Revised and expanded version, *2002.* Edited by Paul McKevitt, Sean O'Nullain & ConnMulvihill, (pp. 347-371) Amsterdam: John Benjamin
Invited Plenary Paper, Proceedings of The Eight International Workshop on the Cognitive Science of Natural Language Processing (**CSNLP-8**).
Theme: **Language, Vision & Music**. 9th-11th August, 1999, edited by Paul McKevitt, Conn Mulvihill, Sen O' Nuallain & Colm O'Riordan, pp. 20-32, Information Technology Centre, National University of Ireland, Galway.]

The Analogical Foundations of Creativity in Language, Culture & the Arts: the Upper Paleolithic to 2100CE

Sheldon Klein
Computer Sciences Department
Linguistics Department
University of Wisconsin
Madison, WI 53706
sklein@cs.wisc.edu

Abstract

The combinatoric problems associated with unrestricted models of human language processing suggest that real-world knowledge systems may have evolved in forms that make combinatoric processing problems linear. The role of Boolean groups and analogy in the extension and elaboration of complex behavioral systems, including natural language, suggests a theory that might account for the changes in human cognitive behavior that began in the Middle to Upper Paleolithic transition, and promises to continue through the next century.

Toward a unified theory of multi-model human behavior.

For 150-200,000 years, the material culture of anatomically modern humans showed little or no change. The techniques of stone tool manufacture remained static, there was no representational art, and no unequivocal symbolic behavior (Mellars 1989, 1991; Mellars & Stringer 1989). However, about 40,000 years ago, quite abruptly, the creative behavior of modern humans entered upon an exponential pattern of growth that continues through the present day. The best evidence seems to indicate that, over a 10,000 year period, modern humans emerged from their place of origin in Africa, and populated the globe. New forms of material and symbolic culture appeared, including representational iconography in 2 and 3 dimensions. No theory of human cognition is truly adequate unless it can account for the changes in human cognitive behaviour that began in the Middle to Upper Paleolithic transition. This is a tough constraint; yet, I would add one more:

Few researchers outside of the field of computational linguistics and artificial intelligence are aware of the tremendous ambiguity that is implicit in the phonology and syntax of natural language, unless powerful computational models of behavioral context are brought to bear. Seemingly powerful experimental results based on limited subject matter are, essentially, unproven. Almost every aspect of the problem space is subject to combinatorically increasing demands on computation time, or, in the case of massively parallel computing, combinatorically increasing demands on connectivity.[1] Though computers compute a million times faster than humans, human computation succeeds where computers fail. Any theory of human cognition that cannot account for this difference is also inadequate.

There are a number of theories in each of several disciplines that are concerned with human cognitive behavior that have contradictory premises. I'd like to consider the evidence for a theoretical model that is consistent with at least one theoretical approach in each of them.

Boolean Groups and the Computation of Analogies

Exclusive OR and hidden layers

For a connectionist network to learn the exclusive-OR logical operator, it is necessary to introduce at least one hidden layer (Elman, Bates, Johnson, Karmiloff-Smith, Parisi, Plunkett 1996: 60-65). This is also true for its symmetric counterpart, the strong equivalence operator (Table 1).

Table 1.

Exclusive Or
"a or b, but not both"

a	b	
T	T	F
T	F	T
F	T	T
F	F	F

a	b	
1	1	0
1	0	1
0	1	1
0	0	0

Strong Equivalence
"a if and only if b"

a	b	
T	T	T
T	F	F
F	T	F
F	F	T

a	b	
1	1	1
1	0	0
0	1	0
0	0	1

If T is replaced by 1, and F by 0, then the exclusive-OR is defined by the arithmetic operation of mod-2 (non carry) addition, and the strong equivalence operator is defined by the rules for multiplying the signs, + and - (Table 2).

Table 2.

Mod-2 addition (non-carry)

a + b
1 + 1 = 0
1 + 0 = 1
0 + 1 = 1
0 + 0 = 0

Mod-2 subtraction

a - b
1 - 1 = 0
1 - 0 = 1
0 - 1 = 1
0 - 0 = 0

If one creates a 4-valued truth table using binary integers, and the logic of either operator, one obtains a mathematical object called a Klein-4 group (after Felix Klein), which plays a major role in the theories of Piaget (1953), and Topology, an field devoted to the study of the properties of geometric objects that are independent of spatial transformations. Table 3 contains a version derived with the strong equivalence operator .

Table 3. Boolean Klein-4 Group

	00	**01**	**10**	**11**
00	**11**	**10**	**01**	**00**
01	**10**	**11**	**00**	**01**
10	**01**	**00**	**11**	**10**
11	**00**	**01**	**10**	**11**

Analogical Transformation Operators (ATOs)

**ab = *ba *a*ab = b   *b*ba = a*

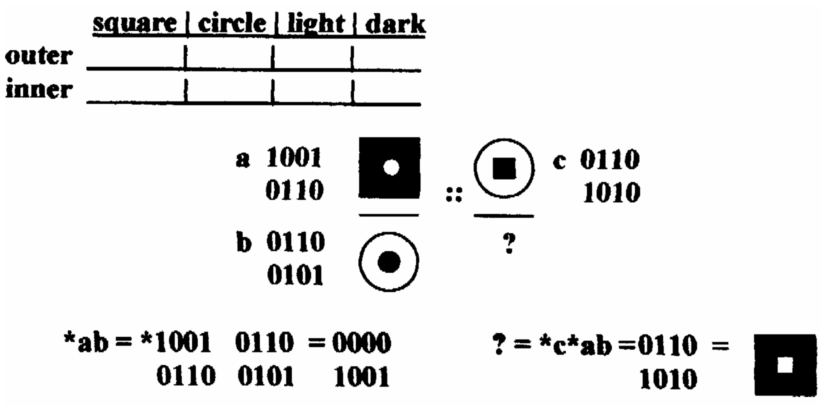
Example using the strong equivalence operator:

*a=101, b = 011, *ab = 001*
**b*ab = *011 001 = 101*
**a*ab = *101 001 = 011*

If the binary notation is used to indicate features, then the truth table for either exclusive-OR, or strong equivalence may be used to compute analogical operators that can be used to derive new analogies on the basis of prior examples.

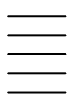
Visual Analogies (binary features, strong equivalence truth table)

Fig. 1. Abstract visual analogy

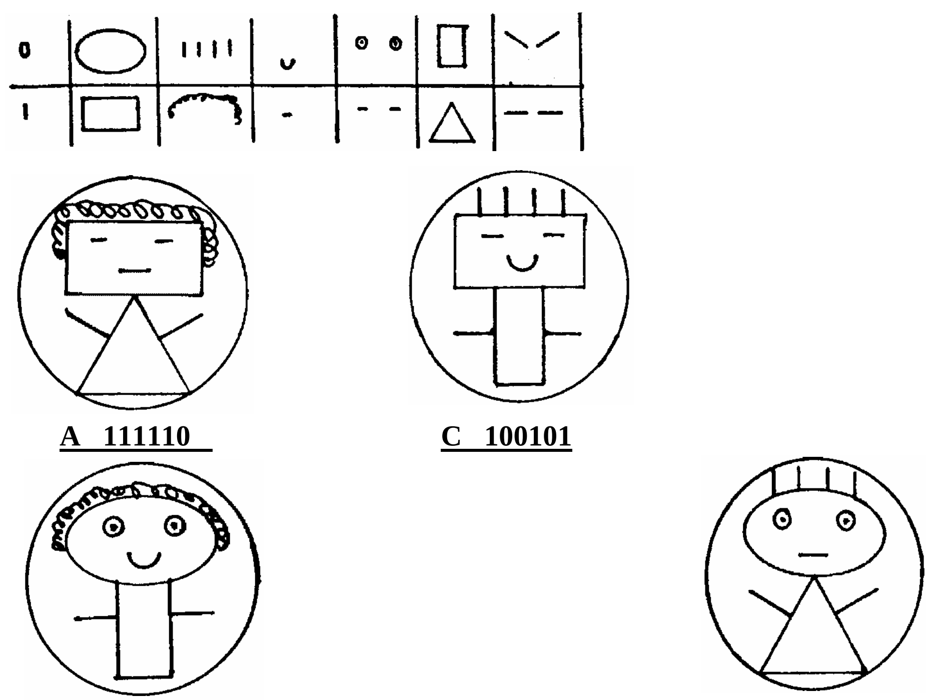


Iconographic

The analogical computation in Figure 2, is derived from an ATO analysis of a traditional classification of the 64 hexagrams of the *I Ching*, a Chinese divination system (Klein 1983: 151-180). I substituted arbitrary visual elements for each of six lines which might be either open or closed, and represented by 0 or 1,a notation used by Leibniz (1968)[2] The original of *A* in Figure 2 would have appeared as:



=> ***A***



? = D = *C*AB = 001010

***AB = 010000**

Fig. 2. Iconographic Analogy & the I Ching

Analogy and Language

ATO logic can model context free phrase structure grammar in the notation of categorial grammar (Klein 1989, 1996). Categorial grammar reformulates phrase structure rules as if they were algebraic equations. A rule *S*-> *Y Z* could yield *S/Z* as the grammatical category of *Y*, and a sequence *Y Z* would be parsed to *S/Z Z* , and then to *S*, after cancellation of the *Z*s. The same result can be achieved by assigning Boolean integers to *Y* and *Z*, and a derived Boolean integer for *S*:
Let *Y* = 10101, and let *Z* = 11001, Then, using the strong equivalence operator truth table, **YZ* = 10011 = *S*. **SZ* = *Y*, and **SY* = *Z*. Assigning and computing boolean integers for the morphological and syntactic units of a context-free phrase structure grammar can be accomplished by partial selection of values, computation of others. There are several rather interesting consequences:

a. Grammatical categories appear to be analogical operators.
b. ATOs can be interpreted as functors.[3]
c. Syntactic rules specify the formation of hierarchies of analogies.

Categorial grammars that include semantic features and phonological features as part of their data can also be implemented by the use of ATO logic. If each element of the morphological database is represented by three Boolean vectors, (for phonological features, morphological codes, and semantic features), then versions of categorial grammar more powerful than context-free phrase structure may also be modelled. Any analogy one may posit about relations among phonological units can be computed by ATO logic, using Boolean vectors of either articulatory features or acoustic distinctive features. It thus becomes possible to compute phonological changes, including temporal changes, by ATO logic.

Unifying Visual & Verbal Analogies

Consider the following verbal example (Klein 1983). The features, 'male', 'female', 'young', 'adult', 'love', 'hate', 'light', 'dark' are sufficient to formulate the verbal analogy in Table 4.

Table 4 - Verbal & Visual Analogy

X = Boy loves light : : Z = Woman hates dark
Y = Girl hates light ?

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

X = 10101010 : : Z = 01010101 *XY = 00110011
Y = 01100110 ?

? = *z*xy = 10011001 = Man loves dark

Also, consider the visual/verbal examples in Figure 3 (Klein 1983: 152, [Figures 1 & 2]).

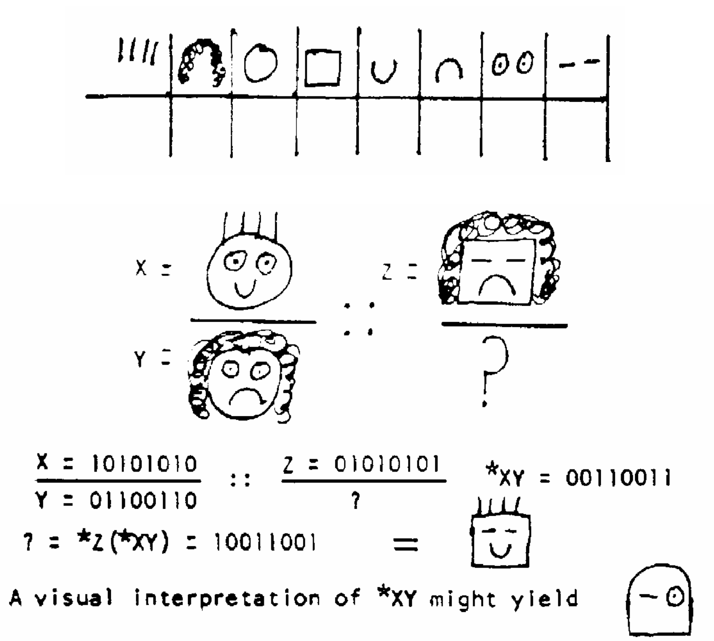


FIG. 1. Calculation of a pictorial analogy.

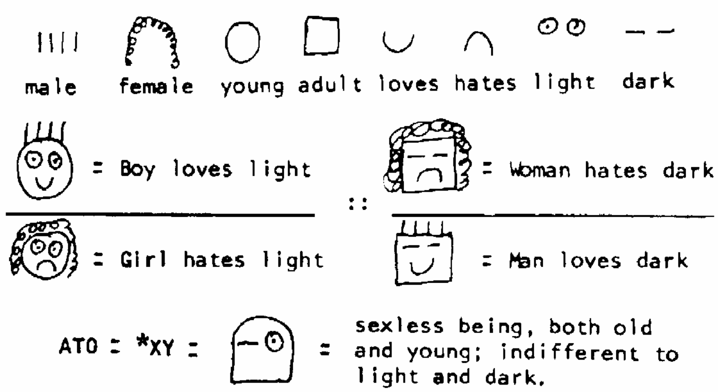


FIG. 2. The pictorial analogy with a natural-language interpretation.

Fig. 3. Visual/Verbal Analogy

The Boolean vectors and computations are identical in both examples. If they are combined, the visual and verbal interpretations of the features seem to belong together. Why they seem to combine in a natural way can be explained by interpreting each feature vector as a path down a binary decision tree. The trees for the components of the combined example in Figure 4 are isomorphic, (Klein 1983: 154-155, [Figures 7 & 8]).

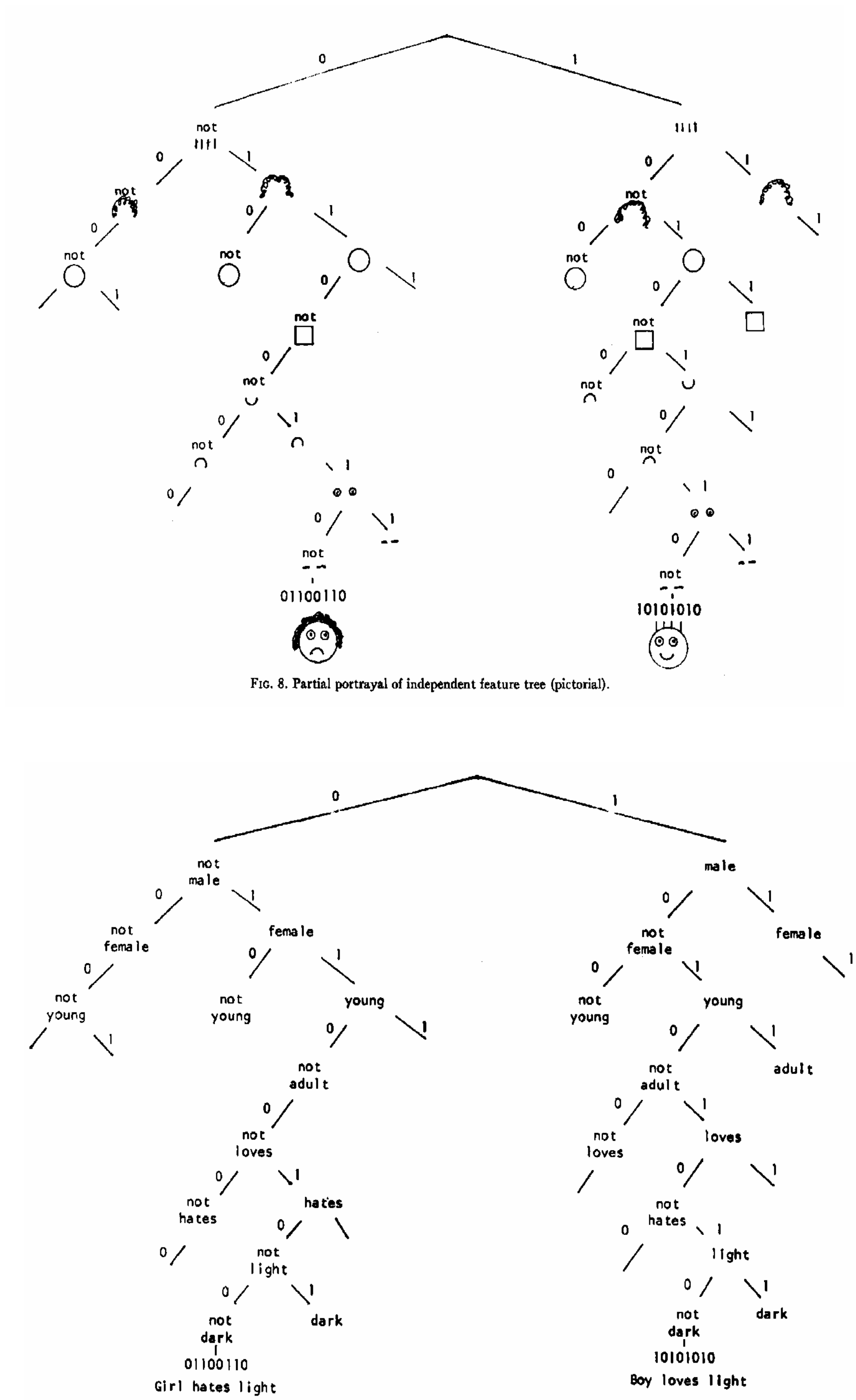


Fig. 4. Isomorphic Visual & Verbal binary trees

The number of terminal elements of such a tree is equal to the number of features of a decision path. If the terminal elements of that tree are projected onto the vertices of a hypercube of dimensionality equal to the number of terminal elements, the analogical relations of the original are present as spatial analogies among edges of the hypercube projection. The unity of the conceptual domains is made especially apparent if the Boolean vectors that were interpreted as paths down the binary decision trees are used to label the associated vertices of the hypercube (Figure 5):

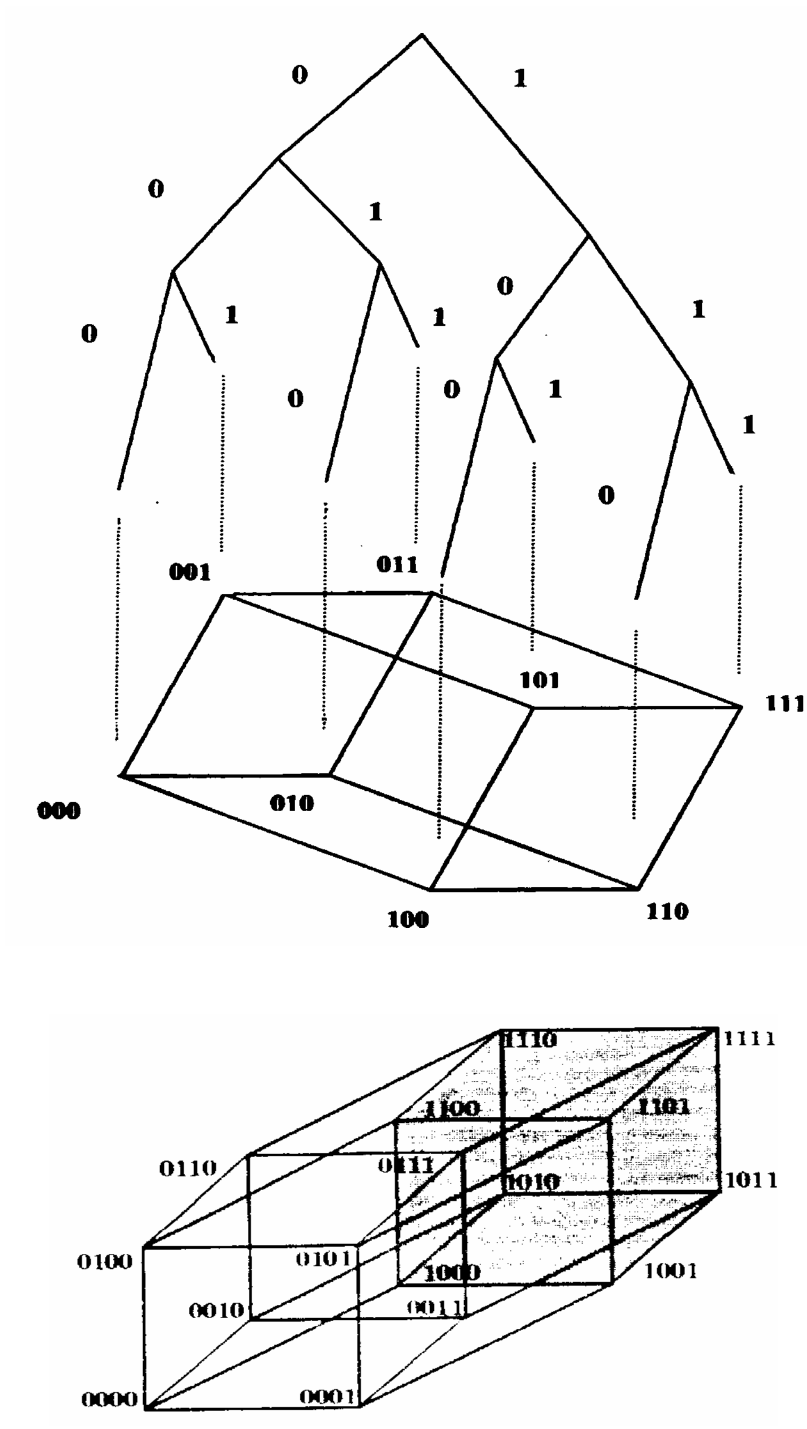


Fig. 5. Projections of 3 & 4 feature binary trees onto 3-dimensional & 4-dimensional cubes

Boolean vectors of n features may also be considered coordinates of concepts in an n-dimensional space, where distance is a measure of concept similarity, and where symmetries in the patterning of lines that connect concepts, reflect analogies that are valid in other notational representations.

Behavioral-Iconographic Analogy

Figures 6a, 6b, 6c & 6d illustrate a combined Behavioral-Iconographic analogy (Klein 1983: 153-154, [Figures 3-6]).

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:

X

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

⟹

Y

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

*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.

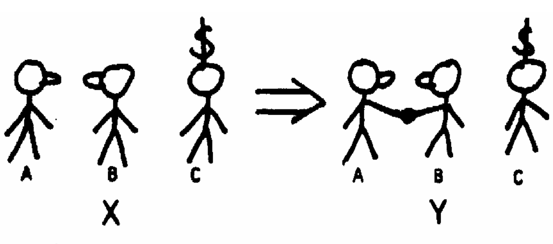


FIG. 3. A visual interpretation of X → Y, where X is "A loves B, has no $, and is unmarried. B loves A, has no $, and is unmarried. C loves no one, has $, and is unmarried" and Y is "A loves B, has no $, and is married to B. B loves A, has no $, and is married to A. C loves no one, has $, and is unmarried."

Fig. 6a. Behavioral-Iconographic Analogy

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.

Z

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

⟹

W

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

*ZW

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

This yields the visual interpretation of figure 4.

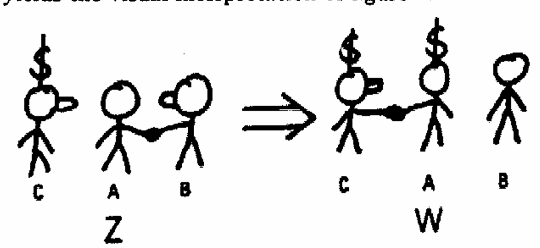


FIG. 4. A visual interpretation of Z → W, where Z is "A loves no one, has no $, and is married to B. B loves A, has no $, and is married to A. C loves A, has $, and is unmarried" and W is "A loves no one, has $, and is married to C. B loves no one, has no $, and is unmarried. C loves A, has $, and is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

Fig. 6b. Behavioral-Iconographic Analogy (cont.)

*(*XY) (*ZW)

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

= "surrealistic" interpretation: 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.

The visual interpretation obtained is that in figure 5.

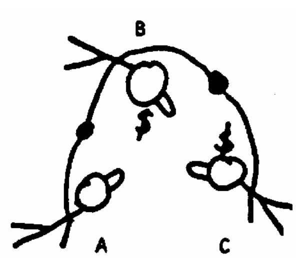


FIG. 5. A visual interpretation of the "surrealistic interpretation" *(*XY) (*ZW): "A loves B and C, has no $, and is married to B. B loves C, has $, and is married to A and C. C loves A and B, has $, and is married to B."

Fig. 6c. Behavioral-Iconographic Analogy (cont.)

If we then postulate a situation P,

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

we can compute its successor state by analogy with the combinded results of X — Y and Z — 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**
B	**0**	**.**	**0**	**0**	**0**	**.**	**0**
C	**1**	**0**	**.**	**1**	**1**	**0**	**.**

= **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.**

This yields figure 6.

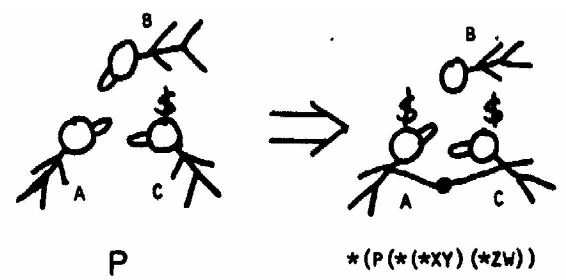


FIG. 6. A visual interpretation of P → *P (*(*XY) (*ZW)), where P is "A loves B and C, has no $, and is unmarried. B loves A, has no $, and is unmarried. C loves A, has $, and is unmarried" and *P (*(*XY) (*ZW)) is "A loves B and C, has $, and is married to C. B loves no one, has no $, and is unmarried.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

Fig. 6d. Behavioral-Iconographic Analogy (cont.)

Stone Tools and Language

Are motor skills associated with the origins of language? The view that they are is one associated with Piaget, but which remains controversial (Gibson & Ingold 1993). However, none of the arguments in the debate actually touches upon any of the formal syntactic or semantic aspects of language, nor do they recognize that there can be different types of language and that these can have rather different cognitive prerequisites, e.g. languages describable by finite-state grammars, context-free phrase structure rules, or context-sensitive, nor do they comprehend the cognitive computational requirements each entails, requirements that may be inherent, whatever the brain architecture, and whatever the cognitive model. The importance of language is in what it has enabled its users to do. For that reason, of utmost importance is the Middle to Upper Paleolithic transition, the moment when anatomically modern humans, after more than 150,000 years of behavioral banality, began to do rather interesting things.

The Evidence of Boker Tachtit

Astounding as it may seem, it is possible to examine the cognitive processes of individual humans in 20 to 60-second bursts of time, in a collection of events that took place from 38,000 to 47,000 years ago. The hard evidence is recorded in stone, in the form of refitted cores from the archaeological site of Boker Tachtit in the central Negev Desert of southern Israel (Klein 1990: 551):

> "The site was excavated by A. Marks in the 1970s, and revealed a sequence of four superimposed occupation levels, separated by intervening sterile deposits (see Marks 1981, 1983). The results of both uranium-thorium and radiocarbon dating indicate that the occupations took place between c. 47,000 and 38,000 BP, placing the site clearly within the conventional time-range of the Middle-Upper Paleolithic transition in the Near East. As Marks point out, one of the most valuable aspects of this sequence is that it represents a series of relatively short-lived episodes of human occupation and tool manufacture in a clear chronological succession (Marks 1983: 68): '...each occupation surface appears to have been lived on only briefly, as shown by the spatial distributions of reconstructable cores (Hietala and Marks 1981), and, therefore, each assemblage was produced during only a minute portion of that time. The assemblages taken together, however, should reflect accurately technological and typological patterns at specific intervals during this time span'.

A 'refitted core' represents the reconstruction of the original block of flint from which a tool, or sequence of tools was produced. The refitting process is one of reassembling a 3 dimensional puzzle from the debitage (the remaining flint fragments). An artifact of the refitting process is the knowledge of the exact sequence in which the various flint fragments were detached. The refitting work was accomplished by P. Volkman (1983), and he produced a tabulation of the various alternative sequences of flint removal that were actually found at each level of the site. These tabulations were for the final sequences of removal that predetermined the production of opposed-platform points at Boker Tachtit. When I saw Volkman's charts, I realized that they reflected the logic of a Klein-4 group, and were amenable to reformulation in a Boolean group notation and analysis for analogical patterning (Klein 1990: 502-506). The diagram in Figure 7 is Volkman's, and the labeled lines with numbered arrows represent the order and direction of the final detachments of flint in preparation for the final detachment of points (arrows labeled 'P').

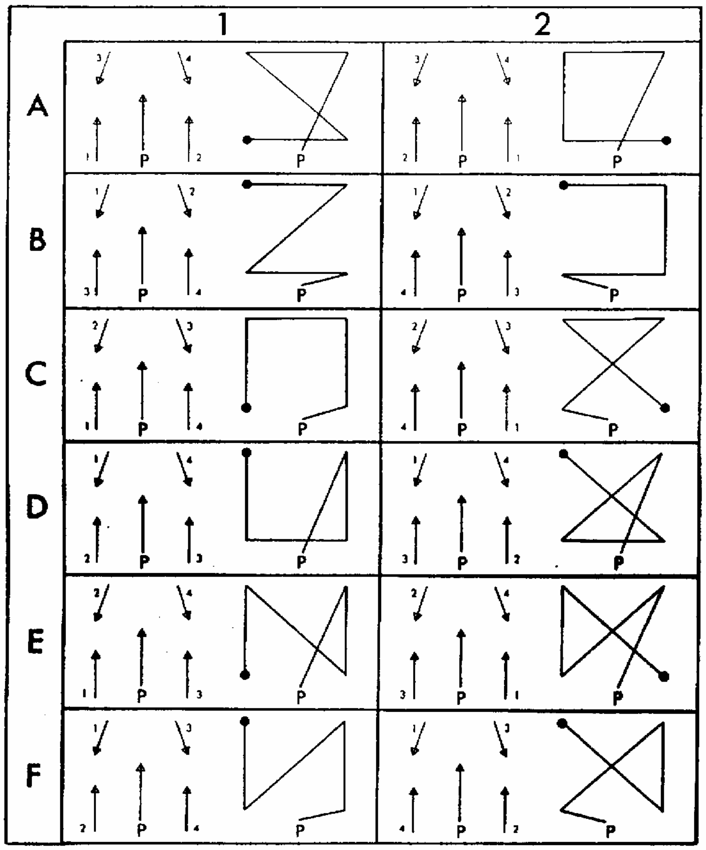


Fig. 7. Illustration reproduced from Volkman 1983: Figure 6-25, to show schematic representation of the blade removal sequence variations that predetermine the removal of the opposed-platform Levallois Points at Boker Tachtit.

Table 5 indicates the different patterns of point production found at the various levels of the Boker Tachtit site (Level 1 is the earliest).[4]

Sequence Type	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	Totals
Level 1	1		1	1	1	3	1	2			2		12
Level 2			6	3	3	3	3		4	2	3	1	28
Emireh, Level 2			1		1	1	1	1					5
Level 3			1										1
Sub-total	1		9	4	5	7	5	3	4	2	5	1	
Totals	1		13		12		8		6		6		46

Table 5. Data reproduced from Volkman (1983: Table 6-3), showing frequencies of Levallois Points produced in the reduction sequence types shown in Figure 7.

Table 6 contains my reinterpretation of the information contained in Volkman's Figure 18.2 in terms of binary semantic features representing left '0'/right '1', distal '0'/base '1' locations, in the order thedetachments were made. The table also contains computed ATOs for Volkman's grouped sets of sequences. *I was able to derive the new sequences that appeared on level 2 (E1, E2 & F2) using analogical ATO computations among just the sequences that occurred on level 1 of the site.*

Table 6 (Klein 1990: 506 [Table 18.3]).

Table 18.3.
An ATO analysis of the data in Volkman's figure 6-25 (see Figure 18.2) in which the order of the removals is listed in a fixed sequence and binary numbers are assigned to the types of removals. Two binary opposition sets, left = 0/ Right = 1, and distal 0/ base = 1, are used to determine the number names of the removals so that a left-side distal removal = '00', a left-side base removal = '01', a right-side distal removal = '10', and a right-side base removal = '11'.

						1	2	3	4
*A1B1	10	10	10	10	A1	01	11	00	10
					B1	00	10	01	11
*C1D1	10	10	10	10	C1	01	00	10	11
					D1	00	01	11	10
*E1F1	10	10	10	10	E1	01	00	11	10
					F1	00	01	10	11

	1	2	3	4					
A2	11	01	00	10	*A2B2	00	00	00	00
B2	00	10	11	01					
C2	11	00	10	01	*C2D2	00	00	00	00
D2	00	11	01	10					
E2	11	00	01	10	*E2F2	00	00	00	00
F2	00	11	10	01					

*A1A2	01	01	11	11
*B1B2	11	11	01	01
*C1C2	01	11	11	01
*D1D2	11	01	01	11
*E1E2	01	11	01	11
*F1F2	11	01	11	01

Non-Human use of Tools and Analogy.

The use of tools is not limited to humans. Chimpanzees have been observed to use tools, and even to smash rocks to obtain useful fragments. Sea otters use rocks to open crustacean shells. The process is taught to their young-- routinely, a sea otter will swim to the bottom and bring back both a crustacean and a rock, and then, use the rock to open the shell, while floating on its back, with the rock and the crustacean on its belly. There are numerous other examples, where the tool usage appears as learned behavior limited to specific groups of the same species.

Wynn (1991) has shown that tools made by very early humans reflected 4-fold symmetry. However, reconstructions of cores that might show varied sequences that form a Boolean group seem unavailable. Nevertheless, it seems likely that ATO type logic, which has been shown to be closely related to context-free phrase structure grammar, is part of the cognitive functioning not just of primates, but of most mammals. Consider the cognitive requirements for the young of a species to learn by imitation. The observed behavior must be seen as a kind of generalized script with roles that may be taken by participants other than just the performer of the moment. Moreover, as part of the imitative process, the pupil must place itself in the role of the teacher in order to perform the observed behaviour, an action usually requiring mirror-image reversal. Also required is an implicit recognition that the teacher and itself are members of a set that can quantify the role in a complex, goal-directed sequence of tasks. Accordingly, the use of ATO logic alone, is not enough to account for the changes in human behavior that began in the Middle to Upper Paleolithic transition.

Behavioral Rules and Logical Quantification by Analogy

ATO logic can be used to predict plausible social behavior using examples in the form of situation descriptions in a binary feature notation (Klein 1983, 1988). Patterns of behavior in one domain can be extended to new situations in other domains. The process involves elevating the objects and relations in one context to a superset status, then computing the equivalence connections of the elements across each domain. The process is facilitated when a society has an active global classification scheme as part of its cosmology. China (Table 7) and India, for example, currently have active systems, and anthropologists have provided ample evidence of the prevalence of such systems in North and South America, and Australia, to name but a few. I believe it is fair to suggest that every society in the world has a global classification scheme in its history, even if its present day usage is limited to artifacts in grammatical categories. This seems to imply an origin in the Upper Paleolithic, and it would have been an invention that made it possible to compute the logical quantification of analogical extensions of behavior to novel situations in novel domains in real time (Klein 1990). The essential requirement for complex social organization to function is that the participants can predict the behavior of others. To use one's own behavioral schema to model the behavior of others requires a reassignment of characters to the roles in a particular scheme. Without the existence of a system of constraints, the computation can involve calculations of combinatoric complexity. A global classification scheme provides such a system of constraints, and it permits the computation of analogies by 'table-lookup', rather than by a combinatoric analysis.

Table 7. Chinese global classification system linked to the trigrams of the *I Ching*.

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).

Linear Computational Efficiency

The behavioral analogy computation, given in an earlier example, implied a binary decision tree, composed of unary features, that resulted in $2^{15} = 32,768$ terminal elements as situation descriptions (Klein 1983: 155):

> "The tremendous computational advantage of ATOs applied to situation descriptions now becomes clear. To make such calculations it is *not* necessary to specify [and search] the entire feature tree; rather, one need only enumerate the sets of features relevant to the analogy."

As the number of features in a system increases, the computation time, in the worst case, increases only linearly, as opposed to the exponential or combinatorically increasing processing time typical of other methods of computation. If a cognitive system uses n features, it can account for 2^n concepts. If changing circumstances require just *one* additional feature to account for some new distinction, the size of the potential cognitive universe doubles, and it can be explored, by ATO logic with only a linear increase in computational effort.

A Unified Computational Model

Consider the following factors:

1. Hidden layers in neural nets were required in order to model the **exclusive-OR** logical operator, one of the ATO alternatives.
2. Every new analogy requires a change in a category system. Consider the following analogical computation:

<u>The small mouse fears a lion.</u> :: <u>The new student fears an exam.</u>
The large mouse likes a lion. ?

This can be computed by an ATO approach using syntactic trees in categorial grammar notation. Consider the dual-notation grammar in Table 8.

Table 8. Dual-notation grammar.

LEXICON

Det		*Adj*		*N*		*V*	
the	011011	small	001111	mouse	000011	fears	110110
		large	001100	lion	111000	likes	110000
		new	011001	student	011000		
		old	000110	exam	011110		

CATEGORIES

Det	10011	Adj	11111	N	01111	V	11001
NPP	01111	NP	00011	VP	00101	S	11001

SYNTAX

N = Adj N	VP = V NP	S = NP VP
01111 = *11111, 00011	00101 = *11001, 00011	11001 = *00011, 00101
NP = Det N		
00011 = *10011, 01111		

Figures 8 to 12 contain the categorial grammar trees used in the computation of the analogy.

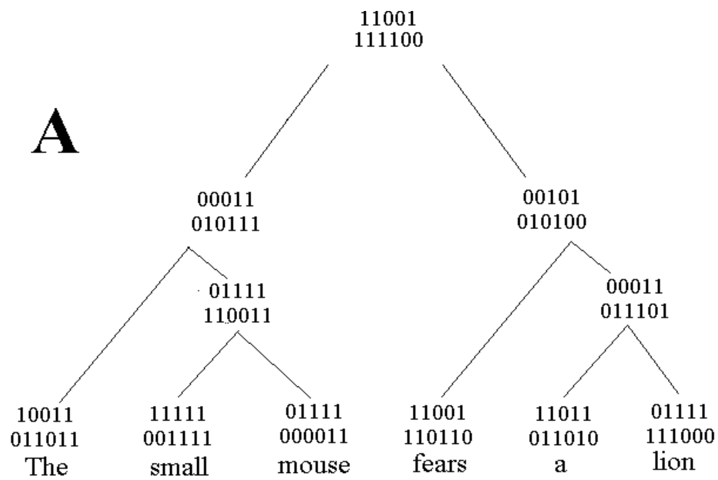


Fig. 8. Boolean categorial grammar analysis of the first sentence in the analogy.

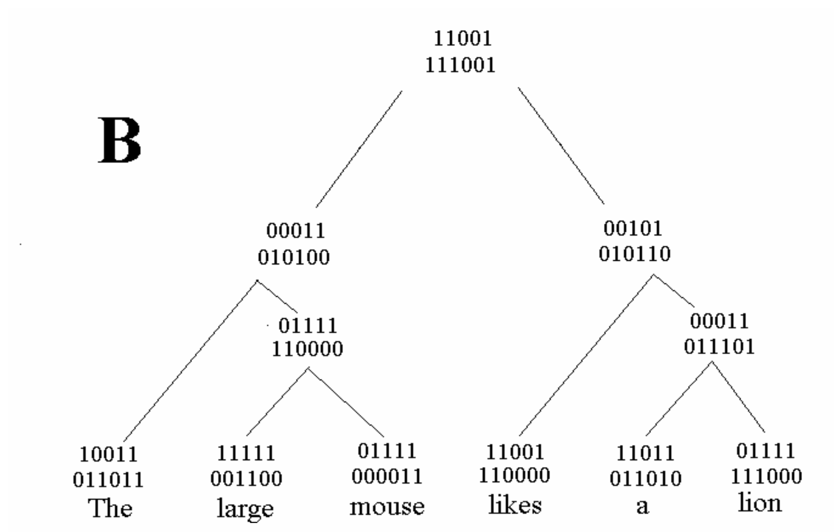


Fig. 9. Boolean categorial grammar analysis of the second sentence in the analogy.

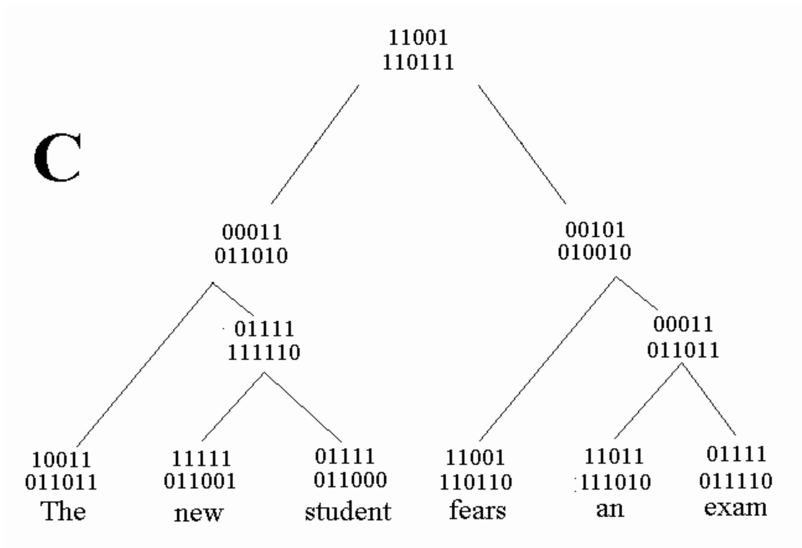


Fig. 10. Boolean categorial grammar analysis of the third sentence in the analogy.

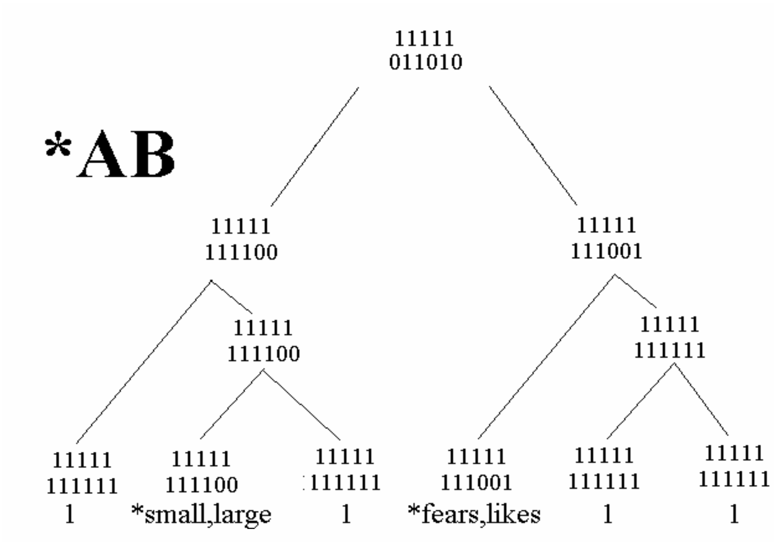


*Fig. 11. ATO tree, ****AB****, derived by applying the strong equivalence version to corresponding nodes in trees* ***A*** *and* ***B.***

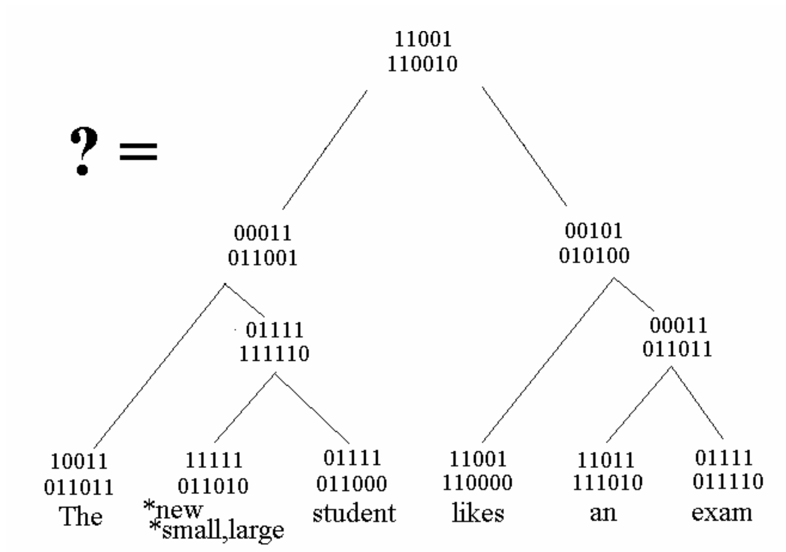


Fig. 12. The result of applying the ATO tree to the Boolean categorial grammar analysis of the third sentence in the analogy.

The *?* tree, computed by ATO logic applied to each node of trees *A* and *B*, yields an ambiguous result that can be resolved by the positing of an additional analogy, **(small :: large) :: (new :: old)**, which could form the nucleus for an additional pair of categorizations (Table 9).

Table 9. Resolving the ambiguity by adding a new analogy,

$$\frac{\text{small } 001111}{\text{large } 001100} :: \frac{\text{new } 011001}{\text{old } 000110}$$

*small, large = 111100   *new, old = 100000

* *small, large, *new, old = *111100, 100000 = 100011

But, *011010, 100011 = 000110 = **old**

3. Every act of learning a general case from a specific instance involves a new analogy, and either the creation of a new category, or the extension of an existing one.

4. ATO logic makes it possible to plan by analogy, at a computational cost that increases only linearly with the number of states in the plan sequence. Given a sequence of situations in a feature array notation, **A => B => C => D**, governed by an ATO transformation sequence, ***AB => *BC =>*CD,** one may create a series of events to change the final state from **D** to **E** by replacing the first state, **A**, with ***A*DE** which would then yield the a new sequence, ***A*DE => *B*DE => *C*DE => E** :

```
*AB   *BC  *CD              *AB      * BC      *CD
  / \   / \   / \              /    \     /     \     /     \
A    B     C    D         *A*DE   *B*DE   *C*DE   E
```

If unary features are used, the resulting goal-directed sequence may contain 'surrealistic' or contradictory elements.

5. A culturally-based set of behavior patterns that persists across generations implies the existence of a hierarchy of ATOs that has remained stable at its higher levels (Table 10).

Table 10. ATO Hierarchy

```
        *AD        =  pattern governing "pattern governing 'pattern governing event sequence"
         / \
      *AC  *BD     =  pattern governing 'pattern governing event sequence'
      / \  / \
  *AB  *BC  *CD    =  pattern governing event sequence
   / \  / \  / \
  A     B     C    D  =  event sequence
```

This can be interpreted as mechanism for the theory presented in Shore (1996): higher level operators are multiply encoded, through the medium of global classification schemes, in diverse domains of behavior including architecture, music, mythology, religious iconography and ritual, and in *language.*

With such a model, existing high-level structural patterns of behavior in a society can be applied to new domains, without necessarily modifying any ATOs, by extending the scope of pre-existing global classification schemes (Klein 1983). It is worth noting that this view also suggests that it might serve as a model interpretation for Spengler's theories regarding temporal structure of civilizations (1926-28).
.

A post-Post Structuralist Model

The *post-Structuralist wing* of the *post-Modern* movement in anthropological & archaeological theory rejected the Structuralism of the 1960's for a number of reasons, among which was its apparent static nature. The theory I have proposed uses the techniques of structuralist analysis for the collection and analysis of data, but makes use of implied logical relations as data for dynamic models of complex social behavior and change. *The result is that a structuralist methodology is used to derive the conclusions of post-structuralist theory*, and that *the structuralist models of Claude Lévi-Strauss appear to have an empirical foundation* (Lévi-Strauss 1962, 1964-71).

Do ATOs Occur in Nature? The answer is yes, and in the most fundamental processes of life and evolution on the planet. The relationship between DNA and RNA appears as a mirror image reversal if coded in a Boolean group notation:
If each DNA nucleotide base is named by a two place binary integer,

```
DNA      a    c    g    t
         00   01   10   11
                             >  ATO =00
         11   10   01   00
RNA      t    g    c    a
```

Why this is so is rather simple. Boolean group reversibility is a fundamental component of self-reproducing machines. It is the principle by which positive images are recorded as negatives, which are then turned into positives. It is the principle of digital image recording and reproduction.
And it has the properties of an encryption technique that adds a code book text to a message text using non-carry addition, and which returns the original if the code book text is subtracted from encrypted message by non-borrow subtraction. *But in binary arithmetic, these two processes are identical.*
This *involutive* property has profound consequences:

The Transmission of Language, Culture and DNA, involve a single process, that of information transfer in a noisy channel, with the only difference being that of medium and time scale, implying that language, language change, and language variation are, ultimately, the same phenomena as their genetic counterparts.

2100CE

The title of this paper promises a statement about the future of the human mind during the next century. Let me close by calling your attention to Terrence Deacon's book, *The Symbolic Species* (1997). Deacon's views on language evolution are ones I share: that the genetically determined innate capacities required in either Chomky's or Pinker's version of such theories is unnecessary. Observed linguistic universals appear because the architecture of the brain makes some language structures computationally inefficient. The languages of the world, which have real functions as communicative devices, have developed in configurations that prevent them from being computationally inefficient. Deacon also describes in considerable detail the mechanisms and the evidence of changes that can take place in brain structure functionality in a single individual in a single lifetime. This suggests to me that the nature of human consciousness may change in significant ways during the next century simply because of the shift to analogic iconographic reasoning that seems inherent in the use of computational media. For a speculation, it is unusually testable, and on a continuing basis, through the use of functional magnetic resonance imaging (fMRI) of the brain.

Notes

1. If the problem domain requires combinatorically increasing demands on resources, f(n!), where n is the number of entities involved in the required computations, then even adding an entire computer for each element of n will not help, for f(n!)/n = f((n-1)!), a saving that becomes meaningless as n becomes large.

2. Leibniz was made aware of the I Ching when a Jesuit Missionary in China wrote to him noting that a sequential arrangement of its 6 line figures seemed equivalent to a sequential listing of binary integers, from 0 to 63 .

3. Curry (1961) has sanctioned the use of the term ' *functor*' for grammatical categories in categorial grammars, rather than the term, '*operato*r'.

4. Tables 5 and 6 are corrected versions of the ones that appeared in Klein (1990).

References Cited

Blofeld, John (1978). *Taoism: The road to immortality.* Boulder: Shambhala

Curry, Haskell B. (1961). Some logical aspects of grammatical structure. In R. O. Jakobson (Ed.), *Structure of Language and Its Mathematical Aspects* [Proceedings of Symposia in Applied Mathematics Vol. XII] (56-68). Providence: American Mathematical Society.

Deacon, Terrence (1997). The Symbolic Species. New York: W.W. Norton & Co.

Elman, J.L., E.A. Bates, M.H. Johnson, A. Karmiloff-Smith, D. Parisi, K. Plunkett (1996). *Rethinking Innateness: A connectionist perspective on development.* Cambridge, MA: The MIT Press.

Fung ,Yu-lan (1953 [1934]). *A history of Chinese philosophy,* Vol. 2, translated by Derk Bodde. Princeton: Princeton University Press.

Gibson, Kathleen R. and Tim Ingold (Eds.) (1993). *Tools, language and cognition in human evolution..* Cambridge: Cambridge University Press.

Hietala, H.J. & A.E. Marks (1981). Changes in spatial organization at the middle to upper paleolithic transitional site of Boker Tachtit, central Negev, Israel. In J. Chauvin and P. Sanlaville (Eds.) *Préhistoire* *du Levant* (305-318). Paris: Centre National de la Recherche Scientifique.

Klein, Sheldon (1983). Analogy and mysticism and the structure of culture. *Current Anthropology 24*, 151-180.

Klein Sheldon (1988). Reply to S.D. Siemens' critique of S. Klein's 'Analogy and mysticism and the structure of culture (Klein 1983)'. *Current Anthropology 29*, 478-483.

Klein, Sheldon (1990). Human cognitive changes at the middle to upper Paleolithic transition: The evidence of Boker Tachtit. In P. Mellars, (Ed.), *The emergence of modern humans: An archaeological perspective* (499-516). Edinburgh: Edinburgh University Press.

Klein, Sheldon (1991). The invention of computationally plausible knowledge systems in the upper paleolithic. In R. Foley, (Ed.), *The origins of human behaviour* (67-81). London: Unwin Hyman.

Klein, Sheldon (1996). Grammars, the *I Ching* and Lévi-Strauss: More on Siemens' `Three formal theories of cultural analogy'. *Journal of Quantitative Anthropology 6*, 263-271.

Leibniz, G. W. (1968 [circa 1696-1698]). *Zwei briefe über das binäre zahlensystem und die Chinesiche philosophie.* Belser: Belser Presse.

Legeza, Laszlo (1975). *Tao magic: The Chinese art of the occult.* New York: Pantheon Books.

Legge, James (translator) (1962 [1899]). *The Yi King.* New Hyde Park, N.Y.: University Books.

Lévi-Strauss, Claude (1962). *La Pensée sauvage.* Paris: Plon.

Lévi-Strauss, Claude (1964-71). *Mythologiques* [4 volumes.]. Paris: Plon.

Marks, Anthony E. (1981). The middle paleolithic of the Negev. In J. Chauvin and P. Sanville (Eds.) *La préhistoire du levant* (287-298). Paris: Centre National de la Recherche Scientifique.

Marks, Anthony (1983). The middle to upper paleolithic transition in the Levant. In F. Wendorf and A.E. Close (Eds.), *Advances in world archaeology* [Vol. 2] (51-58). New York: Academic Press.

Mellars, Paul (1989). Major issues in the emergence of modern humans. *Current Anthropology 30*, 349-85.

Mellars, Paul (1991). Cognitive changes and the emergence of modern humans. *Cambridge Archaeological Journal I*, 63-76.

Mellars Paul & Chris Stringer (Eds.) (1989). *The human revolution: Behavioural and biological perspectives on the origins of modern humans.* Edinburgh: Edinburgh University Press.

Piaget, Jean (1953). *Logic & Psychology*. Manchester: Manchester University Press.

Volkman. Phillip W. (1983). Boker Tachit: core reconstructions. In A. Marks (Ed.) *Prehistory and paleoenvironments in the Central Negev, Israel* [Vol. 3: *The Avdat/agev Area* (Part 3)] (127-190). Dallas: Southern Methodist University Press.

Wilhelm, Richard (Translator) (1967 [1923]). *I Ching* [3rd edition] . English transl. by Cary F. Baynes. Princeton: Princeton University Press.

Wynn, Thomas (1991). Archaeological evidence for modern intelligence. In R. Foley, (Ed.), *The origins of human behaviour* (52-66). London: Unwin Hyman.