) *Genealogical Mathematics* Mouton 1974; Chapter 5 "Evolutionary Implications" of Ballonoff 1987, and in P. Ballonoff "On the Origins of Self-Awareness" in Trappl (ed) *Cybernetics and Systems 2000, Volume II, Proceedings*

Structures contains an equation that has a singularity with real-world interpretation, also supports the view that cultural theory is little different from physical theory.

As the mathematics of cultural theory is better derived, we should expect that more realms of cultural description will yield to description and inference by mathematical techniques. Cultural theory is in fact a hard physical science, dealing with real natural events in the real and natural world.

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of the EMCSR April 2000, Vienna, Austrian Society for Cybernetic Studies. This last listed paper is based on a singularity of the equations laid out in the two papers dated 1982, cited in footnote 9.

Challenges of Cultural Theory: Theory of Cognitive States

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"Man is the measure of all things - of things that are, that they are, of things that are not that they are not" (Protagoras, "Truth")

Abstract. *Cultures are classically considered as being "in the heads" of culture members, humans, and of course in the minds of the anthropologists who analyze them. Anthropology may be considered as a natural science dealing with description of human cultures, and with understanding and predicting their properties. The possibility of constructing a comprehensive theory for this science is now within reach.*

1. Challenges of Cultural Theory

Anthropology requires a comprehensive and rigorous cultural theory. First, such theory should be able to describe and record (reflect) diverse cultural experiences. From these, the theory should be able to generate different forms of knowledge. This may include cultural knowledge (about environment, beliefs, concepts, structures, behavior, etc.), as well as knowledge about culture itself (such as, what anthropologists describe). The theory should include the tools necessary to update this knowledge in a flexible way as information and experience change. In particular the theory should be able to generate and recognize the most stable cultural patterns, including the cultural rules, relations, ideas, metaphors, analogies, behavior patterns, etc., extract these patterns from the available experiences, predict their embodiment in possible cultural languages, and also predict their dynamics and evolution. It would be useful if the theory could, from any particular pattern, find the net of other cultural objects and experiences related to it. It has to be able to describe the cause of these patterns; when and how they arise; when, how and why they remain stable; how they change; how they relate to each other; how they may be transmitted among culture members and between members of different cultures; how they may be replicated over time; how new patterns may emerge from existing patterns; and how they may eventually die.

Next the theory should be able to describe what is "in the heads" of the individual actors in the culture, or of subgroups of actors (such as families, women, men, fishermen, metal workers, etc), as well as of divers communities and societies with specific forms of organization and activity. It should predict the relationships of such actors in common activities, describe possible ways of communication between these actors, and perhaps even, predict the communications that might occur between different cultures. This should allow the ability to "restore" or model the concepts and behavior of diverse actors, such as from analyses of their specific experiences as well as from the evidence of their action. (Archeology, for example, often does it from physical evidence, though not in a rigorous way). And again, such theory should be able to build all of these patterns and their causes as computable consequences of the available experiences. In doing so the theory should recognize and use the most relevant representations for each purpose. Thus the theory should also predict the more general forms of these representations, which are the diverse kinds of languages and other structured forms of communication used by cultures, and other cultural patterns. Moreover the theory needs to embody this experience and knowledge in a general cognitive framework, which should include classifications of perception, and language of a culture, as well as the "sub-knowledge" of subgroups or subcultures within the culture.

2. The theory of cognitive states

Information technology evolved in the last several decades in part, to model human intelligence and cognition in the machine. Much of physical theory became comprehensible in a single framework, once it was recognized that Hilbert Spaces provided a basis for representation of mathematical objects useful to that theory. Operators describing relationships of physical theory are thus now often represented as operators in and on Hilbert Spaces. This can also be done for anthropology using a mathematical theory of cognitive spaces. This work was partly published in 1975-2001[11] and summarized as "universal expert systems" or as "contextual systems". The relationship of these to cultural theory applications (characterized as "Ezhkova machines" or here "E-machines"), including some references to previous publications, may be found in[12]. Such E-machines are entities equipped with contextual systems.

Philosophically, this theory had some roots in the work of ancient sophists such as Protagoras, and later of Kant, Hegel, Nietzsche and W. James, and then also of later Wittgenstein, Quine, Kuhn, Winch, Goodman, Rorty, Gadamer, Foucault, and Derrida. Technically, the theory constructed a vector space of observables, on which operators relevant to the above forms of cultural analysis can be constructed, which observables and operators follow definable rules of logic on the spaces, and which develop and apply specified measures on the observations. This framework allows one to map available experience to appropriate symbolic representations, knowledge and other patterns in systematic ways.

The basic idea of the approach is to construct the cognitive state of each cultural actor A based on their "relevant experience" E(A,t) at moment t. Relevant experience E(A, t) may reflect not only empirical experience of actor A, but also all available to actor A knowledge at moment t, as well as relevant to actor A at this moment interests, motivations, emotions, etc. Depending on relevant experience different actors will respond differently to the same problem. In particular, the same problem P(t) at moment t will be considered by different actors A in a frame of different contexts C_P. In doing so each actor will result in the specific cognitive state $G_{A,P}(t)$. The cognitive space $S_{A,P}$ for representing cognitively normalized measurements in such cognitive state is constructed.

This transition to the relevant cognitive state for each actor can be described by the ***principle of cognitive relativity:***

$$F: (P(t), E(A,t)) \rightarrow (S_{A,P}, G_{A,P}(t), C_P),$$

where F represents the mapping of relevant experience of actor A to the cognitive state $G_{A,P}(t)$ of actor A at moment t, with relevant to this state cognitive space $S_{A,P}$ for cognitively normalized measurements in this state, and to appropriate to actor A context C_P of consideration the problem P(t). In general the cognitive state $G_K(t)$ of the culture K at moment t is characterized by

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[11] I.Ezhkova 'Automatic Logic Inference and its Application to Planning and Diagnostics." Doctoral thesis on Physical-Mathematical Sciences, (Mathematical Cybernetics), Moscow, 1978, 293 pp, (in Russian).

I.Ezhkova 'Knowledge Formation through Context Formalization.' Computers and Artificial Intelligence, Vol. 8, No. 4, 1989, pp. 305-322.
I.Ezhkova 'Is Universal Expert System Possible?' " Software & Systems, N. 2, 1991, pp.19-29,

I.Ezhkova, L. Bianco 'Application of Contextual Technology for Supporting Decision Making in Transportation.' Proceedings of the 7-th International Symposium on transportation Systems: Theory and Application of Advanced Technology (IFAC TS'94), Tianjin, China, 1994.

[12] P.A. Ballonoff. 'Notes towards a mathematical theory of culture', Mathematical Anthropology and Cultural Theory: an International Journal, 1(1), 2000. (http://www.sbbay.org/MACT/)

$$G_K(t) = \{G_{A,P}(t)\} \text{ for all A and all pcP,}$$

where $G_{A,P}(t)$ are cognitive states for all possible actors at time t, for all cultural actors and their communities, for all possible problems pcP faced by that culture. In general case this set of cultural actors includes as well those who do not exist as physical humans, such as diverse institutions, including those that keep the "global" cultural heritage and memories, as well as those which mostly exist "in our heads" (such as perhaps, religions and sciences or technological knowledge.

Another basic principle of this approach is the ***principle of cognitive rationality***: in making any decision each actor is based on cognitively relevant experience. Thus different actors can make different choices to maximize their own cognitive rationality. In response to any decision making problem an appropriate cognitive state and cognitive space for related to this problem measurements are constructed. Cognitive normalized measures of confidence in possible solutions are calculated. If degree of confidence in a particular choice is not high "enough" for actor A to conclude any particular choice, actor A may "postpone" the procedure of making decision. Reasonability, reliability of possible choices as well as confidentiality in recognized concepts, patterns, relations, causes and structures are computable consequences of relevant experience.

Tuning to the context C_P permits to generate set of descriptions of all related to cognitive state knowledge $\{D_{A,P}(t)\}$. Depending on interests and points of view different conceptual "anchors" can be fixed to organize net (web, etc.) of knowledge in one or another way. Such knowledge can be "rerepresented" when another "anchors" and degree of granularity are chosen. Thus causality can be observed as computable consequences from relevant experience and direction of interest (problem in study). In particularly, this may explain why so often we have so many wrong interpretations, explanations and predictions of cultural, historical, political and economical events. Thus the theory of cognitive states permits flexible and sensitive way of knowledge generation and effective treatment of causality, context dependability, negation and functionality.

Normalized distances in such cognitive spaces, and computable measurements of similarities based on them, provide a basis for modeling different kinds of intellectual activity in a fixed cognitive space of one actor and in the space of all possible cognitive states of all possible actors. This includes the ability: to describe concepts, relations among them and their possible structures (nets, semantic webs, etc.) in a given context; to update descriptions as time or experience change; to recognize more stable patterns among them, including behavioral patterns, which might then be preserved in the memory of actors; to discover more appropriate statements of problems, new concepts, relations and structures and, as a result, to construct new sets of cognitive spaces and cognitive states adapted to them; and to represent and re-represent all of this knowledge in the most appropriate way. Algebra and logic of contexts, formalizing such operations as union, intersection, immersion, different kinds of mappings upon contexts and cognitive states (including by analogy, by association, by metaphor, etc.), results in a set of operations in the space of all possible cognitive states. This provides a theoretical framework for modeling diverse forms of interaction and communication between all possible actors. This includes reconstruction by one actor of cognitive spaces of other actors with diverse forms of reflexivity; restoration of their possible experiences by observing their behavior; prediction of their knowledge and behavior patterns; recognition of the most appropriate, stable and productive patterns of behavior and communication; interpretation and construction of possible forms of symbolic communication, including such as verbalization, etc.

A full set of stable contexts, patterns, concepts, their relations and possible structures (nets, webs, etc.) represents knowledge $W_K(t) \subset \{D_K(A,t)\}$ of the culture K at a given moment t. At each moment t, the culture may thus be characterized as a cortege:

$$K(t) = < G_K(t), W_K(t) >$$

In particular the subset of problems related to the specific activities pcP_I and specific set of knowledge $W_I(t)$ of a specific institution *I* defines the culture of that institution: $I(t) = < G_I(t), W_I(t) >$, where "institution" *I* could be any single actor, community, society, collection of interacting actors, subculture, community of cultures, or etc. Thus the theory of cognitive states forms a basis for modeling effective behavior of a single actor, as well as a community of actors. Diverse forms of their activities, including decision making, self organization, adaptation, etc. can be modeled in the frame of this theory. It also permits to reconstruct, analyze and predict possible ways and forms of development of cognition and even its embodiment.

3. Embodiment of cultural theory in E-machines

3.1 Individual E-machines. Consider first modeling the individual actor. The individual actor (here the E-machine) first collects experiences. This would include the results of interactions with the physical environment but also especially of interactions with other humans, including the things learned from other humans, or derived from various knowledge bases or other "libraries" available from the culture (including for example folktales, bodies of law perhaps, written literatures, technical libraries or technical knowledge as available, and so forth). When the E-machine is confronted with a problem, perhaps a need to act or a question from some other actor, it then consults this body of experience, and selects the relevant subset for that problem. By analysis of this relevant subset of experience it "tunes" to the relevant cognitive space for the problem, at that moment for that E-machine with that particular body of experience. That is in accordance with the principle of cognitive relativity: different experiences will result in different cognitive states and spaces.

Next, the E-machine tries to solve the problem by analysis of this relevant cognitive state. Depending on the degree of confidence the E-machine has at that stage, it may also, where possible, consult other bodies of experience, such as to ask other individuals (other E-machines) about their experience, or when available consult libraries or other bodies of collected experience. In effect the E-machine generates the relevant body of knowledge for that problem at that moment, adequate to satisfy some desired degree of confidence that may be possible to achieve within the available time. In doing so, the E-machine might rely only on its own "internal language" as derived from its own accumulated experience, or may rely on that plus the "common language" it uses to communicate with other individuals and information sources available in the environment. As appropriate the E-machine may then act. In effect also, the E-machine constructs the relevant context for each problem.

The entire sequence above then itself becomes part of the acquired experience of the E-machine. In future similar situations, it might initially identify the already collected relevant knowledge, or consult the previously constructed behavioral "rule" constructed as a result of that prior analysis and action, and result of action. Likewise, within any such analysis the E-machine may rely on techniques such as analogy, metaphor, allegory, association, and so forth, to construct either the relevant body of experience (relevant knowledge) or to construct an applicable rule of action. All such operations are formalized in the framework described above, and are based on the analysis of contextual spaces as well as on the algebra and logic of contexts.

The ability of E-machines to use different cognitive spaces permits each to formulate, reformulate or re-represent knowledge. Such cognitive spaces may be those of the particular actor or culture, including new cognitive spaces discovered by analysis or additional experience, or by imagining the experience or cognitive space of another actor. In this last case, the result is to restore (model) the experiences or cognitive state of that other actor. This also permits E-machine to predict the description of the same situation from the point of view of another actor.

3.2 Actors, their interaction and communication as E-machines. E-machines may represent all possible cultural actors, including individuals; institutions; subcultures; cultures; communities of cultures (such as

the European Union or NATO) which may be observed as a single actor and which has its own experiences, interests, etc., and who may respond as a single entity to problems. E-machines compute an appropriate set of cognitive states, and find a correct critical perception of the context of the problem. Libraries of relatively specialized sets of experience or cultural patterns mentioned earlier may be also viewed as E-machines of similar construction; they are essentially bodies of accumulated previous experience and perhaps resulting behavioral prescriptions or proscriptions. These institutions (rituals, bodies of law or etc.) are consulted to find the relevant subset that is the appropriate cognitive space for the immediate problem, which generates the appropriate knowledge given that experience for the solution of the problem, which prescribes or proscribes an appropriate rule of behavior, and which may then accumulate the outcome and learn from that experience.

When two different actors with the E-machine equipment communicate, their respective cognitive states may be considered as interacting. It is possible to find where their representations "interfere" with each other (in the sense that two waves may interfere into a stable picture) and thus form relative maxima or relatively stable patterns that are common to the experiences of each actor. In the process of such communications they may adapt patterns from one-another's cognitive spaces. Study of such common stable patterns or points of "interference" in a community of actors leads to the ability to reconstruct common symbols, descriptions and languages. Attempts at communication might arise initially as learned behavior of each E-machine based on experience in interacting with others. But at some point it becomes beneficial for the E-machines to realize that certain actions or patterns of actions can be taken to have predictable responses in other E-machines. Language can thus arise (or any other form of symbolic communication) through the same processes already described.

Thus a set of similarly equipped interacting E-machines can generate common bodies of experience and associated common patterns of applicable rules, including modes of communication (such as language). These can then be described as some for on collective (common) behavior. Thus this group of interacting individual E-machines can self-organize into an entity with a common culture, with the same mechanisms of operation as does the individual e-machine cognition or culture described above.

3.3 Relativity through Uniqueness. Above we discussed how an individual E-machine constructs its internal cognitive spaces, in effect, its own "culture". Therefore the cognition of each E-machine might be completely unique to that E-machine, given its own history of experience, and thus the relevant cognitive spaces generated in each case, and resulting behavioral rules, might also be unique. E-machine cognition therefore also exhibits another feature important to cultural theory: cultural relativity. This occurs due to the principle of cognitive relativity described above. Under this principle each cognitive space generated in each instance, whether at the level of the individual E-machine or of the culture or of a cultural institution, is expressed relative to the particular problem, based on the specific history of experience and any already evolved systems of representation or history of successful behavioral rules, etc., of that E-machine. In the operations of such an e-machine, relativity may be precisely defined and described.

Note first that each individual E-machine acts using it's own experience, including where possible what it may have learned from other E-machines. Thus, each can be quite idiosyncratic, depending on the particular history of accumulated experience and transmitted resulting behavioral rules. Just as for actual humans, accidental features can affect the cultures that evolve. As a simple example, perhaps in the initial instance of some event the times for relevant action were different for one set of E-machines than another. Then the analysis of the relevant cognitive spaces differed, and thus the resulting action chosen, and effect of that action differ. Since these form part of the accumulated experience, then the accumulated experience, including prior history of reliable rules of action, differ.

Being idiosyncratic however does not imply irrational. Just the opposite, in correspondence with principle of cognitive rationality, since the e-machines learn from their own past behavior and other experience,

especially, in solving problems vital to their continued existence, then they will also learn to act "rationally". The cognitive space of the individual or of the culture might not even have an explicit "science". For example, the planting cycles might be expressed entirely by religious rituals. But even so, the selections of behaviors that result from this process will exhibit rationality within the normally experienced environment. That is, as the system learns and acts, it applies the principle of cognitive rationality: any actor, at any moment, in response to problem P, selects the solution that maximizes the actors' confidence.

3.4 Dynamics and Evolution. Cultural systems are open to unpredictable variations and should be able to react to them. Thus occurs in part due to the presence in the environment of each E-machine (or in a real culture, each human) of so many other similarly constructed E-machines (other humans), each with unique histories of experience. Each actor finds only some subset of the set of all possible experience, hence may evaluate problems in relatively unique ways. Mathematically, these accumulated experiences and resulting rules might act like "filters" in forming future cultural behaviors. Practically, this implies that the E-machine framework allows study of cultural evolution, as well as cultural variation. The dynamics and evolution of cognitive states of knowledge of each culture (or subculture) may be computed (characterized) by time dependent functions of their changing experiences.

Research on the evolution of intelligence shows that a critical ability of human intelligence is the ability to re-represent knowledge[13]. The ability of E-machines to re-represent knowledge and develop appropriate languages, models this very important feature of intelligence. The depth and flexibility of this feature of intelligence of actors defines their survival and success. It supports the ability to develop common representations and languages, as well as sensitivity to new problems. This results in a Darwinian vision of the evolution of cultures, because each is subject to some form of selection for effectiveness of its own action. Perhaps it is not unfair to think of each culture as an evolving organism, adapting to an ever-changing external and thus internal world.

4. Conclusion. Cognitive theory, E-machines and Anthropology.

The theory of cognitive states and its embodiment in E-machines forms a comprehensive framework for a theory of culture. As we discussed above anthropological theory needs to deal with three related problems: the culture as constructed by individuals, the culture as shared among individuals in the "same" culture, and the observations about either created by anthropologists. The operations of each of these can be constructed as an E-machine. The mathematical theory of E-machines permits that the various objects constructed by the operation of the E-machine are themselves subject to mathematical operations, including as appropriate various logics or algebras, in which the experience itself and/or the constructed objects, are the objects on which these operations take place. Thus it is possible to study effectively self-consistency, conflicts, basis for doubt, and so forth, within this framework. Because the E-machine itself can also do this, as it has such mathematical analytical capabilities, this is also part of how it may learn from experience, etc.

Also it was shown how this logic of E-machines enables anthropologists to do their work. If one knows that an E-machine is the general operation of the culture, then the job of the anthropologist, at least in part, is to observe the behaviors, and reconstruct the logics, etc. that create them. That is, knowing the general structure of the E-machine, the anthropologist can then "reverse engineer" the operation of the E-machine given knowledge of the outcome of operation. By observation, the anthropologist can "restore" what may have been "in the heads of" the culture members (the individual E-machines), and/or, restore the contents of the various cultural institutions, which as explained, are themselves constructed as such E-machines.

[13]See R. Davis 'What is Intelligence, and Why?' *Presidential address, Proceedings of the AAAI conference,* 1996.

Idiosyncratic behavior of such E-machines of course also means that the anthropologists may have their own unique perspectives. Anthropologists are after all just humans, each using their own internal "E-machine" (including the specialized cognitive space of knowledge called "anthropological theory") to study the operations of cultural E-machines. This also helps explain why the field of anthropology, itself a natural science, has found it so much more difficult to develop as a rigorous science than the more overtly physical sciences.

Classification, Symbolic Representation and Ritual: Information vs meaning in cultural processes

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Anthropologists synthesize collective representations at a symbolic level. Using a range of literary and expository techniques and conventions, they communicate a sense of the content of these representations, how they vary, and how these change over time. They also produce detailed descriptions of human behaviour, though of necessity these are also often synthetic, drawn from a lot of partial experiences or individual's accounts of experience.

Where anthropologists have found difficulty is in the critical area of relating the symbolic to the descriptive. As D'Andrade (1995) relates in his account of the development of cognitive anthropology, it is only since the 1950s that explicit systemic relations/distinctions between concepts and behaviours has been available to anthropology, though one can find less explicit use of this idea in earlier work, especially that of Whorf as early as the 1930s. However, the norm is to either consider the idea and the action as one (e.g. if X says she does Y, QED she does Y), to produce analyses of the world as if it were contained in language, or to produce detailed descriptions of behaviours with some handwaving interconnection with 'beliefs'. Such descriptions make no distinction between the two, e.g. between what is ëknownî or ‘believed’ need be enacted, and the actions themselves. The excuses for this have not been very convincing.

Anthropologists have been long concerned over the analysis of the less material creations of people. In particular those entities that appear to be creations of the mind. However there are severe problems with the approaches that have been used. Firstly, symbolic approaches have been rather successful at uncovering good ideas for relationships within society, possibly the only manner for producing these. However, they fall short in being able to establish that these ideas are anything beyond good ideas. That is, there is no immediate method for testing these revelations. The classical methods for doing this, triangulation and participant observation go some of the way, but fail to provide methods of confirmation that themselves can be easily compared or generalised. Results from four prior research projects together with some pilot research suggests that suitable application of information theory may provide an initial means of extending the range and power of more traditional methods, at least for a limited domain of ethnographic problems.

Investigating the interface between ideational and material systems .

Although meaning and ideas are rather more than information, these are impossible without information and the channels through which information flows. Information theory suggests a number of conditions that must exist for meaning and knowledge to exist.

What we would hope to accomplish using information theory to investigate the structure of symbols used to represent different contexts? What is the contribution of the presence of a given symbol in terms of information - of the different possible interpretations, what is the information potential of the sign/symbol with respect to each interpretation? And what is the information potential of the interpretations with respect to the symbol? It may be the case that symbols imply many more contexts than each context implies symbols. That is, symbols are associated with contexts, rather than contexts associated with symbols. This would be the case if, as we often assume in discourse, symbols are more general instantiations than contexts. This, of course, makes a bit of nonsense of the notion that the meaning of symbols is context dependent. What we should be saying in this case is that symbols are classificatory targets associated with contexts. Their meaning is the context plus the information potential of the context as instantiated by the symbols that can be associated with the context. The symbols are not in the context at all, they are products of the context.

We can measure this potential in a number of ways. Across subjects we could use correlation, with r-squared being the information potential. But this is difficult to control, and very difficult to accomplish under fieldwork conditions. Another approach is to produce deontic parameters rather than probabilities ones. Probabilistic parameters operate on the assumption of direct or indirect causality; e.g. either one factor causes another, or the factor is proportional to another (perhaps unknown) parameter that causes the variation in the second. Deontic parameters indicate enablement as the principle representation of variability. Non-variation is handled by obliged and ~permitted operators. The permitted operation is also itself non-variable. But within a flow of independent stochastic events, permitting and ~permitting formulae can modulate the flow of logic in response to these events using much simpler models that would be required if we were to insist on a local causal model incorporating both variable values and variable degrees of applicability which can get very messy very quickly.

The deontic formulation requires finding/constructing absolute enabling conditions, which can have a complex aetiology. However, this is much easier than collecting reliable data to support overtly causal analysis. Indeed the use of a distributed deontic framework for situating data collection and analysis may prove to be a useful starting point for progressing more detailed quantitative approaches.

Entropy and information in culture.

What are the costs of maintaining one cultural knowledge vs many. Indeed what is the cost in information of too many. Is there a practical way to implement measurement in a meaningful fashion based on information and entropy.

Entropy is a measure of order in a system of structures. A system of structures can be seen as the predictability of a system. Human systems must fall within certain boundaries to work, not too little entropy, else the system be too rigid, and not too much or predictability falls below limits necessary for survival or communication. The system of structures here falls into two categories. First, the system as perceived by the agent. Second the system as it 'really' is. The difference in potential entropy between the two systems is very interesting.

People work through models of systems, not the systems themselves. Information theory, while it cannot address issues of content or interpretation of the symbols information etc., can address the foundations upon which these must depend, providing a basis for more rigorous argument, and providing a means to support one view over another, since some arguments will depend on informational structures that can be proven not to exist give specific data. It also provides a way to evaluate phenomenological arguments - although we cannot prove that we know how people perceive their world, we can know something about the structure of what there is to know, and how limited the constructions are to deviate on specific issues.

Thus in the case of the Nggwun ritual of the Mambila of Somié [Zeitlyn and Fischer 2002], we cannot know what or how the Mambila perceive Nggwun, but we are certain they do perceive it as it is their ritual after all. We can make judgements about the entropy of their model of Nggwun (indeed their model of Nggwun generates a reality that we must produce a model of to describe and understand).

The major aspects of IT that we can exploit here are levels of entropy, and more specifically the intervals these represent. There is the ambient entropy, E_0, that which we would expect to find if all the considered information in the system was independent of all other information under consideration and is equiprobable. E_1 is the entropy that takes into account the relative frequencies of the information designators. E_2 is the entropy that takes the conditional probability of the information in pairs. E_3 the entropy based of conditional probability in triples, etc.

This is fine for situations where we have complete inventories of possible symbols and accurate counts. But many of the problems we might like to apply this method to are not so well defined. We can, of course, work with the inventory we identify. Indeed we may be able to devise a test to establish the etic/emic status of a symbol by the way its entropy is patterned. Deontic reckoning would be based on the

total number of contexts where we believe that a symbol could be present relative to the number that it appears in relative to another symbol, the number it appears in relative to the absence of this same symbol, and the number of contexts where it does not appear.

Thus E_0 is simply the number of symbols divided against the number of contexts. E_1 is the number based on the actual presence or absence of the symbol and context. E_2 is the co-occurrence with and without a given symbol and the number in which it does not appear with and without this symbol. E_3 is this relative to pairs of symbols, etc.

Pragmatic Information Theory and Cultural information - OR - Nonmonotonic Information Theory and Powerful Knowledge

If culture is truly 'shared' the information content of many cultural acts is very low or zero - no information is required to 'anticipate' the act. This does not mean it is not useful but simply that no information is transmitted because the message, as such, is already known.

If there is information transmitted it is only because it is possible that the message is not the only message. There must be contingency for there to be information. ?There are two possible states when there is contingency. One is if the 'expected' response occurs that no information is transmitted because the message was anticipated and expected, e.g. the expected entropy is zero (although the actual entropy for the situation may well not be!). However, there is entropy if the response is marked, because it was not anticipated. This ties into the marking theory of (Trubetskoi/Jakobson). What would our formulation of information theory be if some of the messages have zero information and some messages have information? Indeed, can we predict the typical amount of contingency in a system, or can we treat all information laden responses as effectively the same (though with differential probability), but the zero meaning message being the most probable in a situation.

On the other hand where the expected message is itself based on prior information (like social status), where is the information...in the indices of social status, or indeed does the message itself have meaning because it denotes social status. E.g. the message has zero information relating to the primary domain of the message (such as discussing women), but itself represents information because it denotes information by being the contingent response it is
To the extent meaning and information are related, there is no meaning if we know. There is information if we learn.

In the end, a zero state of information required for cultural systems to work. There are, of course, two possible zero states; one where no messages (which in our terms suggests no interactions), and one where all the messages are known and expected. The latter would necessarily be the zero information state for

culture, by definition, once we had actually evolved culture. But likewise human culture requires contingency to operate. The trick is to identify the balance of contingency within which cultures (or more accurately, cultural beings) operate.

This is possibly one of the misunderstanding points between Evolutionary Psychology and Cultural Anthropology. Does EP explore some partially specified set of zero points, or does it indeed define some of the strategies for deviating from the zero point? Or does it, as some anthropologists claim, represent a different kind of currency altogether.

This is an interesting issue, and one that can be addressed based on evolutionary evidence. In looking at the development of intelligence in the hominids we have three kinds of phenomena that we can look for traces of, and possibly simulate some of the properties of.

First is the development of innate cognitive strategies. E.g. what phenomenal attractors have developed over time to benefit hominid populations? These would include the capacities needed for creating and reproducing tools. These would be abilities that were not just the simple product of learning, though they could be related to those in the second point. Second, is the incremental development of intelligence. This indicates abilities that can be recreated by individuals each generation with limited input from others

Third is the development of transgenerational knowledge. This may be simply a feature of one and two, but more likely depends of the development of some cognitive features beyond that.

What would be the nature of these 'innovations'? Not 'hard wiring' in the traditional sense, but some kind of tools for doing what we do. Thus violence need not be an inherent factor for humans, but we know how to do it and use it as a tool without education. But education can improve its use. Society can create situations where the violence tool is of limited or directed use or even counter-productive.

We can start with a simple sequence of models:

1) Model 1. Increasing intelligence, individual animals. No communication between organisms, each has to discover properties for themselves.

2) Model 2. Increasing intelligence, egalitarian social structure. Individuals follow individual who seems to know what to do.

3) Model 3. Increasing intelligence, dominance behaviour. Most organisms follow a few dominant organisms.

4) Model 4. Elementary learning from others.

5) Model 5. Elementary transgenerational learning.

6) Model 6. Full scale transgenerational learning.

Accounting for human activity through physics

Paul Jorion

> « After all why should the way mathematics is used to talk about people differ from the way it's used to talk about planets » (Sneed 1979: xxiii)

> « Aristotle was a thorough-paced scientific man such as we see nowadays, except for this, that he ranged over all knowledge. As a man of scientific instinct, he classed metaphysics, in which I doubt not he included logic, as a matter of course, among the sciences, - sciences in *our* sense, I mean, what *he* called theoretical sciences, - along with Mathematics and Natural Science, - natural science embracing what we call the Physical Sciences and the Psychical Sciences, generally. This theoretical science was for him one thing, animated by one spirit and having knowledge of theory as its ultimate end and aim » (Peirce 1992 [1898]: 107)

It has now become possible to encompass most aspects of human activity within the scope of *theoretical physics*. Bringing this task to fruition requires but a slight change of perspective in the way all manners of human activity are currently envisaged.

As a way of introduction, a brief portrait of theoretical physics is depicted in such a manner that the expansion of physics into the human realm becomes evident in the process of exposition.

Theoretical physics is defined here as a composite model of the workings of nature (ancient Greek *physis*) whereof the four main components are *classical mechanics*, *quantum mechanics*, *thermodynamics* and *relativity theory*. The reason for distinguishing these four components is double. Firstly, the combining of them is currently not seamless; secondly, it is the rationale underlying the current imperfect articulation of these four components which surprisingly opens physics to its expansion into the human world.

Historically and conceptually, *quantum mechanics* lies in the continuation of *classical mechanics*: the discovery by Max Planck that there is an irreducible size for units of energy came as a surprise when tackling a specific problem (black-body radiation) using methods otherwise typical of *classical mechanics*. *Thermodynamics* and *relativity theory* are what Einstein aptly characterised as « principle theories » [14]: theories which do not derive from the necessity of accounting for a discrepant experimental fact, but do generate a novel all-encompassing framework within which to recompose a picture wherein existing theories are rearranged with but modest

[14] « The longer and the more despairingly I tried , the more I came to the conviction that only the discovery of a universal formal principle could lead us to assured results. The example I saw before me was thermodynamics. […] « The laws of physics are invariant with respect to the Lorentz-transformations [...] This is a restricting principle for natural laws, comparable to the restricting principle of the non-existence of the *perpetuum mobile* which underlies thermodynamics. » (Einstein 1949: 53, 57). « Einstein makes the distinction between constructive theories and "theories of principle". Einstein cites as an example of the latter, the relativity theory, and the laws of thermodynamics. » (Holton 1973: 252).

modification. To this extent, *thermodynamics* and *relativity theory* are of a nature similar to that of the *heliocentric model* of Copernicus (Reichenbach 1970 [1942]: 122-123).

In an oversimplified view of the two main theories of knowledge pervading theoretical physics, *positivism* which holds that *ideally* physics should content itself with measurement of natural phenomena, and *philosophy of Nature* which holds that *ideally* physics should be generated on a deductive mode only, *classical* and *quantum mechanics* lean convincingly towards the *positivist* perspective while *thermodynamics* and *relativity theory* lean decisively towards a *philosophy of Nature* standpoint (Meyerson 1995 [1927]: 676-683). As a whole, the integrated body of theoretical physics remains inextricably committed to both measurement and deductive reasoning in equal parts.

The encounter of *quantum mechanical* and *relativistic* approaches when dealing with gravitation demands an interface where, at a certain scale of energetic exchanges, the curvature of space produced by the proximity of a massive body - which accounts for gravitation within the *relativistic* framework - transforms into the dual wave-particle of the *graviton* - which accounts for gravitation within the *quantum mechanical* model. Hence the necessity for considering that certain thresholds of a quasi-"transition phase" nature exist in the physical world and require appropriate description.

The recent « science of complexity » deals especially with such *borders* between energy strata of the physical world. In the idiom of « complexity », *emergent organisation* amounts to the particular *non-linear* ways in which transition occurs on such structural borders within the physical world. The non-linear modelling provides with the « interpreter » translating what takes place on the lower side of the border into what takes place on the upper (Kauffman 1993, 1995, Stein 1989).

Such borders between adjacent strata are not to be seen as « hardwired ». « Coherent » phenomena provide examples where energy borders are trespassed upwards due to the collective and co-ordinated behaviour of elements belonging individually to a lower level. The *maser* and *laser* constitute compelling examples of *quantum mechanical* behaviour displayed at a macroscopic level where the principles of *classical mechanics* apply otherwise. Roger Penrose suggested (1989, 1994), after Hameroff and his collaborators, that « consciousness » in human beings is of such a nature, i.e. a beam of coherent energy quanta travelling through the cytoskeleton of microtubules of cells and of neurones in particular.

Coherent phenomena no doubt undermine the clear-cut picture of a fully stratified world of nature, each stratum displaying its own ways of operating; they do not lead however to the thoroughly « intricate hierarchies » that some have been suggesting. Coherent phenomena irrupt higher on the structural ladder than their *natural* energy level, in a way not dissimilar to that of a geyser erupting intermittently from the entrails of the earth. No more disruptive of the overall picture are the *gravel pits* of « chaos » which, independently of scale, remain self-similar through their full depth, producing at every degree of magnification *fractal* paths of invariant dimension within their phase space, or, the *dissipative systems* - among which, most prominently, living creatures - managing through a constant drain of external energy to keep at bay entropy within a restricted space and for a finite time span only (Glansdorff & Prigogine 1971, Prigogine 1980, Nicolis & Prigogine 1977, 1989).

The reason why attempts at accounting for human activity within the framework of *theoretical physics* have failed so far derive from misgivings about physics' endeavour. *Mechanics*, especially in its Modern Times beginnings, put a premium on *objectivity* understood as the staging of experiments within controlled environments where human interference is reduced as much as can be to a minimum. Such were the constraints for making measurement meaningful. The concern for *objectivity* was so pervasive that in the early stages of *quantum mechanics* one common interpretation for the puzzling nature of complementarity was indeed that of a breach of *objectivity*: the human observer, so the story went, « cannot help » interfering with the experimental set-up once the minuscule energy scale where quantum phenomena are taking place has been reached [15].

Although *objectivity* pertains to the sound methodology of physics, it is independent of its aim of modelling the world of nature. Those who have attempted so far to build a physics of human activity, have failed in their large majority to make such a necessary distinction. They have tried to maintain *objectivity* at all costs, studying man with the self-contradictory - and evidently self-defeating - concern of precluding any human interference with the reality being studied. In so doing, they have shown themselves oblivious of the fact that the phenomena they were examining were in no way disturbed by human actors but purposefully generated by them. Resorting to linear algebra or, in earlier versions, to calculus, *price* has been presented as resulting from the crossing of twin curves standing for *supply* and for *demand* - similar to mechanical forces such as *gravitation* or *electromagnetic forces*. Price results in actuality - and as everyone effectively knows - from the encounter of buyers and sellers, human actors located within a social hierarchy and intending to either make a profit or to reduce their costs. Such purposeful behaviour is intrinsic to the facts and cannot be dismissed as an extraneous factor likely only to blur proper modelling. Similarly, *formal logic* has been constructed as an ortho-modular algebra by theoreticians content to regard truth as a simple multi-valued variable, and to build models purified from meaning, equated here with extraneous « noise ». Theoreticians have this time shown themselves oblivious of the fact that logic is a praxeology, beyond the non-committal nature of mathematics, the land of empty symbols. Theoreticians should have been made aware of this by the observation that logic provides meta-mathematics with its tools (« meaning » makes its presence inescapable at the foundational level of mathematics at least).

The program of an expansion of *theoretical physics* to things human requires that additional strata of structuring be considered, imposed, first by the fact that humans speak and listen, second by the fact that humans have an economy embedded within that speaking nature, implying in particular that goods circulate as to their price. A simplistic example relying on commonplace evidence will be presented first, then a more sophisticated one resulting from the author's own empirical research. The image of an army marching in step recurs in textbook

[15] The actual explanation does not involve any « disturbance » of the type. In the terms of Niels Bohr, one of the early actors in the history of *quantum mechanics*: « ... any measurement of the position of an electron by means of some device, like a microscope, making use of high frequency radiation, will, according to the fundamental relations ($E = h\nu$ and $P = h\sigma$), be connected with a momentum exchange between the electron and the measuring agency, which is the greater the more accurate a position measurement is attempted » (Bohr 1949: 208-209).

explanations of the behaviour of light [16]. The example may be taken literally and then reversed: indeed an army marching in step can be regarded as a coherent *beam* of bodies moving collectively and in synchronicity. That such a « beam » displays behaviour that neither the individual bodies are able to display taken individually, nor a similar collection of them when not acting collectively in a coherent manner, is revealed by the fact that a regiment is able through the harmonics produced by the coherent shock waves of its synchronised step to make a bridge crossed by it to collapse [17]. The coherence in behaviour has in this instance triggered a « generalised catastrophic » process which in circumstances where no human beings are involved only natural phenomena mobilising considerable levels of energy are likely to provoke, such as a hurricane or an earthquake. To pursue further with the army example: armies are able to bring levels of destruction which are only partially attributable to the sheer mass of men involved, the moving force lies here in fact essentially in the co-ordinated effort of the participating actors.

Now for a somewhat more sophisticated example. Human populations are constrained just as any other living population by the carrying capacity of their environment. In the slash and burn type of agriculture, human dwellings meet at some point of their demographic development the diminishing returns linked to too remote fields having to be tilled. At such point in time, fission of villages occur and part of the population emigrate to colonise more distant land. The fact remains that slash and burn agriculturists lack the reflective skills which would allow them, firstly to become fully aware that they have exhausted the carrying capacity of their environment, and secondly, to take the rational decision of splitting. What is observed in practice (see Jorion 1987) is that in the period that precedes village fission, witchcraft accusations flourish, more especially between chief sons who are the most likely candidates to ultimately either conduct an emigrating party or to take the lead of the part of the population which stays at the original dwelling. Similarly, I have described (Jorion 1982, Delbos & Jorion 1984) effects of economic pressure due to growing families ending up in the fission of European fishing boat crews (mutual accusations of sabotage taking here the role played by witchcraft accusations in Africa).

Now about the need for adding new strata to a representation of the physical world due to the special nature of man as a speaking, working and trading animal. Let us think of a particular type of marching army, that of a crusade. The regiment crossing the bridge is being commanded: there is a commander yelling orders and making sure when some start walking out of step, that a co-ordinated step is regained. *Commands* generate the type of action at a distance which has been the source of much puzzlement in the history of *mechanics*. When it comes to human beings, non-local effects due to the usage of language are so familiar that they have ceased to be a source of amazement. Words constitute the main spring for co-ordinated behaviour in human beings. It may be supposed that a contemporary army only walks in step because of a considerable degree of coercion being exercised onto its members. Let us leave aside here the hypothesis that the crusades which shook the West and the Near-East in the Middle Ages played a role of *fissioning* larger communities in an environment where carrying capacity was depleted (as described above) and let us concentrate on the fact that crusades involved armies essentially moved by a

[16] About Huygens's explanation of refraction, Michael Sobel writes: « Or thinking of an analogy, ranks of marching soldiers crossing a boundary from concrete to sand. » (Sobel 1987: 11).
[17] More recently, for Great Britain's 2001 « Science Day », children of school age managed to trigger a measurable earthquake by jumping up and down for a minute over the whole country.

common belief. (This applies more especially to these spontaneous crusades such as the « children crusade » which ended pathetically in drowning in a process reminiscent of the *coherent* behaviour of lemmings in their frenzied - and often ill-fated - race towards an environment where a *carrying capacity* untapped by their species remains).

From a physical point of view, belief systems are nothing more than « words » organised in a particular way and attached to emotional values: words which have grown « natural » connections between them, which we label their « meaning ». Words only hold the pervasive powers which is theirs because of the human disposition to « believe » in them, to let them « gain the soul » as the ancient Greeks used to say, or to adhere to their meaning as we would state in modern parlance (Jorion 1990a). Human beings in their capacity of *speaking* creatures behave to a large extent in the way expected from particles in a field. Of course the *field of language* has no materiality, the older philosophy would call it « spiritual », but no less than for instance an *electro-magnetic field.* There is no substrate to language other than the bodies of the speaking humans, in the same way as it was proven at the beginning of the twentieth century that there is no « ether » required to carry the *electro-magnetic field* (Balibar 1992).

To *command* is to express commands, but commanding as Adam Smith observed, is also « passing commands », i.e. ordering goods (Smith 1976 [1776]: 48). As had been noticed before Smith by Quesnay, *commanding* goods can only be done through making *advances*. The type of societies wherein we live happen to be themselves stratified in such a manner that it is the same individuals who are in a position both to *command* as do army chiefs and *command* through making *advances*. Reviving a suggestion made initially by Aristotle I have in several instances (Jorion 1990b, 1992, 1994a & b, 1995, 1998) shown that *prices* are being formed in a way which reflects fully the *social forces* which permeate human societies and which the relative status of buyer and seller allows to measure exactly. From the situations of barter which Aristotle had in mind down to the contemporary financial markets, prices are fixed by the objective forces of *buyers* and *sellers* and determined in such a manner that the relative status of the social groups involved is automatically reproduced in its *status quo ante*.

The « fields » of *words* and of *prices* shape in their own ways human activity in our contemporary human societies. The specificity of these *fields* needs to be fully investigated and determined as physics would do with other natural forces: a universe of inquiry opens up where the power of words is shown to shape the working activity of the human animal.

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Culture and Society: the Role of Distributed Cognition

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"Society", in social science, normally refers to patterns of grouping and interaction via which a collection of individuals forms some extra-individual entity. The mere proximal juxtaposition of some set of individuals is not enough; the individual have to behave in some way such that their behaviors are interdependent and organized. There must, thus, exist some basis by which goals, emotional states, intended actions, and so forth are shared, and by which members of the given social unit and/or system are distinguished from non-members. For some biological species this needed information seems perhaps to be innately given, but for human societies the rule of such innate bases seems much more minimal and less direct.

"Culture" normally refers to the shared system of knowledge, feelings, and behavior (and, sometimes, their products) that characterizes one human community vs. another. Culture, thus, is not directly innate (though it may well be responsive to various innate dispositions) but is learned. At the same time, in general, it is not explicitly or formally taught; we glean its regularities from our experience with others and we each construct our representations of the shared system on the basis our our experience. Shared experiences plus exigencies of communication--whether direct or indirect (via the requirements of shared or interactive behavior)--keep the individual representations of members of any given community adequately similar.

Either included within culture, or standing as a major parallel learned system, is language. Language is in many ways tightly structured and susceptible of rigorous formal characterization. Attempts have long been made to pattern understandings and representations of culture on those of language. The problem is that culture is nowhere nearly as tightly structured, but us much more of, in words Robert Lowid took from Shakespeare, "a thing of shreds and patches". Like the pieces in a patchwork quilt, parts of culture (such as kinship, ethnobotany, and--most extremely--language) are tightly and coherently organized, while other parts seem less so; and like the patchwork quilt, the whole has a shape and form, but no overarching structure.

Culture and society, as seen here, are mutually constitutive. Culture provides the shared knowledge system which enables members of a society to recognize fellow members and to coordinate

their actions with one another, while society provides the communities, and thus the patterned interactions and experiences, out of which individuals construct their representations of culture.

Since culture (like language) is intrinsically social, and only exists as a social device, it cannot be what is in any single head, but has to consist of socially shared forms. But since culture has no existence outside of our individual representations of it, and since these representations are variable, there exists no single place where the whole of any culture is stored or represented. Thus culture is necessarily and intrinsically a distributed system.

At the same time, culture's various sub-systems--the various patches--consist not in memorized behaviors or fixed knowledge but in productive representations (based on flexible and adaptively growing knowledge systems) that are capable of generating novel responses to novel situations that are still systematic enough to be understood and appropriately responded to by others in the given social system.

The social system is similarly complex. We do not belong to few and fixed social groups, but a great number of ones that range in size from a few people to millions, that range in durability from evanescent to a duration of centuries, that range in awareness from totally subconscious to publicly and legally inscribed. The groups include occupational groups, ethnic groups, recreational groups, neighborhood groups, etc. Many participate in hierarchical levels of inclusion (as where a neighborhood is part of a town which is part of a region). We share many of our memberships with many of those around us but we share them all with no one and no two share the same precise membership.

The preceding suggests a mode of cognitive functioning that is oriented toward rapid leaps (vs. careful inductive generalization) to tentative generalizations (categorizations, but also what are often called rules)--and rapid reassessment of generalizations that don't appear to work. Work in cognitive psychology concerning information processing has offered some insight into how this process works. Many of these generalizations are about the physical world, but others are about the social world of individuals and groups of individuals. We seem disposed to distinguish, inter alia, between animate or willful beings and other stuff. In understanding the behavior of animate beings we, I think, refer it to our own motivations and linkages--to what would produce the given behavior in ourselves. Prototypically this reference pertains to other humans, but I think it also extends to other animate objects--animals, cartoon characters (as in the dish that is running away with the spoon), and to apparently capricious machines. I think also that this self reference is how we seek to understand the behavior of collectivities or groups; we think of them as if they were individuals and assess their behavior--with motives, instrumentalities, etc. accordingly. As described, this mode of functioning is particularly human, but I do want to suggest that much of it is more generally mammalian--especially as seen in social carnivores--and maybe avian.

Analytic and experimental questions on the social side include how we link individuals to groups--and, thus, how we recognize social entities (categories and groupings). Is it an even or a process; what sorts of feedback and interaction are involved. On the cognitive side they include how we form our hypotheses, how we recognize and respond to feedback, how we emend our hypotheses. How do we decide which groups to link which cognitive properties to ? In that process how do we deal with the myriad of overlapping groups with which we interact. Remember all that we actually, directly experience are individuals; we then have to determine to which larger entities to ascribe what of their behavior and what of the motivations, values, perceptions, and so forth that we infer from that behavior.

It is in this context that potential alternative kinds of cognitive structure become important. Are we talking of rules for behaving (as in formal grammars) or of more externally perceived patterns on which we then might model our own behavior or our interpretation of the behavior of others? Are we recognizing encountered situations on the basis of the intersection of defining attributes or on the basis of some similarity to some prototypic situation; is the prototype defined by an abstract set of defining features or by some more whole gestalt? If prototypes be the basis, to what degree or under what conditions are alternative groups defined by differing patterns of extension from shared prototypes--vs. by contrasting prototypes ? To what degree (or, under what conditions) are our prototypes relatively static or fixed pictures--vs. dynamic moving scenarios ? Can they be simply propositional? And so forth to many more such questions.

I have been involved in two kinds of research aimed at exploring and understanding these cultural and social processes. I used a computer simulation of a collection of simple critters ("starlings" in one context) to explore the minimal properties necessary for a social group as opposed to a simple collection of individuals--i.e., Durkheim's emergent properties. More recently I have increasingly become involved in experiments with and analyses of "cultural models"--posited shared conceptual structures (deriving from schema theory in psychology) that pull together culturally standardized knowledge, motivation, affect, values, goals, and so forth and that relate these to action or behavior. In this latter research I have been particularly concerned with problems of definition (what is a cultural model), of boundaries (what is in one vs. out, and how can you tell), of structure (how do they differ from individual schemas, how are they organized, and so forth), and of how individual people evoke them and use them in deciding how to behave and how to interpret the behavior of others. I have also been concerned with how different cultural models and variant forms of any given cultural model are related to different social groups.

And this research has involved several kinds of conceptual systems. I have aimed at a rich understanding of the social, conceptual, and cognitive aspects of kinship systems and, more thinly, of ethnicity and ethnic groups, and more recently have begun working on cultural models of romantic love. More narrowly I have worked on the everyday semantics of common concepts such as cups vs. glasses,

pens vs. pencils, books vs. magazines vs...., and so forth--how we understand these terms in the abstract and how we use them for communication in the messy world of everyday experience.

What is “formal” analysis?

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THE PROBLEM.

The idea of “formal” analysis has had a long history in modern social science theorizing, particularly in the positivist tradition. James Mill, Ricardo, and John Stuart Mill developed the idea of formal theory generally, with Mill’s methods being a general exposition of the idea and his economics being a supposed application. Weber’s concept of a “rational” bureaucracy imposing rational laws rested entirely on the notion that law was, or should be, entirely a matter of “formal” reasoning and “formal” procedures. Parsons’ “general” did not have to be based on evidence, and was in fact logically prior to evidence, because general theory was in the nature of the case formal rather than descriptive. The logical positivists program was to unify the sciences by translating all the various statements of the several sciences into a single unified “mathematico-deductive system” following a single set of formal rules and embodying a single set of relations between statements and their referents. And in the same vein the aim of componential analysis in kinship was to reduce endlessly varying indigenous definitions of kinship terms to certain universal “formal” components represented in a “formal” way.

Exactly what “formal” means, however, is never made very clear in any of these cases. What we get is a not a clear description or explanation but a set of vague and often actually contradictory associations. It usually has something to do with logic and the notion that logic and mathematics are formal. It is connected to the idea that what was formal is somehow universal. It usually has something to do with an idea of a kind of conceptual or argumentative framework, into which more substantive terms might somehow be inserted. And as part of all this it usually has an association with a referential theory of meaning, the idea that the meanings of words or statements do not consist of ideas but somehow in what they refer to or designate.

For componential analysis, the imagery was that there was something like one universal kinship pie or grid and that different cultures represented different ways of dividing it up. The method was to translate the terms into combinations of “kintypes” that were considered to be their universal components of meaning. The kintypes in turn were symbolized by one or two letters, so as to seem schematic, although in actual fact their definitions were the same as those for the core English kin terms: M or Ma for mother, F or Fa for father, S or So for son, D or Da for daughter, B for brother, Si or Z for sister, and

H or W for husband or wife, sometimes with added qualifiers for age and the like. Different analysts had slightly different schemes and rationales. With them, a term like the Punjabi *caacaa,* for example, would be translated as FyB while *maamaa* would be MB, although in Punjabi both cover many more possible ways the relationship might be arrived at and in fact are considered to overlap. The components would then be arranged so as to make a taxonomic grid that would, it was claimed, neatly divide up the actual kin referred to in the same way as the indigenous terms.

In all of these ideas of formal analysis, and many more, there is a basic problem. How can something I stipulate for all societies on the grounds that it is absolutely free of substantive meaning be then held to have substantive meaning for purpose of analyzing any particular society? How, that is, can something be both non-substantive and substantive? If it is inherently tied to anything in any particular culture, it is not formal and if it is purely formal how can it actually apply anywhere? If two and two equals for, for example, has absolutely no substantive meaning, how would I know what it apply it to at all? In actual fact those who use the distinction generally hold both positions: that formal claims are independent of nature when they wish to defend them against hostile evidence, but that it apply to nature when they wish to say that they are relevant, important, or useful. And in fact what are usually claimed as formal features are usually quite substantive. Weber was quite clear that his idea of "formal" law defended the interests of capitalists against claims for social justice for the poor. Parsons was quite clear that his formal theory described society as a single monolithic whole, and what the componential analysts held to be the universal meanings of all kin terms were, as David Schneider argued at great length, only somewhat stripped-down versions of the peculiar ideas of blood and marriage implicit in the core terms of the American system. The more other systems relied on ideas not contained in the American definitions, the more they would be distorted.

ITS HISTORY.

The formal-substantive distinction goes back to Plato's form-matter distinction as the basis of his analysis of thought, in which form was thought of as ideal and as something on the model of an architect's plan while "matter" was the absolutely unformed stuff of which the brick, for example, might made. Plato attributed the distinction to Socrates and explored its internal paradoxes and difficulties in a number of dialogues. The Timaeus provides an especially extended discussion which develops what is called the problem of the "third man" – that the distinction leads to an infinite regress that reduces the idea of a neat form-matter relation to absurdity. Timaeus' question is how does the matter know what form it is to "participate" in. The answer is that there must be form for the relationship. But how does that

form and matter come to participate in the form of that form-mater relation? Well, there must be another form for that, and so on. Aristotle finessed Plato's argument by largely brushing matter aside and arguing that the essences of things lay in their substance, which was formal and not material, and went on to argue that the order of nature was a hierarchy of such forms. This was also, in the nature of the case, a hierarchy of thought. There must be, in fact, just one scheme of ideas governed by one set of rules that not only represented nature but actually constituted it. While he proposed to arrive at such rules inductively through his sequence of prior and posterior analytics, in fact he ended with what he started with: class inclusion logic. Mideavil Scholasticism was a Christianization of the scheme to support Church authority by identifying the basis of these rules of thought with God, and taking the Church as natural source for understanding what God was.

Scholasticism began to lose steam academically in the middle of the 1300's, when the Italian universities decided to replace rhetoric in the curriculum with mathematics on grounds of utility. At the time, mathematics was quite separate from logic and closely intertwined with practical applications in engineering, architecture, naval astronomy, navigation, geography, cartography and business. The split between logic and mathematics continued to expand into the rupture between theology and empiricism represented by Copernicus, Tyco Brahe and Galileo. Then, however, Descartes, came to the Church's rescue by rephrasing an essentially religious position in terms of mathematics rather than logic. Instead of being the product of a hierarchy of forms in a logical sense, the visible world was a finite collection of extended objects created by the locations or movements of an infinite number of unextended objects.

One of the most important features of the idea of "formal" or formal analysis in modern debates is the assumption that formally true means true by definition and therefore not true substantively or by observation, as if something must be one or the other. I cannot say exactly where this comes from, but we do not see it in Galileo and do see it Descartes. Descartes' criterion of truth was subjective conviction, or perhaps more strongly subjective entailment. That is, if was something that he could not deny without denying his own existence, it was true, and he held the basic ideas of his geometry (ie: extension and non-extension, space, and location) to be of this sort. Hobbes was Descartes' close associate in the circle of Mersenne, and used the same basic ideas in his argument for absolute monarchy. It recurs in Locke's distinction between truths about "relations of ideas" versus "matters of fact."

The line of speculative cosmology that began with Plato and ran through Locke effectively was brought to an end by Hume and then Kant. Hume's response to Locke was pure empiricism—basically "just look." Locke's distinction between relations of ideas and matters of fact turned on the idea that ideas were associated by cause and effect, which created necessary associations. Hume's reply was that there was no such thing as necessary associations. Pick up something and drop it many times. It drops.

This does not, however, prevent you from holding it up yet again and imagining that it will do something else. You can easily think it might stay or go up. So, very simply, we do not get the idea that it will fall from having seen it do so. What then? Hume's answer was "custom and habit." We would say culture. We have learned it from and with others. This, according to Kant, was his own starting point and from there the line leads, for example, to Wundt's experimental psychology, Herder and Grimm in linguistics, and modern pragmatism. Positivism, however, was something different.

Positivism was an effort to bring back the assumptions of Descartes, Locke, and others in a new form that would escape the Kantian critiques. This was done by shifting the nominal focus of the discussion. Instead of knowledge in general the focus was shifted to "science" and instead of the relations between ideas in the mind and objects "out there" in nature that produce sensations or sense impressions it was shifted to statements and their referents. But the underlying Cartesian idealism and Locke-like mind-body dualism is unchanged. The shift is made in Comte's *Course in Positive Philosophy* and J. S. Mill's *System of Logic* (1843) and *Principles of Political Economy* (1848), and runs throughout the French and German positivists. The logical positivists draw equally on Mill and Comte, but see them through Ernst Mach and as part of a somewhat broader tradition that looks back to the Encyclopedists and Hegel.

Proponents of logical positivism describe it as having begun with the Vienna Circle, a group of philosophers who gathered in the 1920's around Moritz Schlick, newly brought from Kiel to become Professor of Inductive Sciences at the University of Vienna (Ayer, 1959:3). With respect to the vision of science it projects there is little sense separating logical positivism in this narrow sense from a larger stream of positivistic development that led to it. Unifying the "present isolation of the sciences" by logically integrating "the most important doctrines of each science" with the other sciences and general knowledge was a central promise of Comte's *Positive Philosophy* (1851; 35). The idea of treating science as a body of statements or propositions was Mill's, and the idea of carrying out such an integration by means of a conceptual and programmatic encyclopedia went directly back to Hegel's 1817 *Encyclopedia of the Philosophical Sciences.* Using Comte's and Mill's basic ideas of eliminating "metaphysics" in favor of "science," reconstructing science into a single monolithic logical system, and proposing to carry out the reconstruction by viewing science not as a set of results but as a set of statements whose meaning could be divided into a logical/mathematical component that was true a priori and a synthetic or referential component that was true contingently, arguments were quickly developed representing all the major dualistic philosophical options as though the Kantian critique had never existed: idealist and materialist, realist and nominalist.

The chair Schlick occupied had been created for Ernst Mach in 1895, and most of the ideas Schlick's group drew on had been formulated between the late 1870's and the turn of the century by Mach, Henri Poincaré, Gottlob Frege, A. N. Whitehead and Bertrand Russell, among others. Building in part on the idealistic neo-realism of Brentano and Meinong, who incorporated Kant's recognition of the purposes of ideas into the idea of meaning itself as "intentionality," and thereby reasserted the legitimacy of philosophy as an *a priori* analysis of what ideas were rather than recognizing the need to move to an empirical analysis of how they were used. On this basis, and more simply on the basis of a refusal to concede the force of Kant's characterization of the relative unimportance of the analytic *a priori*, they had been developing what Russell has called "the philosophy of logical analysis" (1945:828), "analytical empiricism" (p.834), or "mathematical philosophy," and others have called "logical empiricism."[18] Drawing on scientific uses of ideas like uncertainty and probability, they restated the claim that while matter exists it is in a sense fundamentally unordered, and what order it does exhibit is what the mind—or language— imposes upon it. The structure of the world is, therefore, a logical structure, with important weight on "the" and "a". What was wrong with the earlier programs was not the general aim but their specific methods. With more general and more flexible axioms that integrated both traditional mathematics and traditional logic, it could yet be accomplished.

The Vienna circle proposed to integrate and universalize science by translating the propositions of science into ordinary language while stripping ordinary language of its subjective and emotive baggage and putting it in a uniform and universal form. Although there were several different ideas of what such a science might look like, the main prototype appears to have been Ernst Mach's sensationalism.

Mach and Poincaré are consistently credited by later logical positivists with the "epistemological purging" of physics, otherwise described as the elimination of metaphysics (cf. Carnap 1958: 164; Neurath 1958: 262; Schlick 1958:86, all first appearing in 1931 or 1932). Mach's thesis, as Peter Alexander puts it, was that: "There can be no *a priori* knowledge in mechanics; the basis and origin of all scientific knowledge is sense experience." (Alexander 1967; 116). But what Mach means by sense experience has nothing to do with experiment. Experiment, for Mach, was "misplaced rigor" because it rested on what was taken for *a priori* knowledge but what was often actually just unfounded beliefs and earlier half-forgotten experiences (*ibid*.). What Mach meant was "sensations."

In *The Analysis of Sensations and the Relation of Physical to the Psychical* (1959; first published in 1885), an initial list of sensations is "colors, sounds, temperatures, pressures, spaces, times, and so forth.," which form a "fabric" (1959:2). Mach phrases his argument as a rejection of Kant's idea of the

[18] For a full account, see Passmore 1951, 1967.

thing-in-itself, which he construes as though Kant was speaking of Mill's substances — real things underneath the qualities. By his own account, when "at about the age of fifteen" he read a copy of the *Prolegomena,* it "made a powerful and ineffaceable impression" upon him. But:

> Some two or three years later the superfluity of the rôle played by "the thing in itself" abruptly dawned upon me. On a bright summer day in the open air, the world with my ego suddenly appeared to me as *one* coherent mass of sensations, only more strongly coherent in the ego. (1959:30, n.1)

What Mach realized was that he could reduce Mill's qualities and substances to qualities alone if, as Mach argues, time, space and direction are also sensations. "Bodies do not produce sensations, but complexes of elements (complexes of sensations) make up bodies." (1959:29; parenthesis his). *Does* this eliminate metaphysics? The scheme is nothing if not Berkeley's or Leibniz's idealism merged with Descartes' geometry by supposing one could replace points and dimensions with sensations of qualities and sensations of space and time.

By 1936, the leading figures of the Vienna Circle had fled Vienna, renamed themselves the Unity of Science movement, and established a new center at the University of Chicago. There, Rudolph Carnap, Otto Neurath, and others organized the *International Encyclopedia for a Unified Science,* which drew in many social scientists. An introductory essay by Neurath extravagantly praises the intellectual vision of the French Encyclopedists, Hegel and Comte and, citing Neitzche, rejects the "anti-scientific attitude" of Kant's system (1938: 11):

> The unified-science attitude based on the simplicity and straightforwardness of scientific empiricism is concentrating its attention on generalizations and predictions made by the debaters. What people in all the countries expect scientists to do is always to predict successfully by means of so-called scientific procedure; one hopes that a surgeon who knows about bones and veins will make a diagnosis and then perform a satisfactory operation, that a historian . . . can foretell the main results of a newly undertaken excavation, that an economist judging from the first symptoms can warn the public of an impending slump, that a political leader can systematically predict social changes which are arising.
>
> One can state all these scientific prognostications in terms of everyday language — the language which is common to all men . . . irrespective of the fact that the scientist himself uses expressions and symbols in preparatory work which are mostly of an international character. Unified science is therefore supported . . . by the scientific attitude which is based on the

internationality of the use of language of everyday life and the on the internationality of the use of scientific language.

It may happen that people create and prefer certain terms and formulations not for universal understanding but for stimulating certain emotions, and may decide that in a certain case an emotional activity is more important than a scientific attitude. It is not the subject of a scientific explanation to support or oppose such a decision. If one prefers a comprehensive scientific attitude, this *Encyclopedia* tries to show him the spectrum of scientific thinking. (Neurath 1955:22-23).

Clearly "empiricism" here does not depend on experiment or "so-called scientific procedure," and has nothing to do with skepticism. It is, implicitly, the sum total of all referential statements — which is precisely why it makes sense to Neurath to say that it is nothing but an accumulation and precisely what makes it seem that unifying it would be only a matter of restating everything in terms with clear referents and a uniform system of logical relations to permit successful predictions (express regularities). To do this, ordinary language would suffice, once it was cleaned of that part of its content that merely "stimulates emotions"— which included, in their view, all statements expressing evaluative or moral judgments and/or all normative statements. The unity of science would follow from classifying these statements according to a uniform scheme, and this classification in turn would depend not on anything factual but on *a priori* rules of logic that the positivists themselves promised to set out. Accordingly, the great bulk of the work original to the movement was in analyses or construction of what were held to be the necessary foundations of this program: the idea of ordinary language, the supposed bases of logic and mathematics, unending attempts to make sense of the idea of referential meaning, and arguments about language construction.

It is important to understand how what might seem to be a quintessentially empirical program — coordinating and integrating the results of science — could be undertaken without any actual empiricism at all. Three crucial works will suffice: Ludwig Wittgenstein's 1922 *Tractatus Logico-Philosophicus* and Rudolph Carnap's *The Logical Structure of the World (Logische aufbau der Welt,* 1928) and the related "Logical Foundations of the Unity of Science" in the *International Encyclopedia of Unified Science* (Carnap 1955b).

The *Tractatus* was an intensely convoluted effort to argue that ordinary language must be a monolithic system of logically interrelated meanings analogous to the closed systems they wanted to make for science. The basic argue appears to be that since words always refer to other words, there must

be an ultimate structure of words. Since Russell and Whitehead's *Principia Mathematica* had already argued for the total unity of mathematics and logic, the two arguments together seemed to provide a comprehensive justification of the positivists program. There was, therefore, much consternation when Wittgenstein later repudiated the argument in favor of the clearly pragmatic idea that meanings are only made clear through what he calls the "language game" a word or idea is associated with. That is, the meanings of words lie not in the relations between words and other words, but words and communicative and purposeful activities.

Carnap's *The Logical Structure of the World* set out to justify the idea of building an artificial language of science by the seemingly direct expedient of setting up a "constitution-system" in which, as A. J. Ayer puts it, "the various types of linguistic expressions, or concepts, were assigned their proper places in a deductive hierarchy." (Ayer 1959: 24). "The Logical Foundations of the Unity of Science" argued that "we mean by 'results' [of science] certain linguistic expressions, viz., the statements asserted by science." (p.42) whose "logical syntax" it would "the task of the theory of science" to analyze (p. 43). The analysis would have "two chief parts" (ibid.): the ways the terms of science were defined by other terms of science and the ways terms of science were connected to objects. Since this brings him back to the distinction between analytic truth and denotation, the question is how he will make sense of it when no else has. His answer on the analytic side was itself analytic: he proposed an axiomatic system that had the necessary properties by definition, an "analytic" language. On the denotative side it was to argue for physicalism. The objects to which words were connected could not be ideas or values but had to be things like Mach's sensations or something similarly "objective." If "a sentence about other minds" did not refer to "physical processes in the body of the person in question," it was "meaningless." (Carnap 1959: 191).

Within this broad movement to return to create a unified cosmology by unifying the sciences through some formal scheme or language, the long-standing separation of logic and mathematics was an obvious problem. This is where Russell and Whitehead's *Principia Mathematica* fits in. Their claim was that they showing that logic and mathematics were in fact one system, and the argument was itself formal. They showed, or claimed to show, that logic could in fact generate mathematics. They did so not by actually doing it, however, but rather by arguing that it was possible in principle.

This type of analysis has now lost its charm in philosophy and has been largely displaced by postmodernism. For those who could not see through the nonsense on their own, there were three main reasons. The first was Goedel's 1931 argument to show that Russel and Whitehead's scheme was either inconsistent if complete or incomplete if consistent. The second was Wittgenstein's development of his idea of meaning as lying in a "language game in his in the blue and brown books and *Philosophical*

Investigations (1953). The third was W. V. O. Quine's 1951 "The Two Dogmas of Empiricism" (reprinted in Quine, 1953).

The two dogmas were reductionism and the analytic-synthetic distinction. Quine rejected both. Reductionism was the notion that every factual statement could be reduced to a posit or construction upon experience, understood as some concatenation of "sensations" or "sense impressions." The analytic-synthetic distinction was their claim that propositions were of two kinds: either analytic or synthetic, true by meaning alone or true in virtue of what they refer to. The two dogmas were related in that "synthetic" statements were generally understood to be interpreted reductionistically.

Quine's approach was shotgun: a list of different arguments to deal with different points. His main argument concerning the analytic-synthetic distinction was that if we operationalize it in a reasonable way by asking how we are to judge synonymy (that is, when two words have the same meaning) and how propositions are to be verified, what we find is that we cannot make sense of it. We cannot find analytic propositions and we cannot find synthetic propositions. His alternative was to replace the idea that verifiability inhered in individual statements with the idea that it could be found by taking "total science" as the "unit of empirical significance." He described total science, in turn, as a network of interconnected statements touching on experience only at some points but remote at others (1953: 42). Exactly what those points were at any given moment was a matter of "posits." This was meant to suggest that they were changeable, and is apparently another way in which the formulation seemed to some to be like those of the pragmatists.

The critique was considered devastating and has still not been answered. The most common response that while the authors could not show what was wrong with Quine's objections, they would continue to use the distinctions anyway because their entire enterprise depended on them (cf. Ebersole, 1956; Pasche 1956; Grice and Strawson 1956; Epstein 1958).

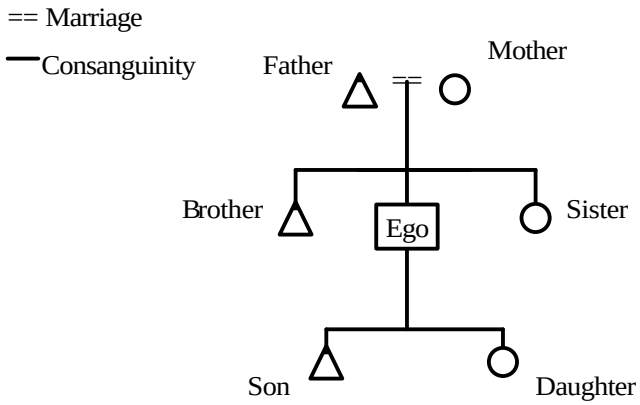
THE ALTERNATIVE.

Of course the critiques do not prove that there is no such thing as an architect's plan or an idea according to which we may shape a thing. They do not refute mathematics or invalidate logic. They simply demystify them and expose the conceptual weaknesses in the arguments to the effect that the logic of plans is radically independent of and prior to the logic of buildings, that the logic of arguments is radically independent of subject matter of arguments, and the logic of mathematics is based on some sort of permanent and unchanging principles that have nothing to do with what mathematics is used to represent.

If “formal” means things like plans, mental models, the rules of logic and mathematics, mathematical or conceptual figures, and the like, then the destruction of the philosophical basis of the logical positivists’ view of scientific theory means that we cannot find other people’s formal structures in our own preconceptions or arbitrary inventions. We must find them in what is supposed to embody them, empirically. “Formal” will then be two things. First of all and most basically, it will be whatever such things we find that of this sort, whatever looks like a plan, diagram, schematic representation, mode of reasoning, mathematical system, and so on—a huge array of different kinds of conceptual models. Secondly, however, it will also be our analysis of whatever actually makes each model seem to *be* formal: what shapes it, what holds it together and gives it the properties that it is reported to have.

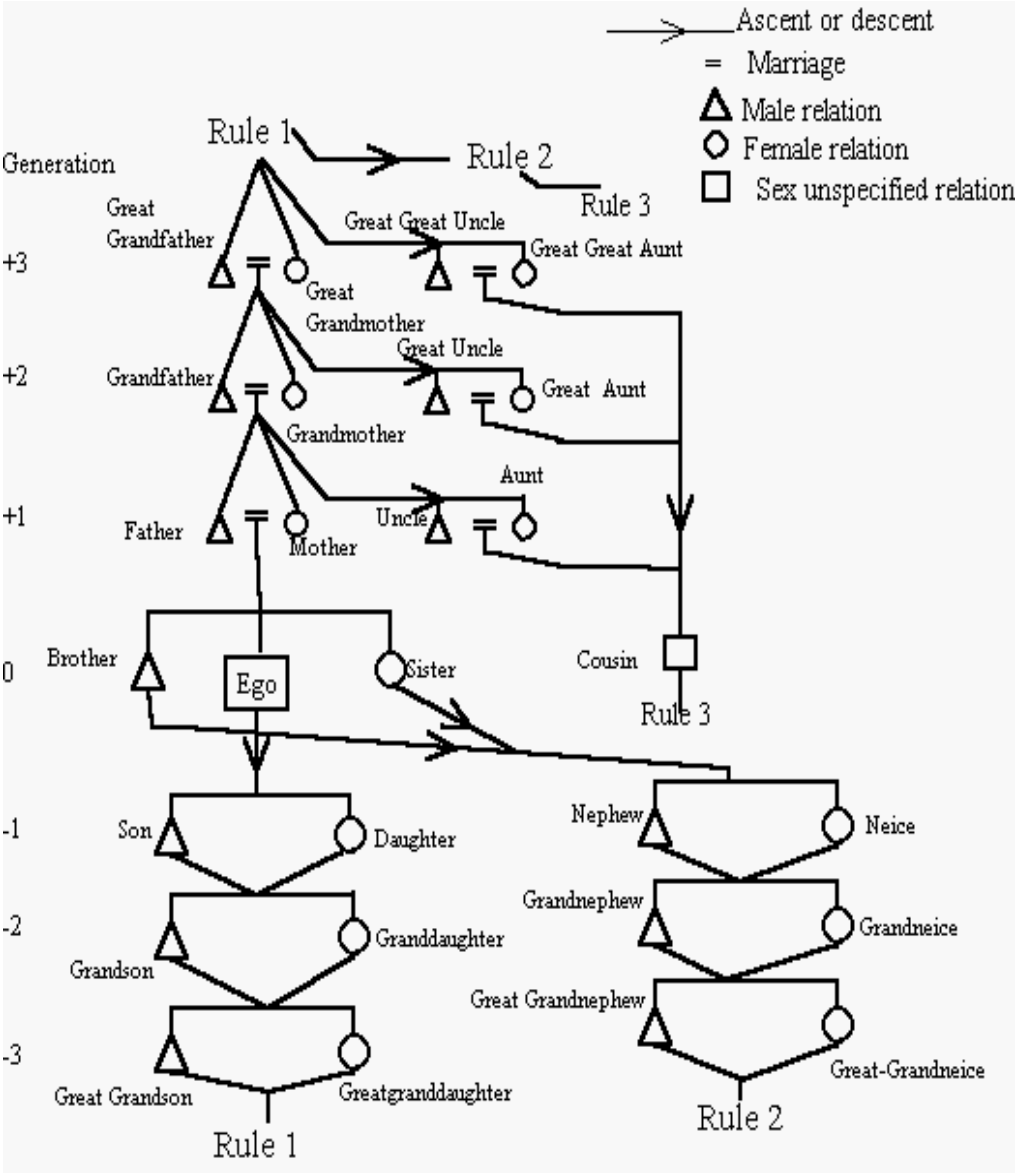
I have argued elsewhere that social relations of different types are defined by systems of cultural ideas. There are also systems of cultural ideas that define technical subject mattress, such as bodies of agricultural knowledge, the knowledge of trades, and the sciences (Leaf, 1972; 1984). All such systems, as systems, have formal properties, in the sense of some specific features that are more important in holding them together as systems than other features. The problem of finding what those features are may require us to fall back on ideas we deem analytic, such as ideas from “formal” logic or mathematics, but they are not on that account non-substantive. For the sake of time, I will confine the rest of my argument only to those systems that define social relations, rather than bodies of technical knowledge. As one quick example, let me site the American system of definitions of kinship relations, more usually (but misleadingly) called the American Kinship terminology.

Using a purely ethnographic elicitation technique that consists of eliciting a core set of “direct” relatives, as indicated in figure 1.



I then use these core relatives as an eliciting frame to obtain all the additional definitions, or rules for generating them, and when this is gathered and simplified so that each conceptual position is represented by one and only one graphic figure and the graphic links between each position and all the

other positions represent all the other possible definitions, I arrive at figure 2, which I have described as the American kinship map.



Rule 1, 2, and 3 are rules for infinite further extension. Rules 1, 2, and 3 are limits because they are rules for indefinite extension. Ascendant and descendant relations go on forever according to the rule, but there is nothing beyond the rule. Rule 1 is that for each succeeding ancestor beyond great grandfather one simply adds a great, and the same is true for the reciprocal—each succeedingly more remote descendant beyond great grandson or great granddaughter. Rule 2 the comparable rule for collaterals, the uncle and aunt positions and their nephew and niece reciprocals. And rule 3 is that any descendant of a cousin is a cousin. With these rules, the system is complete and logically closed, with every term defined in relation to every other term.

This is a kinship map because it literally lets us "get to" any position from the ego position, and by reversing whatever links we traverse to get to that position we can also get to the reciprocal. That is, if we have person up one consanguinial link from ego, that is ego's father. Reversing the link we get the position down one consanguinial link from ego and if ego is male that is son. If we go up two and over one to a male that is uncle. If we reverse this and go over one and down to and ego is a male, that is nephew, and so on.

More detail can be added, but this is enough to make the basic point: clearly this can reasonably be described as a "formal model," at two levels. First and most simply, it is formal in the way a house-plan or, more exactly, something like a wiring schematic is formal. It is simple and schematic, but, more importantly, it shows what all the parts of a system are and how they are interconnected. Secondly, more complexly, it is formal in the way a geometrical figure or mathematical proof is formal. A geometrical figure is formal not only in the sense that it has a shape but also in the more important sense that it represents in a highly compressed form an enormous number of discrete but interconnected relationships—as for example all the relations between sides and between angles and between sides and angles of a right triangle in trigonometry. A mathematical proof is formal in the sense that it is concerned, at bottom, with the maintenance of continuity in definition only. If each step between premise and conclusion preserves the assumptions of the system and no step violates the conditions stated in the premise, then the proof is good. If not, it is not good.

Now, if this is accepted, the next step is to ask what it tells us about such elicited, indigenous, formal models in general, and the first thing to note is that does not exhaust the subject matter, in two senses. First, this is not the only way to represent the same basic definitions. And secondly, as with mathematics and other such formal systems, it is always possible for formally analyze any formal analysis. Let me briefly illustrated both points.

The first pertains to the fact that formal models can, as a rule, be transposed—restated in other ways. So in principle there can never be *the* formal analyze of anything, on *a* formal analysis. I do not mean only that we could have carried the ascending and descending lines farther out before ending them in Rules 1, 2, and 3 or that we might have drawn the collaterals on the right instead of the left or used other symbols, although all these points are relevant. I mean that we could have got at the same underlying system in different ways. I might, for example, do what Schneider did and ask who one's relatives are and what they are called, and arrived at what the kind of diagram one commonly gets if you ask people to diagram their relations: one set on the mothers side and another on the father's. In this case, the rule that one graphic figure represents on definition would now be interpreted as allowing "uncle on mother's side" to be considered a different definition or different position from "uncle on father's side." It

would be less economical, but basically still the same set of ideas, represented with a slightly different emphasis that brings out the notion of “sides” more and shifts emphasis away from the strong lineal character. Which is true? I would say that the figure 2 is easier to read and also that if asked most people or probably all people would say that an uncle on the mother’s side is not really a different kind of relation than uncle on mother’s side, that an uncle was an uncle, but I would not say that therefore the two sided representation is absolutely wrong. People do talk like that as well, and when they do this figure would represent the ideas they will use in that context. The real point, however, is that they are related. They are not simply equivalences because the two-sided model introduces an additional consideration, but they are clearly related. In other societies, similarly related models may, for example, connect a model representing purely positional aspects with a model emphasizing clan membership, or with a model emphasizing localization. As in geometry or mathematics, one rarely has a once-and-for-all kinship model of this sort that has one and only one shape. Rather, one has related sets that can emphasize different but related ideas. That is the first point.

The second point is quite different. It that even given all this extended as far as we might, there is also a role for a formal analysis of an entirely different sort and more extrinsic sort aimed not just at describing the uses of the model but at describing its formal properties as such. We can *test* its formality and say more precisely, in established terms, what it consists in.

This is what Dwight Read has done in testing this same diagram for consistency and reproducibility by rewriting the relationships mathematically and use the results to program a computer that produces a related, and comparable, diagram whose nodes can be seen to correspond to the nodes of figure 2. Read’s method replaces the core configuration of the graphic representation with a set of what he describes as “structural equations” translating the logic of the definitional core into algebraic mapping relations. For the American system there are six such equations, plus a rule for sex marking and rule for cousin terminology. The first three of the six are, for example, parent of child = self, spouse of spouse = self, and spouse of parent = parent. This has two important features. The first is that Read can use the equations to demonstrate that all other definitions are consistent with the definitions of the core. The second is that they always also define what Read calls a “focal term.” A focal term may be recognized by the users of the terminology as a formal kinship term contrasting with other such terms, or like "self" or "my" or ego for English and Punjabi it may be considered to be a position they imply or assume. Either way, however, like the ego in the diagrammatic representations, it is a central position from which relations to all other positions can be mapped by kin term product definitions. This makes it absolutely clear that the positions make up one and only one system, one formal structure, in its own terms.

Read has used the method on kinship systems from a wide range of old and new world cultures, from industrial states to Amazonian swidden farmers, beginning with the American as represented here and including Punjabi. So far, all have proved consistent (Read 1984; Read and Behrens 1990; personal communications). This means that they have all proved to be logical structures in their own right in the clearest and most definite possible sense. They are cultural structures. This is an extremely important conceptual breakthrough.

Read's method has nothing to do with finding what the terms "refer" to but only how their definitions are mutually interrelated, and for this purpose the very simple and highly abstract concepts he draws from abstract algebras are both appropriate and adequate. The most important test, however, was using these same concepts to write computer programs to generate the definitional patterns automatically. Although the resulting diagrams do not look exactly like the graphs above, they are easily seen to be the equivalent in the sense that they have the same nodes in the same mutual relationships. It is conceivable that in drawing a graphic representation I might connect two or more concepts or groups when their basic definitions do not really justify it, but it is not readily conceivable that a computer would do so. Computers just follow the instructions they are given and either generate a coherent system or rubbish, or they cannot follow the instructions and stop. On Read's analysis, the relations among the definitions have the distinctive mathematical properties of certain specific kinds of algebraic structures known as semigroups. The structure is in the definitions and it is real. It is not external and imposed.

Systems of ideas that define social relations uniformly have the formal property of being logically circular and closed, which means that the definitions of their elements form chains that ultimately come back to their origins. The definitions are also relatively few in number—if they were not, it would not be possible to be sure the systems were closed. They also are so arranged that the positions they defined have specifiable properties with regard to reciprocity. They define different, and usually characteristic, relations of I to Thou and it. In some cases, as usually are found in kinship systems, the relations are in very definite reciprocal pairs. In others, as for example in what we take as governmental or professional systems, an "I" may have any of several reciprocal "Thou"s. Very often, perhaps always, these "I-Thou-it" relations form closed systems that can graphically represented as closed figures: tables of organization, kinship charts, genealogies, clan systems, chiefly hierarchies, or systems of divisions or branches of government. When they can, the logical structure is especially easy to see.

Systems of social positions always include ideas or definitions for recruitment to such positions. One might be assigned a position from birth, by election, by meeting some criteria of merit, by being a certain sex and age, by being the eldest in clan or community, and so on. It can be that being in one position is permanent or temporary or for a fixed term or a flexible term. One position may lead to

another or exclude another, and so on. Each such idea has its own distinctive logic, its own implications concerning what other ideas may be consistent with it and what other ideas will not. The idea of a position being assigned from birth fits with the idea that it is permanent. The idea that a position is based on absolute age fits with the idea that it will be temporary over time. If it is based on merit it cannot include everyone, and so on.

Whatever such recruitment ideas are, it is a point of fundamental importance that they act as premises to the system of positions in a logical sense. What semantically appears to us as rules for recruitment to social positions functions logically as the rules that determine how the definition of one social position can be connected to the definition of another, and hence produce the shape and meaning of the overall structure. They are what determine the connections between one position and another, and thereby also where one system leaves off and another begins. We literally cannot imagine one system that incorporates several logically incompatible criteria, any more than we can imagine one mathematics embodying several inconsistent ideas of number. The "meaning" of recruitment rules and the formal structure of systems of positions to which those rules apply are two sides of a single coin.

This is not to say that there is not something in nature that kinship ideas organize. Of course there is, but it is to say that it does not exist *apart from* this organization in any actionable way precisely as time and space do not exist apart from the ways we organize them (or it). The way to think about kinship concepts and what they refer to is not in terms of dividing a pie or grid but in terms of the pragmatic idea of formalizing an intuition. We recognize that there is a "something there" but also recognize that they are many different ways to articulate it and that none can take any necessary precedence over the other as being any more correct or "objective." It depends upon (but also shapes) your purposes. The structure is in the definitions and it is real. It is not external and imposed.

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On the Application of Discrete Mathematics to Questions in Anthropology

F. K. L. Chit Hlaing

ABSTRACT

Mathematical Anthropology and Culture Theory Panel
European Meeting on Cybernetics and Systems Research 2002
2-5 April, 2002
Vienna

From the Draft set of Questions to be Addressed by the Panel I choose to address my remarks to four of them: (1), (4), (7) and 11).

(1) What does mathematics have to do with the study of religious belief, etc? I shall argue that the basic answer is that any organised domain of knowledge has to be relational in character and therefore the specification of the relationality of such structures is, in the final analysis, necessarily mathematical, algebraic more narrowly. I shall elaborate on this theme from my own work in kinship, in cosmology (Buddhist religious systems of South Eastern Asia) and perhaps other domains and examples.

(4) What are some notable past successes? Kinship in particular. Why? Because, as I have argued elsewhere and shall also elaborate here, there is a good, functional reason why kinship is, say uniquely amongst all human social institutions, *pure relational* in its basic definition of category identities.

(7) What are research questions you have been addressing and in what ways have mathematical theory and models been relevant to your research? My own work spans linguistics, anthropology and cognitive science and, I have had to be centrally concerned with the question of *meaning and category definition*. In particular it has turned out that the solution to many such puzzles, not least having to do with real-world cultural systems of categories, and especially having regard to the relationship between knowledge and behaviour (cf. the Agency problem of Question 11). Depends upon one's choice of (a) the right axiomatisation of the theory of Sets — not the usual Zermelo-Fraenkel axiomatisation but rather the Gödel-Bernays-von Neumann axiomatisation, and (b) and appropriate generalisation of Quantification. I shall develop this theme above all in my talk. For while it is understood that the two axiomatisations are formally commutable in fact there are empirical consequences of fundamental importance in choosing to distinguish between Set and Proper Class. And, as to (b), a properly algebraic notion of quantification (instead of the usual formal-logical one) has, amongst other things, the advantage of allowing for further solutions to the Instantiation Problem with regard to Question (11) as well as, for instance, allowing one to say something more useful than has been common about the connection between mental or conceptual systems of Sense and Reference, namely, to the development of a properly *intensional* theory of meaning applied to cultural systems.

Mathematical Modeling Issues in Analytical Representations of Human Societies

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Draft paper for the Panel Discussion, *Mathematical Modeling and Anthropology: Its Rationale, Past Successes and Future Directions*, European Meeting on Cybernetics and System Research 2002 (EMCSR 2002) April 2 - 5, 2002, University of Vienna.

The application of mathematical models to anthropology has had a long history, with examples as varied in their content as is the field of anthropology (see Read 1996 for a recent overview of the use of mathematical models in anthropology). Anthropologists have made extensive use of mathematical procedures ranging from statistical methods for elucidation patterns in behavior to mathematical representation of the logic of native conceptual systems such as kinship terminologies. Mathematical models and mathematical modeling has been considered by some metaphorically as a tool and by others as a way to extend anthropological or archaeological reasoning. Yet others have decried the use of mathematical, and in particular, statistical and quantitative modeling, as fundamentally in opposition to a humanistic approach to understanding human behavior that must take into account contingency and historical embeddedness and decries universality. For some the power of mathematical models is in providing a metaphorical language for expressing aspects of behavior, while for others mathematical representation of fundamental concepts is a sign of the growing maturity of anthropology as a science. In many cases models are borrowed from sister disciplines that address what appear to be similar issues, such as the application of Optimal Foraging Theory from ecology to hunting strategies in human foraging societies, linear programming to diet choice among hunters and gatherers, or game theory to choices made by Jamaican fishermen. In other cases the models derive from the characteristics and properties of the data being examined or the anthropological arguments being made, such as models of prescriptive marriage systems as found among aboriginal Australian populations.

While models borrowed from other disciplines have been effectively applied, these models often do not fully take into account the implications of the cultural aspect of human social systems. Economic models, for example, typically are based on assumptions of rationality, equal access to all information when economic decisions are being made, assumption of a fixed utility function and do not consider where the utilities themselves come from. For example, the economist Friedman commented "The economist has little to say about the formation of wants…" (1962) and later the economist Becker wrote "Economists generally take 'tastes' as given and … [assume] that tastes do not change" (1976). Problematic from an anthropological viewpoint is the presumption of a fixed structure within which decision making takes place. The cultural component is critical, for, as noted by Pollak and Watkins (1993) " … accounts that emphasize the unity of culture, viewing culture as a coherent whole, a bundle of practices and values" are "incompatible with the rational actor model" (490).

But what is meant by the cultural component varies widely and ranges from viewing culture as socially learned and transmitted behaviors to culture viewed as made up of abstract symbolic systems with an internal logic giving a symbolic system its structure. If the former then it is the process by which transmission takes place from one person to another that is central to elucidating the role of culture in human behavior. If the latter then culture plays a far-reaching and constructive role with respect to patterns of behavior that cannot be induced simply through observation of behaviors however sophisticated the statistical analysis as the structuring power of culture under this assumption is only partially captured by the process through which behaviors are transmitted from one individual to another or in the range of behaviors that occur. The same situation would arise as occurs with language acquisition. For there to be language acquisition there must be a cognatic process by which a finite corpus of language utterances experienced by a child leads to internalization of an underlying grammar that transcends the specific features of that finite corpus of utterances. Likewise, if culture consists of abstract symbol systems whose form is the consequence of an internal logic, a child learns not just specific instances of the usage of that symbol system but derives from those instances a cognatically based understanding of the internal logic of the symbol system.

In contrast, if culture consists of socially learned and transmitted behaviors then the cognatic aspects of the human brain play a relatively minor role when constructing models of behavior and of social/cultural systems. The cognatic aspect of the brain that is needed in this framework is primarily a decision process by which one either accepts or rejects a behavior as part of one's own repertoire of behaviors. In addition, the decision process under this scenario should be specifiable in terms of a structuring process external to the individual such as natural selection since the decision process for accepting or rejecting behaviors will have direct implication for the (Darwinian) fitness of an individual.

Of these two scenarios for the definition of culture, culture as socially learned and transmitted behaviors appears to be inadequate and lacking in the depth needed to encompass the full range of cultural phenomena. Cultural constructs such as kinship terminologies, for example, cannot be specified simply in terms of behaviors that occur among kin-related individuals since one's kin is a culturally constructed category and determined through the persons to whom one has a determinable kin term relationship. Among the !Kung san, for example, being a non-kin and being a stranger are synonymous (Marshall 19xx:xxxx) and both are potential sources of harm. Social intercourse takes place among the world of kin and one's kin are determined through knowing the kin term relationship of ego to alter. The latter depend upon the kinship terminology having two features: (1) the kin terms constituting a symbolic system structured by a logic or grammar that gives the symbolic systems its particular form and (2) a means, or set of rules, for mapping abstract symbols onto individuals (that is, a mapping from the ideational domain of a kinship terminology as a cultural construct to the phenomenological domain of individuals organized by kin term relationships—or lack of a kin term relationship—linking individuals to one another.

The two parts being identified here—an abstract, conceptual structure and instantiation of that conceptual structure—are not unique to kinship and kinship terminologies but are found, I argue, where ever we find a culturally determined model for the organization of some aspect of human social systems. In effect, we appear to have two ways in which we cognize, represent and make sense of phenomena that impinge on our sensory apparatus. First, there is a level of cognition that we share, to varying degrees, with other organisms. This level would include cognatic modeling that we may do at a non-conscious level that serves to provide an internal organization of external phenomena and to provide the basis upon which behavior takes place. Second, there is a culturally constructed representation of external phenomena that also provide an internal organization for external phenomena, but where the form of the representation arises through formulating an abstract, conceptual structure that provides form and organization for external phenomena in a manner that need not be consistent with the form and patterning of those phenomena as external phenomena; that is, the cultural construct provides a "constructed reality," to use a current, but much abused, phrase. The two parts are shown schematically in Figure 1, where the cognitive system is shared, to one degree or another and produces an organization for and representation of the external world that serves as the basis upon which decision making that leads to behavior takes place. A cultural construct is represented by the symbol system and the symbol system also provides an organization and representation of the external world, but one that is not constrained by its degree of concordance with the external world but by its coherence as a conceptual system organized by an internal logic or "grammar."

The implications for mathematical modeling of human systems are threefold. First, modeling of a cultural construct as a symbol system organized by an internal logic or "grammar." Second, modeling of

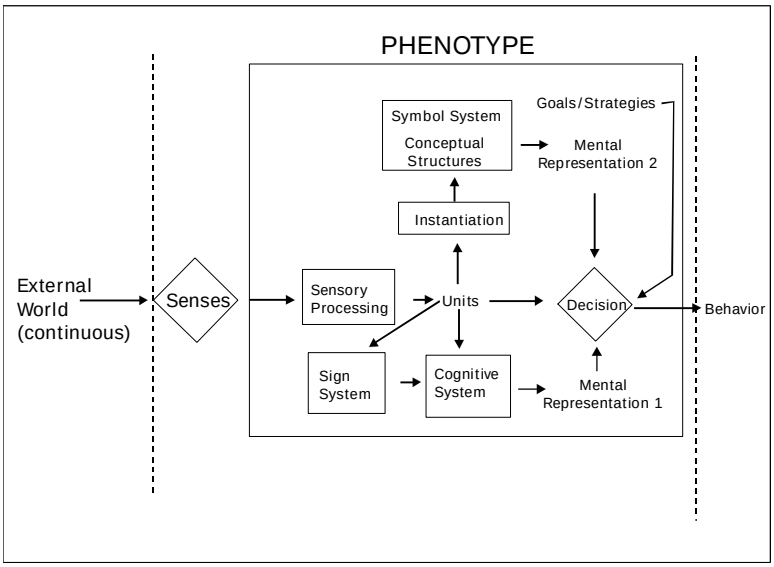

Figure 1: Schematic diagram of the cognitive system of an individual consisting of two separate systems: a cognitive system and a symbol system.

the process of instantiation whereby abstract symbols and relations are provided with more concrete content. The process of instantiation is not derivable from the form and properties of the cultural construct being instantiated, but has its own logic—what Bourdieu has called the "logic of practice"—and its own dynamic character and time-embeddedness. The latter is a key aspect of instantiation that translate static structure into dynamic social organization. And third there is modeling of the ongoing set of behaviors and relationships of one individual to another, such as the networks to identify the actual pattern of interactions of individuals along one or more dimensions deemed to be relevant for the organizational form of the individuals making up a social unit.

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Why model?

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It seems to me that the questions posed by the organisers of this session boil down to: "If and when you are able to observe human behaviour all around you, why would you want to model such behaviour? And if you do, what can you hope to achieve?" I will try to answer them, and some others, from the narrow perspective of one of anthropology's sub-disciplines: environmental archaeology.

Four particularities about that sub-discipline are important in this context. Firstly, we deal with a distant past about which we often know as little as about the future. Archaeologists have been called "prophet[s] turned backwards". They cannot assume that their sense of the relationships between cause and effect, or between people and their artefacts, is the same as that of the people they study. It has been argued that "the past is a foreign country" – we can therefore not be sure in how far to use 'common sense' in our interpretations, or even the observed behaviour of other human beings.

Secondly, in the absence of writing, our data are non-relational. They reflect the *results* of relationships between people and materials, landscapes, monuments, etc., but they do not reflect these relationships themselves. They therefore do not point to specific relationships between cause and effect as observed by the people who left the remains behind.

Thirdly, archaeology bases its interpretations on few and meager clues about the past. In contrast to most other disciplines, it does not aim to reduce a wealth of data to a few essentials, but to do the reverse. To put flesh and clothing on 'bare bones'.

Finally our discipline is fundamentally 'interdisciplinary' in, the traditional sense. We use information that is derived from widely different kinds of data, interpretations that attempt to combine the natural and life sciences and the social sciences and humanities etc.

Why, then, model? Formal models are extremely valuable tools in the arsenal of the researcher, which enable him or her to economically describe a wide range of *relationships* with *a degree of precision* usually not attained by the only other tools we have to describe them: natural languages. Moreover, certain kinds of formal models are able to describe the *changes* occurring in complex sets of relationships with such precision and economy of space. Due to these properties, modelling is very *suitable to formalise dynamical theories* about certain phenomena, which can then be compared with our observations.

In a social science context, another important aspect of formal models is that they are not formulated in the same language as describes the phenomena to be modelled. That has several advantages, of which the most important is possibly that it allows us to abstract, to highlight features that are in our opinion relevant. It is a common assumption, for example, that one may not compare apples and oranges. Yet if one wishes to *explain* why oranges are better at rolling in a straight line than apples, one invokes an abstract dimension (roundness) and compares both kinds of fruits in terms of that dimension. The applicability of any particular model to a set of phenomena does not follow 'naturally' from the nature of the phenomena, but is defined by the person who applies the model. Models can therefore, at least in theory, be useful in solving problems in which it is important to infer relationships between the observed behaviour of certain phenomena, and characteristics of these phenomena which have as yet not been identified.

The domain of application of formal models is unlimited. It therefore includes all aspects of anthropology, including kinship, ritual, choice, behaviour, etc. But while that may be a necessary reason to use formal models, it is not a sufficient one. I find formal models particularly useful in an interdisciplinary context, as they are sufficiently abstract not to be confounded with reality, and sufficiently detailed, rigorous and (in the case of some computer models) 'realistic' to force people with different backgrounds to focus on the same relational and behavioural issues.

What can one hope to achieve by using formal models? Maybe the best way to answer that is by referring to some of the models we have designed and used in the context of our study of the causes and consequences of desertification, land degradation and land abandonment. A first series of models, of the Palaeolithic dynamics of herbivore and carnivore fauna, attempted to get a sense of the natural dynamics in the mediterranean environment before the impact of human beings transformed that environment. Studying a model based on extant predator-prey equations, we came to the conclusion that the predicted dynamics did not come anywhere near the real ones. We then built a multi-agent model of the same situation, and in running it discovered that the 'overkill' hypothesis on which these equations are based does not explain much unless the behaviour of the individual animals is spatialised. Coupling a GIS-based map of the main landscape units to the simulation allowed us to predict with reasonable accuracy the dynamics that could be inferred from the data.

Another series of models dealt with rural-urban dynamics. These dynamics concern many different spatio-temporal scales. We combined a multi-agent model of the last 2000 years of settlement dynamics for a part of Southern France, based mainly on historical and archaeological evidence, with a similar model of the dynamics of individual migration in the area in recent times. The former model concerned the interaction of whole settlements (from small villages to towns). After many runs, we had to conclude that the parameters included in it would not explain the present-day spatial configuration of urban centres in the area. These parameters were based on a conceptual model of rural-urban interaction which is valid for the roman and medieval periods. By adding a set of self-triggered parameters based on a conceptual model of industrial towns, however, we achieved a model that did replicate the whole of the settlement system reasonably well. These parameters began to kick in after about 1500 (yearly) cycles of the model. Interpreted in historical terms, this exercise pointed out that the dynamics occurring from about 1500 AD on, are indeed qualitatively different from those driving earlier developments of the system.

On a different, decadal time-scale, the urban system of southern France is heavily dependent on migration, and the above model cannot take that into account. We therefore built another multi-agent model of the population dynamics in Southern France as a function of individuals' life-time decisions, from conception and birth, through education, partner choice, career development etc., to death. This model allowed us to gain additional insights in the operation of the settlement system dynamics, which were not to be gleaned from the first (settlement-level) model.

In a third case-study, of the agricultural dynamics of a region in southern Greece, we built a whole series of models, ranging from relatively abstract, master-equation-based and only roughly spatialised models to detailed, multi-agent models of decision-making which took local decision-making procedures and –criteria into account. Experimenting with each model in turn taught us the need to view environmental problems as the result of a co-evolution, and allowed us to assess the adequacy of our ideas by successively adding more and more parameters to an initially relatively simple model. In conclusion, in our work the possibility to falsify a conceptual model by implementing it and testing it against observed data turned out to be one of the two major gains of a modelling approach.

But the second major gain was at least as important. We heavily exploited the possibility offered by dynamic modelling, to focus the minds of many people from different disciplines and cultural backgrounds on the same set of phenomena. The multi-agent models used rapidly became the focus of true interdisciplinary collaboration in the project. This seems due to two facts. Firstly that they act as a kind of mirror that reflects the implications of different conceptual models in a neutral way, and secondly that multi-agent models are based on a bottom-up principle which facilitates implementing combinations of conceptual models about individual behaviour. It thus reduces the numbers of degrees of freedom to be input, without jeopardising the degrees of freedom inherent in the interaction between people.

Network Analysis and Social Dynamics

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Abstract

Network analysis, an area of mathematical sociology and anthropology crucial to the linking of theory and observation, developed dramatically in recent decades. Methodological developments are recounted that make possible a theoretical synthesis of social network theory in relation to understanding of social dynamics.

The past 35 years saw a massive development of tools for network analysis, spurred by anthropologist Clyde Mitchell and sociologist Harrison White, and burgeoning applications to ever-wider sets of problems in the social sciences. The trajectories of social network analysis in the two disciplines were very different, however. In anthropology, where it was introduced in the 1960s as a collateral tool to institutional and cultural analysis, the network paradigm did not become a central contributor to theory, as in sociology.[19] Still, even in sociology, the development of methodology (Wasserman and Faust 1994) has far outstripped that of an integrated theory of networks that situates explanatory principles in a common conceptual framework, and the lack of such developments is noted in both disciplines. My discussion will focus on application of explanatory frameworks in an emergent network theory as used by research collaborators (including myself and graph theorist Frank Harary) in a series of long-term field sites. The aspects of the project I will discuss are integrated through a NSF grant in which I am PI and Harary is the consultant.[20]

1 Conceptual Perspective.

One of the key ingredients of scientific explanation and the testing of theory is the development of models that relate first principles (e.g., interaction, structure) to a diversity of observable outcomes (e.g., as a function of simpler parameters or measures). Network theory, in so doing, attempts to explicate how social and cultural

[19] Unlike sociology, which defined and forged ahead with social networks as a theoretical paradigm (Mullins 1975, Berkowitz 1982, Burt 1982) on a par with "heavy-duty approaches such as structure-functionalism, Marxism, and ethnomethodology" (Wellman 2000:4), interest in networks largely died out in anthropology once those experimenting with the approach in the 1960s and early 1970s turned from problems of fluid social structure to the study of transactions, ritual enactment, symbolic action, and contemporary themes of cultural anthropology. Anthropologists with a cognitive focus narrowed their studies to the shared components of egocentric cognitive constructions in relation to observed behavior, studies that unfortunately didn't recapture the interests of the field at large.

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phenomena emerge out of interaction by measuring, across observable networks of communication and of social and instrumental relations, events and activities, and ideally, through time, different kinds of emergent structure. **Table 1** shows some of the network concepts applicable to domains of social theory. Coupled with the modeling of fundamental interaction processes, they are designed to allow for structural emergents to be measured and to test hypotheses about processes, interactions and outcomes.

Concepts and some numbered principles	Network Aspects	Measures of Network Structure	Methods Authors	Classics
A Solidarity	Intragroup	**Pattern 1**		
Group (1)	A' **Cohesion**	k-connectedness	Harary & D.White	Lewin
Culture	A" Consensus	1-dimensional covariance	Romney & Batchelder	Tylor
Moral econ.	A"' Affect	k-balance	Harary, Davis	Heider
B Soc.Relations	Intergroup	**Pattern 2**		
Economy (2)	B' **Exchange**	graph homomorphism	Harary	
Amoral econ	B" Conflict	graph homomorphism	Harary	Simmel,Coser, Gluckman
Law	B"' Mediation	Conditional homomorph.	Simmel	Lévi-Strauss, Nadel
C Specialization	Activity	**Patterns 3-4**		
Position (3)	C' **Str. Equiv.**	Structural homomorph.	H.White	Homans
Analogy (3)		regular. homomorph., overlap lattice	White&Reitz Ganter & Wille	Merton, Goodenough
Specialty (4)	C"' **Div of Labor**	task allocation homomorph.	Oeser &Harary	Durkheim
D Inequality	Ordination	**Pattern 5**		
Centrality (5)	D' Influence	betweenness	Freeman	Bavelas
Supervisory authority	D" Power	triadic interlock	J.Davis, D.White	Nadel
Hierarchy	D"' Authority	levels measure	Reitz	Lewin
E Redistributed Transformation		**Pattern 6**		

Table 1: Networks Concepts in the Literature Streams of Social Theory

The middle column in Table 1 lists the typical kind of mathematical model used for a particular concept. As in the Table, Frank Harary (a principal logician of social networks and founder of the mathematical field of graph theory) and I myself as project PI and consultant, respectively, are heavily involved in the development of such models. How these different models relate to one another is a current focus of our research interest. How can they be used in combination both to build a general framework of interrelated models useful for formulating network theory, and to help test some of the hypotheses derived from network theory?

2 Dynamics

Figure 1 summarizes the heuristic hypotheses and puts them in a dynamical context. In addition to tipping points in the assortment of relations across formal structural patterns, one of the principal sources of dynamical instability occurs in the variable ways that the coarser grouping and group exchange formal patterns are mapped onto the more nuanced logics of analogy and allocation that are discussed below.

3 Potentials for Integration of Theory and Measurement

3.1 The Dynamical Evolution of Coherence among Formal Patterns.

One of the goals of the present research is to develop a process model of relational coherence: how do elements assort and then cohere and synchronize in a (complex) social system (see also Watts 1999a,b)? A central heuristic construct for us is the use of "structural coherence" to express how these different formal aspects of the mathematical structure of sociocultural phenomena are embedded in real-world material, spatiotemporal, cognitive and communicative processes. Our guiding hypothesis is that the engines of structural coherence are coupling processes generated by the synchronization and **bundling** of tasks and activities – behaviorally, cognitively and communicatively – within a field of social action. A related goal is to articulate this theory in terms of networked processes and emergent structures, with the six patterns numbered

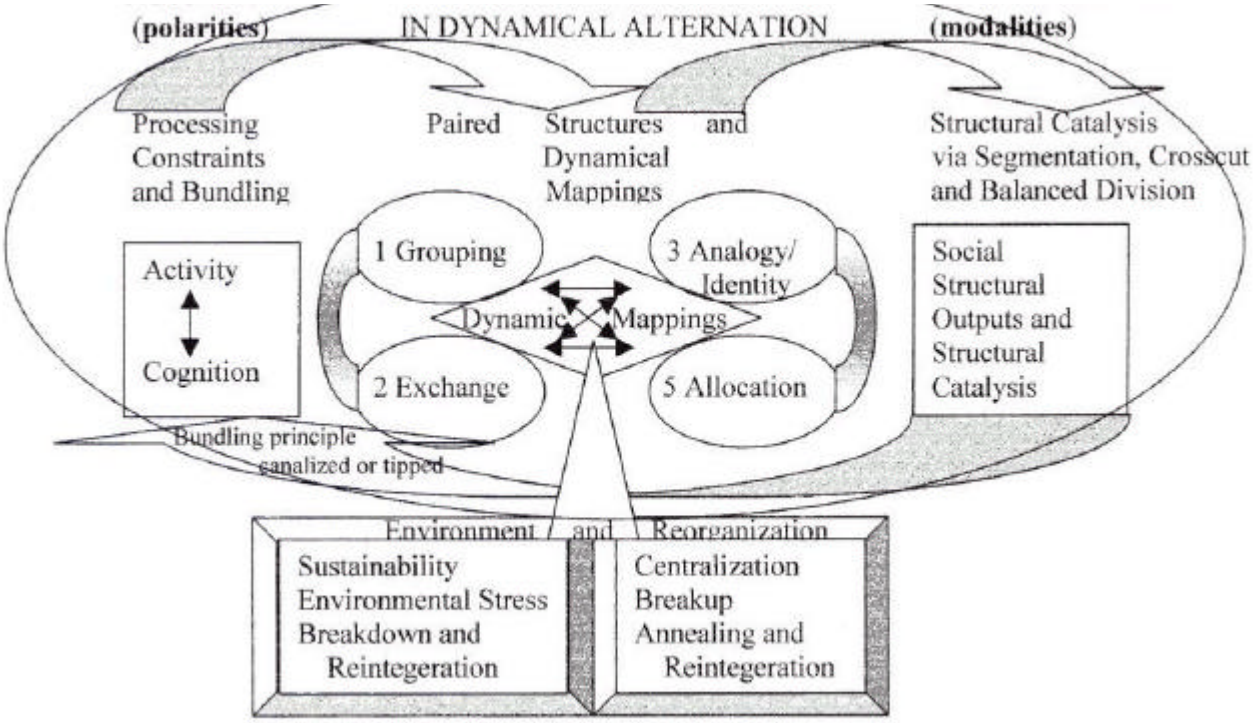

Figure 1: Process Model of Relational Coherence between Statics and Dynamics

in Table 1, as detailed in Table 2, being the principal formal patterns that we will investigate. Some of the insights of complexity theory are articulated within this framework and generate the following kinds of heuristic hypotheses:

3.1.1 Structural catalysis

Catalysis is regulation of processes through slowing down or speeding up their temporal rates or contracting/diffusing their temporal scales. Structural catalysis refers to the emergence of shared perception, language, and auto-regulatory communication, which requires or presupposes the emergence of a perceptible formal pattern of a social field such as the four pattern principles in networks of relations. E.g.: **Pattern 1** (**cohesion** measured by multiconnectivity, White and Harary 2001) is fundamental to the grouping principle. **Pattern 2** (**balance** measured within partitions of connected networks, Harary 1953) is an essential basis for understanding exchange (Gregory 1982 H.White 2002). **Pattern 3** (**positional equivalence and analogy**, Lorrain 1974, Lorrain and White 1981) is fundamental to thought, narrative structure, the 'situatedness' of intelligibility (Hofstadter et al. 1985, and Fauconnier 1997), and the recognition process in social identity, role, and attributed motivation and reputation (H.White 1992). **Pattern 4** (**specialization and division of labor**) is the recognized basis of formal organizations, office holding and the allocation of responsibility. **Pattern 5** (**centralization**, Freeman 1979) is one of the modalites (see below) by which other patterns are integrated.

3.1.2 Tipping points

Tipping points (Gladwell 2000) occur in historical trajectories where, although networks are still composed of the same types of relations, the way that the relations are distributed across formal structural patterns (and functions) is dramatically altered. **Pattern 6** (**distributed transformation**) is the result of reweighting of network elements, the tipping of network structures into a redistribution of elements that may once have been centralized. Structural catalysis may alter which kinds of relations are utilized as the basis of grouping and/or as the basis of exchange. Similarly for how relations are distributed in the logic of analogy/identity and the logic of allocation.

3.1.3 Interdependence

Interdependence among the four pattern principles in Table 2 occurs in **pairings** (see Figure 1): the grouping logic of relational solidarity is paired with an exchange logic between groups (which are not however automatically solidarity); and the analogous-positions logic in a behavioral system is paired with the formal or organizational activity allocation logic (but these two logics are not necessarily well coordinated). Pairing principles come out of balance theory as a principle of structural cohesion.

3.1.4 Modalities

Modalities by which the pairs of pattern principles (1 and 2; 3 and 4) are articulated are segmentation (as in homomorphic equivalence classes) and crosscutting integration (as in cohesive blocking and set intersection). Further, if the pairings are in perfect alignment they are more likely to neatly **segment** and/or segregate a social field (and its perceptual and communicative superstructures); if they are in misalignment they **crosscut** and thereby integrate a field through overlap, association and attendant ambiguity.

3.1.5 Morphogenesis

Morphogenesis as an aspect of coherence results from the fact that the segmentary versus crosscut patterns, among others, have very different and very severe implications and consequences (they strongly affect the path dependence of evolution and historical trajectories). White (1969) established through comparative ethnographic analysis that morphogenic coherence occurs between the degree of crosscut integration in a social structure and the degree of cooperativity required in the labor processes. Grannis (1998) established the converse for urban systems: the greater the segmentation of transport and communication systems into tree-like structures with cul-de-sacs, the lower the social integration and cooperativity, as measured by various indices.

3.1.6 Bundling

Bundling of activities in ways that satisfy easily executable behavioral routines is a necessary feature of spatiotemporal and sociocognitive (shared information) systems Goodenough (1963 Ch. 10) develops this into a principle of cultural organization and dynamics. Morphogenic and network pattern principles come to bear on this fundamental organization problem. Coherence in the expressive behavior, because of activity and cognitive constraints similar to those that require bundling, also requires high coherence in coordinate mapping with the labor domain. Hence:

3.1.7 Polarity reduction

Polarity reduction occurs between activity and cognition, and between expressive and task behavior –one has only see the films of Alan Lomax (1976) to recognize the coherence between them – as they are brought into coherent interdependence. In this process, for example, significant low frequency activities (e.g., mortuary ceremonies) are brought into resonance or synchronization with high frequency ones (e.g., daily or seasonally recurrent activities).

3.1.8 Structural catalysis

Structural catalysis again (the emergence from a perceptible formal pattern of a field of perception, language, and auto regulatory communication) plays a role in bundling and polarity reduction. For example, analogous conceptual structures (pattern principle 3) map onto diverse activity sets, and ‘unify’ them culturally. Similarly, formal principles of political, organizational and task allocation (pattern principle 4) require synchronization through structural catalysis of principles of recruitment, succession and inheritance with activity and auto regulation processes.

1. From smallest details up to the largest of abstract patterns of activity, **structural catalysis** is at work on different spatiotemporal and sociocognitive scales, that is, in a temporal and spatial spectrum, and in a social and cognitive spectrum of process. This is what dynamicists Iberall and Soodak (1978) call the stack

of 'factory day' processes that make up the spectra of activities of any complex system, subject to near-equilibrium material and energetic constraints on repetitive activity cycles.

2. The two sets of pattern principles (1&2 vs 3&4) are articulated by dynamic mappings some of which involve further individuated network attributes such as centralities and diversity in other attributes that serve as the basis for recruitment, etc.
3. Within the group-level hierarchies of cohesion and adhesion there is room for further variability at the individual and subgroup level, including **centralization and** variability in relative centrality of nodes or subgroups (**Pattern 5**). Centrality structures are constrained, however, by levels of cohesion and adhesion. A star pattern of maximal centralization, for example, can occur where adhesion is high but cohesion is low, whereas high cohesion (which entails high adhesion as well) places a limit on centralization.
4. In fluctuating environmental interactions, coherent systems may breakup, and their resilient components reconfigure in **redistributed transformations** (**Pattern 6**).

3.2 Measurement: Detecting Patterns in Networks

Cohesive blocking is a methodology recently refined by White and Harary (2001) that is crucial to theorizing about clusters of meaningfully related elements such as people in social groups, items in a material culture, or concepts in a symbolic world. A k-connected (or k-edge-connected) block in a graph of relationships is a maximal set of nodes in which no pair can be disconnected by removal of fewer than k nodes (or edges). Nodes versus edge connectivity define cohesive and adhesive blocks in networks, respectively. A k-cohesive block is also a maximal set of nodes where every pair has k or more paths that are node-independent (with no intermediate nodes in common). White and Newman (2001) give a fast algorithm to compute all such paths for large networks. The predictive consequences of measures of cohesion or adhesion for substantive variables in ethnographic and sociological studies have been shown for social class (Brudner and White 1997), leadership and group solidarity (Johansen and White 2002), group segmentation in conflict (White and Harary 2001), and attachment to school (Moody and White 2001), for example.

As shown in Table 2, while in cohesive blocking connections are grouped *within* sets, graph coloring is a homomorphism (generating color equivalence as a partition of nodes; edges can also be partitioned ed by similar principles) that goes in the opposite direction to observe the organization of equivalence sets when connections are limited to those *between* sets. Homomorphisms such as colorings are complementary to lattice structures (such as cohesive blocking hierarchies, which do not result in partitions) as principles in graph theory. Like colorings (and unlike cohesive blocks), block modeling is a homomorphism that generates a partition of nodes into nonoverlapping sets, but without the constraints of graph colorings (which cannot put two connected nodes in the same equivalence set). Sociological block modeling (Lorrain and White 1970, White, Boorman and Breiger 1975) is to the concept of role (analogous or similar position emerging out of a system of relations) what cohesive and adhesive blocking is to that of group. In the next phase of research we will generalize cohesive blocking to the study of role structure as developed by Oeser and Harary (1964, 1979), where we try to find tasks that cohere with one another, people who cohere with tasks, and coherence among formal roles (algebraic products of people by positions and positions by tasks) as opposed to emergent ones (people by people and people by tasks). Table 2 shows some of the ways in which these approaches differ. No one as yet has shown how these different aspects of network modeling might be unified around an integrated sociocultural theory, mathematically well formulated, of the socially interactive basis of cognition and the coherence of human behavioral systems (see Hutchins 1996; Moore 1998; Goodenough Ch. 10 1963). At the mathematical level, our research steps will be to establish a common formal language for comparison and integration of these four approaches, then to formally restate each model in the common language of graph theory, and finally to work on the formal conditional relationships amongst them (as we have done with connectivity and conditional density in developing the methodology of cohesive blocking). The next stages, discussed below, are to develop a substantive theoretical framework of hypotheses that allow us to measure and integrate the formal aspects or dimensions of these models in relation to empirically testable applications.

	Pattern 1	Pattern 2	Pattern 3	Pattern 4
	Cohesive Blocks	**Graph Homomorphisms**	**Blockmodel (Informal Roles)**	**Role Structure (Formal Roles)**
Coherence	Group Blocking	Exchange Opposition (Balance, Clustering)	Analogous Positions	Allocated Positions
Relations	Multiple	Single	Multiple	Tripartite*
--Within Sets	Connectivity	Disconnection	Similarity	HxH social PxP formal TxT task seq.
--Between Sets	Inclusion	Connection	Similarity	Bipartite maps
Structure	Hierarchy	Partition	Partition	H/T=H/P x P/T
Equivalence	(None:overlap)	Coloring	Regular	Multiple
Overlap	Minimum	None	None	
Reflexivity	n.a.	Disallowed	Allowed	

* H=Humans, P=Positions and T=Tasks (Oeser and Harary 1964, 1979)

Table 2: Formal Patterns in Networks (as elements in the study of coherence)

4 Some problems being investigated

***Problem 1*: Cohesive Unity**. What are the large as well as the smaller scale cohesive bases of cooperativity in social systems? What kinds of stable platforms for social, political and cultural organization (including knowledge bases) are formed on the basis of cohesive units?

***Problem 2*: Exchange Balances and Multilevel Graphs**. Complementary to the formation of social, political, and territorial groups is the process of establishing exchange relationships between them. Unlike transactions carried out within a group, cross-boundary relations take on the possibility of exchange or opposition. Graph homomorphisms, like the coloring of territorial maps of polities, preserve the distinctness of groups connected by such cross-boundary edges. To our knowledge, the relationship between cohesive connectivity groups in networks (where the 'positive' or in-group relations are of interest) and the partitioning or colorings of nodes by graph equivalence, where 'negative' out-group or exchange relations are involved, has only begun to be studied (White and Harary 2001). This combined approach allows the study of competition and trade-offs between solidarity (in-group) and exchange (between group), and the emergence of complex divisions of labor induced by cohesive hierarchies. A key idea here is that cohesive groups are nested in hierarchies according to the degree of cohesion, so that exchange colorings may operate at different hierarchical levels. A second related idea is that the hierarchical or embedded relationship of different units or subgraphs is such that we may usefully consider modeling complex systems as multilevel graphs where lower-order graphs are embedded in the nodes of higher-order graphs (Harary and Batell 1981).

Problems 3 and 4*: *Bundling and Scaling. When social, physical and communicative processes are connected in a network in which costs and outcomes can be optimized under time and channel capacity constraints, small random or exploratory perturbations allow the material and energy allocations to drift towards an optimized network configuration. A structural prediction is that sequential sets of structurally equivalent nodes – connected to the same others – will tend to develop a coherently optimized role structure. Role structures become templates for organizing bundled sets of activities and actors, and are extended in social and cognitive systems into analog (regular equivalence) models where the mapping of the template onto a new domain preserves the structure of linkages (White and Reitz 1983). Bundling principles provide dynamical processes partly responsible for construction of stable platforms or multi-unit systems of organization.

A second principle closely related to bundling in constructing multi-level platforms of network organization is that of *scaling*, which is related to the distribution of capacities of individual nodes and channels in a network in relation to the distribution of nodes and channels across a spatial or network topology. Biology has recently made massive progress with the scaling approach (West 1999). One of the key sociological insights of Powell, White, Koput and Owen-Smith (2001), using this approach, is that the processes by which the network is populated with actors (recruitment, persistence, disappearance) and by which actors grow their links to others (e.g., individual level decisions) tend to be determinant of the overall network topology (Albert and Barabasi 2001).

***Problem 5*: Distributive Transformation**, the long term: longitudinal analysis of network structure and dynamics in relation to social and economic transformations is challenging but has high scientific payoffs in terms of understanding the linkages between structure and dynamics.

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