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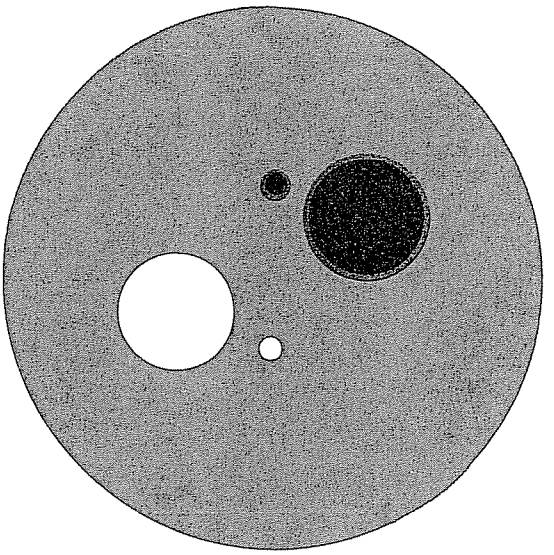

THE INVENTION OF COMPUTATIONALLY PLAUSIBLE KNOWLEDGE SYSTEMS IN THE UPPER PALEOLITHIC

by

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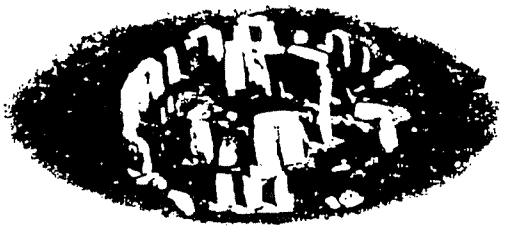

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ABSTRACT

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The problem of computing human behavior by rules can become intractable with large scale knowledge systems if the human brain, like a computer, is a finite state automaton. The problem of making such computations at a pace fast enough for ordinary social interaction can be solved if appropriate constraints apply to the structure of those rules. There is evidence that systems of such constraints were invented in the Upper Paleolithic, and were of sufficient power to guarantee that the time necessary for computation of behavior would increase only linearly with increases in the size and heterogeneity of world knowledge systems. Fundamentally, there was just one type of computational invention, capable of unifying the full range of human sensory domains, and consisting of an analogical reasoning method in combination with a global classification scheme. The invention may have been responsible for the elaboration of language and culture structures in a process of co-evolution. The encoding of the analogical mechanism in iconic visual imagery and myth structures may have given rise to the phenomenon of Shamanism. The theory is testable, and one of its implications is that the structuralism of Lévi-Strauss has an empirical foundation.

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The Problem of Computing Human Behavior by Rules

Contemporary artificial intelligence researchers find the problem of computing human behavior by rules intractable for large scale knowledge systems. While excellent results have been obtained for small scale knowledge domains, the time it takes to make such computations can increase exponentially or even combinatorially with the size and heterogeneity of the knowledge system. If the human brain, like a computer, is a finite state automaton, then the problem of generating and parsing behavior must present the same computational difficulty for the human mind.[1] The problem of making such computations at a pace fast enough for ordinary social interaction can be solved if appropriate constraints apply to the structure of the rules. There seems to be evidence that systems of such constraints were invented in the Upper Paleolithic, and were of such power as to guarantee that the time necessary for computation of behavior would increase only linearly with the size and heterogeneity of the world knowledge systems. The evidence can be found in the material and symbolic artifacts of a variety of cultures, and the major sources are classification schemes, divination systems, iconographic systems, language structures and shamanistic/mythic/religious systems.

The Basic Structure of the Invention

Fundamentally, there was one computational invention, capable of unifying the full range of human sensory domains, and consisting of an analogical reasoning method used in combination with global classification schemes. The structure of the human brain may be a factor in the history of this invention, but its utility exists independently of such a connection. Every culture seems to have a global classification scheme in the history of its knowledge structures and, usually, such schemes can be linked to myth systems. The use of this invention to compute human behavior is explicated in Klein (1983).

The strong equivalence operator of logic is shown to define ATO's (appositional transformation operators) that relate the input and output states of behaviorial rules by analogical transformations. It is argued that a given culture has a relatively small set of such ATO's, and that they apply to diverse domains of human behavior, and with a processing time that increases only linearly with the number of elements relevant to those rules. The global classification scheme makes it possible to select and apply the appropriate ATO's in a variety of domains by specifying equivalence classes of elements that may serve as substitution sets for the extension of each ATO. The result can be compared to a set of canonical analogies for which the extension and application are determined by equivalent analogs in the global classification scheme. The classification scheme for Chinese culture is a typical example (Klein, 1983:159):

TABLE 2

SOME TRIGRAM CORRESPONDENCES

	001 thunder	110 wind	101 fire	100 mountain	000 earth	111 heaven	011 lake	010 water
Element	wood		fire	earth		metal		water
Direction	East		South	Center		West		North
Color	blue		red	yellow		white		black
Season	spring		summer	*"fang"*		autumn		winter
Climate	windy		hot	humid		dry		cold
Planet	Jupiter		Mars	Saturn		Venus		Mercury
Sound	shouting		laughing	singing		weeping		groaning
Musical note	*chüeh*		*chih*	*kung*		*shang*		*yü*
Emotion	anger		joy	sympathy		grief		fear
Animal	dragon	fowl	pheasant	dog	ox	horse	sheep	pig
Family	1st son	1st da	2d da	3d son	mother	father	3d da	2d son
Body part	foot	thigh	eye	hand	belly	head	mouth	ear
Attribute	movement	penetration	brightness	standstill	docility	strength	pleasure	danger

SOURCES: Blofeld (1978:190–91), Wilhelm (1967 [1923]:1–11, 310), Legge (1964 [1899]:xliv–v), Legeza (1975:11), Fung Yu-lan (1953 [1934]:40–42, 86–132).

Each semantic domain is seen to have its equivalent in another domain. For example, 'East' is the direction counterpart of the element, 'wood', and its season companion is 'Spring'. Each of these terms is itself a metonym representing another class of items. The Chinese scheme is also linked to the I Ching divination system, which may be viewed as a knowledge based query system based on analogical principles. The divination system is associated with a set of canonical texts containing specific terms of reference that function as metonyms for higher level classes. Each text may be viewed as a formulaic behavior pattern awaiting the substitution of appropriate values for its variable terms by the user of the divination system. The computationally

difficult problem is the selection of a culturally consistent set of elements for the terms in the text. For a computer program operating with rules formulated in propositional logic, this could involve a combinatoric computation process. The Chinese global classification scheme reduces the process to looking up the corresponding elements in a table. However, the classification scheme used in a given divination is actually a transformation of the basic one indicated in the preceeding table. The divination process yields an ATO which generates an analogical realignment of the original table in correspondence with the situation of the moment, as determined by the divination process. A widespread African divination system operates on the same principles, and they can be seen to work also in the visual and verbal iconography of Navaho curative ceremonies. Tibetan and Esoteric Japanese Buddhist iconography functions as an ATO system which is a visual encoding of ATO's applicable to specific world domains, in conjunction with a myth system and a global classification scheme (Klein, 1983).

At this point let me offer some intuitive examples of how ATO's work in verbal and visual analogical reasoning problems, and also examples of analogical computation of behavior using situation descriptions linked by ATO's (Klein, 1983:152-154):

ATOs AND ANALOGICAL INFERENCE

ATOs relate situational descriptions in the form of feature arrays. A two-valued version, essentially, is the strong-equivalence operator of mathematical logic. If the interpretations of 1 and 0 are reversed, the operator is equivalent to non-carry, binary addition. The ATO is actually an array of bit operators defined as follows:

* a b	=	c
0 0		1
0 1		0
1 0		0
1 1		1
. .		.

where "." means "does not apply," making this specification two-valued, with some augmentation.

The operator has the following properties:

*ab	=	"ATO"
*ab	=	*ba
*a(*ab)	=	b
*b(*ab)	=	a

For example,

a		b
110	⟷	011
011	⟷	100
1.1		0.0

*ab
010
000 = "ATO"
0.0

. . .

A feature array referencing "male," "female," "young," "adult," "love," "hate," "light," "dark," is sufficient to formulate the following analogy:

$$\frac{X = \text{Boy loves light}}{Y = \text{Woman hates light}} :: \frac{Z = \text{Girl hates dark}}{?}$$

M	F	Y	A	L	H	Lt	Dk

where M = male, F = female, Y = young, A = adult, L = love, H = hate, Lt = light, Dk = dark

$$\frac{X = 10101010}{Y = 01010110} :: \frac{Z = 01100101}{?} \quad {}^{*}XY = 00000011$$

$$? = {}^{*}Z({}^{*}XY) = 10011001 = \text{Man loves dark}$$

Another example:

$$\frac{X = \text{Man hates dark}}{Y = \text{Woman loves light}} :: \frac{Z = \text{Boy hates light}}{?}$$

$$\frac{X = 10010101}{Y = 01011010} :: \frac{Z = 10100110}{?} \quad {}^{*}XY = 00110000$$

$$? = {}^{*}Z({}^{*}XY) = 01101001 = \text{Girl loves dark}$$

The same method can be applied to visual analogies. For example, if a set of visual features is used to create a pictorial analogy, the answer can be calculated using ATOs (fig. 1). If we give natural-language interpretations to these visual features, we can obtain the results shown in figure 2.

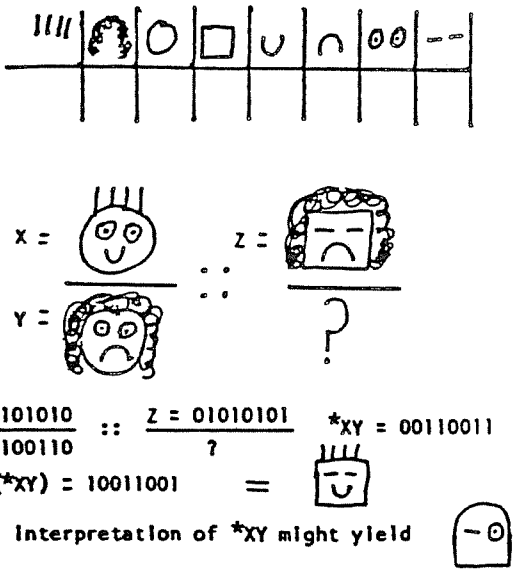


FIG. 1. Calculation of a pictorial analogy.

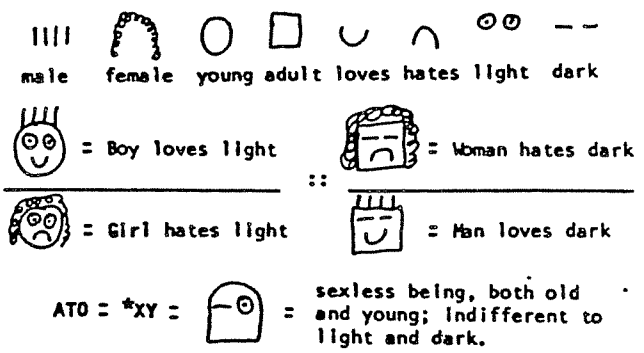


FIG. 2. The pictorial analogy with a natural-language interpretation.

Complex analogies may also be computed, as in the following abstract example:

If ((X :: Y) :: (Z :: W)) :: (P :: ?), then

? = *P(*(XY) (*ZW)).

A concrete illustration of this abstract example is as follows:

X		Y
A loves B, has no $, and is not married. B loves A, has no $, and is not married. C loves no one, has $, and is unmarried.	⟶	A loves B, has no $, is married to B. B loves A, has no $, is married to A. C loves no one, has $, and is unmarried.

Where La = "loves A," etc., $ = "has money," and Ma = "married to A," etc., the X and Y states may be represented as follows:

	La	Lb	Lc	$	Ma	Mb	Mc
A	.	1	0	0	.	0	0
B	1	.	0	0	0	.	0
C	0	0	.	1	0	0	.

X

⇒

	La	Lb	Lc	$	Ma	Mb	Mc
A	.	1	0	0	.	1	0
B	1	.	0	0	1	.	0
C	0	0	.	1	0	0	.

Y

*XY

.	1	1	1	.	0	1
1	.	1	1	0	.	1
1	1	.	1	1	1	.

If we depict "loves" as a nose pointing at the beloved (in between, if two loves), if a noseless state means "loves no one," if holding hands depicts "married to," and if a "$" indicates "has money," we can obtain the visual interpretation of figure 3.

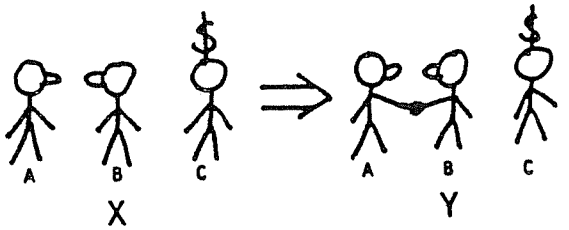


FIG. 3. A visual interpretation of X → Y, where X is "A loves B, has no $, and is unmarried. B loves A, has no $, and is unmarried. C loves no one, has $, and is unmarried" and Y is "A loves B, has no $, and is married to B. B loves A, has no $, and is married to A. C loves no one, has $, and is unmarried."

Continuing with this complex example:

Z	W
A loves no one, has no \$, and is married to B. B loves A, has no \$, and is married to A. C loves A, has \$, and is unmarried.	A loves no one, has \$, and is married to C. B loves no one, has no \$, and is unmarried. C loves A, has \$, and is married to A.

	La	Lb	Lc	\$	Ma	Mb	Mc
A	.	0	0	0	.	1	0
B	1	.	0	0	1	.	0
C	1	0	.	1	0	0	.

Z

	La	Lb	Lc	\$	Ma	Mb	Mc
A	.	0	0	1	.	0	1
B	0	.	0	0	0	.	0
C	1	0	.	1	1	0	.

W

*ZW
. 1 1 0 . 0 0
0 . 1 1 0 . 1
1 1 . 1 0 1 .

This yields the visual interpretation of figure 4.

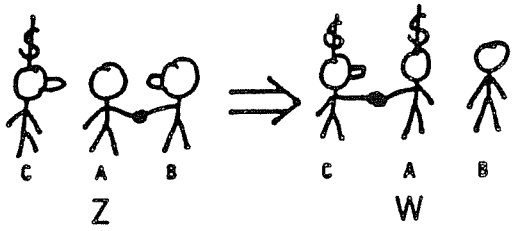


FIG. 4. A visual interpretation of Z → W, where Z is "A loves no one, has no \$, and is married to B. B loves A, has no \$, and is married to A. C loves A, has \$, and is unmarried" and W is "A loves no one, has \$, and is married to C. B loves no one, has no \$, and is unmarried. C loves A, has \$, and is married to A."

*(*XY) (*ZW)		"surrealistic" interpretation
. 1 1 0 . 1 0		A loves B and C, has no \$, and is married to B. B loves C, has \$, and is married to A and C. C loves A and B, has \$, and is married to B.
0 . 1 1 1 . 1	=	
1 1 . 1 0 1 .		

The visual interpretation obtained is that in figure 5.

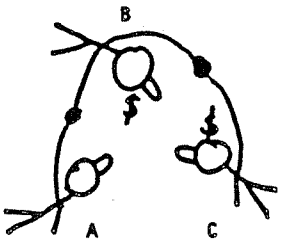


FIG. 5. A visual interpretation of the "surrealistic interpretation" *(*XY) (*ZW): "A loves B and C, has no \$, and is married to B. B loves C, has \$, and is married to A and C. C loves A and B, has \$, and is married to B."

If we then postulate a situation P,

	La	Lb	Lc	$	Ma	Mb	Mc	
A	.	1	1	0	.	0	0	A loves B and C, has no $, and is unmarried. B loves A, has no $, and is unmarried. C loves A, has $, and is unmarried.
B	1	.	0	0	0	.	0	=
C	1	0	.	1	0	0	.	

we can compute its successor state by analogy with the combinded results of $X \Rightarrow Y$ and $Z \Rightarrow W$ by solving

$$((X :: Y) :: (Z :: W)) :: (P :: ?),$$

where ? = *P(*(*XY) (*ZW)), which can be represented as follows:

	La	Lb	Lc	$	Ma	Mb	Mc	
A	.	1	1	1	.	0	1	A loves B and C, has $, and is married to C. B loves no one, has no $, and is unmarried. C loves A, has $, and is married to A.
B	0	.	0	0	0	.	0	=
C	1	0	.	1	1	0	.	

This yields figure 6.

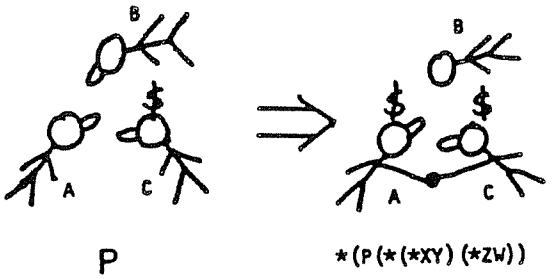


FIG. 6. A visual interpretation of P → *P (*(*XY) (*ZW)), where P is "A loves B and C, has no $, and is unmarried. B loves A, has no $, and is unmarried. C loves A, has $, and is unmarried" and *P (*(*XY) (*ZW)) is "A loves B and C, has $, and is married to C. B loves no one, has no $, and is unmarried. C loves A, has $, and is married to A."

ATO's, Language and Culture

I wish to argue that the invention, itself, consisting of the idea of a global classification scheme, in combination with behavior rules related by a limited set of analogical transformation operators, was responsible for the elaboration of language and culture structures in a process of co-evolution. Phrase structure grammar operates on ATO principles; this can be verified by creating a categorial grammar in which grammar codes consist of appropriately chosen binary integers. If one adds information indicating right or left combining properties and, also, semantic feature vectors, it is possible to use ATO logic for decoding both syntax and semantics in the same

notation. An implication is that world knowledge systems and language systems have co-evolved. If this is so, then,

1. The Sapir-Whorf hypothesis that the structure of grammar determines world view may remain true synchronically; diachronically, however, the two systems are in an intimate relationship of mutual influence and modification.

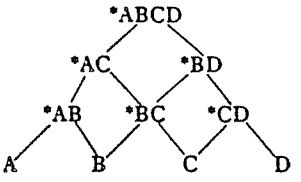
2. While the ATO model does not 'refute' Chomsky's view that there is an innate, genetic basis for language structure, it makes that assumption unnecessary to account for human linguistic behavior. The structure of the human brain may be a passive factor in the invention of structures that are computationally efficient in a given 'hardware' environment.

The extension and elaboration of culture content can be interpreted as the extension of the global classification scheme to new elements, and as the application of existing ATO patterns to new behavioral situations. The result is a formally definable explanation of the process of creating new patterns of behavior by analogy with patterns in other domains. If this process is part of the growth of a culture and its social institutions, then its symbolic, behavioral and material artifacts will contain many homologies. It is this aspect that gives a culture its coherency, and which enables its members to know what culture elements are appropriate.

ATO's and the Ontogeny of Shamanism

Religious systems can be interpreted as the symbolic medium in which ATO systems are encoded. The hierarchy of ATO's that govern the structure of a culture inevitably are encoded surrealistically in verbal and plastic domains, including myth systems and representations of spirits and deities. Consider the following aspects of the computation of behavior with ATO's (Klein, 1983:154)

If a sequence of events, A, B, C, D, occurs, then



= pattern behind patterns behind patterns behind events,
= patterns behind patterns behind events,
= ATO patterns behind events,
= event sequence.

If we wish to obtain a state E instead of D, *without changing* any of the ATOs, we derive, by analogy, a sequence leading to E by replacing A, B, C, respectively, with *A(*DE), *B(*DE), *C(*DE). If we wish to make a plan that specifies more than one goal state in the event sequence, we must alter some ATOs.

> The meaning of "culturally defined behavior" is that members of a society plan in a way that minimizes the level and number of ATOs affected. It follows that deviant behavior may be interpreted as behavior that violates acceptable levels and numbers of ATOs. ATO patterns are part of the knowledge acquired by children. They are encoded in multiple media of expression, both material and symbolic, and are the source of metaphor. It is this encoding that gives form to a culture, and it is their widely distributed presence in the environment that makes calculation of social behavior computationally feasible for the human mind.

The emergence of a canonical hierarchy of ATO's, applicable to multiple domains of social reality through the mediation of a global classification scheme, would be a natural consequence of organizing social life on the basis of ATO logic. If we make the assumption that the human mind encodes ATO's in iconic imagery, we may also suggest that such imagery is given metaphysical interpretation. A hierarchic ATO system may be interpreted by the human mind as a hierarchy of spiritual beings, and the spirit journey of a Shaman seeking to resolve problems in a spirit realm can be interpreted as precisely the kind of ATO manipulation described in the preceeding quotation. Magic spells and rituals would appear as devices for inserting desirable ATO's in given situations, and it might be possible to predict their form and general content from the global classification scheme. The implication of this model is that Shamanism is a consequence of the adoption of computationally plausible knowledge systems. Several theoretical possibilities are implied:

1. The ATO system concept was invented once, and spread by diffusion.

2. Computation with ATO logic may be a part of the functioning of the human brain.

3. ATO systems may have been invented independently, in conjunction with elaboration of social life.

4. If '2' and '3' are true, then the concept of 'the Shamanistic Tradition' may reflect phenomena which are of independent origin (Eliade,1964; artscanada, 1973/74).

The Evidence of Lévi-Strauss

The ATO logic described in Klein (1983) is a model of the structuralism of Claude Lévi-Strauss. It was originally formulated in 1976-77 in an attempt to replicate the reasoning processes that Lévi-Strauss used in Mythologiques (Lévi-Strauss, 1964-71). Given his semantic units, the arguments linking myth structures can be verified and replicated by ATO computation (Klein, 1977). The Klein (1983) paper was intended as a validation of the ATO concept with independent data. La pensée sauvage (Lévi-Strauss, 1962) is an explication of human reasoning with ATO systems; the four volumes of Mythologiques represent an overwhelming body of empirical evidence that ATO systems exist. The work is an analogue of historical reconstruction in linguistics. While he does not reconstruct a proto system, Lévi-Strauss has demonstrated that proto ATO systems must have existed at least as early as the Upper Paleolithic and that they have contemporary descendants. Given this perspective, much work seemingly critical of the structuralism of Lévi-Strauss can be reinterpreted as supportive (Hodder, 1982; Miller, 1982; Tilley 1982; Wylie, 1982).[2]

Testing the ATO Model in Historical Time

A discussion of ways one might obtain empirical validation of the ATO concept is given in Klein (1983: 178) and includes the following observations:

"4. The ATO model can be used as a heuristic device to suggest cultural correlations that can be verified by other methods. This approach might even extend to predictions about the location of buildings with specific functions in archaeological sites. Analysis of symbolic artifacts by ATO logic might help to decode or unlock large systems of correlations. ...

"5. One might examine the possibility that ATOs can be sources of social and cultural change. A large-scale classification system can imply a structured universe which no participant in a culture can contemplate as a whole. If a classification system incorporates 50 features, it can imply a conceptual universe with $2^n = 2^{50}$ elements. ATOs that function in a subset of the implied universe can be used as an exploratory tool to extend knowledge by analogy. A sudden, externally caused change in iconography (or mythology) would imply a new system of correlations and would offer the potential for new analogies about the structure of the world that might imply new patterns of behavior. A test of such a possibility would require an adequately documented historical situation."

Major testing of the theory requires a detailed analytic perusal of broad streams of history in a number of cultures. I would cautiously cite Toynbee (1934-1961) and Spengler (1926-1928(1918-1922)), whose general theoretical analyses can be interpreted in an ATO framework. I do not endorse any particular details of their analyses, but rather note that in their surveys of massive amounts of data they found relations and structures which are compatible with the theory of ATO systems. The principle that I value in Toynbee is his relation of religious systems to sociocultural systems (after disassociating it from his personal religious bias). In the case of Spengler, I value (minus the Germanic bias) the perception of the analogical relationships among the artifacts of a culture (Spengler, 1926:47):

"From this moment on, relations and connexions--previously often suspected, sometimes touched on but never comprehended--presented themselves in ever increasing volume. The forms of the arts linked themselves to the forms of war and state-policy. Deep relations were revealed between political and mathematical aspects of the same Culture, between religious and technical conceptions, between mathematics, music and sculpture, between economics and cognition-forms. Clearly and unmistakably there appeared the fundamental dependence of the most modern physical and chemical theories on the mythological concepts of our Germanic ancestors, the style-congruence of tragedy and power-technics and up-to-date finance, and the fact (bizarre at first but soon self-evident) that oil-painting perspective, printing, the credit system, long-range weapons, and contrapuntal music in one case, and the nude statue, the city-state and coin-currency (discovered by the Greeks) in another were identical expressions of one and the same spiritual principle."

Concluding Remarks

The criterion that a model of human cognition account for the ability of humans to compute social behavior in real time has, to my knowledge, not been addressed before. The thesis that ATO systems were invented in the Upper Paleolithic and are responsible for the growth of sociocultural structures provides mechanism for a variety of seemingly disparate theories. It makes structuralism and systems anthropology appear as different aspects of the same phenomenon and, if ATO logic proves to be hardwired in the human brain, it will be particularly compatible with sociobiology.

Notes

1. An assumption that the brain is a parallel computer does not mitigate the problem. The addition of parallel processors can reduce computation time linearly. The problem domain involves processing time that increases exponentially or even combinatorially.

2. The seemingly supportive evidence of Leroi-Gourhan (1965) is not supportive because it is not substantiated by knowledge of the global classification scheme of the culture that produced the Lascaux paintings. A recent discussion of the evidence is contained in Marshack (1985: 538-539).

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