A THEORY OF THE LIVING ORGANIZATION
07-16-80 22-29-49—6720$$3201
AE-AUTO-6720 Operator 65(32x) Tape 1, P. 383

Chapter 16
Organizational Closure of Potentially Conscious Systems*

Gordon Pask

16.1 Introduction

The notion of organizationally closed and autopoietic systems has been invented more or less independently and in various contexts, though the term itself and its careful application to living systems is due to Maturana and Varela. For example, much of von Neumann's work on reproductive automata and the content of the early Macey Foundation meetings on cybernetics refers to similar constructs. So, on serious examination, does von Foerster's first enunciation of "Self Organization" in 1958, as does McCulloch's notion, "Redundancy of Potential Command." Much the same is true of work in other disciplines: including that of Wiener and Svoboda in mathematical cybernetics, Herbst in logic, Bateson and Mead in social anthropology, Waddington, Tyler Bonner, and others in embryology and genetics, Wynne Edwards in ethology, Ackoff and Beer in operational research, and numerous cosmologists and theoretical physicists. The list is enormous, because this quite basic reappraisal of what systems are and what stability is reflects a very fundamental change in thinking. Only in recent years, however, has there been either the language required to express the pertinent notions or a sufficiently large body of shared concepts to render these notions communicable and generally intelligible.

In this paper I attempt to give a systematic theoretical account of my own ideas, which originated independently (whatever that means, and I

* Prepared for the NATO International Conference on Applied General Systems Research: Recent Developments and Trends, and presented at Binghamton, New York on 22 August, 1978.

am no longer at all certain) but fell into the context about 15 years ago of those of von Foerster, Maturana, and Varela. The concept of organizational closure is crucial to a psychological or social "theory of conversations," in which the minimal *conscious* autopoietic system is known as a "P individual" (psychological individual). The empirical background for my own work came in part from studies of complex skill learning, especially from detailed examination of the conceptual mechanisms of educational psychology. More recently the work has been augmented by studies, in similarly detail of enquiry, concerned with complex decision making, social organization innovation (creativity, design, and the burgeoning field of applied epistemology).

16.2 Process Execution

Let Z be a variable with values A, B, ... that designate *processes* or active systems. This paper concerns those values of Z, say $Z^* \subset Z$, designating processes that are sites or progenitors of consciousness. For generality, these are known as "conscious systems." Particular interest is accorded to conscious systems for which, at any rate in principle, an external observer can determine the content of consciousness by observing a sharp-valued event called in Section 16.3 an understanding and the extent of the consciousness by a fuzzy (*not* sharp-valued) measure.

Given a process, it is often convenient to distinguish between a processor and a code or program (in general, a nondeterministic program, in a slightly special sense, a fuzzy program [Zadeh 1973]). To avoid misinterpretation, let us call a code or program when it is undergoing execution, a *procedure* (or, for brevity, a Proc). In this case, the processor of $Z = A, B, \ldots$ is $\lambda(Z)$ and the code or program of $Z = A, B, \ldots$ is $\pi(Z)$. It is also useful to employ the notations $\pi(A) = a$, $\pi(B) = b$ .....; and $\lambda(A) = \alpha$, $\lambda(B) = \beta$: Note, however, that Z does not have a value on "a alone," or "α alone," or on "b alone" or "β alone," for where Z has a value there is invariably a process (a procedure undergoing execution).

There is a sense, to be developed, in which $\pi(Z)$ constitutes the formal linguistic or syntactic aspect of whatever is designated by a value of Z and $\lambda(Z)$ constitutes its interpretative or semantic aspect. Pragmatics appear (hence, a complete semiotic is attained) only if both aspects are brought into consideration. But these images, though useful in their own way, reflect an underlying reality: Z does not point at objects $A, B, \ldots$ that can properly receive *only* impersonal or *it* reference.

16.3 Conversations, Explanations, Concepts, and Participants

Most of the empirical support for the notions spelled out in the sequel comes from work upon conscious human beings. Values $A, B, \ldots$ of Z designate human beings or groups of two or more human beings engaged in conversation. In concert with Dienes, Piaget, Landa, Luria, Vygotsky, and many others, we have found it fruitful to regard a conversation as the minimal situation for observing psychological events of which the participants are conscious (in contrast, for example, to an input–output or stimulus–response situation), and it has been possible to develop a theory of conversations (Pask 1973, 1975 a,b, 1976 a–c, 1977a,b), in which the event of understanding is definable and pivotal.

Frequently, the conversation between two human beings, or a normally internal conversation (thinking) between perspectives or roles adopted by one human being, takes place *through* a computer-regulated interface designed to exteriorize normally hidden conceptual operations and to expedite the observation of understandings. In these conditions, the conversational language need not be a verbal, natural language, though a rich symbolic medium with many of the properties of natural language is mandatory. This medium is a language, although not a spoken language, called L. For $Z = A, B, \ldots$ $\pi(Z)$ is a collection of L expressions; for example, programs (or codes) are L expressions.

We are particularly interested in program listings, conceived as explanations, since the basic and sharp-valued measurements we can make (as observers of understandings) consist in explanations of explanations (which are subsets of coherent and symbolically represented beliefs). One obstacle in the way of psychological enquiry, in the interview mode, is that ordinary language is ambiguous in the sense that there is no easy or systematic means of determining what *is* an explanation (still less an explanation *of* an explanation). For example, explanations do not have to be "true," or "veridical," and most of them are not. Hypotheses and coherent myths are permissible explanations. This difficulty is surmounted in a nonverbal language like L, for an explanation is clearly a prescription (or a prescriptive behavior) involved in L programming a working model (L program) that is constructible and works. It may be a piece of sculpture, incidentally, just as well as a piece of standard calculation or the demonstration of a physical principle.

In L, verbal explanations can be disambiguated as nonverbal, model-building, L explanations; understandings are detectable as cycles involving explanations of explanations. Under these circumstances, it is possible to speak of strict conversations (understandings are ordered in a strict sequence) as contrasted with liberally organized conversations. To quantify the understanding in the latter case, a minimal equipment is an epistemological laboratory (Figure 1) in which it is possible to record and regulate nonverbal, but symbolic, interactions (L interactions), which correspond to most types of verbal dialogue encountered in interpersonal discussion, learning, innovation, agreement reaching, design, evaluation, theory building, and the like. This appears to be the proper equipment for paradigmatic studies of consciousness, where results obtained by field investigation can be refined and their conceptual basis well specified. The

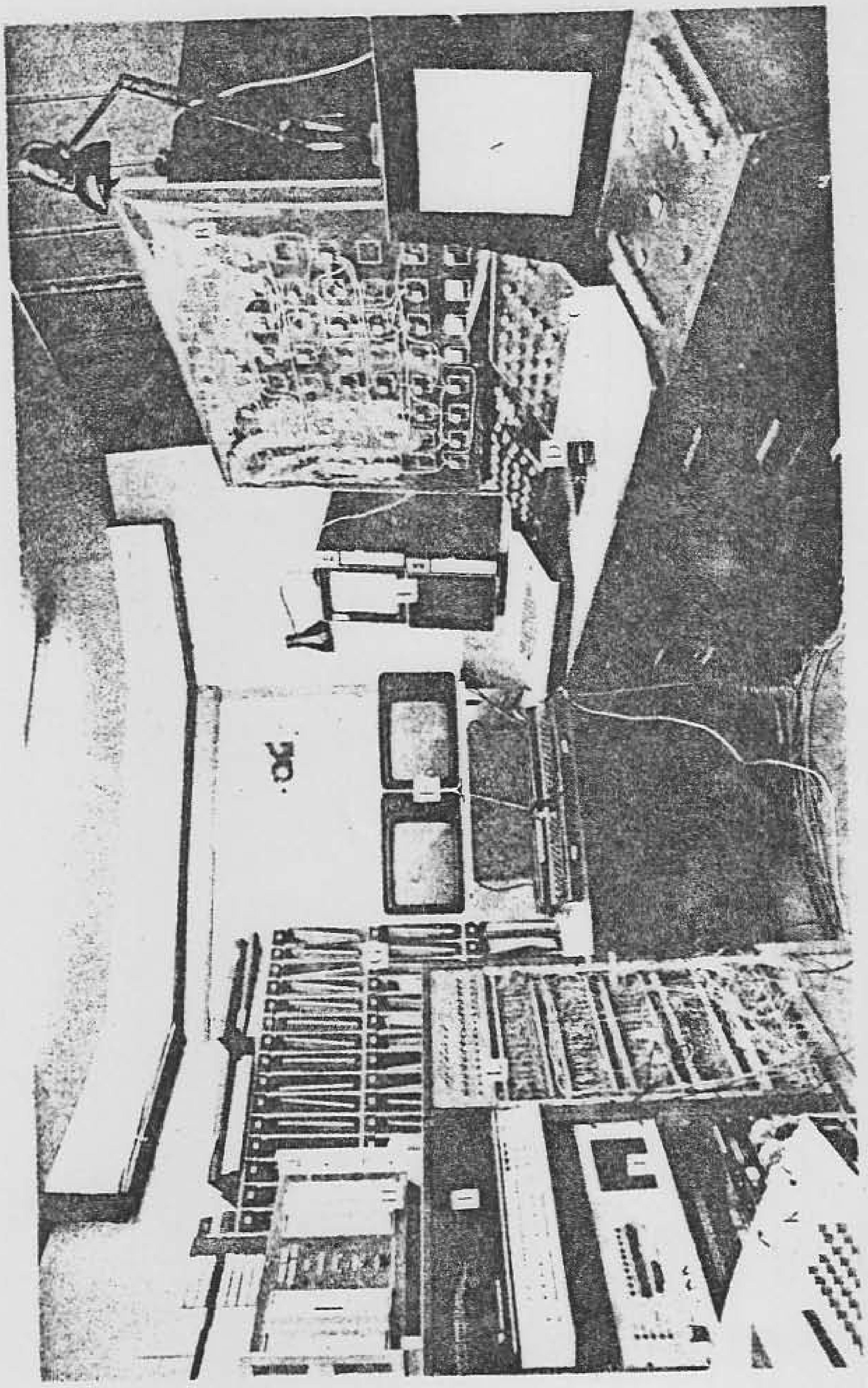


Figure 1. An epistemological laboratory. The figure is placed first to give an idea of how empirical results are obtained but many of the labels will not be intelligible until, at a later stage in the paper, the functioning of the equipment and the types of man machine transactions are spelled out. The key is as follows:

A. Random access slide projector with control keyboard, for displaying slide mounted graphics.
B. Entailment mesh display with overlay multi sheets, containing 60 node positions and 4 × 60 independently addressed coloured signal lamps and touch sensors.
C. Tutorial mode keyboard with special function keys.
D. Course assembly mode keyboard with special function keys.
E. ARDS graphic display tubes with control unit and keyboard used for displaying "pruned" meshes.
F. Video display units with control keyboards used for topic text input–output.
G. Pigeon holes filing system with slots for 60 files and containing 3 × 60 independently addressed signal lamps and 60 sensors.
H. Dual drive floppy disc unit.
I. CAI 32k computer.
J. Digital Cassette unit used as mass storage device.
K. ASR 33 teletype used for "hard copy" output.
L. Electronics rack, containing special electronics and system interface.

RESET FIGURE LEGEND X

appropriate frame of reference, *relative* to which conversations are studied, is a possibly evolving "conversational domain," that is, the "environment" of conversation theory.

The reader may find it useful to keep these empirical comments in mind, without supposing that consciousness is necessarily restricted to people or groups of them.

In the same spirit let us use commonplace terms, such as "concept" (abbreviated to Con), "memory" (abbreviated to Mem), and "topic," in a precise, but somewhat broader-than-usual sense.

Although it sounds to speak generally of memories and concepts, the argument is rendered succinct and intelligible because we are familiar with these things by personal experience.[1]

The theory of conversations of both relativistic and reflective; only in a logically degenerate but highly developed form is the theory simply a relativistic theory. The fully-fledged version is a theory of participants *in* conversations, not merely a theory *about* participants, couched in an external observer's terms relative to a conversational domain. The sharp-valued events of a conversation, namely understandings, are quantifiable but not, strictly speaking, *objective*. They are not *it*-referenced events but subjective (I-, you-referenced) events, either in whole or in part. Only stable processes are observable sharp-valued understandings.

16.4 Organization Closure, Distinction, and Independence

A stable process is "organizationally closed" (von Foerster 1976; Varela 1975, 1976; Goguen 1975; Bråten 1976). In biology it is called an autopoietic system (Varela, Maturana, and Uribe 1974; Maturana and Varela 1976) and autopoiesis characteristic of life.

It should be emphasized that the stability criterion of organizational closure if quite distinct from the classical notion of stability (i.e., a system with states represented as points in a prespecified structural framework of coordinates, having behavioral trajectories that converge to a fixed point, or to a limit cycle to which they return if disturbed by small, but arbitrary, perturbations). Classical stability is a special case of organizational closure.

In the sequel, "stable" means "organizationally closed" and might be rephrased as inherently self-reproductive. For example, Löfgren's (1972, 1975) reproductive Turing systems are simulations of organizational closure. Without denying their utility or failing to appreciate the elegance of simulations, it is important to realize they (or like constructs, open to

[1] I formerly thought this mode of speaking was little more than an expository trick, a use of metaphor. Today, I know it is a metaphor, but also that it is much more than a trick of exposition.

realization in ordinary digital computers) are posited as simulations of general systems; notably of systems involving "organizational closure" (see, for example, Ben Eli 1976; Ben Eli and Tountas 1976).

If an organizationally closed system is "opened," for instance, by distinguishing structure and behavior, or by demarcating the linguistic interchange of a conversation, or by instituting the cleavage of Z into $\pi(Z)$, $\lambda(Z)$, then it is reproductive and productive. This last idea, "reproductive and productive," has a lengthy history and, in psychology at least, has been the focal point for considerable and occasionally acrimonious debate. For instance, the associationists were plagued by the difference between reproduction (in the sense of strict replication, through associative principles, of ideas, sense data, etc.) Seltz, and later the Gestalt psychologists concerned with problem solving and thinking, for example, Duncker and Wertheimer, saw through the distinction, but did not have the notation required to give it expression. So, in a different, more eclectic, tradition did Bartlett. Even today, it is quite difficult to point out that, in *general*, reproduction is productive, and replication is a limiting case of reproduction.

Here the required meaning is approximated by speaking of *fuzzy reproductive processes*, which reconstruct classes of somehow equivalent processes and patterns. The connotation of "fuzzy" is compatible with Zadeh's or Gaines' use of the term (though it is not quite identical with the usage of either). The notion of fuzzy production and reproduction is refined beginning in Section 5. ~~The following propositions specify, as a first step, process and abstraction.~~

1. Process is a more fundamental notion than time. In particular, the point interval (Newtonian) time, evident in the following comments, is a very specialized frame of measurement (see Atkin 1977).
2. Two different events may only occur at the same place (common location in a storage medium) if they occur at different times.
3. Two different events may only occur at the same time if they are at different places.
4. These differences reflect independence.
5. Processes *are* asynchronous if they occur in different processors. (They *may* be asynchronous in the same processor if it has a rich enough structure; for example, if it is a concurrent machine.)
6. Two independent systems are rendered dependent by information transfer, in Petri's (1965) sense.
7. Equally, two asynchronous systems may be coupled or rendered partly or locally synchronous by information transfer.
8. The most fundamental analogy relations (hence, the broadest and most general) are static inscriptions of coupling or dependency or local syn-

chronicity, between otherwise independent or otherwise asynchronous processes.

To manufacture independence is to make a distinction. Only a process *can* make a distinction. The most fundamental distinction is *any* distinction, predication unqualified (Spenser Brown's 7 operation). But suppose that in a system that is a process there exist (relative to this system) certain subsystems; then the distinction may be reversible or not. We should expect to, and do, retrieve this basic difference, as analogies of form, which are symmetric, and analogies of method, which are not symmetric, except when no point of view (perspective) is adopted (or, to put it in another way, when there is only the system's point of view).[2]

16.5 Universes and Independent Precursors; Consistency, Subsistency, and Coherence as Truth Values

A *universe* is an a priori independent processor: it is a set (the usual connotation of "universe") but with action built into it. In classical model theory, a model is a relation, induced by an interpretation of a linguistic statement, upon a set called the universe. A logic (i.e., the interpreted language and a calculus for statement generation) is *consistent* if all *true* statements of the logic have models in all possible universes.

In nonclassical model theory, the model is a working or dynamic model; that is, a program compiled and interpreted in a processor. If the program is executed as a process, then a relation, or a "classical model," is "brought about" or satisfied in the product of the program input domain and its output domain.

As Löfgren (1975) points out, it is frequently sufficient to be content with *subsistency* rather than *consistency* in a logic; that is, true statements have models in *some*, but not necessarily in *all* independent universes. The nearest we come to veridical truth is "subsistence truth." Further, the truth value set is "executability–incoherence," rather than "true–false," and often there are degrees of subsistence truth.

In addition, we invoke coherence or systemic truth (Rescher 1973) to form a logic of agreement (in contrast to absolute veridicality). Rescher specifies coherence truth within the propositional calculus, pointing out that the same ideas are readily extended to a predicate calculus. He is, for example, concerned with the problem of accepting or rejecting date that have truth *candidacy* as part of a set of not-inconsistent propositions (perhaps the basis for a theory shared by several observers who are testing

[2] I owe this insight to J. Goguen and F. Varela and independently to S. Beer, to J. Zeidner, and to S. Bråten, all in personal communications (1976,1977). The matter is discussed succinctly in the Appendix of *The Human Dyad: Systems and Simulations* (Bråten 1977), which recounts a seminar with P. G. Herbst.

it). It is particularly valuable to have an incisive distinction between coherence of a set of beliefs (the theory) and a set of data (the truth candidates), in contrast to mere consensus of beliefs. However, as it stands, the coherency is based upon a process-free logical property; the implications of statements are thoughout inside the observers.

For the present purpose, we need to regard coherence as a property of statements undergoing execution—that is, coherence between processes—and this extension of Rescher's idea, though it involves some technical difficulties, does not appear to change the fundamental notion. In fact, as much is suggested by Rescher's occasional use of the term "systemic" truth as "coherence" truth.

Specifically, we regard a process (X) as being coherent with a process (Y) insofar as X and Y can be executed without computational conflict. We thus augment the original idea by making it processor dependent. Whether or not the π component of X, $\pi(X)$, is coherent with the π component of Y, $\pi(Y)$, depends upon the processor $\lambda(X, Y)$ in which these programs are executed, as well as the programs or statements themselves. For example, the processor may be serial, concurrent, or parallel, and composed of many independent processing units. The program of code (Prog) of a procedure (Proc) is commonly a set of L production rules and the procedures under execution (Proc) figure as interpreted production rules undergoing execution. We do *not*, however, insist upon "serial execution" unless specifically stipulated and, in general, are concerned with L productions carried out over several nonclassical universes (i.e., several processors).

16.6 Concepts, procedures, and the processes in which they are executed to yield descriptions or behaviors

Let a concept (Con) be a procedure, or a class of procedures, at least some of which are executed concurrently (Petri 1964; McCulloch 1966) but tend, in the limit, to parallel execution. Let $\triangleq$ stand, as usual, for "defined as equal to." If a class of entirely (conflict-free) parallel Procs $\triangleq$ [Proc] and, if a class of simultaneously executed Procs (with some computational conflict) $\triangleq$ {Proc} then, if $\langle$ and $\rangle$ indicate ordered entities,

$$\text{Con} \triangleq \text{Proc or } \langle\{\text{Proc}\}, [\text{Proc}]\rangle \text{ or } [\text{Proc}],$$

such that, under continual execution, $\{\text{Proc}\} \rightarrow [\text{Proc}]$.

Let Inter be the compilation of a Prog in a given processor, so that it may be executed as a process. That is, Proc $\triangleq$ $\langle$Prog, Inter$\rangle$. Just as $\lambda(A) = \alpha$, $\lambda(B) = \beta$, or $\lambda(A) = a$, $\lambda(B) = b$, so also $\lambda(\text{Proc})$ = Inter and $\pi(\text{Proc})$ = Prog.

The requirement that $\{\text{Proc}\} \rightarrow [\text{Proc}]$ under continual execution may be regarded as a property of the class of processors, among them brains, in which the Prog are compiled (as well as a property of the programs themselves). The compilation of programs is reorganized (the programs are recompiled) to achieve the parallelism.

Let $\bar{R}_i, \bar{R}_j, \ldots$ be interpreted relations in the product of the input and output domains of Proc. If Ex stands for "execution of," then

$$\text{Ex(Proc } i) \Rightarrow \bar{R}_i, \qquad \text{Ex(Proc } j) \Rightarrow \bar{R}_j.$$

Let $p, q, \ldots$ be indices of Prog $\triangleq \pi$(Proc) and let $u, v, \ldots$ be indices of Inter $\triangleq \lambda$(Proc) that are a priori independent processors.

$$\text{Proc } i = \langle \text{Prog } p, \text{Inter } u \rangle,$$
$$\text{Proc } j = \langle \text{Prog } q, \text{Inter } u \rangle,$$
$$\text{Proc } l = \langle \text{Prog } p, \text{Inter } v \rangle.$$

Ex(Proc l) $\Rightarrow \bar{R}_k$ but $\bar{R}_l \neq \bar{R}_i$, even though the same Prog is involved (namely, Prog p), since $u \neq v$. Hence $\bar{R}_i, \bar{R}_j, \ldots$ are *interpreted* relations given, in extenso, as *descriptions*.

The usual "relation in extenso," regarded as a subset of an m-fold product set and represented by a list of ordered m-tuples, is a description; but, equally, a relation obtained from other relations through relational operators as in Codd (1970) is a *description*. In the sequel, the term description is often equisignificant with *goal*. Partial, or incomplete, descriptions are permitted, as fuzzy relations R_i (omission of the overbar is deliberate), such that $\bar{R}_{1i}, \bar{R}_{2i}, \ldots$ satisfy R_1.

We say that Proc i *produces and reproduces* $\bar{R}_i$. There may be many Proc i that produce and reproduce $\bar{R}_i$, thus Proc r, i, Proc s, i, ...; in fact, there are indefinitely many. By the same token there are many Proc r, $i1$, Proc s, $i1$, ... that produce and reproduce $\bar{R}_{i1}$; many Proc r, $i2$, Proc s, $i2$, ... that produce and reproduce $\bar{R}_{i2}$ ... or in general R_i.

From the definition of Con we say that a concept Con i fuzzily reproduces or reproduces R_i [i.e., Ex(Con i) $\Rightarrow R_i$], noting that R_i is any *interpreted* relation (possibly a periodic process) and is, in general, a fuzzy relation (hence R_i rather than $\bar{R}_i$). R_i may be realized in the input–output domain of a processor $\lambda(A)$, $\lambda(B)$ (notably, A's brain or B's brain) as an apparition or impression: it may be a percept or form a part of a behavior.

16.7 Agreement and Concept Sharing

Speaking of human beings, if a concept Con i is the intention of connotation of i, then R_i is its extension or denotation. But these statements only make sense for some one or several values of the variable Z; that is A's concept of i, namely $\text{Con}_A\ i$, or B's concept of i, namely $\text{Con}_B\ i$.

It is also possible for A and B to *agree* about their concepts of i. A general L agreement is achieved if the participants in a conversation (A and B) ask each other "how" questions eliciting L explanations that are Progs in $\pi(\mathrm{Con}_A\ i)$ and $\pi(\mathrm{Con}_B\ i)$. General agreement implies that some A explanations (L listings of Progs in $\pi(\mathrm{Con}_A\ i)$) are coherent under execution in $\lambda(B)$ of $\pi(\mathrm{Con}_B\ i)$ and that some B explanations (L-listings of Progs in $\pi(\mathrm{Con}_B\ i)$ are coherent under execution in $\lambda(A)$ of $\pi(\mathrm{Con}_A\ i)$.

Obviously, agreement does not imply that $\mathrm{Con}_A\ i = \mathrm{Con}_B\ i$, for the equality is nonsensical (A is not B, whatever else). Nor does agreement usually imply isomorphism between $\mathrm{Con}_A\ i$, $\mathrm{Con}_B\ i$, or R_Ai, or R_Bi (at most a "depersonalized" intention of i would be some definitional or explanatory matching of Prog in $\mathrm{Con}_A\ i$, $\mathrm{Con}_B\ i$: at most, a "depersonalized" extension of i would be a matching of ostended members of R_Ai and those of R_Bi; of course, $Z = A, B, \ldots..$ may have values over a population, civilization, culture, or group).

An operational or behavioral type of A and B agreement is obtained as follows. Equip both A and B with separate modeling facilities, MF_A, MF_B, of Figure 2 (for example, independent programmable computers), in which they can express nonverbal explanations that are L listings of Progs in $\pi(\mathrm{Con}_A\ i)$ and Progs in $\pi(\mathrm{Con}_B\ i)$, to obtain working models (M_Ai and M_Bi) that are independently executable in MF_A, MF_B. Upon exteriorized execution, suppose that M_Ai induces a relation $R_A{}^*i$ in the input–output domain (U_A) of MF_A and that M_Bi induces a relation $R_B{}^*i$ in the input–output domain (U_B) of MF_B. If, perhaps, after trial execution, remodeling, and so on, the following conditions all hold, then A and B are said to agree about a concept of i.

1. M_Ai is executable in MF_A, M_Bi executable in MF_B.
2. $R_A{}^*i$ is in U_A and $R_B{}^*i$ in U_B (by independent execution).
3. $R_A{}^*i \subset R_Ai$ and $R_B{}^*i \subset R_Bi$ ($\subset$ stands for inclusion).
4. $R_Ai \langle = \rangle R_Bi$ (where $\langle = \rangle$ stands for "isomorphism").
5. $\pi(M_Ai) \subset \pi(\mathrm{Con}_A\ i)$ and $\pi(M_Bi) \subset \pi(\mathrm{Con}_B\ i)$.
6. $\pi(M_Ai)$ is executable as coherent with $\mathrm{Con}_A\ i$ in $\lambda(B)$.
7. $\pi(M_Bi)$ is executable as coherent with $\mathrm{Con}_B\ i$ in $\lambda(A)$.
8. M_Ai is "extensionally equivalent" to M_Bi (i.e., upon execution one does the same thing as the other).

Clearly, this form of agreement is limited by the capabilities of MF_A and MF_B; for example, if MF_A and MF_B are serial computers, then only serial programs can be compiled to represent members of $\mathrm{Con}_A\ i$ and $\mathrm{Con}_B\ i$ even though other kinds of program may be expressed by L explanations.

There are also difficulties over conditions 6–8, and since no criterion is given for determining whether they are satisfied or not. These difficulties are addressed as part and parcel of concept stability in the following sections.

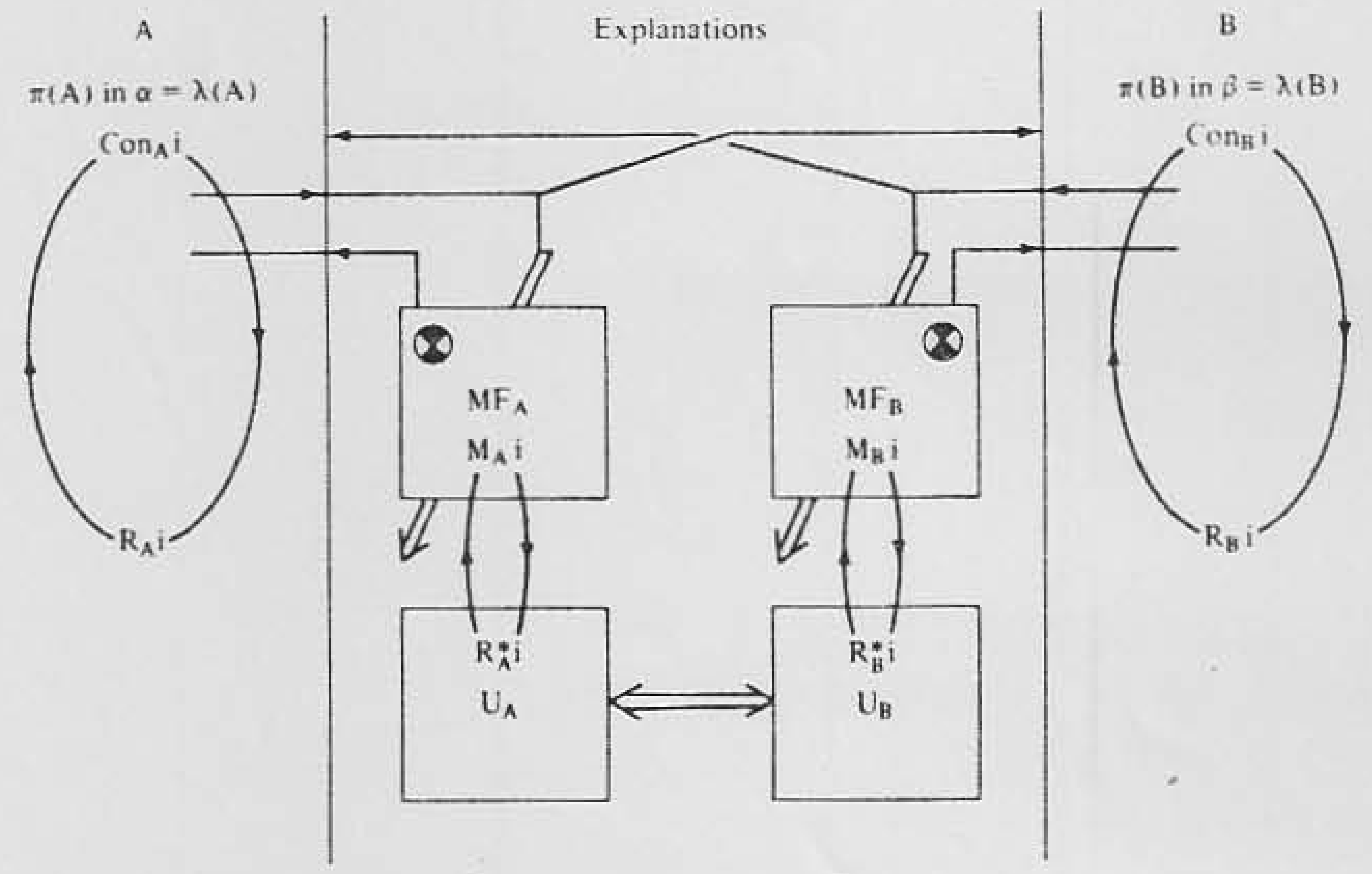


Figure 2. A simple (as it stands, inadequate) form of agreement MF_A, MF_B are independent modelling facilities, such as distinct computers equipped with LOGO, or SMALLTALK, or explanatory forms of PLATO and the necessary peripherals. (In our laboratory, as in most Piagetian experiments, they are special purpose, computing, or model construction systems, designed for one subject matter.) U_A is the MF_A input–output domain and U_B is the MF_B input–output domain. Execution of A's model M_Ai (after correction and trial by A), gives rise to $R_A{}^*i$ in U_A; similarly, for B. ⊗ is descriptive feedback obtained for correction by participants and the double arrow is programming or model building, in contrast to execution MF_A, MF_B. Execution of $\text{Con}_A\ i$ in A's brain α gives rise to R_Ai and of $\text{Con}_B\ i$ in B's brain β to R_Bi.

16.8 Stable Concepts, Learning, and Memory

Just as Ex(Proc i) $\Rightarrow \bar{R}i$ produces or reproduces $\bar{R}i$ (which may be a process, for example, of regulation), so there are Procs that operate upon and produce or reproduce other Procs under appropriate conditions, notably, if a *goal* (alias a *description*), is given in their argument. Thus

$$\text{Proc}\dagger,\ (\text{Proc}\ i)\ \Rightarrow\ \text{Proc}.$$

But Proc† is not necessarily distinct from Proc.

Just as Ex(Proc $i \Rightarrow \bar{R}i$, so Ex($\text{Con}_A\ i$) $\Rightarrow R_i$, fuzzily produces or reproduces R_i. Further,

$$\text{Ex Con}\dagger(\text{Con}\ i)\ \ =\rangle\ \ \text{Proc in Con}\ i.$$

Although Con† is not necessarily distinct from Con, it is often convenient to regard the acquisition of a novel concept as *learning*, and its reconstruction (possibly also productive) as a *memory*. In the latter case the notation

$$\text{Ex(Mem } i) \Rightarrow \text{Proc in Con } i$$

is neater than

$$\text{Ex(Con}^{\dagger}\text{(Con } i) \Rightarrow \text{Proc in Con } i.$$

In general, (see Section 16.5) Procs are production systems. There is empirical evidence that *most* (perhaps all) productive and reproductive operations in conscious human beings involve mutualism between two types of Proc.

Among the Procs that produce and reproduce Procs, distinguish two classes, namely, description building ($\bar{D}\bar{B}$) and procedure building ($\bar{P}\bar{B}$). It is not maintained that *all* of the productions acting upon Procs to produce or reproduce them (even in human beings) are of the these two kinds. As a rule, it is quite unnecessary (and it may be impossible) to know what the production systems *are*, in computational detail. Although there is plenty of evidence that people have learning styles and adopt learning strategies explicable in terms of a balance between the relative efficiency, numerousness, and accessibility of description building and procedure building productions, the evidence does not warrant supposing that people compute in the same way. It may be that all of us have entirely different kinds of productions and, so long as certain requirements are satisfied (preserving specificity, for example), the kind does not matter. The $\bar{D}\bar{B}$ and $\bar{P}\bar{B}$ are characterized insofar as they operate upon different arguments; generically, the $\bar{D}\bar{B}$ productions operate upon descriptions to produce descriptions—their arguments may be any number of descriptions (i.e., interpreted relations, $\hat{R}_i$, $\hat{R}_j$)—while the $\bar{P}\bar{B}$ productions operate upon any number of Procs in combination with one or more descriptions. Thus

$$\text{Ex } \bar{D}\bar{B}(\hat{R}_i, \hat{R}_j) \Rightarrow \hat{R}_k,$$

$$\text{Ex } \bar{P}\bar{B}(\text{Proc }, \text{Proc } j, \hat{R}_k) \Rightarrow \text{Proc } k.$$

If is also happens that

$$\text{Ex } \bar{D}\bar{B}(\hat{R}_j, \hat{R}_k) \Rightarrow \hat{R}_i,$$

$$\text{Ex } \bar{D}\bar{B}(\hat{R}_i, \hat{R}_k) \Rightarrow \hat{R}_j,$$

$$\text{Ex } \bar{P}\bar{B}(\text{Proc } j, \text{Proc } k, \hat{R}_i) \Rightarrow \text{Proc } i,$$

$$\text{Ex } \bar{P}\bar{B}(\text{Proc } i, \text{Proc } k, \hat{R}_j) \Rightarrow \text{Proc } j,$$

then, since

$$\text{Ex(Proc } i) \Rightarrow \hat{R}_i, \quad \text{Ex(Proc } j) \Rightarrow \hat{R}_j, \quad \text{Ex(Proc } k) \Rightarrow \hat{R}_k.$$

The entire system is self-reproducing and is characterized by the fixed point values R_i, R_j, R_k on iterative execution. Such systems are readily simulated by various computer programs, acting as tesselation of kinematic images of von Neumann (1966)/self-reproduction of λ(Proc) is held constant (i.e., if Inter in Proc = ⟨Prog, Inter⟩ is fixed). One arrangement of considerable generality is obtained by taking $\bar{D}\bar{B}$ as the relational operators *Join*, *Restriction* and taking *PB* as a productive algorithm, such as that of Chang and Lee (1973) A^*. However, this construction is no more than a piece of intellectual scaffolding intended to point out a principle more elegantly expressed by von Foerster (1975), who noted that $\bar{R}_i$, $\bar{R}_j$, $\bar{R}_k$ are defined for Procs that are eigenoperations or eigenfunctions that yield eigenvalues on infinite iteration (are recursive).

Contemplate the following replacements:

$$\bar{R}_i \text{ into } R_i, \quad \bar{R}_j \text{ into } R_j, \quad \bar{R}_k \text{ into } R_k;$$

$$\bar{D}\bar{B} \text{ into } DB,$$

where *DB* is a class of Cons (not just Procs);

$$\bar{P}\bar{B} \text{ into } PB,$$

where *PB* is a class of Cons (not just Procs).

The replacements make sense insofar as each Con is subscripted by a value *A*,*B*, ... of *Z*, for example, by *A*.

$$\text{Ex}(\text{Con}_A\ i) \ \Rightarrow\ R_i$$

$$\text{Ex}(\text{Mem}_A\ i) = \text{Ex}(\text{Con}_A{}^{\dagger}(\text{Con}_A\ i) \ \Rightarrow\ \text{Proc in Con}_A\ i$$

This is nontrivial insofar as λ(Proc) or λ(Con) is not *held* constant, though constancy may be achieved in execution. The system of productions is shown pictorially in Figure 3, where the double arrows indicate productions and single arrows ~~indicate~~ represent paths by which products can be retrieved and entered into the argument of a production. Such pictures are probably more familiar to biochemists or people from the hybrid computer era than they are to mathematicians or computer scientists today, but they do have interesting properties. Perhaps the mathematicians and the computer scientists will suppress some (to their discipline) obvious objections (for example, how are the productions organized) until later, when these objections will be answered, or accounted for.

If the Cons in Figure 3 are subscripted by a value, say *A*, of variable *Z*, then the process depicted is a stable concept, meaning that it exists and can be reconstructed; that there is a pair, Stab_A = ⟨(Mem$_A$, Con$_A$)⟩ that is organizationally closed.

Suppose we ask, "*what* is it a stable concept *of*?"; we must have recourse to the index, *A*'s name, and we will say that even in the minimal

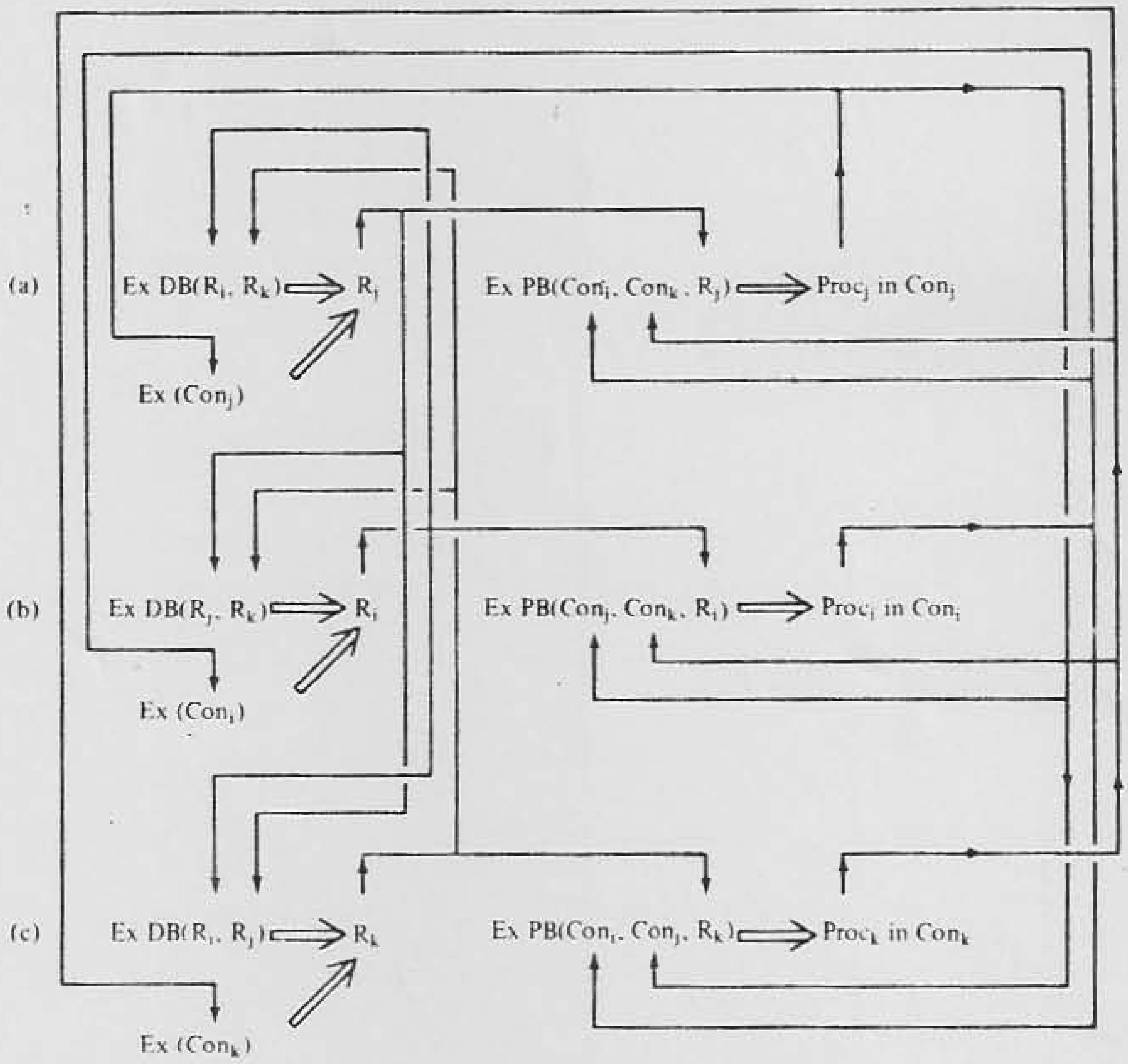


Figure 3. A simple construction for Mem *i* and Con *i* (or, just as well, of Mem *j*, Con *j*; Mem *k*, Con *k*). Suppose that Con *i* and Con *j* exist but that Con *k* does not, and is learned, then line c productions represent the production (rather than the reproduction) of Con *k*; a similar comment applies to line a and the learning of Con *j* on line b and the learning of Con *i*. Once the configuration exists, it is inherently stable, as it will be if Con is subscripted by $Z = A, B$ ... If so, for example, if Con_A *i*, then *A*'s *perspective* may be *i*, *j*, or *k*. Again, if Con_A *k* does not exist, though Con_A *i*, Con_A *j* do so, then *A*'s *learning* of Con *k* consists in the production of a description R_k of *k* and the subsequent production of Con *k* to realise R_k. The entire system is $Stab_A$ *k* (the acquisition by *A* of a stable concept of *k*), where $\pi(Stab_A\ k)$ is *A*'s *understanding* of *k*. The isolation of such a system is a pure convention and, in fact, it always exists in the context of other and related systems. Its productions are used as arguments (or conditions) by other production systems and it receives and acts upon the products of other production systems, notably those of *A* (hence, the edict that the system is meaningful only if the constituents are subscripted by a value *A*, *B*,... of *Z*.

case the answer depends upon A's *perspective* or point of view. If A is asked to say what his stable concept *is*, thus *introducing* directionality and consequently temporality into the picture by requiring an L utterance, any of the following are possible as long as the stable concept exists, implied by the replies i or j or k:

If i, then $\langle \text{Mem}_A\ i, \text{Con}_A\ i\rangle = \text{Stab}_A\ i$ (perspective i);

If j, then $\langle \text{Mem}_A\ j, \text{Con}_A\ j\rangle = \text{Stab}_A\ j$ (perspective j);

If k, then $\langle \text{Mem}_A\ k, \text{Con}_A\ k\rangle = \text{Stab}_A\ k$ (perspective k).

Notice that by so doing we require A to act in a specialized manner, that is, to entertain *one* perspective at *once* (perspective i, j, or k), which amounts to making A say "I am A" and "this is my perspective" (conversely, as we shall see, A is an individualized conscious system *because* he *may* adopt such a unique perspective).

Again, suppose that A imposes his own directionality or temporality by "learning about k"; that is, $\text{Stab}_A\ i$ exists, $\text{Stab}_A\ j$ exists, but $\text{Stab}_A\ k$ does not exist. If so, then A may choose among a finite or indefinite number of possible DB operations that are at his disposal to build a description R_k and to pursue R_k.

16.9 The Status of Topics and Conversational Domains

This circumstance involves and underlines another important point: $\text{Stab}_A\ i$ and $\text{Stab}_A\ j$ are not uniquely defined in Figure 3 which artificially isolates a minimal unit called Stab. For example, by adjoining the productions $DB(R_l, R_m) \Rightarrow R_i$ with $PB(\text{Con}_l, \text{Con}_m, R_i) \Rightarrow$ Proc in Con i, and $DB(R_n, R_o) \Rightarrow R_j$ with $PB(\text{Con}_n, \text{Con}_o, R_j) \Rightarrow$ Proc in Con j and adding the necessary product collecting arcs, we obtain a network in which exist $\text{Stab}_A\ i$ and $\text{Stab}_A\ j$ but *not yet* $\text{Stab}_A\ k$, which is to be created, or constructed, or learned.

To avoid drawing out such complicated networks, the static inscription of Figure 4 may be employed to depict stable conditions like Stab_A (before) and Stab_A (now)—or, equally, Stab_A (now) and Stab_A (later). The static inscription is meaningful, of course, only if the cycle production system it stands for exists as a process, and is identified with part of the processes legitimately designated by values A, B, ... of Z.

If that assurance is provided, then the nodes are known as *topics* (which designate concepts and interpreted relations), chiefly because most of our work has been in educational psychology. In other contexts, the word "topic" might be replaced by "objects and actions" (in the manner of Glanville 1976) or "coherent behaviors" in the manner of von Foerster (1975). The directed arcs relating these nodes represent the operation of

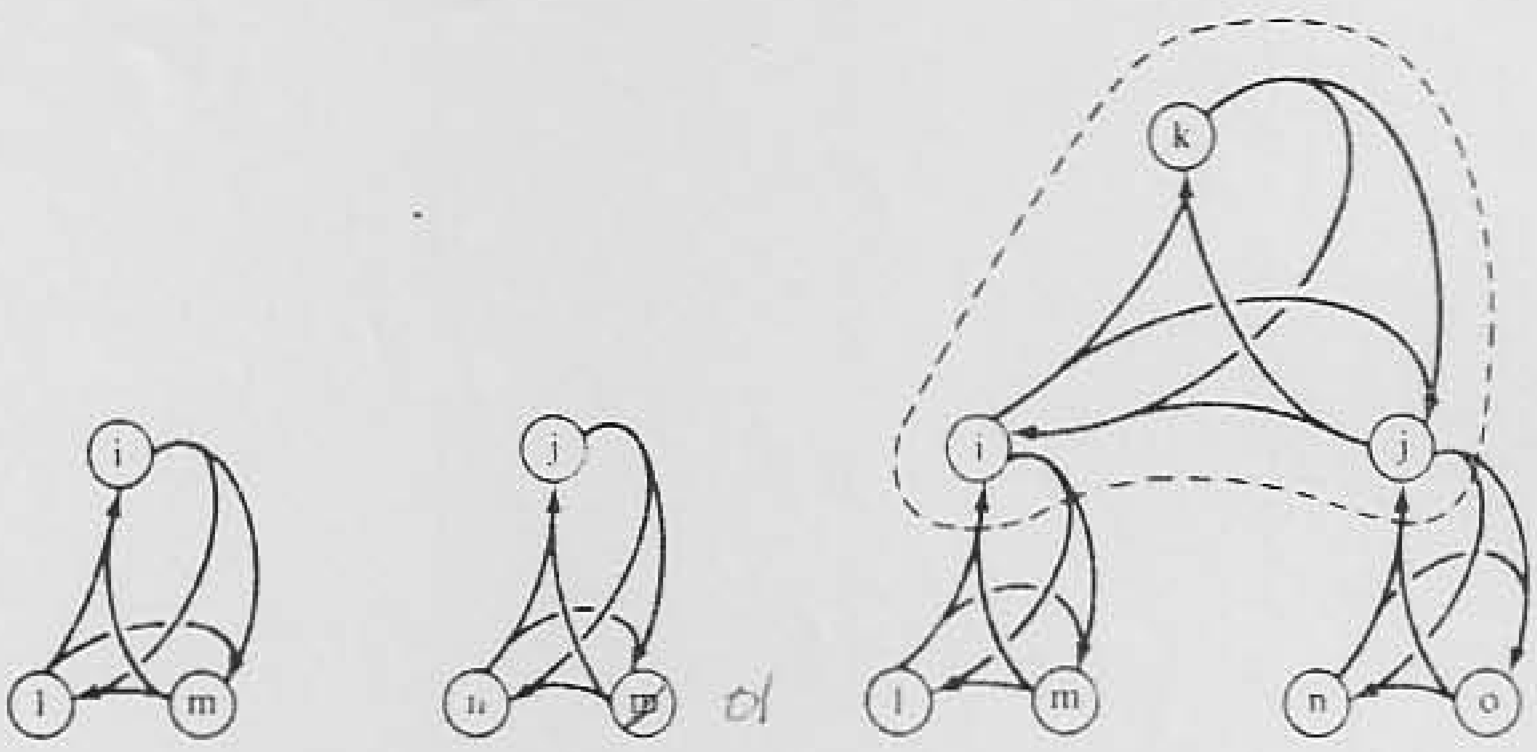


Figure 4. Notation employed for static inscriptions of codes of production system capable of producing and reproducing concepts. On the left are depicted Stab_A (before) and on the right Stab_A (now) [as an alternative, Stab_A (now) and Stab_A (later)]. The dotted region encloses the production system in the text and represents *A*'s learning of a novel concept *k*. However, once established, this system (in the dotted line enclosure) may be interpreted as $\mathrm{Stab}_A\ i$, $\mathrm{Stab}_A\ j$, or $\mathrm{Stab}_A\ k$ depending upon *A*'s perspective, focusing attention upon concept *i*, *j*, or *k*, respectively. Stable concepts are known as topics. Any topic has a kernel. On the left, *i* has the kernel (*l*, *m*), *l* has the kernel (*i*, *m*), and *m* has the kernel (*l*, *i*): on the right, *k* has the kernels (*i*, (*l*, *m*), *j* (*n*, *o*)), and *i* has the kernels (*l*, *m*) and, in addition, the kernel (*k*, *j*).

DB and *PB* productions that are presumed to exist in any process legitimately tagged by a vlaue of *Z*; that is,

$$\text{topic } k \triangleq \textit{static inscription}\ [\pi(\mathrm{Stab}_Z\ k)] \qquad \text{for some Z.}$$

Topics (for given values of $Z = A, B, \ldots$) are those interpreted relations generated as fixed point values by inherently self-reproducing processes. Relations are thus defined in terms of processes (not vice versa), and they are discrete because fixed-point transformations lead to discrete values on indefinite iteration. Topics may be agreed on between conscious systems.

16.10 Explanations, Derivations, and Entailment Meshes

Let us examine the evidence needed to give the required assurance. Superficially, it varies depending upon the particular circumstances, and several cases (by no means exhaustive) will be examined. However, on closer scrutiny, the evidence has many features in common. It firms up the agreement criteria of Section 16.7 and Figure 2, and expresses the fact that if this agreement were itself given a static inscription (supposing an agreement to be reached) then this would be an *analogy* (or an *analogical* topic).

Case 1. Assume that a static inscription in *given*, though not yet legitimized, and that $Z = A, B$ are two people. Here, $\pi(A)$ is A's personality; his system of coherent beliefs; $\pi(B)$ is B's personality. $\lambda(A) = \alpha$ is A's brain, assumed to be a priori independent of $\lambda(B) = \beta$, or B's brain. Let $\pi(\text{Stab}_A\ k)$ be A's *understanding* of k from the *perspective* of k. Let $\pi(\text{Stab}_B\ k)$ be B's *understanding* of k from the *perspective* of k. Let A and B have the same perspective as indicated by pointing at the topic in an external static inscription. Impose the operational requirements of Section 16.3 and provide an interface (such as THOUGHTSTICKER of Figure 1) through which an agreement over understandings may be reached.

Consider Figure 5, which extends Figure 2 by adjoining a static inscription. This inscription is called an *entailment mesh* (EM) because we are concerned not about the particulars of operations DB and PB but only that they exist (psychologists lump them together as "discovery"). The static inscription of "discovery" is entailment.

Thus, from Section 16.9,

$EM \triangleq$ for some z (*Static Inscription* (*Superimposition* $\pi(Stab_Z\ r)$) for $r = 1, 2, \ldots,$ for all s, with s in power set of index set r

= a related collection of topics seen from all perspectives

Suppose that A and B in conversation about topics represented in an entailment mesh are pointing, upon some occasion, at topic k (henceforward T_k). One reason may be that one of the participants in the conversation (B, say) has the dominant role of "teacher," while the other (A) is a "student." If so, B has available a stock of possible explanations, which can be used to demonstrate T_k, together with descriptors which can be used to focus A's attention upon T_k, and that B deems it tutorially wise to do so. Alternatively (and, for this purpose we need not press the distinction), the entailment mesh is augmented by a stock of potential explanations of demonstrations (one stock to each topic) and commonly understood descriptors that allow A and B to direct attention at topics. In the latter case there is no necessary dominance on B's part; it is simply that A and B are "learning together" about the mesh-related topics.

The required augmentation (explanations–demonstrations of topics and a scheme of descriptors–predicates for accessing topics) converts the *entailment mesh* into the *conversational domain* of Section 16.3.

Either by tuition, involving "how" and "why" questions, or by accord, A and B not only explain T_k to each other and reach agreement in the matter (nonverbally, both in Figures 2 and 5), but they also explain how they constructed their explanations. To do so they exchange and reach agreement upon *derivations* ($\text{Der}_A\ k$, $\text{Der}_B\ k$, in Figure 5). This they may also do, given an entailment mesh and a facility, such as THOUGHT-

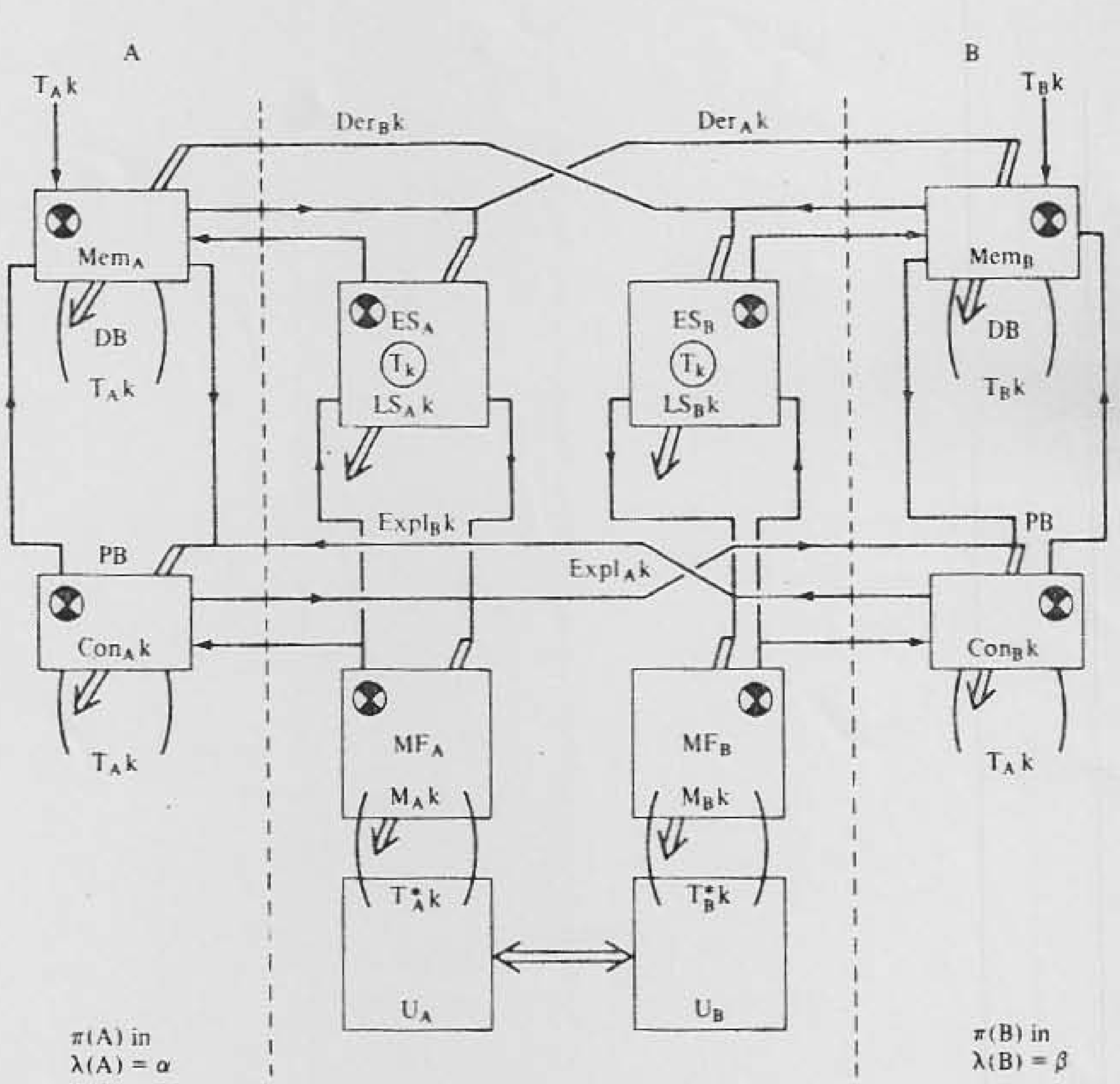


Figure 5. Agreement over an understanding of topic k in conversation between A and B. The participants are interpreted as being $\pi(A)$ and $\pi(B)$ assigned as in Figure 2 to distinct, a priori independent, brains $\lambda(A = \alpha$ and $\lambda(B) = \beta$/ $\mathrm{Expl}_A\ k$, represented, nonverbally, as $M_A k$ in MF_A and $\mathrm{Expl}_B\ k$ as $M_B\ k$ are explanations; $\mathrm{Der}_A\ k$ and $\mathrm{Der}_B\ k$ are derivations (i.e., explanations of explanations, or justifications of why a particular explanation is given and how it is derived), represented nonverbally as learning strategies $LS_A k$ and $LS_B k$ in an entailment mesh EM_A, EM_B. Either EM_A, EM_B, are given and contain topic T_k or evolving (in which case, delete T_k from each). From ($\mathrm{Mem}_A\ k$), the DB operations compute $T_A k$ (equivalent to the execution of $\mathrm{Con}_A\ k$). From ($\mathrm{Mem}_B\ k$) the DB operations compute $T_B k$ (equivalent to the execution of $\mathrm{Con}_B\ k$). The PB operations of A compute Proc in $\mathrm{Con}_a\ k$ and the PB operation of B compute Proc in $\mathrm{Con}_B\ k$, if $\mathrm{Stab}_A\ k$, $\mathrm{Stab}_B\ k$ exist. In addition, the agreements over $\pi(\mathrm{Stab}_A\ k) \not\subset \langle \mathrm{Der}_A\ k, \mathrm{Expl}_A\ k\rangle \equiv \langle LS_A k, M_A k\rangle$ and $\pi(\mathrm{Stab}_B\ k) \not\subset \langle \mathrm{Der}_B\ k, \mathrm{Expl}_B\ k\rangle \equiv \langle LS_B k, M_B k\rangle$ ensure that PB operations in Mem_A compute Proc coherent in $\mathrm{Con}_B\ k$ (as well as $\mathrm{Con}_A\ k$) and that PB operations in Mem_B compute Proc coherent as part of $\mathrm{Con}_A\ k$, as well as $\mathrm{Con}_B\ k$ (conditions 6) and 7 of Section 16.7) and DB operations in Mem_A compute $T_A k$ that are part of $T_B k$, and DB operations in $\mathrm{Mem}_B\ k$ compute $T_B k$ that are part of $T_A k$ (condition 8 of Section 16.7).

STICKER (Figure 1), by nonverbal model-building behaviors. Such behavior is manifest as the exteriorized learning strategy LS_A or LS_B used respectively, for building $\mathrm{Con}_A\ k$ or $\mathrm{Con}_B\ k$. An A,B agreement, in this case, means that A could (not necessarily *would*) perform B's construction and vice versa. Phrased differently, Proc in $\mathrm{Con}_A\ k$ are manufacturable by Mem_B and Proc in $\mathrm{Con}_B\ k$ are manufacturable by Mem_A. We call this complex (A,B) agreement, an *understanding* of T_k by A with B; an understanding is evidence for $\mathrm{Stab}_A\ k$, $\mathrm{Stab}_B\ k$. As in the caption of Figure 5, we have the minimal requirement, to complete the conditions in Section 16.7, that

$$\pi(\mathrm{Stab}_A\ k \not\subset \langle \mathrm{Der}_A\ k,\ \mathrm{Expl}_A\ k\rangle \equiv \langle LS_A k,\ M_A k\rangle$$

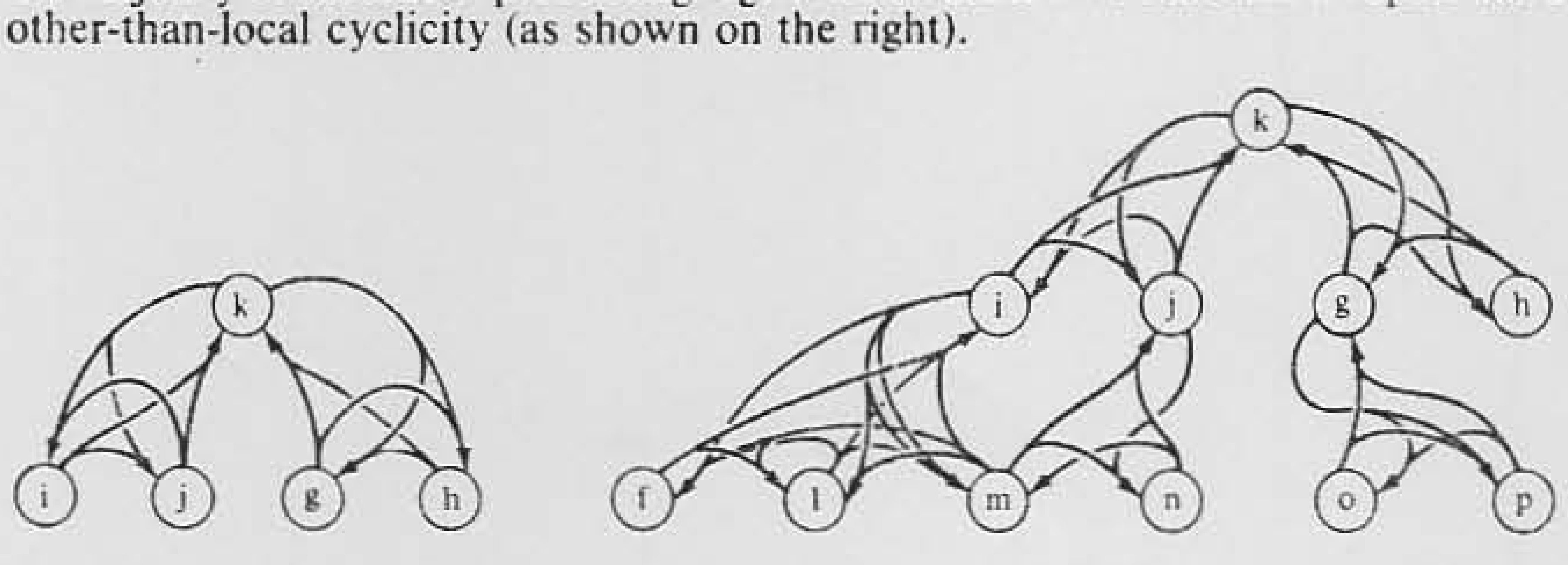
and that

$$\pi(\mathrm{Stab}_B\ k \not\subset \langle \mathrm{Der}_B\ k,\ \mathrm{Expl}_B\ k\rangle \equiv \langle LS_B k,\ M_B k\rangle;$$

or, in general, that an A, B understanding, in language L, of T_k is the coherent part of $\pi(\mathrm{Stab}_A\ k)$ and $\pi(\mathrm{Stab}_B\ k)$. There is ample and quite diverse empirical evidence that insofar as understanding is achieved concept k is stable and increasingly resilient to interference.

There is, of course, no requirement that $\mathrm{Der}_A\ k$ and $\mathrm{Der}_B\ k$ (or that the corresponding learning strategies LS_A and LS_B be the same). Entailment meshes commonly do admit of many and complex derivation paths as suggested in Figure 6. For example, let topic k (in Figure 6) be "the surface of a cylinder"; topic f, "a rectangle labeled a, b, c, d"; topic g, "join edge ab to cd or edge ad to bc but not both"; topic h, "a torus"; topic g, "cut in half along any one slicing plane"; and topic f, "join the free edges."

Figure 6. It is not at all necessary that only one derivation is countenanced provided that both participants are able to construct $\mathrm{Stab}_A\ k$ as a result of either. For example, it may be that A regards k as derivable from i and j whereas B regards k as derivable from g and h (perhaps only after learning to understand g and k). Such disjunctive derivations are common and represented by a notation with several kernels (on the left). Again, although local cyclicity is mandatory, the majority of meshes representing algebraic or otherwise redundant topics have other-than-local cyclicity (as shown on the right).



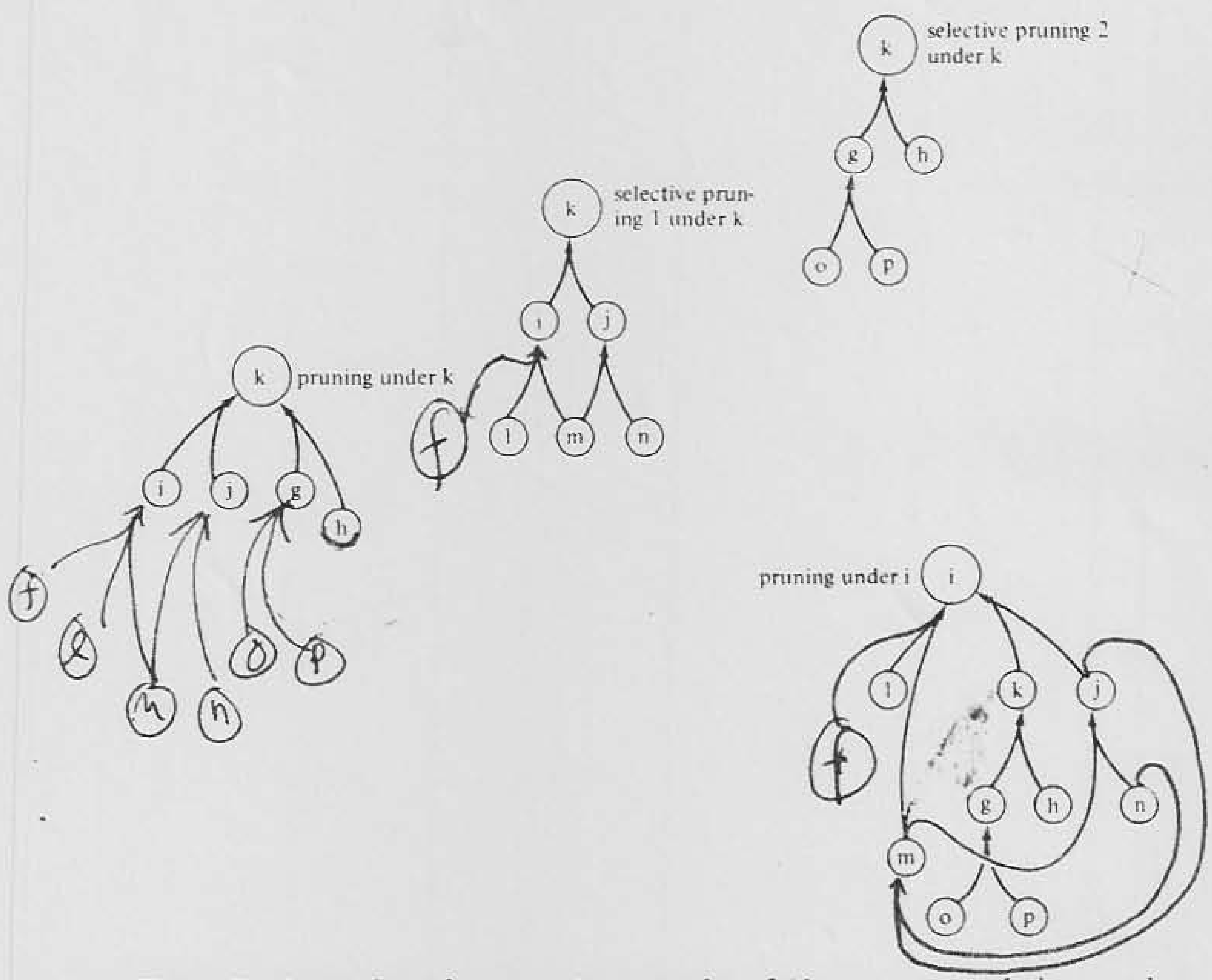


Figure 7. The notion of *perspective*, or point of view, corresponds in a static inscription to a *pruning* of which there are as many as there are (other than primitive) topics and from any one topic several conjunctive or kernel-unique prunings. For example, the rightmost mesh in Figure 6 has been pruned selectively under topic *k* and also under topic *i*. To prune, it is necessary to specify a direction and a topic. Selective prunings are unfoldments for entailment meshes into trees that are truncated when periodicity appears, or at a given depth.

A learning strategy is a *selective pruning* or *unfoldment* of an entailment mesh (Figure 7); it is quite possible, for example, that *A* employs the selective pruning 1 of Figure 7, whereas *B* employs selective pruning 2 of Figure 7 (in the literature a pruning, unqualified, or a union of them, is called an entailment structure). Such a pruning is the static inscription of a perspective, taken by *A* and *B* or taken by some other person, a theorist or a subject matter expert, who produced the static entailment mesh as an encoding of his theory.

Insofar as the entailment mesh or the associated conversational domain represent knowable topics, they are finite samples. No knowledge is depersonalized; these samples are peoples' theories.

Case II. Let A and B be distinct people, as in Case I, but they construct their own static inscription as the framework in which they exteriorize their thinking. The entailment mesh is permitted to evolve, representing the theories of A and B, so that, although still finite, it is representative of these particular people. To depict this circumstance in Figure 5, it is only necessary to delete the topic T_k from ES_A and ES_B. In this case, A and B construct and exteriorize a shared perspective (any perspective about which they agree); around such perspectives they construct their personal theories.

The facility of THOUGHTSTICKER (Figure 1) allows for precisely this kind of evolution (hence, it is an epistemological laboratory and finds just as much practical application in structuring the theories or expositions of authors as it does for learning experiments).

In order to count as an entailment mesh, the inscription of a theory must satisfy syntactic constraints that ensure that each minimal inscription of a topic (Figure 4) does represent a productive and reproductive Stab (Figure 3). The rules are detailed elsewhere (reports 1975–1977 or the references to conversation theory); they are not "mathematically presented" and strike subject matter experts, for example, as rules of decent exposition.

Some of the equipment in Figure 1 is devoted to ensuring that these rules are satisfied; some of it to making extrapolations, or overgeneralizations (open to denial by users, learners, author teams) that spur the users on to further learning or exposition.

Of course, in both Cases I and II, we have taken a distinction for granted; that $\lambda(A) = \alpha$ (one brain) and $\lambda(B) = \beta$ (another brain) are a priori independent processors. This distinction is intuitively plausible but quite arbitrary. It is clear, for example, that agreement over an understanding of any topic (one given to begin with, or one that is invented) implies that some Progs in $\pi(A)$ undergo execution in $\beta = \lambda(B)$ and, vice versa, that some Progs in $\pi(B)$ undergo execution in $\alpha = \lambda(A)$. The fact is that *any* distinction would suffice.

Case III. Consider somebody learning or problem solving alone through the interface of a *fixed* entailment mesh (or, usually, its conversational domain, complete with descriptors and a stock of demonstrations). Provision of the interface makes clear what us usually meant by phrases like "I am learning this myself," or "I am solving these problems myself." Insofar as the ruminations in question enter the public scene (and, by hypothesis, insofar as they go at all), there are two or more individuals (roles or perspectives) accommodated in *one* brain. The mental operations exteriorized for public scrutiny are as much as can be captured of an internal conversation. We capture them by insisting (through THOUGHT-

STICKER or some surrogate of an other than mechanical kind, such as an interview situation) that each topic addressed is understood. For consistency we call the roles or perspectives coexisting in this one person $\lambda(A)$ and $\pi(B)$, noting that $\lambda(A) = \alpha = \lambda(B)$. In Figure 5 replace β by α and join the lower ends of the vertical dotted lines by a horizontal dotted line.

Case IV. Consider the same situation, when the entailment mesh evolves under the control of the user (A and B in one brain α). Here, in practical studies of design (Reports 1976, 1977), the reality of an "internal conversation that is exteriorized" is even more obtrusive, for each topic enstated as the justification or explanation of a design must be understood.

It may be sensible to write, in either case, an expression for distinct values A and B of Z that distinguishes a priori independent parts of one processor (brain α), namely,

$$\lambda(A) = \alpha_1, \qquad \pi(B) = \alpha_2,$$

but strictly, this is unnecessary. The important point is that brains as processors (and brains are not necessarily unique in this respect) have the ability to predicate, to make distinctions of the kind already made (but arbitrarily made) in Cases I and II. It may be that the distinctions are only of perspective (as when $\alpha_1 = \alpha_2 = \alpha$) or that they cut apart functionally independent processors (as in α_1 and α_2), or that they demarcate organisms (α and β), or that they demarcate kinds of universe X (for example, electrical entities, poetical entities) as distinct from Y (for example, mechanical entities, pieces of music or drama). This property appeared, covertly perhaps, in Section 16.6 in the context of interpretation functions, Inter (programs that are differently compiled or interpreted do, as a rule, yield different interpreted relations when executed in a processor). It is an essential part of any other-than-trivial identification of organizational closure, autopoiesis, or the like and consciousness (if not observed, the crucial features disappear in a cloud of algebraic manipulation).

16.11 Concurrent Execution, Closure, and Independence

In Section 16.8 I asked the reader to defer judgement upon the organization of production systems, and I take the matter up again at this juncture. Using a standard digital computer, it would clearly be necessary to organize the production system in Figure 3 or its generalization (shown as a static inscription in Figure 4) by means of many program statements, which, in turn, would depend upon criteria of "priority" assignment, "randomization," and the like. Even in the most fitting programming language, the serial simulation of a few lines of production rules gives rise to a few pages of instructions. Of course this can be done, at the price of painstaking labor and largely arbitrary assumptions that demolish the meaning of the original statements.

It is true that some order or sequence *must* be imposed: for example, that if Proc k is to be added, as a new procedure to an existing coherent Stab, then *before* the new Proc k is constructed by a *PB* production, there must be an R_k constructed by a *DB* production; also, that execution of procedures shall not destructively interfere during execution, even before the coherence of entire parallelism (Con = [Proc i]) is achieved.

A sufficient order is obtained if one (or as later, several perspective(s) are adopted, provided that the following conditions are imposed upon the processors α, β, ..., which may legitimately figure as $\lambda(Z)$ for all values of $Z^* \subset Z$ (Section 16.2).

1. The processor must be able to execute concurrent processes both by acting in a strictly parallel mode (and thus *guaranteeing* the independence of the processes) and as a device in which destructive interaction is avoided through information transfer between coexisting ("actor"-like) loci of control.
2. The processor is never quiescent; it *must* do something, it does not *halt*.
3. At least two loci of control are invariably active to realize on the one hand, the productive and reproductive transformations of Figure 3 and, on the other hand, execution of Procs; that is, learning *must* take place, though *what* is learned is not determined.
4. Repetitive execution of Procs leads to a fully parallel mode. Con i $\triangleq$ ⟨{Proc i}, [Proc i]⟩ or Proc i tends, upon repetition, to Con i $\triangleq$ [Proc i], as in Section 16.6. The mechanism of recompilation in brains, qua processors, was pointed out by Grey Walter in the mid-1950s; it is, however, a general entrainment property of many nonlinear active media.
5. The processor may distinguish an indefinite number of universes of complication or interpretation (u, v, of Section 16.6 or, if realized externally, X, Y of Section 16.7). It may make any number of distinctions.
6. For a class of processes that are both organizationally closed and informationally open some distinctions *must* arise, and lacking further specificity these are distinctions of an indifferentiated independence (cleavage of a processor into independent parts or mustering further processors from a stack).
7. Processes of this type are potentially conscious (in the sense of Section 16.12) and may be identified with conversations.
8. Independence is introduced or computed by any production that violates the interference condition of Section 16.11, which leads to

an essential or structural bifurcation in the system's behaviour; that is, novel variables are created; it is not just a matter of giving ambiguous values to the existing variables. Stated conversely, if information transfer between organizationally closed systems is conserved then bifurcation *must* take place and leads, without further specificity, to an independence.

It should be emphasized that these properties are common. Only the idiosyncratic development of mathematics in concert with computer architecture leads us to regard them as "strange." The serial, digital computer is really a "strange," though convenient, specialization of computing media in general.

16.12 Consciousness and Information Transfer

To reach agreement (in particular, over an understanding) there must be a *distinction* cleaving a process into independent parts. In Case I and Case II this distinction *seems* to be "given" through α and β. In Case III or Case IV, it seems to "emerge" (for example, as α_1, α_2). In fact, in either case, it is *computed* (or *recognized*).

This independence is reduced by information transfer, namely, information transfer that is required, with equal significance, to render incoherent operations coherent or to render asynchronous operations locally synchronous (Section 16.4) where understandings are exteriorized. Information transfer is what happens in a conversation, when it is *consciousness*. Otherwise, it is *awareness*, which is unobservable.

The degree of consciousness is a fuzzy-valued measure of *doubt*, or its converse, *belief*. (I say doubt, rather than uncertainty, because there are many kinds of doubt, including at least the following: doubt regarding *perspective*; doubt, if a perspective exists, regarding a description R_k or the values of some coordinates of this description if others are given, i.e., doubt about outcomes; doubt, given a description, about a procedure to realize that description; doubt about which procedure to employ i.e., doubt about the method).

The sharp-valued *content* of consciousness is an understanding and the remaining contents are those apparitions, images, or emotions that accompany the productive and reproductive operations of reaching an agreement over an understanding. Consider, for example, the acquisition of a stable concept $\text{Stab}_A\ k$ given $\text{Stab}_A\ i$ and $\text{Stab}_A\ j$. Commonly, the sequence is as shown in Table 1.

In Section16.8 we concentrated upon a particular kind of (*DB*, *PB*) productive system and believe it is more efficient than others, at any rate for deductive or inductive thought. However, this is not the *only* kind of system; for example, Procs may be arbitrarily composed or concatenated, lacking a "goal" or "description" as in the expression *PC* (Proc *a*,

Table 1[a,b]

Doubt about perspective	Doubt about description (or outcome)	Doubt about procedure	Doubt about method
1. High until $\bar{D}\bar{B}$ production is found	High until DB production provides an argument for some *PB*	High until there is some *PB*	High since there is no $\mathrm{Proc}_A k$
2. Low, if *DB* found that works	Reduced, but still high (*PB* can operate on partial description.)	High until *PB* found	High
3. Low	Reduced	Low if any *PB* is found	Still high since there are no $\mathrm{Proc}_A k$
4. Low	Reduced, but higher than doubt about method	Reduced if *PB* works	Low as soon as some $\mathrm{Proc}_A k$ exists
5. Low	Lower	Iteration of $\mathrm{Stab}_A k$ Produced more $\mathrm{Proc}_A k$	Increasing, as concepts or skills are overlearned (It is harder to say *what* procedure is used.)
6. Low	Very low, if concept or skill is overlearned	See below[a,b]	Higher than doubt over outcome (descriptive doubt)

[a] If, for some reason, attention is focused upon one topic so that doubt about *perspective* is held low, consciousness tends to a degree of zero (behavior is automatic) and this condition is only relieved by *PB* operations that introduce fresh procedures (not yet coherent with $\mathrm{Con}_A\ k$), or in skill learning, by mistakes (finding that a well-tried procedure does not work and reconstructing a concept as a result). Again, at the intellectual level, an expert may expound (relearn) his thesis or a teacher may give freshly invented explanations.

[b] In general, however, $\mathrm{Con}_A\ k \rightarrow [\mathrm{Proc}_A\ k]$ (Property 4, given 2 and 3 of Section 16.11) and consciousness is only maintained by changing the attention (redirecting the conversation, thus increasing doubt about the perspective and *current* description) or by innovation or by an autonomous change in perspective. All of these expedients involve a distinction. That such a transformation *must* ossur follows from properties 2 and 3 of Section 16.11; that distinctions *may be made to retain awareness* is guaranteed by property 5; awareness is manifest as consciousness if the distinctions made are represented externally.

Proc $b) \Rightarrow$ Proc c. Such activity seems to go on unconsciously. There is a good chance of expressing its magnitude as a background "noise" or "temperature" of a processor using Caianiello's (1977) thermodynamics of modular systems. By hypothesis, that is the *only* kind of "randomness" involved in productive thought; it provides the "noise" against which the information transfer of awareness or consciousness takes place.

16.13 Analogies of Form and Method; Analogical Topics and Analogy Building

L analogies of form are represented, as static inscriptions in an entailment mesh, by the notation shown in Figure 8a. They relate topics *H* and *I*, which are similar (at most, isomorphic) but are not identical (they may have a difference in content or merely be replicas, somehow distinct).

For example, an electrical and a mechanical linear oscillator are analogous; their similarity involves a second-order differential equation; their difference is the distinction written Dist (electrical, mechanical). An equally good example is provided by analogous music and poetry, whose analogy (similarity) is due to a common theme. These analogies are symmetric.

Pure analogies of form have similarities that are taken as understood and hence are not derived (as in Figure 8a). Often, however, the similarity is derived; for example, consider two vehicles navigating on the surface of a cylinder (*F* and *G*) in Figure 8b. The similarity of *F* and *G* lies in the cylinder (derived as in Figure 6). The difference is the difference between the tracks delineated by the two vehicles, determined by their characteristics as vehicles. Such analogies are mixed since (Figure 8c), if contingent upon the adoption of a method, their similarities are supported by a process—namely, the unfoldment or selective pruning of an entailment mesh. Strictly speaking, they exist in the pruning field (set of all selective prunings as in Figure 7) of a mesh, not in the mesh itself. It follows incidentally that the indefinite unfoldment of a mesh yields interpretations that are generally *not* in the *same* universe (hence, the distinction making property), and that signs like that for implication "→," or other "syntactic" entities also receive an interpretation as actions (hence the earlier insistence upon a logic of action or execution). Hence, mixed analogies are analogies of form and method.

Although the point is not taken up in this paper, it can be shown that all explanations of topics are obtainable as pruned derivations; the distinction between an explanation of a topic and its derivation is made as a matter of convenience, not of fact.

Again, although the matter is not considered in this paper, the lowermost nodes stand for topics that are primitive only in the very special sense that, in the context of the thesis embodied in the entailment mesh, their computation is irrelevant to the thesis. For example, provided a user (student, expert, teacher, designer, decisionmaker) has some interpretation for "→," or for "mechanical–electrical," it does not matter what it is, how the user computes the syntactic form, or what predicates the user evaluates to demarcate mechanical–electrical entities. Obviously, this depends upon the user as well as the thesis. The notion of lowermost or primitive is *relative* to both of them, just as any pruning of a mesh is relative to the perspective.

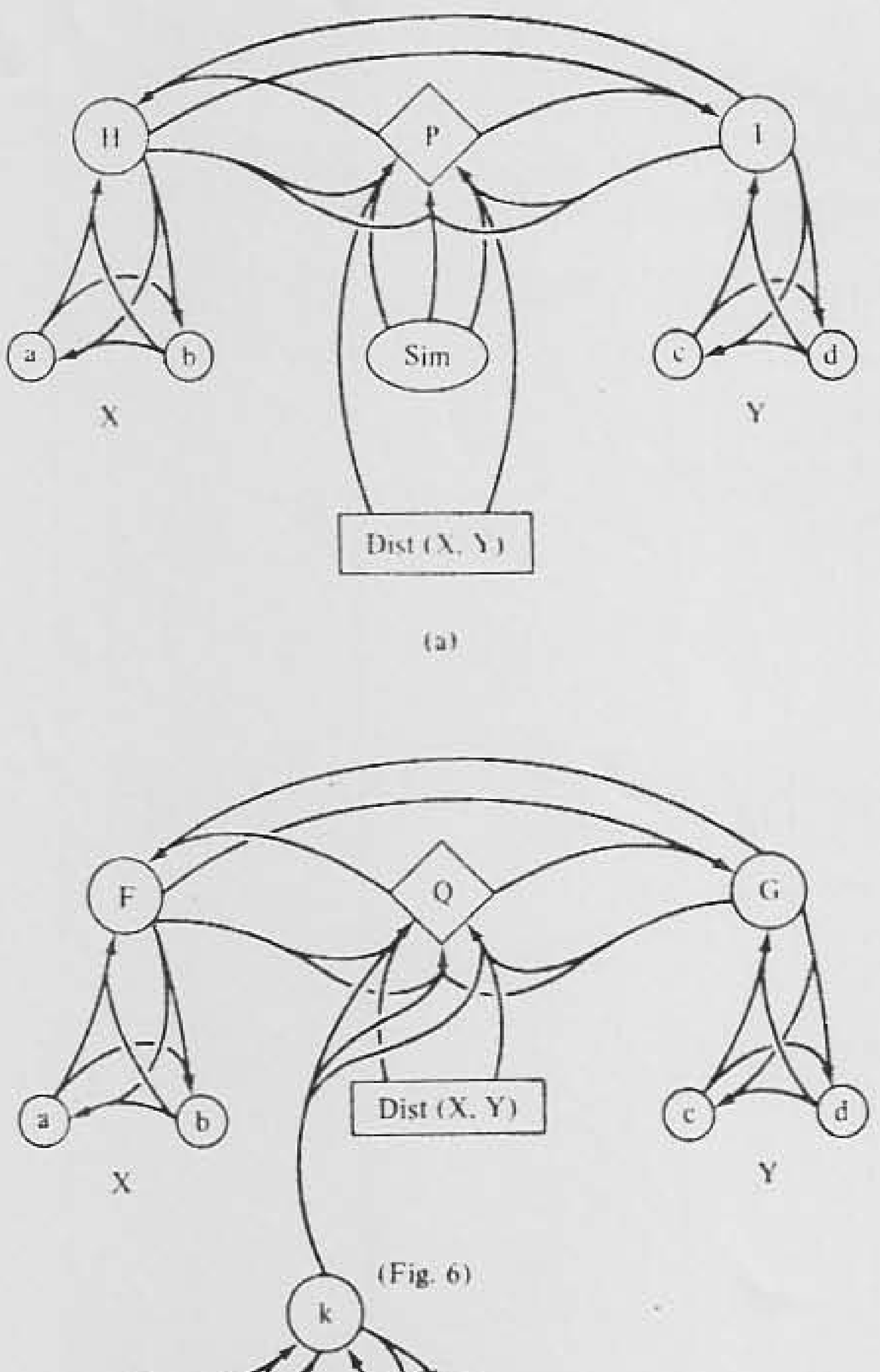
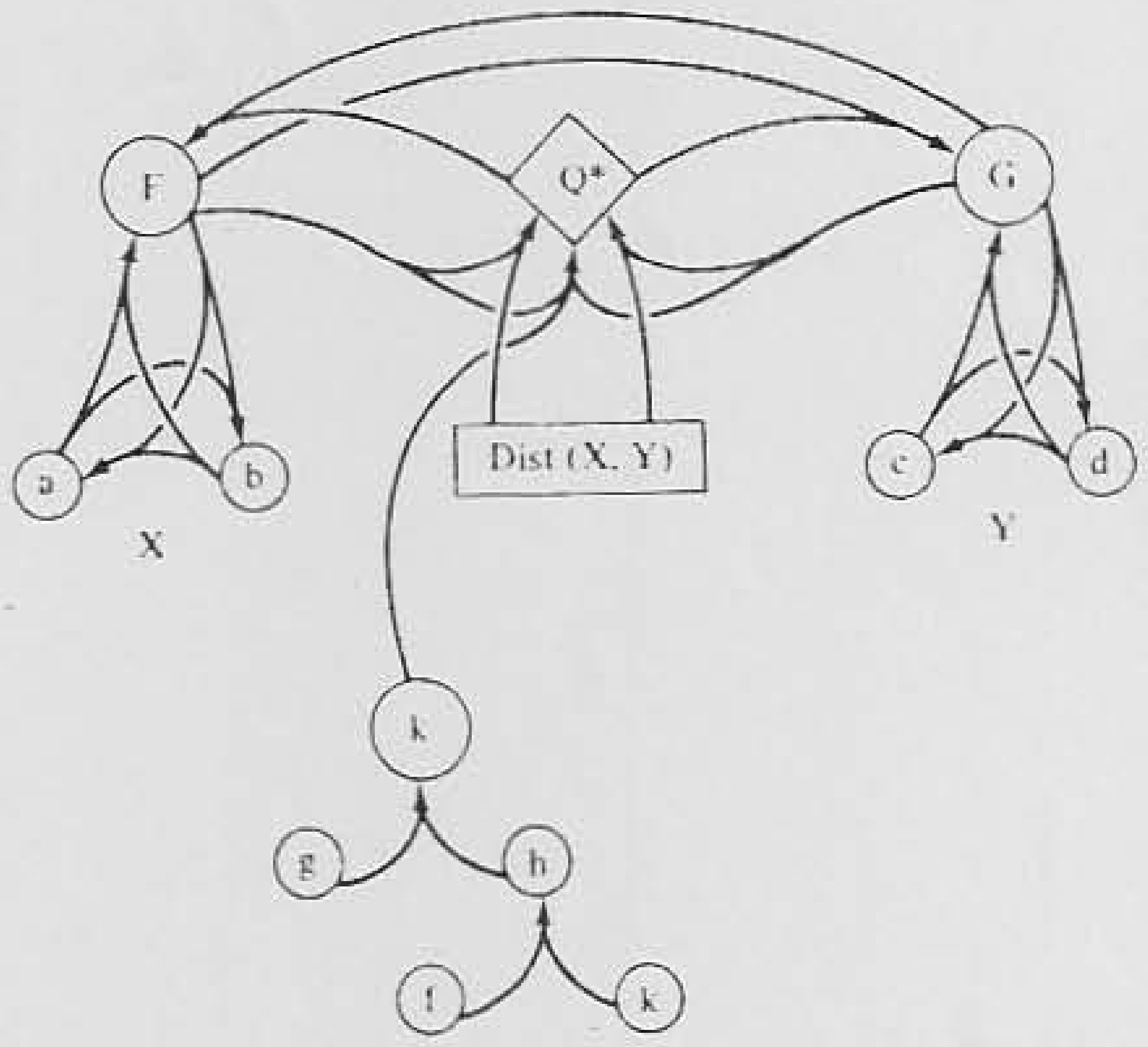
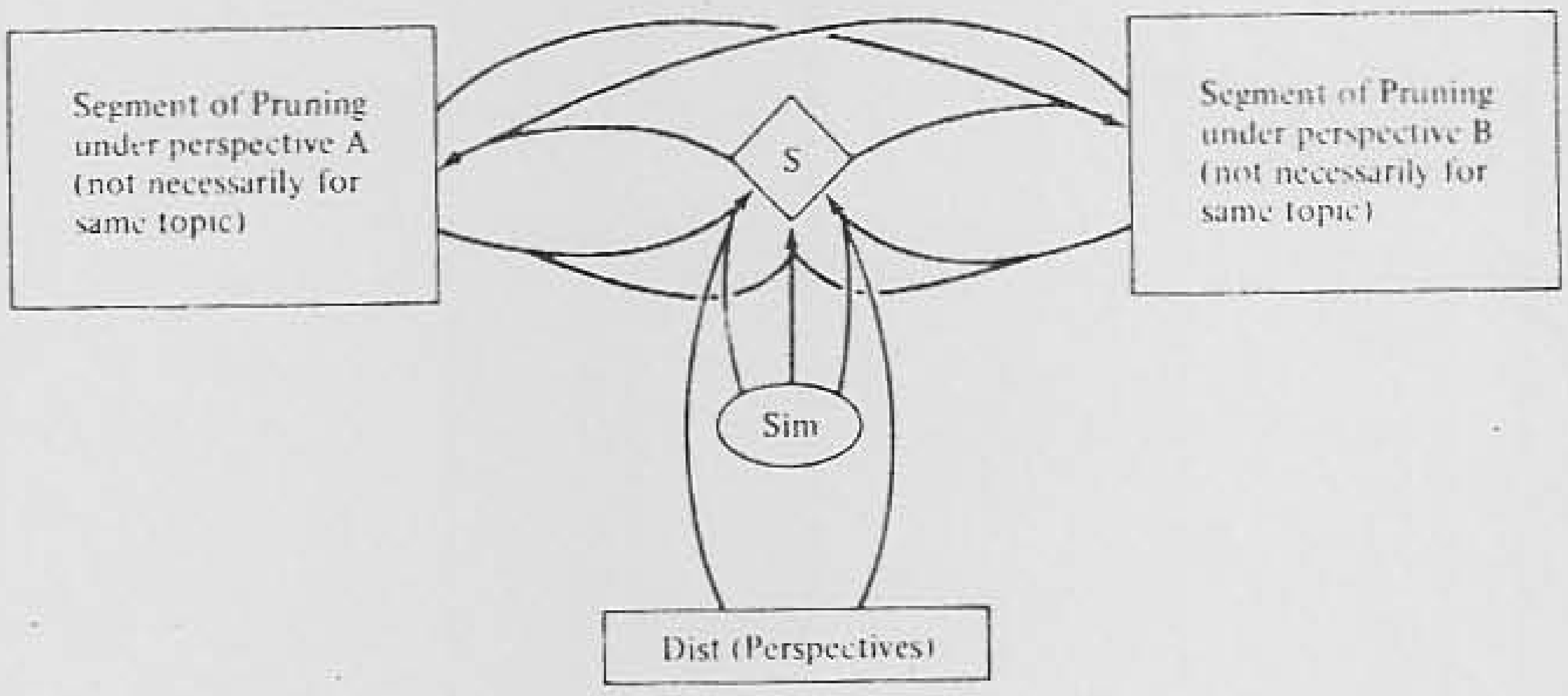


Figure 8. Similarity (Sim) and distinction (Dist). Given analogy *P*, *Q*, topic *H* may be learned if *I* is known (a) or F if G is known (b). Vice Versa, given *P*, *Q*, *I* may be learned if *H* is known, or *G* if *F* is known. *P*, *Q* may be learned by understanding *H and I* (or *G and F*) and the similarity involved *or*, if only one topic is understood, by understanding the similarity *and* understanding the distinction. (a) Pure analogy of form; (b) analogical topic with similarity component that is derived; (c) mixed analogy of form and method; (d) analogy of method, no necessary analogy of form.



(c)



(d)

Finally, there are analogies of method, which in general are asymmetric where there is no analogy of form. For example, mathematical induction may be used in many areas to obtain quite different results; schemes yielding different and possibly contradictory conclusions may be "axiomatically similar." Such analogies exist *only* in the pruning field of a mesh (Figure 8d) or between meshes (see also Steltzer 1976) between axiomatic structures.

If an entailment mesh or a conversational domain is used as a kind of content map for learning about a theory, then learning an analogy is not

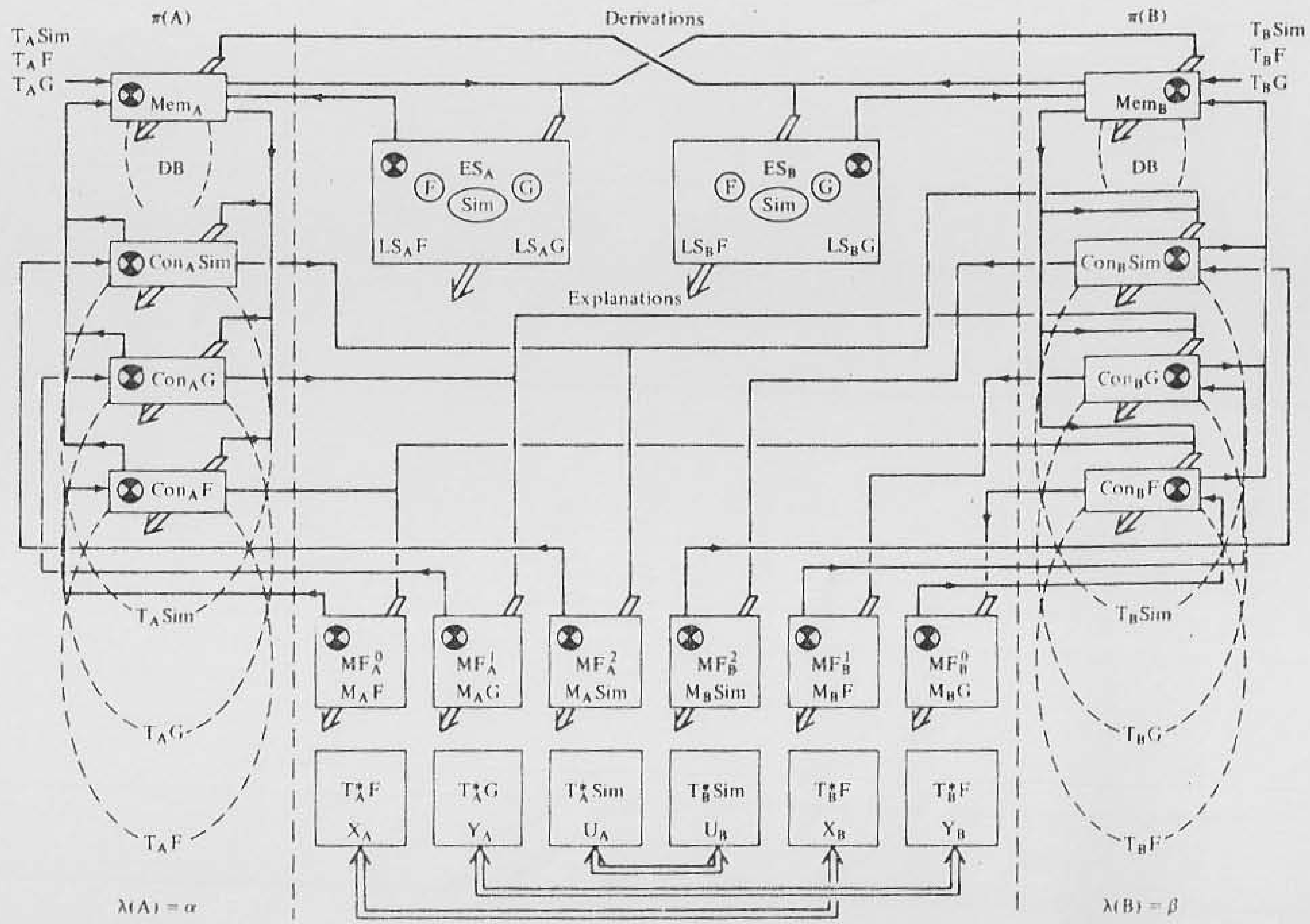


Figure 9. Agreement over and construction of an analogy, by extension of Figure 5 and using the same notation, except that there must be *independent* models constructed by *both* participants in modeling facilities MF^0, MF^1, MF^2, the analogies *between* which become *agreed* to as themselves *analogies* between *perspectives* of the participants.

Reset Figure Legend X

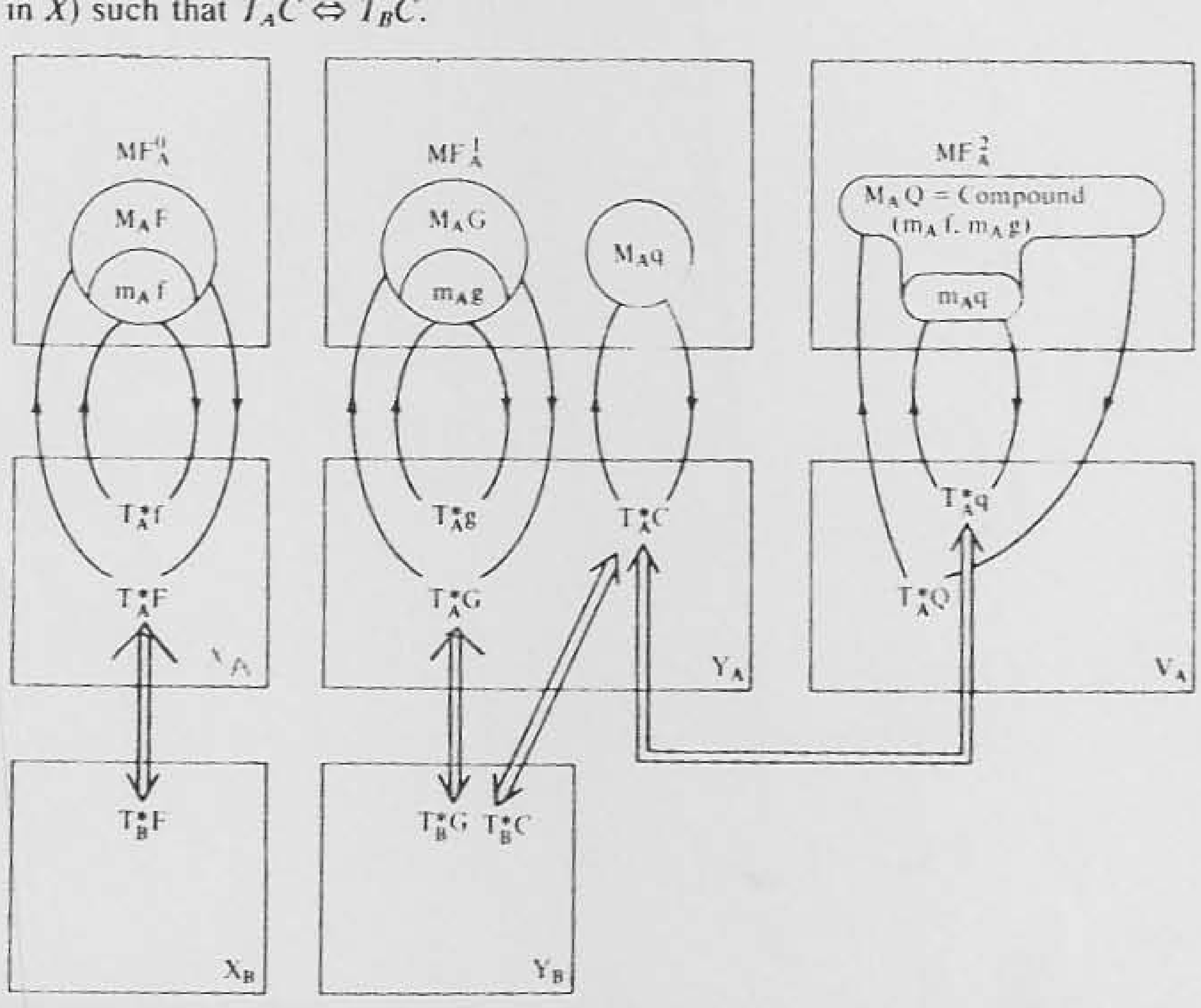
greatly different from learning any other topic. This is not true of constructing and inscribing analogies (one respect of creative thought, at any rate in design—see reports 1976, 1977). Independent models must be constructed, executed independently, and rendered coherent (or dependent) because an analogy is built between them (Figure 9).

16.14 Analogies and Agreements over an Understanding

In a sense, all such analogies are static inscriptions of agreements over understandings.

In general, analogies hold between perspectives. Invariably, they are created by the juxtaposition of perspectives and the resolution of these perspectives. As a rule, this involves a further distinction, which may be an inventive or genuine extension of a theory or a design and leads to the realization of a further analogical universe in which an otherwise inexecutable compound or concurrent model *can* be executed (Figure 10).

Figure 10. A mechanism for creativity or innovation. Let M_{FA} *and* M_{FB} *constitute models, agreed as analogous by* A *and* B *realizing* T_A^*F, T_A^*G, *in* X_A *and* Y_A. *Take any submodels of these and compound them as* Compound $(M_Af, M_Ag) = M_A(Q)$, which *cannot* be realized in X *or* in Y but may be realized by distinguishing a further modeling facility with universe V in which, upon execution, $M_A(Q) \Rightarrow T_A{}^*Q$: Consider a v-realizable submodel m_Aq of $M_A(Q)$, which upon execution gives rise to a relation T_A^*q that is isomorphic to a relation T_AC (say) in Y (or in X) such that $T_AC \Leftrightarrow T_BC$.

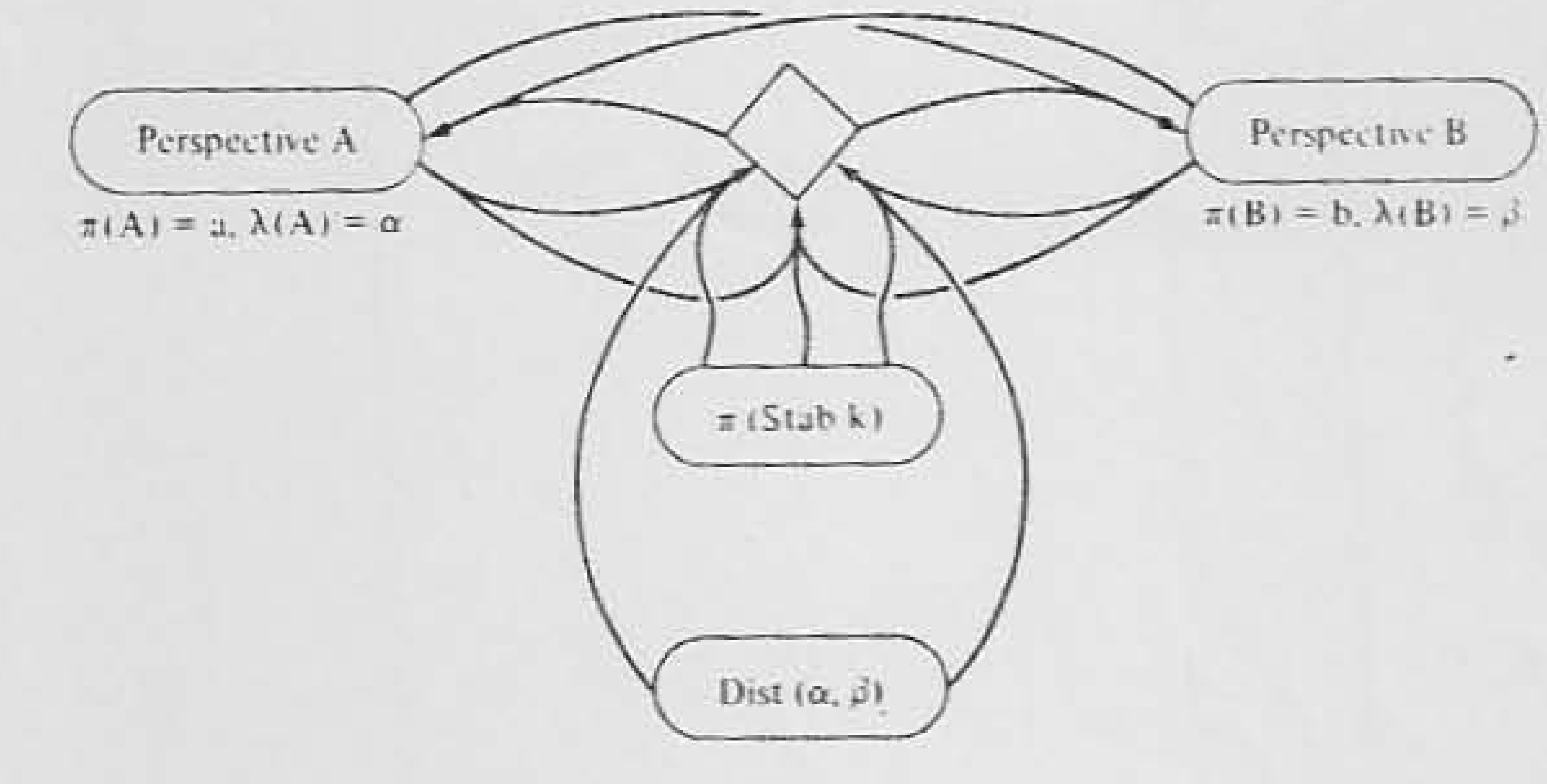


Let us represent Cases I–IV of conversations as analogies (static inscriptions), using the notation of Figure 8. For Case I, the inscription is shown in Figure 11a; Case III, which is similar, is shown in Figure 11b. For Case II and Case IV, an analogy between analogies is required (Figure 11c and Figure 11d). To each of these there is a dual (an analogy of method, not *necessarily* on of form) that preserves the identity of *A* and *B*, even though they learn or invent (Figure 11e or Figure 11f is repre-

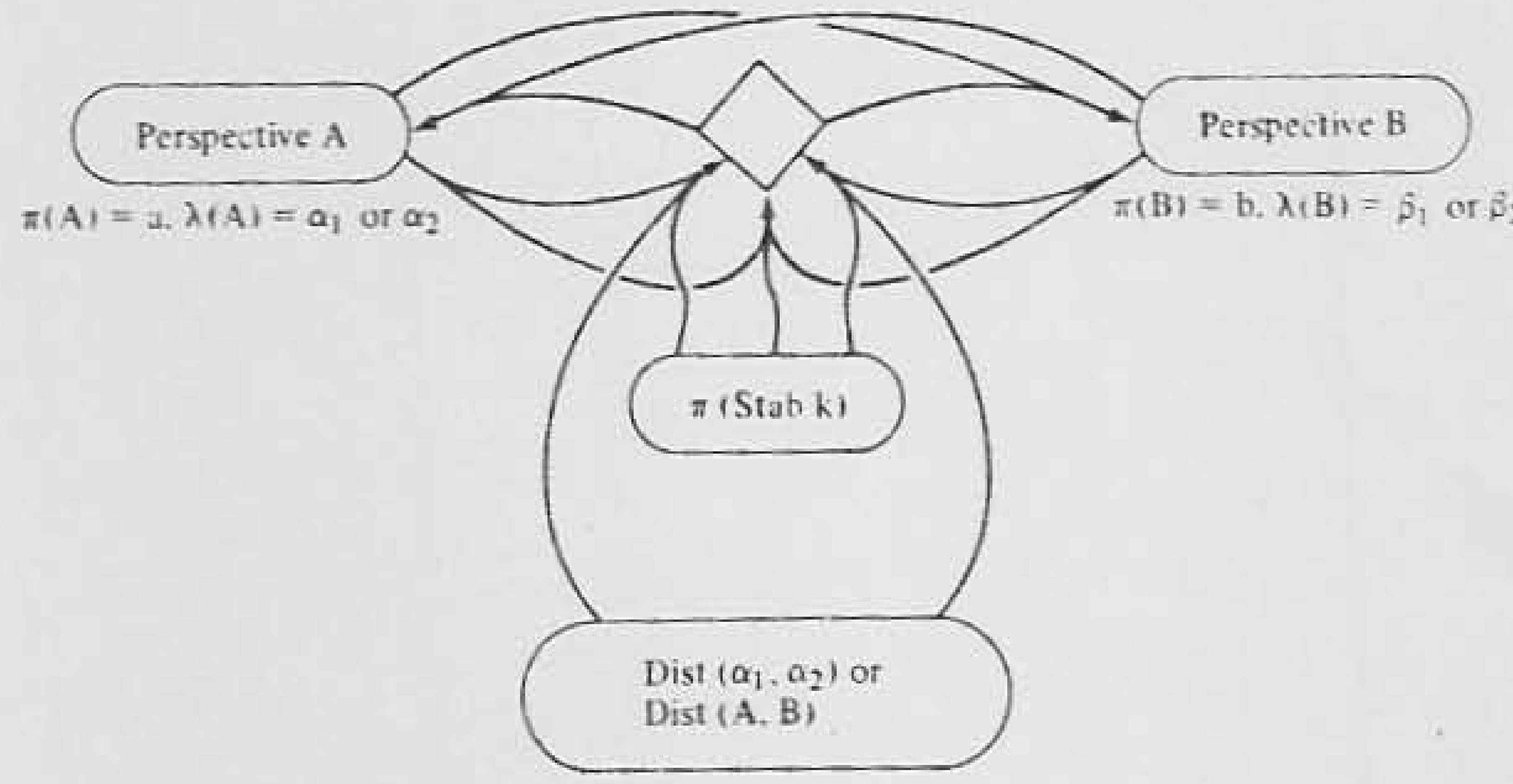
Figure 11. (a) Case I. (b) Case II. (c) Case III. (d) Case IV. Notice that the perspectives are meshes or members of the pruning fields of meshes, however.

(a) $\pi(A) = a,\ \lambda(A) = \alpha$ $\quad\quad$ $\pi(B) = b,\ \lambda(B) = \beta$

(b) $\pi(A) = a,\ \lambda(A) = \alpha_1$ or α_2 $\quad\quad$ $\pi(B) = b,\ \lambda(B) = \beta_1$, or β_2



(a)

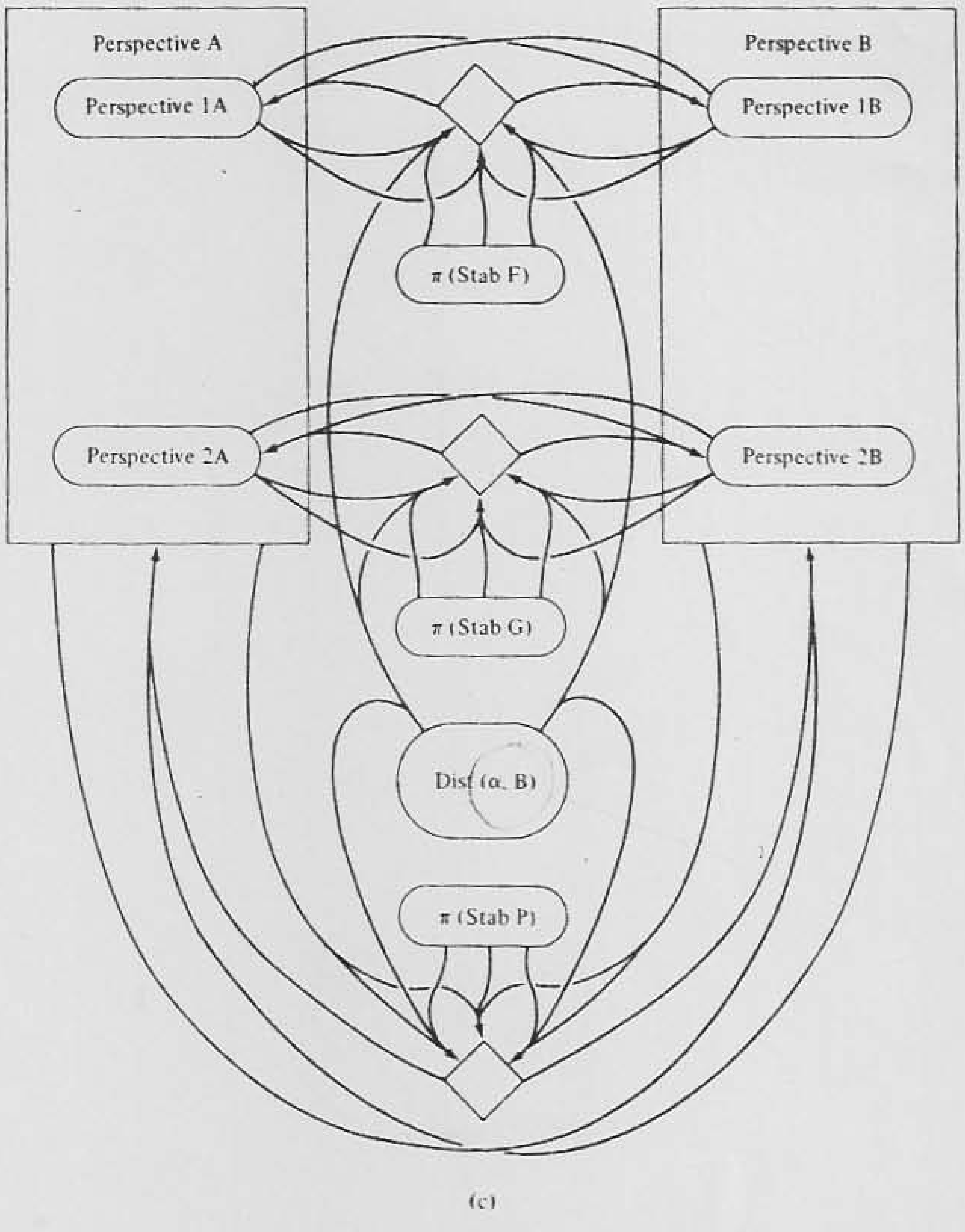


(b)

sentative). These constructions capture the notion of irreversibility, in addition to persistence, as promised in section 16.4.

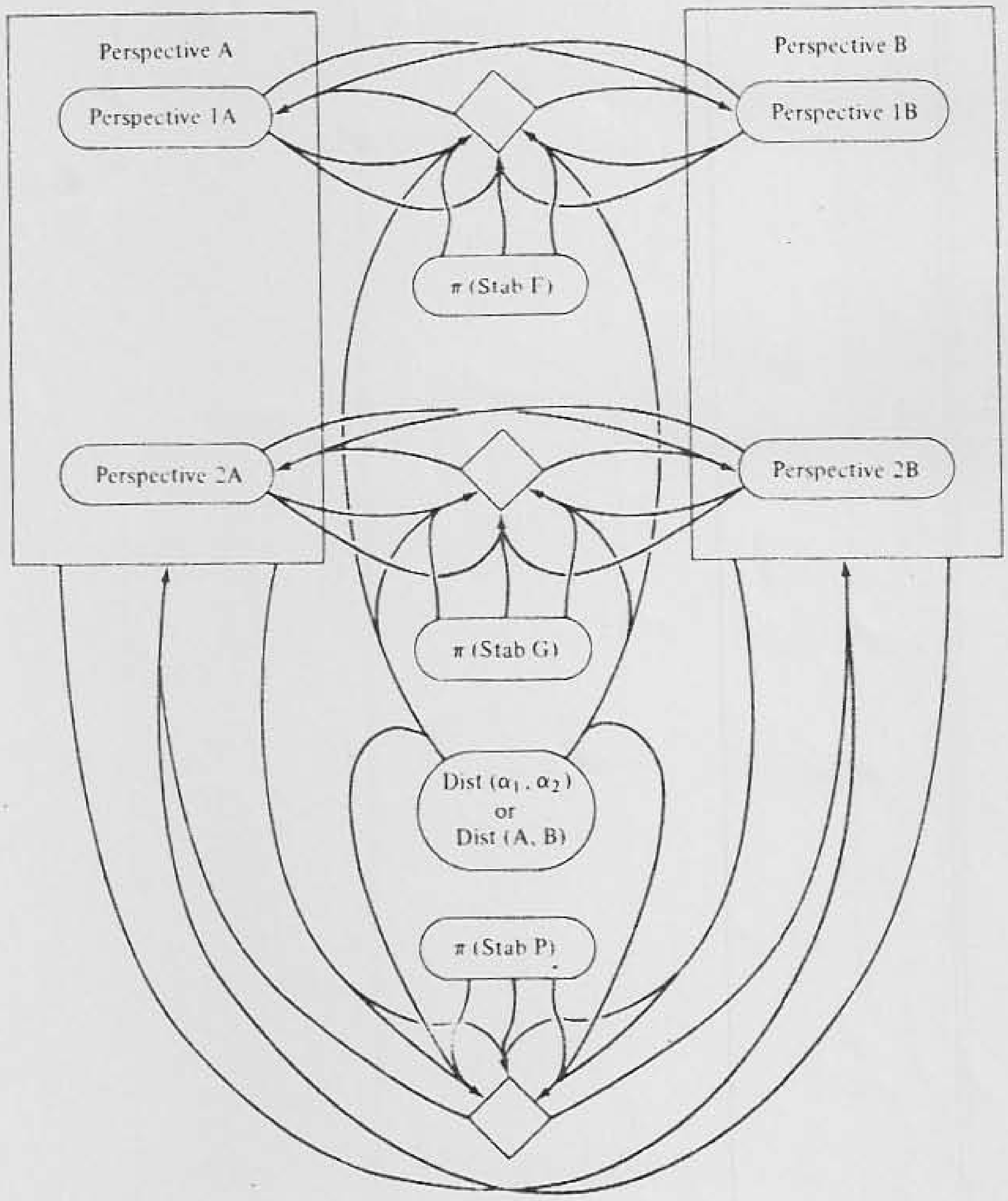
The truth values (executability, in general) of topics, interpreted in different universes that are analogous, is a subsistence truth (Section 16.5). Thus, with referrence to Figure 8, *F* is "true in *X*" and *G* is "true in *Y*." The truth value of the analogy itself is a coherence truth (Section 16.5).

Turning to Figure 11a–d, observe that "true for *A*" and "true for 'B"

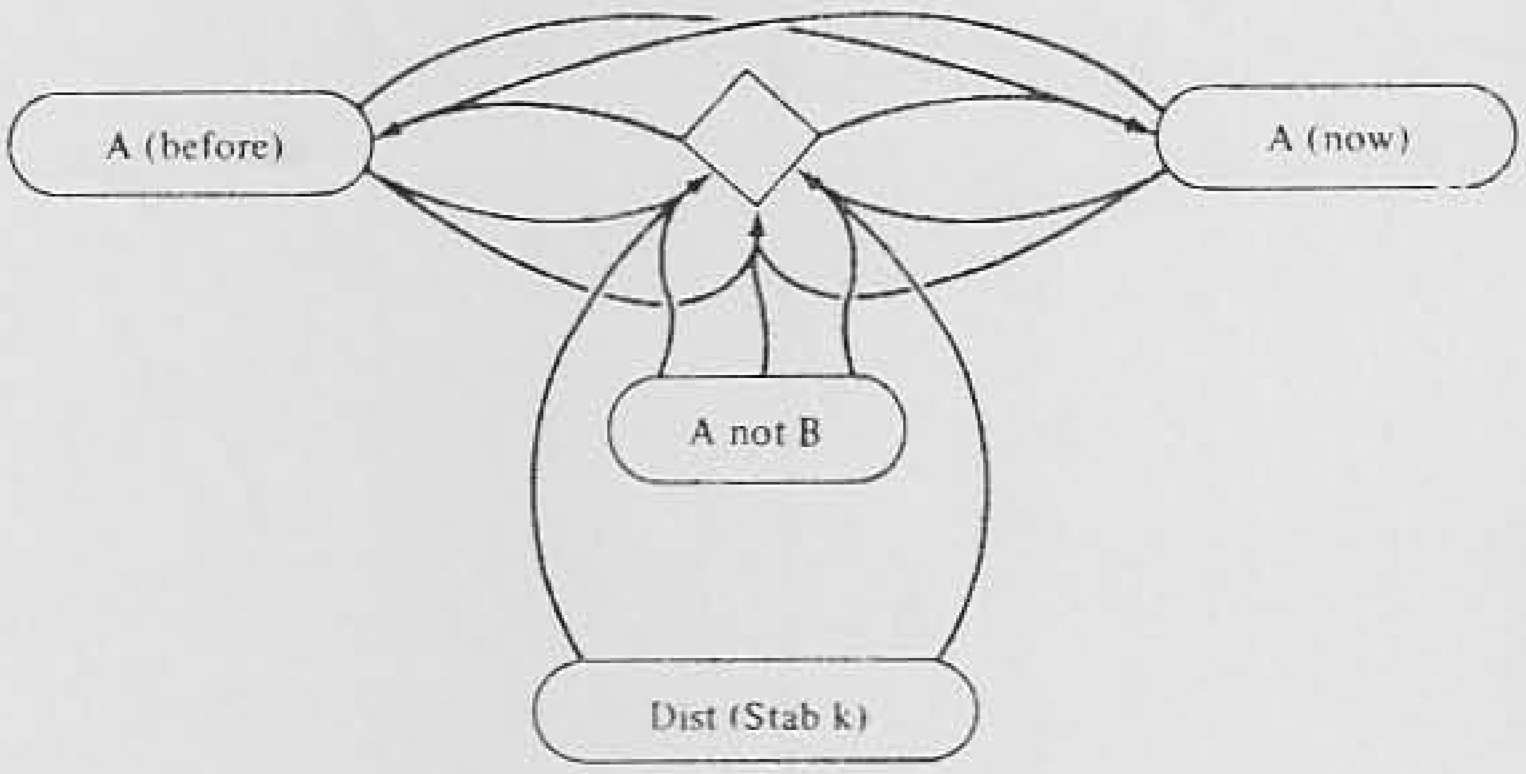


(c)

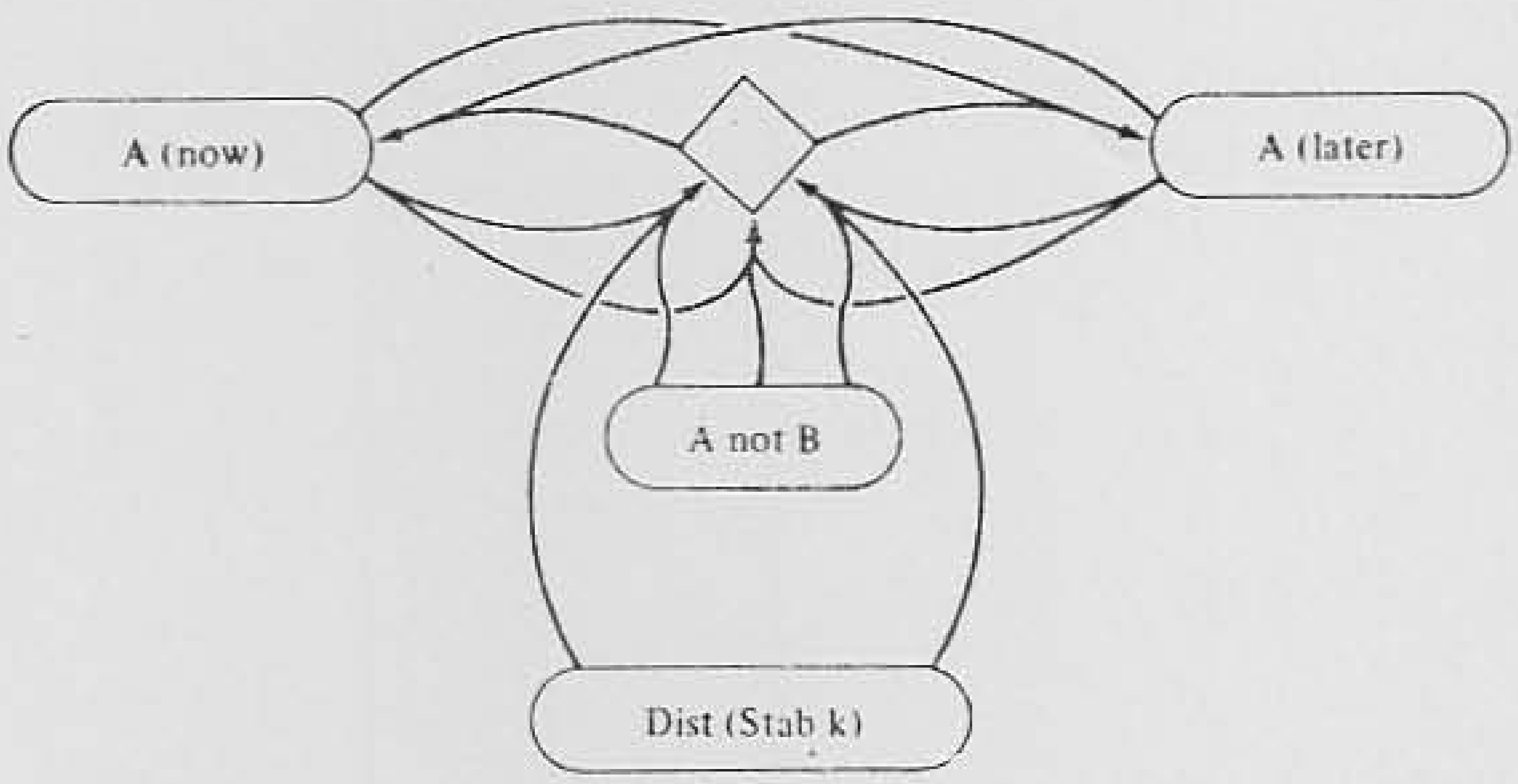
R. H.


Perspective A
Perspective 1A
Perspective B
Perspective 1B
π (Stab F)
Perspective 2A
Perspective 2B
π (Stab G)
Dist (α1, α2)
or
Dist (A, B)
π (Stab P)

(d)



(e)



(f)

are not the same, but *agreed* to (i.e., these personal truths are coherence related. There is a maximal coherence truth, those things that A and B can jointly understand—namely, all possible L expressions or subsets of them that are beliefs shared by a civilization, a culture, a few people in dialogue, or maybe just a hermit talking to himself.

16.15 Limits on a Community of Language Users

However, insofar as understanding takes place, there is no limit to the size of an L-speaking community, provided that, within its shared beliefs, it accommodates an adequate diversity (of subcultures, or deviants, or whatever) to maintain conversation that is genuinely productive [the *disagreement* to engender innovation (Section 16.14) and to accept some of the inventions]—a dialectic (which is also compatible, for example, with Moscovic's (1976) theory of social development).

16.16 Autonomy, Individuality, and Knowledge

What are the stable and organizationally closed systems of cognition and conation, either psychological or social? In the limiting case, there is Stab (Figures 3 and 4) accompanied by an inarticulated awareness, the sentience of a monad.

The least conscious system is a conversation, external or internal, in which agreement is reached between perspectives. I call such an entity a *P individual* (psychological individual).

The least observable conversation places the distinction boundary in such a position that some understandings are exteriorized. The conversation is a P individual, and so are the participants who converse with each other.

There is no limit to the size of a conversation except that it must generate sufficient distinctions to be resolved, that is, sufficient perspectives. Hence, a society or a civilization is organizationally closed (P Individualized), just as is a family or a person. There is no need to ask why there are organizationally closed systems or autopoietic systems. They are the units of reality. The cogent question is whether there are any "allopoietic" (inanimate, "static") systems except those engendered by the artifice of static inscription.

Appendix: Production Schemes for Organizationally Closed and Informationally Open Systems

The entire paper is (obviously) written in a metalanguage, referred to henceforward as $L^{\#}$ over the conversational language L noted in the paper. For example, the process ostending variable Z, the conditions of Z, including the specification of $\pi(Z)$ and $\lambda(Z)$, and the observation of an understanding are $L^{\#}$ statements.

It is assumed that individuals $Z = A$ and $Z = B$ are in conversation, so that it is possible to substitute blanks (Con i, etc.) and consider concepts that belong to A or B ($\mathrm{Con}_A\ i$, $\mathrm{Con}_B\ i$, etc.). For convenience and clarity in drawing out large production schemes, upper-case symbols ($P, Q, \ldots, R, S, \ldots, T$) are used to stand either for an *index* ($i, j, \ldots$) or a *description* produced upon executing $\mathrm{Con}_A\ i$, $\mathrm{Con}_B\ j, \ldots$; so, for example, we write

$$\mathrm{Ex}\ \mathrm{Con}_A(T) \Rightarrow T_A \quad \text{or} \quad \mathrm{Ex}\ \mathrm{Con}_B(T) \Rightarrow T_B.$$

The ambiguity is harmless since, although indices and descriptions are not the *same*, they are in one to one correspondence.

Diagram 1 shows an organizationally closed system obtained by substituting $Z = A$ and by postulating that, depending upon the perspective, A derived T_A from P_A and Q_A, P_A from T_A and Q_A, or Q_A from T_A and P_A; the static inscription

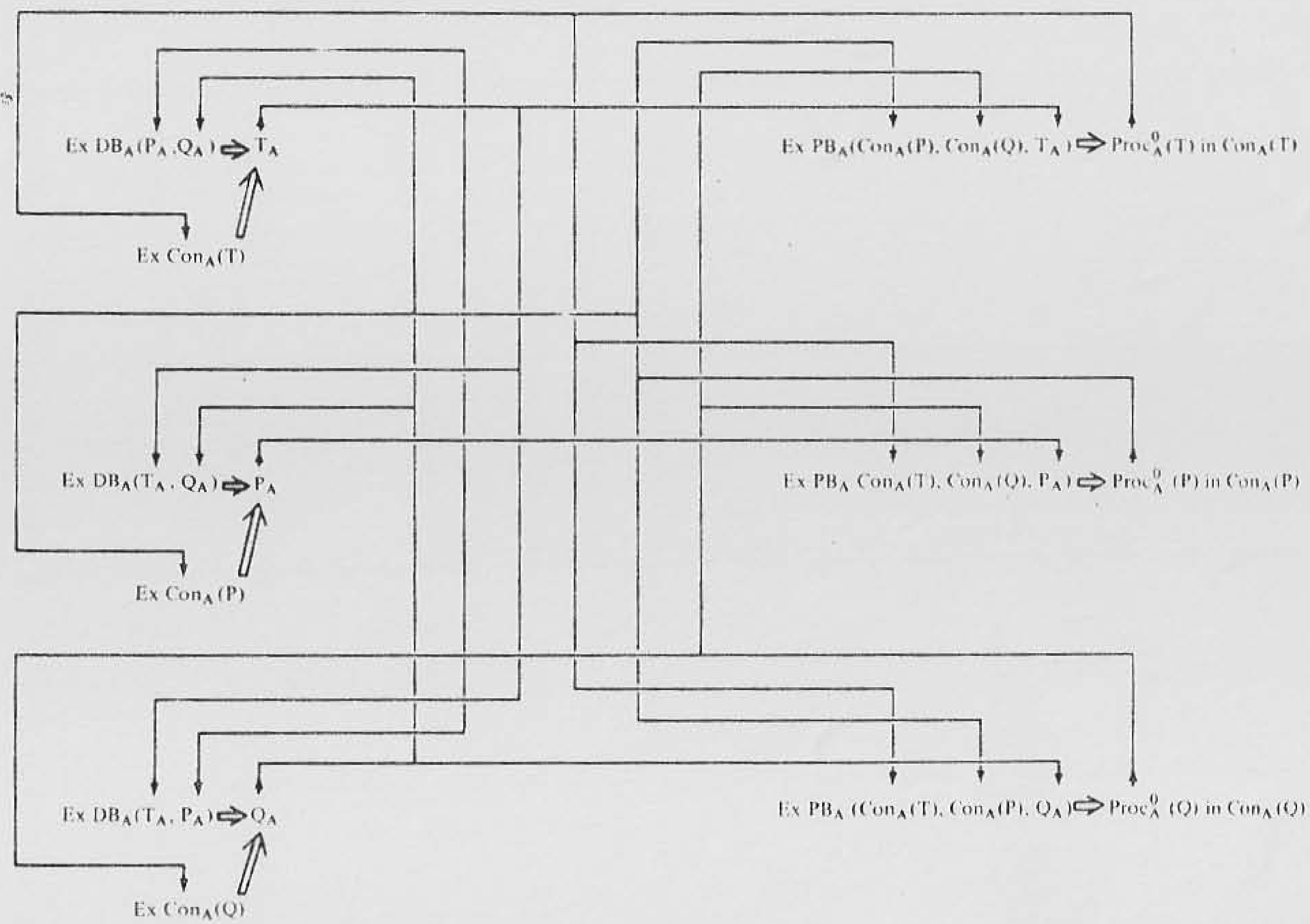


DIAGRAM 1. A stable concept $Mem_A(T)$ is, with equal significance, the organizational closure of a system of productions *PB*, and *DB*, and the concept execution for participant *A* (it is assumed that participant *A* derives a concept for topic *T* from concepts for topic *P* and for topic *Q*). The subscripting notation is (quite deliberately) redundant if *only A* is in mind, but is consistent with the notation required if consideration is also given to participant *B*.

Reset Figure Legend X

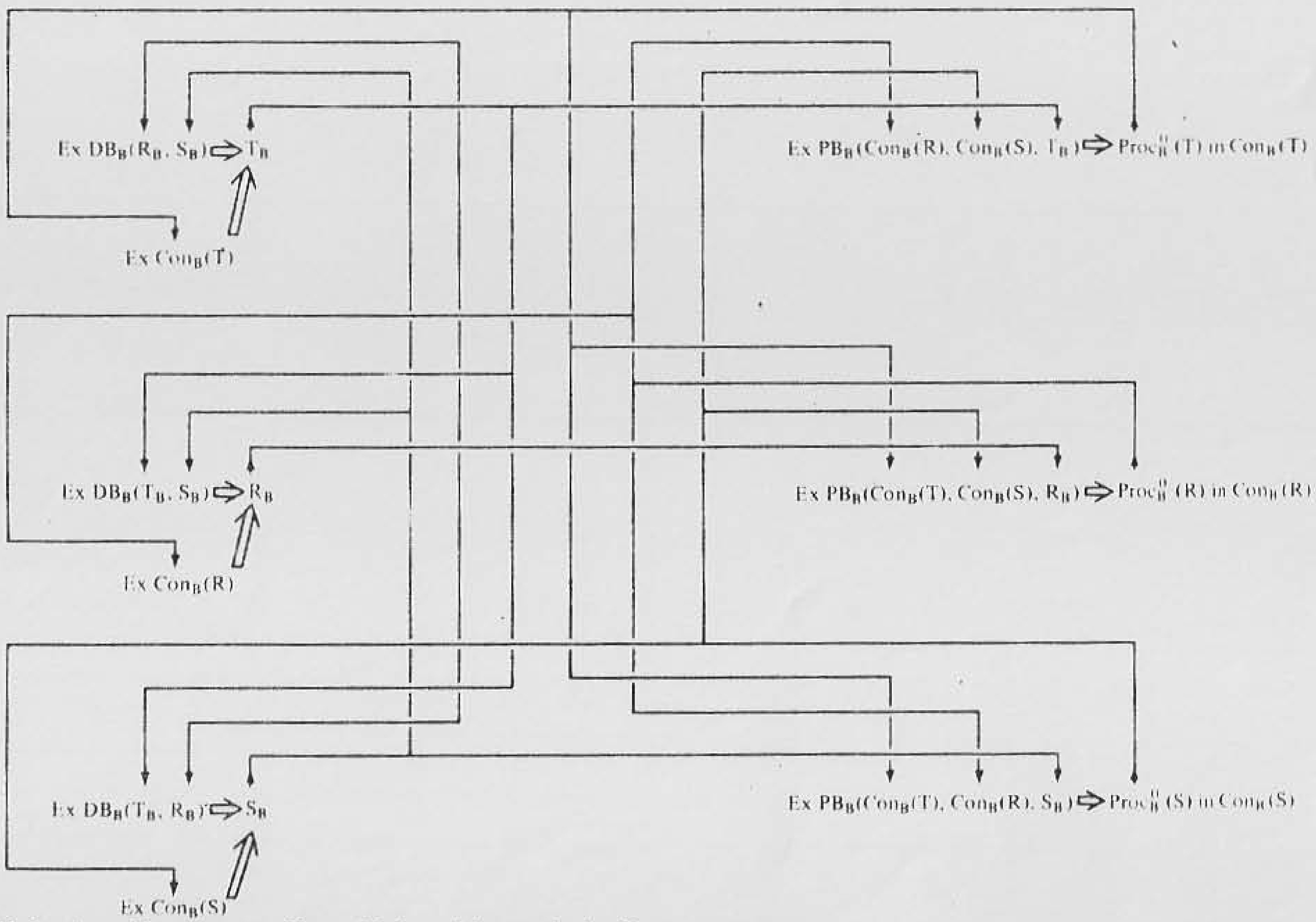


DIAGRAM 2. A stable concept $\mathrm{Mem}_B(T)$ is, with equal significance, the organizational closure of a system of productions *DB*, *PB* and the concept execution for participant *B*. It is assumed that participant *B* derives a concept for *T* from concepts for *R* and for *S*.

Reset Figure Legend X

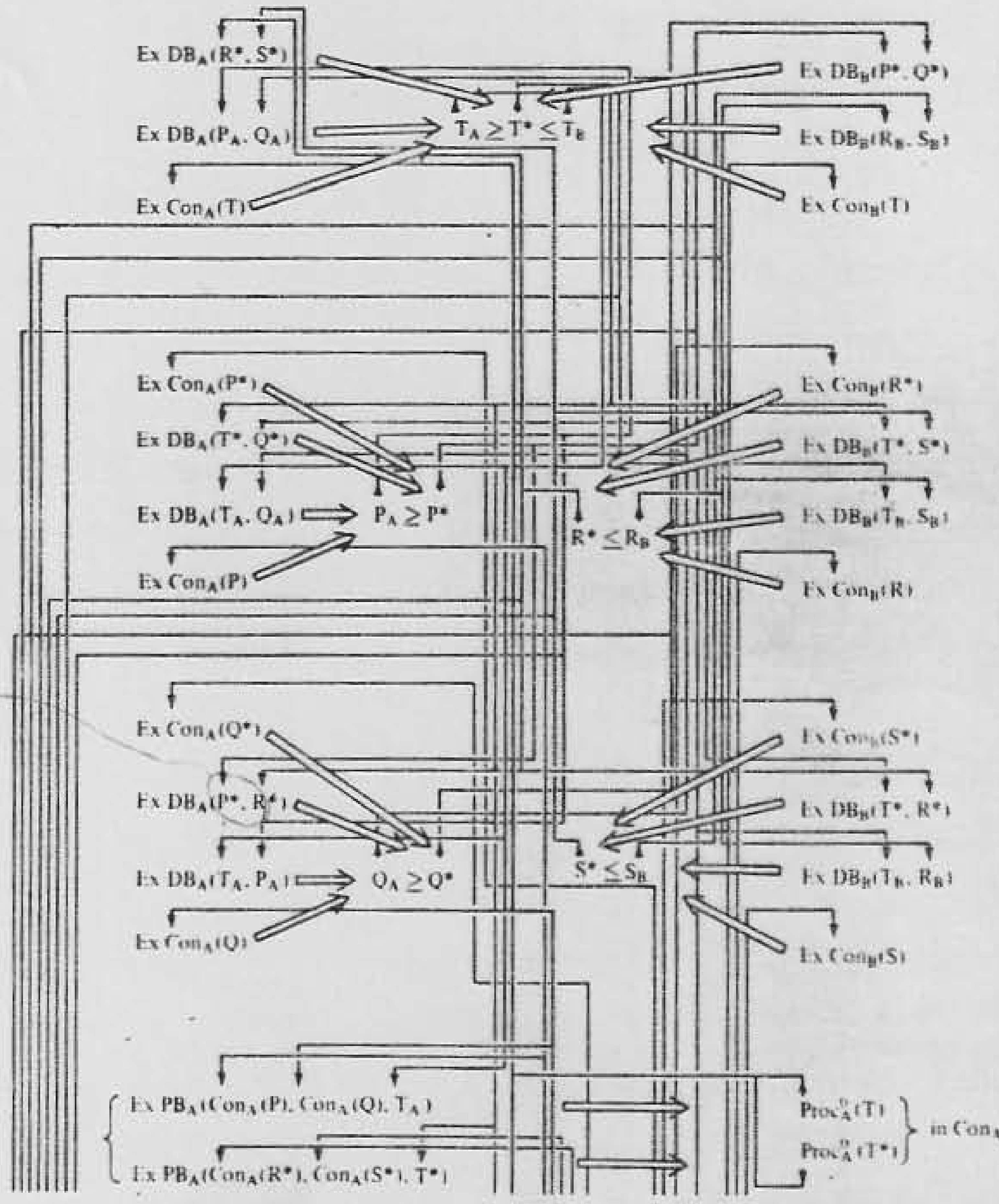
of this system is an entailment mesh in the form of Figure 4 in the with $T = i$, $P = l$, and $Q = m$.

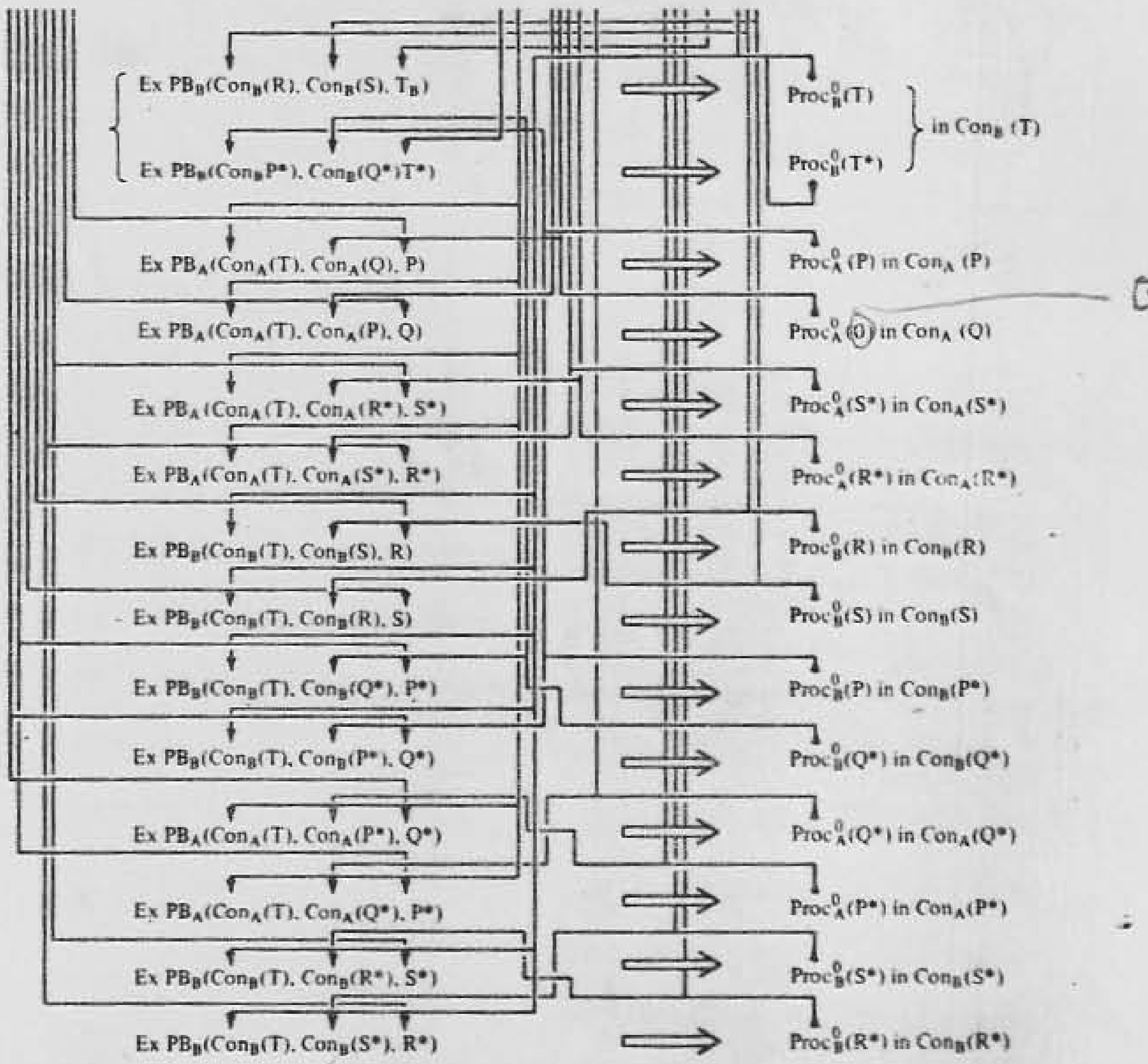
Diagram 2 shows the possibility that B derives T_B from R_B and S_B (with static inscription, again, as in Figure 4).

Diagram 4 shows an agreement, over the understanding of T, by A and B. The commonly shared part of T_A and T_B is T^*. As a result of agreement A may derive a concept for T_A from P_A and Q_A or from $R_A{}^*$ and $S_A{}^*$; B may derive a concept for T_B from R_B and S_B or from $P_B{}^*$ and $Q_B{}^*$.

The event depicted in Diagram 3 (leading from Diagrams 1 and 2 to Diagram 4) is procedure sharing between participants who are regarded, with equal significance, as a priori asychronous or a priori independent; that is, they become locally synchronized or locally dependent because of procedure sharing that is manifest as an L agreement (Figure 5). When this event is observed in the me-

DIAGRAM 3. L agreement over common understanding of topic T. A derives T from P and Q. Participant B derives T from R and S. An agreement may be complete or partial depending upon the isomorphic part.





Dia. 3 continued

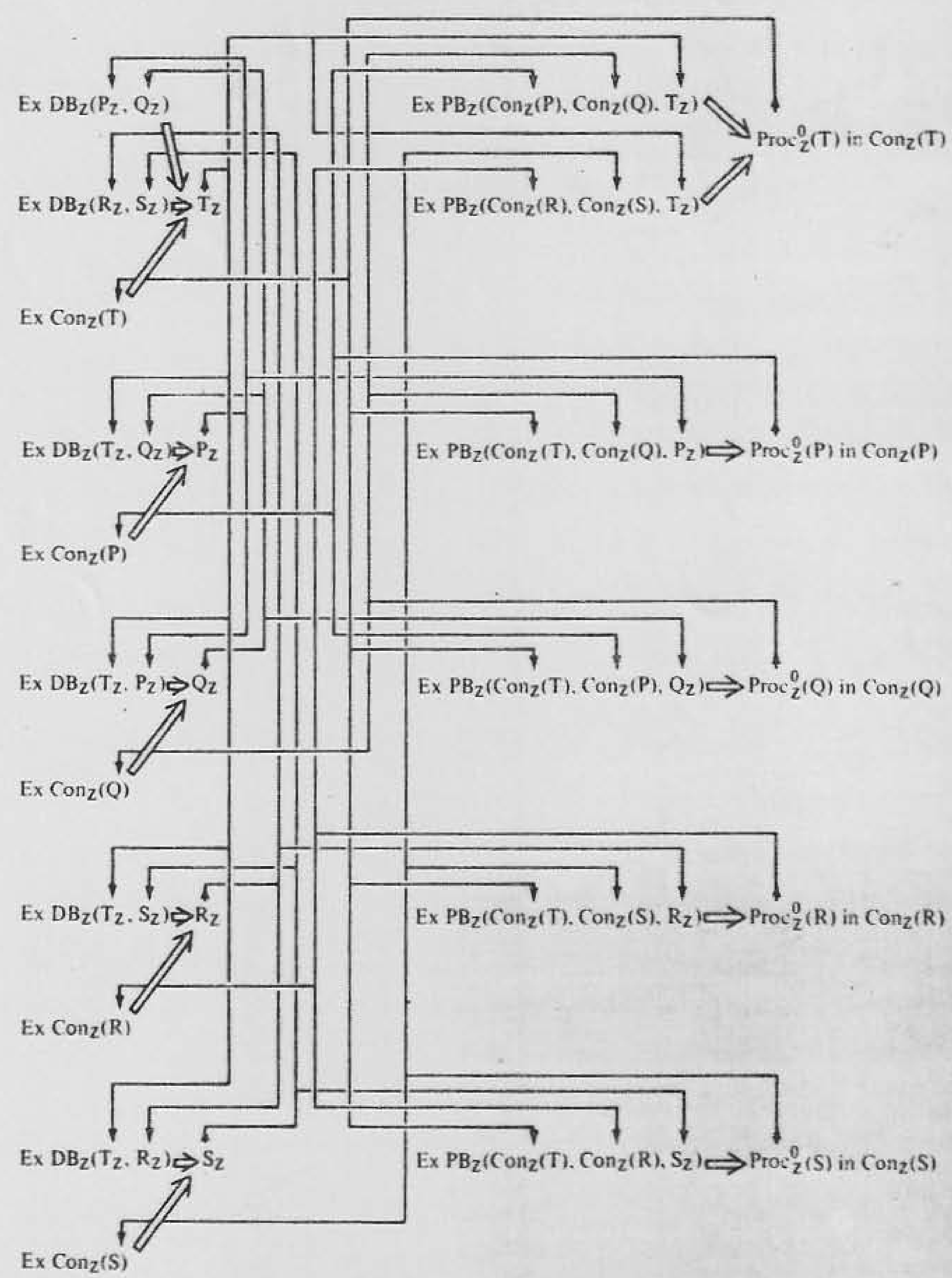


DIAGRAM 4. Given that *T* is learned by one participant (for consistency, participant *A*) who derives a concept of topic *T* from concepts for topic *P* and *Q* or *R* and *S*, the stable concept is an organizationally closed system of productions that take place in one participant.

talanguage L^* it has the form of an L^* metaphor designating an L^* analogy relation. This analogy is veridically subsistent true (or false) with respect to both A and B. The distinction on which it hinges, Dist(A,B), is introduced by an observer who is anxious to make objective (it-referenced) statements about conversations as units.

ACKNOWLEDGMENTS

The research reported in this paper is supported by a Social Science Research Council of Great Britain Research Programme (Grant HR 2708/2), in the context of learning strategies, educational strategies, and subject matter representation, the U.S. Army Research Institute for the Behavioral and Social Sciences (Grant DAERO 76 G 069), through its European Office, in the context of complex decision processes, and by the U.S. Air Force Office of Scientific Research (Contract F44620) through its European Office in the context of innovative design. The work is carried out at System Research Ltd.

References

Atkin, R. (1977), "Methodology of Q-Analysis," Research Report No. 10. Dept. Mathematics, University of Essex.

Ben Eli, M. (1976), "Comments on the Cybernetics of Stability and Regulation in Social Systems," Ph.D. thesis, Brunel Univ., Uxbridge.

Ben Eli, M. and Tountas, C. (1976) The evolution of complexity in a simulated ecology, *Proc SGSR Symposium*, Denver.

Bråten, S. (1976), Computer simulation of communication and consistency, *Proc Int. Association for Cybernetics, Namur, Belgium*.

Bråten, S. (1977), *The Human Dyad. Systems and Simulations*, Inst. of Sociology, Univ. of Oslo.

Caianiello, E. (1977), *Some Remarks on Organization and Structure*, sabbatical project, Inst. of Theoretical Physics, Univ. of Alberta, Canada; Lab. for Cybernetics, CNR, Naples.

Chang, C. L., and Lee, Y. L. (1973), *Symbolic Logic and Mechanical Theorem Proving*, Academic Press, New York.

Codd, E. F. (1970), A relational model of data for large shared data banks, *ACM* 13(b), 337.

von Foerster, H. (1976), papers in collected publications of BCL.

Glanville, R. (1976), "The Object of Objects, the Point of Points—or, Something About Things," Ph.D. thesis, Brunel, Univ. Uxbridge.

Goguen, J. A. (1975), Objects, *Int. J. Gen. Systems* 1, 237–243.

Goguen, J. A., Thatcher, J. W., Wagner, E. G. and Wright, J. B. (1976), *A Junction Between Computer Science and Category Theory, I: Basic Concepts and Examples (Parts 1 and 2)*, IBM Thomas Watson Research Center, Yorktown Heights, N.Y.

Löfgren, L. (1972), Relative explanations of systems, in *Trends in General Systems Theory* (G. Klir, ed.), John Wiley, New York.

Löfgren, L. (1975), *On Existence and Existential Perception* Dept. Automata, Lund Inst. Tech., Lund, Sweden.

Maturana, H. and Varela, F. (1976), Autopoietic systems: A characterisation of the living organisation,

Muscovici, S. (1976), *Social Influence and Social Change*, Academic Press, New York.

Neumann, J. von (1966), *Theory of Self-Reproduction Automata* (A. Burks, ed.), Univ. of Illinois Press, Urbana.

Pask, G. (1973), Artificial intelligence, *Soft Architecture Machinations*,

Pask, G. (1975a), *Conversation Cognition and Learning*, Elsevier, Amsterdam and New York.

Pask, G. (1975b), *The Cybernetics of Human Learning and Performance*, Hutchinson, London.

Pask, G. (1976a), *Conversation Theory: Applications in Education and Epistemology*, Elsevier, Amsterdam and New York.

Pask, G. (1976b), Conversational techniques in the study and practice of education, *Br. J. Educ. Psych.* 46 (Part I),

Pask, G. (1976c), Styles and strategies of learning, *Br. J. Educ. Psych.* 46 (Part II),

Pask, G. (1977a), "Investigations into New Methods of Assessment and Stronger Methods of Curriculum Design, with Particular Reference to Higher Education in the United States, Part I," Ford Foundation Report, IET Open University.

Pask, G. (1977b), Minds and Media in Education and Entertainment, *Procs. 3rd European Meeting on Cybernetics and Systems Research*, Vienna, (R. Trappl, ed); see also Revisions in the foundations of Cybernetics and General Systems Theory ..., *Proceedings 8th International Congress on Cybernetics*, Namur 1976.

Pask, G., and Scott, B. C. E. (1972), "Learning Strategies and Individual Competence", *Int. J. Man–Machine Studies* 4, 217–253.

Pask, G., and Scott, B. C. E. (1973), CASTE: A system for exhibiting learning strategies and regulating uncertainty, *Int. J. Man–Machine Studies* 5, 17–52.

Pask, G., Scott, B. C. E., and Kallikourdis, D. (1973), A theory of conversations and individuals (exemplified by the learning process on CASTE), *Int. J. Man–Machine Studies* 5, 443–556.

Pask, G., Kallikourdis, D., and Scott, B. C. E. (1975) The representation of knowables, *Int. J. Man–Machine Studies* 7, 15–134.

Petri, C. A. (1965), *Communications with Automata*, Jr. Suppl. to Tech. Documentary Rep. (tr. Clifford F. Greene) for Rome Air Development Center, Contract AF30 (602)–3324.

Steltzer, J. (1976), *Classifying and Structuring the Context of Instructural Subject Matter, ARI Report* DAHC 19-74-C0066.

Varela, F. (1975), A calculus for self reference, *Int. J. Gen. Systems* 2, 5–24.

Varela, F. (1976), The arithmetic of closure (R. Trappl, ed.), *Proc. 3rd Europ. Mtg. on Cybernetics and Gen. Systems Research*, Vienna.

Varela, F., Maturana, H. R., and Uribe, R. (1974), Autopoiesis: The organization of living systems, its characterization and a model, *Biosystems* 5, 187–196.