Chapter 5

Description Building and Procedure Building

Chapter 2 contained an informal discussion of categories of mental operation called "Procedure Building" (*PB*) and "Description Building" (*DB*), together with an allusion to a further, hazily specified category of operations called "Procedure Construction" (*PC*). Of these categories *DB* and *PB* (at least) were said to be global or local in form and we hypothesised that globality/localness is a substantially invariant propensity for a given student. Similarly, students may be characterised in terms of the efficacity of the *DB* and *PB* operations in their mental repertoire. "Efficacity" might be no more than preponderance, it might be a more subtle operational quality. At any rate, the characterisation is constant enough to transfer from one task to another and to demarcate sensible individual differences.

By conjoining the combinations *DB not PB*, *PB not DB*, *DB and PB*, *neither DB nor PB*, with the initial global/local distinction, we constructed a table with cells representing the learning performances of students with distinct "competence profiles" (that is, mental repertoires furnished with more or less efficacious *DB* and *PB* operations and particular dispositions to act as globally or as locally as circumstances permit). There is ample evidence, mustered and summarised in Chapter 2, in support of the empirical validity of these discriminations between competence profiles; the evidence is especially clearcut in the case of defects or pathologies of learning manifest repeatedly by people who have different mental equipment. The distinctions in question tally quite well with the predictions made in terms of the competence profiles. If the tutorial context is taken into account, it is possible to infer that the holist/serialist dichotomy (previous monograph) is a result of combining certain competence profiles with specific tutorial situations, especially those in which strict conversation is approximated and understanding is enforced.

Only one caution is required as a preliminary comment. The *DB* operations and the *PB* operations act upon $\underline{\text{Proc}^0\text{s}}$ in a mental repertoire. This statement should be taken literally; the operations act upon both $\underline{\text{Prog}}$ and $\underline{\text{Inter}}$ as the components (Chapter 4) of $\underline{\text{Proc}^0} = \langle \underline{\text{Prog}}, \underline{\text{Inter}} \rangle$.

It now makes sense to detail and enlarge upon the nature and significance of the *DB* and *PB* categories, and to some extent upon the *PC* category also. This endeavour entails translating *DB* operations and *PB* operations in terms of the L^1 procedures ($\underline{\text{Proc}^1}$) and the L^0 procedures ($\underline{\text{Proc}^0}$) which, according to the present theory, are the stock in hand of any mental repertoire whatsoever. The *PC* operations feature as essential ingredients of the mind, but they are ubiquitious, diverse and discussed in a much more cursory fashion.

1. THE GLOBAL AND LOCAL DISTINCTION

As in Table 13 of Chapter 3, we use the convention of *GDB*, *LDB*, to denote global and local *DB* operations, and by the same token, *GPB*, *LPB* to denote global and local *PB* operations. Both kinds of operation, when interpreted within the present theory as cognitive processes, are species of L^1 procedures ($\underline{\text{Proc}^1}$), and the *DB/PB* distinction is a means of partitioning the L^1 procedures into categories germane to the work in hand. This fact is not immediately obvious as the *DB* operate upon topic relations to produce new relations, and the *PB* operate upon L^0 procedures ($\underline{\text{Proc}^0}$), if a relation is given to produce new procedures. Thus:

$$DB(R_i, R_j) \Rightarrow R_k \ ; \qquad PB(\underline{\text{Proc}^0}i, \underline{\text{Proc}^0}j, R_k) \Rightarrow \underline{\text{Proc}^0}k$$

in which R_i, R_j and R_k may be regarded as descriptions of topic relations taken in extenso.

Calling the number of arguments to which the operation is applied the *scope* of the operation, any *GDB* or *GPB* has maximal scope (under the constraints imposed by a situation), which is represented as follows:

$$GDP(R_i \ldots R_j) \Rightarrow R_k \quad \text{and} \quad GPB(\underline{\mathrm{Proc}}^0 i \ldots \underline{\mathrm{Proc}}^0 j,\ R_k) \Rightarrow \underline{\mathrm{Proc}}^0 k\,.$$

Similarly, any *LDB* or *LPB* has a minimal scope (the same caveat holding). Thus:

$$LDB(R_i, R_j) \Rightarrow R_k \quad \text{and} \quad LPB(\underline{\mathrm{Proc}}^0 i, \underline{\mathrm{Proc}}^0 j, R_k) \Rightarrow \underline{\mathrm{Proc}}^0 k$$

The possible *scope* will often depend upon circumstances (the R_i, R_j, R_k involved, for example), hence the maximisation or minimisation caveat. But, it is difficult to imagine any situation in which either R_k or $\underline{\mathrm{Proc}}^0 k$ might not be synthesised from a minimum number of constituents or from many. The bounds upon maximisation and minimisation can be formalised (at any rate in the case of $R_i, R_j \ldots$) either in terms of Ashby's (1964) Cylindrance (a measure of the minimal adicity of a redundantly specified relation), or more comprehensively in terms of Atkin's (1973) Connectivity Analysis of relational systems. The latter method has been elegantly applied by Aish (1974) to express the global and local propensities of designers, as a special but important case, their tendency to act in a holistic or a serialistic manner.

Noting that such a treatment is possible, the global/local distinction will be glossed over until the mechanism of mental computing is discussed (Section 8.2), in order to secure a lucid and unencumbered notation for expressing the sense in which the *DB/PB* distinction partitions the class of $\underline{\mathrm{Proc}}^1$.

2. DESCRIPTION BUILDING

A description in an L-Processor is either the result of executing some $\underline{\mathrm{Proc}}^0$ or the result of applying one or a finite series of $\underline{\mathrm{Proc}}^1$ (imaging a derivation) to the result of executing some $\underline{\mathrm{Proc}}^0$. Denote the result of execution $\underline{\mathrm{Ex}}$ (to avoid confusion with the Execution Sequence (listing) $\underline{\mathrm{Exec}}$ of the previous monograph). A topic relation, as an internal description, in extenso, is

$$R_i = \underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}^0 i; \quad \text{or} \quad R_i^* = \underline{\mathrm{Proc}}_1^1 \ldots \underline{\mathrm{Proc}}_\ell^1 (\underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}^0 i).$$

Thus $DB(R_i, R_j) \Rightarrow R_k$ is a shorthand expression for

$$R_k = \underline{\mathrm{Proc}}_1^1 (\ldots(\underline{\mathrm{Proc}}_\ell^1 (\langle \underline{\mathrm{Proc}}_{\ell+1}^1 \ldots \underline{\mathrm{Proc}}_m^1 (\underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}^0 i)\rangle, \langle \underline{\mathrm{Proc}}_{\ell+1}^1 \ldots \underline{\mathrm{Proc}}_n^1 (\underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}_j^0)\rangle))\ldots).$$

in which $m \geqslant 0$, $n \geqslant 0$ and $\ell + m \geqslant \ell + n$, $\ell > 0$. *

The trick in this definition is that ℓ, m, and n are finite. Descriptive chains, as derived through *DB* operations, are not endless compositions. The *DB* operator itself is to be conceived as a routine that is executed *until* its production (R_k) is *used* (by any of the *PB* operators) in order to build an L^0 Procedure which realises R_k. Failing that, the sequence terminates or is simply not a *DB* sequence. The *DB* are L^1 procedures, $\underline{\text{Proc}}^1$, the number in a chain is called its ℓ-distance.

In particular, an aim corresponds to some topic (the "most ℓ-distant" that can be appreciated or described), regarded psychologically, as a focus of attention. The aim is a description R_i^* at a maximum ℓ-distance from whatever $\underline{\text{Proc}}^0 i$ are undergoing execution. If the aim is referred to a conversational domain, then it means the displayed topic corresponding to a description at maximum ℓ-distance from whatever $\underline{\text{Proc}}^0 i$ are undergoing execution (R_i^* if this is a displayed topic relation, otherwise the topic nearest to R_i^* in the descriptor space).

3. PROCEDURE BUILDING

The *PB* operations are also a class of L^1 procedures, $\underline{\text{Proc}}^1$. The *PB* operators take an argument consisting in a description of a relation and the stable concepts in the repertoire from which the description is derived, and produce a further concept. The shorthand expression is given as

$$PB(\underline{\text{Proc}}^0 i, \underline{\text{Proc}}^0 j, R_k) \Rightarrow \underline{\text{Proc}}^0 k$$

or (from Section 2)

$$PB(\underline{\text{Proc}}^0 i, \underline{\text{Proc}}^0 j, \underline{\text{Proc}}_1^1 \ldots \underline{\text{Proc}}_\ell^1(R_i, R_j)) \Rightarrow \underline{\text{Proc}}^0 k.$$

In particular the $\underline{\text{Proc}}^1$ that merely stabilise or reproduce a concept as veridical memories are members of this class of $\underline{\text{Proc}}^1$. Hence,

$$PB(\underline{\text{Proc}}^0 k, R_k) \Rightarrow \underline{\text{Proc}}^0 k \quad \text{or} \quad PB(\underline{\text{Proc}}^0 k, \underline{\text{Ex}}\ \underline{\text{Proc}}^0 k) \Rightarrow \underline{\text{Proc}}^0 k$$

* This is a convention. If $\underline{\text{Proc}}^0$ is stable, it will be stabilised by a memory, an L^1 procedure which may be written *PB*. If this is counted as one of the derivational procedures, then the inequalities become $m > 1$, $n > 1$, $\ell + m > \ell + n > 1$.

are general ways of stating that a concept $\mathrm{Proc}^0\mathrm{k}$ is (as asserted) stable and compiled in an L-Processor by a memory, $\underline{\mathrm{Proc}}^1\mathrm{k}$. In a conversational domain (with cyclic and consistently related topics by definition), an understanding of $\mathrm{Proc}^0\mathrm{k}$ (or *topic* k) consists in the set

$$DB(\mathrm{R_i}, \mathrm{R_k}) \Rightarrow \mathrm{R_j}: \quad PB(\underline{\mathrm{Proc}}^0\mathrm{i}, \underline{\mathrm{Proc}}^0\mathrm{k}, \mathrm{R_j}) \Rightarrow \underline{\mathrm{Proc}}^0\mathrm{j}: \ \underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}^0_\mathrm{j} \Rightarrow \mathrm{R_j}$$
$$DB(\mathrm{R_j}, \mathrm{R_k}) \Rightarrow \mathrm{R_i}: \quad PB(\underline{\mathrm{Proc}}^0\mathrm{j}, \underline{\mathrm{Proc}}^0\mathrm{k}, \mathrm{R_i}) \Rightarrow \underline{\mathrm{Proc}}^0\mathrm{i}: \ \underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}^0_\mathrm{i} \Rightarrow \mathrm{R_i}$$
$$DB(\mathrm{R_i}, \mathrm{R_j}) \Rightarrow \mathrm{R_k}: \quad PB(\underline{\mathrm{Proc}}^0\mathrm{i}, \underline{\mathrm{Proc}}^0\mathrm{j}, \mathrm{R_k}) \Rightarrow \underline{\mathrm{Proc}}^0\mathrm{k}: \ \underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}^0_\mathrm{k} \Rightarrow \mathrm{R_k}$$

for which Kallikourdis gives a general algorithm.

Since the $\underline{\mathrm{Proc}}^0$ in a realisation of the formulae in Section 2 must be stable, it is clear that if there are *DB* in a repertoire, there must also be some *PB*, but the *PB* could conceivably be restricted to those $\underline{\mathrm{Proc}}^1$s that reconstruct or reproduce $\underline{\mathrm{Proc}}^0$s rather than those which construct them.

4. THE EXTERIORISATION OF AN *UNDERSTANDING*

An *understanding*, the pivotal condition for a strict conversation and, according to this theory, the prerequisite for any perma-

TABLE 5.1

$PB(\underline{\mathrm{Proc}}^0\mathrm{i}, \mathrm{R_i}) \Rightarrow \underline{\mathrm{Proc}}^0\mathrm{i}$ (Concept for topic i is stabilised)	(1)
$PB(\underline{\mathrm{Proc}}^0\mathrm{j}, \mathrm{R_j}) \Rightarrow \underline{\mathrm{Proc}}^0\mathrm{j}$ (Concept for topic j is stabilised)	(2)
$\underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}^0\mathrm{i}$ in L-Processor $\Rightarrow \mathrm{R_i}$ (Students concept of topic i)	(3)
$\underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}^0\mathrm{j}$ in L-Processor $\Rightarrow \mathrm{R_j}$ (Students concept of topic j)	(4)
$\underline{\mathrm{Ex}}\ \mathrm{M_i}$ (Based on S $\underline{\mathrm{Prog}}$ i) in modelling facility $\Rightarrow \mathrm{R_i}$ (Evidence for (1))	(5)
$\underline{\mathrm{Ex}}\ \mathrm{M_j}$ (Based on S $\underline{\mathrm{Prog}}$ j) In modelling facility $\Rightarrow \mathrm{R_j}$ (Evidence for (2))	(6)
$DB(\mathrm{R_i}, \mathrm{R_j}) \Rightarrow \mathrm{R_k}$ (Description of $\mathrm{R_k}$ from topic i, topic j)	(7)
$PB(\underline{\mathrm{Proc}}^0\mathrm{i}, \underline{\mathrm{Proc}}^0\mathrm{j}, \mathrm{R_k}) \Rightarrow \underline{\mathrm{Proc}}^0\mathrm{k}$ (Construction of $\underline{\mathrm{Proc}}^0\mathrm{k}$ given (1), (2), and (7)	(8)
$PB(\underline{\mathrm{Proc}}^0\mathrm{k}, \mathrm{R_k}) \Rightarrow \underline{\mathrm{Proc}}^0\mathrm{k}$ (Concept for topic k is stabilised)	(9)
$\underline{\mathrm{Ex}}\ \underline{\mathrm{Proc}}^0\mathrm{k}$ in L-Processor $\Rightarrow \mathrm{R_k}$ (Students concept of $\mathrm{Proc}^0\mathrm{k}$)	(10)
$\underline{\mathrm{Ex}}\ \mathrm{M_k}$ (Based on S $\underline{\mathrm{Prog}}$ k) in modelling facility $\Rightarrow \mathrm{R_k}$ (Evidence for (10))	(11)
Evidence of (5) and (6) and (11) is Evidence that concept k is understood provided $\mathrm{R_i}$, $\mathrm{R_j}$ and $\mathrm{R_k}$ form part of a cyclic and consistent mesh so that $\mathrm{R_i}$, $\mathrm{R_j}$ are part of $\mathrm{R_k}$	(12)

nent retention of a concept (Section 2), is the conjoint activity of *DB* and *PB* operations. Evidence for the *understanding* of a topic relation, R_k (the acquisition of a concept $\underline{\text{Proc}}^0$k and a memory Proc^1k, to stabilise it), is stated in Table 5.1. Prior *understanding* of topic relations R_i and R_j is assumed.

5. COMBINING OPERATIONS

Apart from the *DB* and *PB* operation categories, it is proposed that further L^1 procedures exist in any mental repertoire, and they are given the general title "Procedure Combining" (*PC*) operations. These are characterised by the formula

$$PC(\underline{\text{Proc}}^0 p, \underline{\text{Proc}}^0 q) \Rightarrow \underline{\text{Proc}}^0 r.$$

The salient difference between *PB* and *PC* is that the latter (*PC*) does not take a description as one of its arguments whereas the former does so.

The result of applying a *PC* is a program which may, in principle, be compiled and executed (in that sense the "combination" is not arbitrary or haphazard). For example, we might set $p = i$, $q = j$, and $r = k$ to obtain the product of Section 4. On the other hand, there is, in general, no guarantee that the product (though realisable) will either be useful or viable in the sense that it is stabilised in the existing repertoire.

There is no objection to postulating a "description combining" operation also. However, its form is identical with the "description building" operation (*DB*) so that the postulate is redundant; that is, *DB* operations could be renamed as combinatory rather than constructive. The issue at stake is really the existence or non existence of a coupling between what may be described and what may be done (computed, brought about, stabilised) as follows.

Consider a repertoire consisting only of *PC* operations and *DC* (alias *DB*) operations, devoid of *PB* operations. Within such an organisation descriptions are computed from the result of executing some *PC* engendered $\underline{\text{Proc}}^0$; but there is no guarantee that this procedure is either useful or viable (in fact, in the absence of *PB* operations "viable" is ambiguous). Similarly, the *PC* operations generate procedures. Such chains of computation could, and possibly do, go on endlessly. They are reminiscent, at the descriptive level, of the arbitrary reprogramming which Evans (1967) regards as a constituent of dreaming; at the operational level, of trial and error. Without further embellishment, there is no coupling condition of the type "memory" or "understanding". Moreover, I have deliberately refrained from equating the levels of activity to the strata L^1, L^0 of the conversational language, L, for just this reason.

Within L, the L^1 descriptors are of things which can be computed or done or that survive as cyclic structures; either that, or the descriptors are evanescent. L^0 procedures, in turn, do things and may also be described. True, the descriptions may be many stages removed from whatever is described, but they are not just arbitrary burgeonings. In a strict L Conversation, it is only possible to observe (as *understandings* and the transactions that exteriorise *understandings*) mental events of this type.

The flux of activity thus discernible, addressable, and manipulable as part of a P-Individual, is the construct which I have elsewhere called a "language oriented system" (Pask 1970) in sharp contrast to a "taciturn system", developed and amplified in Von Foerster (1971) and Von Foerster and Weston (1974). The distinction still seems apposite; a coupled *DB*, *PB* system is "language oriented" or, to qualify it specifically, "L oriented". The *PC* system is "taciturn" or, to qualify it specifically, "L taciturn".

6. COMMENTS ON THE *PC* OPERATIONS

PC operations are surely required to account for the ubiquitous phenomena of adaptation and probably play an essential part in maintaining cognitive fixity. We conjecture that the *PC* procedures are intimately related to the brain, qua L-Processor rather than the integral cognitive organisations (P-Individuals, for example) which inhabit and are executed in the brain. In its role as an L-Processor, the brain is a matrix (a modular computer) made up from ongoing *PC* operations. A simple model of such an equipment is discussed in Appendix B.

PC operations may be held responsible for all manner of conditioning, chaining, and a certain kind of evolutionary learning; as later, selective evolution based upon weak interaction, generation and recombination rules. Essentially, this is trial and error learning, moderated by constraints prohibiting fatuous constructions that cannot be executed.

According to this view of a brain as a taciturn system (an L-Processor), it makes sense to say "we condition a brain" or that "the brain is observed to adapt". It is also likely that brains engage in more or less continual "trial and error" learning, though we prefer to reserve the word "learning" for phenomena that are deductively based and characteristic of language oriented systems; notably, P-Individuals which inhabit brains and appear in this analysis as collections of *DB* and *PB* operations. From the present perspective, we do not "condition" P-Individuals, but talk to them as L oriented systems, and teach them. Conversely, we do not "teach" a brain.

The taciturn and language oriented varieties of systems obviously interact. But, in an educational context, it does not seem too difficult to distinguish between them. *DB/PB* learning and the understandings to which it gives rise is more efficient, by many orders of magnitude, then *PC* "trial and error learning" (which we do not refer to as "learning" at all). This difference is highlighted by numerous studies. Landa's (1971) data on method learning in language comprehension bears impressive testimony to the distinction. Landa's discussion of what it means to learn a logical principle (that any principle is *interpreted*, for example in language usage) makes the same point, though a different terminology is employed. Again, in Scandura's (1973) work, there is ample evidence of a clearcut demarcation, and (with similar reservations over the difference in terminology) his categories of "rule" and "higher order" rule learning are identifiable as *DB*, *PB* mediated *understandings*.

7. INTERPRETATION IN TERMS OF MACHINE COGNITION AND ABSTRACT SYSTEMS

One advantage of partitioning the L^1 procedure into *DB*, *PB* and *PC* is that the learning predicted by conversation theory can be placed in register with well-known processes in the field of cognitive science.

Various algorithms exist for constructing fresh algorithms as compiled programs. Chang and Lee (1973) present their own algorithms and review the field.

It is probably fair to say that all efficient constructive algorithms rely upon a distinction between two aspects of program construction. On the one hand, a relation is described. On the other hand, a program is constructed from existing routines (perhaps as basic as machine code instructions) that if subsequently executed, will satisfy the relation.

For example, consider the "Monkey, Box and Banana problem" (MBBP), so often quoted in the literature of Artificial Intelligence. The relation described is a relation between the elements or subrelations of the "Monkey, Box and Banana" situation (box position, monkey moves and so on), such that MBBP is solved.

In the context of computers it is legitimate to assume certain prerequisites and invariances which cannot be taken for granted in the field of mental activity; for example, that compiled programs remain as stable entities in machine storage and that a fixed set of primitive operations and order relations is known at the outset. If these assumptions are made explicit, they stand in place of dynamic activities which we, from a psychological stance, introduce as part of the process in order to secure equisignificant invariances. Under this transposition, an efficient constructive algorithm, typified by Chang and Lee (1973), has an outline (Table 5.2) identical with the skeleton of *understanding* given in Table 5.1.

Other (fundamentally different) kinds of program construction are far less efficient if a relation can be described. (They are not simply "less efficient" without qualification; under certain conditions they come into their own.)

Evolutionary construction of the sort predictable in a repertoire filled with *PC* operations has been examined and extensively simulated by Fogel, Owens and Walsh (1966). The compiled programs produced as the result of this construction are finite state machines and their input/output sets are interpreted in an (internal) universe of number sequences under a criterion that is satisfied if the next output states of a machine predict the next number in an arbitrary sequence. This criterion is a synonym for a relation which is satisfied (if the criterion is satisfied), and successful machines are those that yield satisfactory predictions.

Initially, finite state machines are produced by random "mutation". The successful variants in a 1st generation are preserved and

TABLE 5.2

Entry in Table 5.1	Process and Inference	
(1), (2)	Basic routines (in the limit, machine instructions and indexed storage locations) exist	Assumption (A)
(3), (4)	The basic routines can be executed	Assumption (B)
(5), (6)	Operation of the basic routines can be deciphered externally and placed in register with variables describing parts of the problem	Assumption (C)
(7)	*DB* (Functions specifying basic routines) $\Rightarrow$ MBB (Description of MBB Problem computed or externally specified)	Process (I)
(8)	*PB* (Basic routines, MBB) $\Rightarrow$ Compiled MBB Program	Process (II)
(9)	MBB Program is compiled or stable	Assumption (D)
(10)	MBB Program can be executed	Assumption (E)
(11)	Operation of MBB Program can be deciphered and placed in register with MBB problem variables	Assumption (F)

mutated to form a 2nd generation (others being discarded), and so the process continues. However, as soon as a population of machines is in existence, the random "mutation" is replaced by recombination rules for forming fresh machines, and these rather than the mutants are the variants tested against the criterion and recycled. At this stage, the process is open to representation in terms of *PC* operations, if i_1, i_2 ... j_1, j_2 ..., index the machines (alias procedures) in the current generation.

$$PC(\underline{\mathrm{Proc}}^0 i_1, \underline{\mathrm{Proc}}^0 j_1) \rightarrow \underline{\mathrm{Proc}}^0 k_1$$
$$PC(\underline{\mathrm{Proc}}^0 i_2, \underline{\mathrm{Proc}}^0 j_2) \rightarrow \underline{\mathrm{Proc}}^0 k_2$$

The most successful of the $\underline{\mathrm{Proc}}^0 k_1$, $\underline{\mathrm{Proc}}^0 k_2$ ... are selected (together with some $\underline{\mathrm{Proc}}^0 k$ and $\underline{\mathrm{Proc}}^0 j$, if they have equal merit) and are recycled.

The evolutionary paradigm is relatively inefficient (though it gains in flexibility as it loses in efficiency). There are, of course, many heuristically-governed, evolutionary-style, artificial intelligence systems intermediary between the *PC* type and the *DB, PB* type, of which the earliest and one of the most elegant is Selfridge's (1959) Pandemonium.

Such intermediaries are believed to characterise mental as well as machine organisation. However, the crucial *understanding* condition is wholly concerned with *DB, PB*, learning. Similarly, insofar as the stable re-entrant organisation of a P-Individual is a collection of *understandings*, any P-Individual is formulated in terms of *DB/PB* operations (in that sense, it is processor-independent).

8. EXPERIMENTAL POSSIBILITIES DUE TO THE *DB/PB* DISTINCTION

Our original motive for classifying cognitive operations as *DB* and *PB* was to explain the empirical competence profiles of Table 3.13 and recapitulated in Table 5.3. The explication is not entirely straightforward because of an indeterminacy in the object of observation which is said to *be* competent (in particular, to have one or other competence profiles). Similar indeterminacies are believed to hamper most types of educational testing, and the easy way out, consisting of glossing over the mixed characterisation either of competence or properties such as "intelligence quotient" or "specific aptitude scores," seems to produce a good deal of harmful and unnecessary obfuscation. Within reason, the parochial discussion of the competence profiles in Table 5.3 can be generalised to cover the wider field of examination, mental testing, assessment procedures and the like.

8.1. Dual Aspect of Competence or Dual Referants of this Property

According to our theory, at least two subjects of observation can be credited with a competence profile.

(a) Competence is a property of a repertoire of *DB, PB* operations which form a P-Individual in some conversational domain(s). In this case, the competence determines the extent to which this repertoire forms a P-Individual in this particular conversational domain.

(b) Competence is a property of a brain, or more generally, an L-Processor. In this case, the competence determines how certain

TABLE 5.3

A Cluster of Mechanisms Sufficient to Account for the Competence Profiles

	Long *DB* Chain Length High *PB* Efficiency	Long *DB* Chain Length Low *PB* Efficiency	Short *DB* Chain Length High *PB* Efficiency	Short *DB* Chain Length Low *PB* Efficiency
TLC like	*GDB* and *GPB* bias	*GDB* bias	*GPB* bias	Neither bias (*PC*)
GPS like	*LDB* and *LPB* bias	*LDB* bias	*LPB* bias	Neither bias (*PC*)

TLC like = Resembles Quillian's "Teachable Language Comprehender" or de Faivre's "Fuzzy" ("global" paradigm). GPS like = Resembles Ernst, Newell, Shaw and Simon's "General Problem Solver" ("Local" paradigm).

DB and *PB* operations will be executed (supposing they are presented for execution) and even whether or not they can be executed in any way. By hypothesis, the competence of a brain reflects the composition of *PC* operations which are executed in order for the brain (or L-Processor) to act as a computing medium that accommodates *DB* and *PB* procedures.

8.2. Tentative Stipulation of Competence Profiles

The profiles of Chapter 3 (Tables 13, 14, 15) can be reconstructed (Table 5.3) using two parameters of *DB*, *PB* operations; the mean length (ℓ, m, n) of the *DB* chains and the efficiency (speed, numerosity) of *PB* operations. The global/local (row of Table 5.3) distinction is identified with a tendency, on the part of a processor (brain) to execute whatever *DB* or *PB* are presented in a particular fashion. Recalling that *DB*, *PB* (or Procs in general) are, by postulate, compiled Fuzzy Programs, it is clearly not absurd to say that they can, and generally will, be executed differently by different processors. Choosing a plausible distinction, a high adicity processor accepts a Fuzzy Program and computes in parallel, i.e., it runs the program without resolution, each stage in computation resulting in a set of data which is input to the next step. A low adicity processor serialises the computation, so far as possible, by tricks equivalent to the expedient of numerical resolution (for example, selecting a maximum value as representative of an extremum such as the Fuzzy Output from a previous stage in the computation). For biological processors, literal *numerical* resolution is improbable; hence, "tricks equivalent to".

8.3. Interaction

The qualities of competence labelled in Table 5.3 are to some extent separable; the column labels refer chiefly to properties of a program suite, and the row labels refer chiefly to a processor type. But the separation is unrealistic for two reasons; first, insofar as any manifestation of competence involves programs and a processor in which they are undergoing execution, and second, because the processor characterisation is believed to represent a dynamic process (the execution of *PC* operations that maintain the brain as a computing medium able to accept and execute *DB*, *PB* procedures).

From the first, our distinction between 8.1(a) and 8.1(b) is (in any actual experiment) a distinction between ways of looking at the same system; in 8.1(a) as a *language oriented* system, in 8.1(b) as a *taciturn system*. From the second, any actual execution of *DB*, *PB* procedures is likely to influence the *PC* operations which sustain the processor. Moreover, from Section 7, it is believed that intermediary types of operation exist.

8.4. Experimental Situations and Basic Indeterminacy

The conditions that favour observation of the language oriented (or 8.1(a)) aspect of competence reduce the information available about the taciturn system responsible for the 8.1(b) aspect of competence. The converse also applies to conditions which tap the (b) aspect of competence and reduce the information available about the (a) aspect. Between them, these trends introduce a measure of indeterminacy; not so much about the value of competence as an operational and predictive quantity, but in respect of the object manifesting competence. That is, an index of competence is contextually bound.

To see this, notice that the (a) aspect calls for information about *understandings* and that *understandings* are only determinable in a conversation; a Piaget like or Vygotsky like or a Landa like interview; a paired experiment; a peer group discussing a project; or (the case to be examined since it is relatively simple though no more effective) a strict conversation anchored upon a conversational domain and maintained by an operating system. In all such situations, the class of procedures which engender *understanding* is liable to be distributed; it is almost nonsensical to say "who is responsible for that *understanding*? who has it?" In our theory, the class of procedures is a P-Individual (so by definition is the conversation itself), but the problem of distribution besets any theory whatsoever. Due to distribution, the process under scrutiny may not be exclusively accommodated in one brain, and the measurements and observations refer to the entire situation.

Conversely, observations of the (b) aspect of competence (of the brain as a taciturn system) are favoured by approaching the stimulus/response or behaviouristic paradigm as closely as possible. For example, stimulus/response, small item tests, are quite effective instruments. The price paid in the limit is that no *understandings* are observable.

8.5. The Function of Complete and Attenuated Operating Systems

In the microcosm of a strict conversational operating system, these peculiarities are open to analysis, though the operating system itself (CASTE or INTUITION) does no more than an interviewer or the experimenter engaged in teachback (previous monograph). The operating system:

(1) Guarantees that if a student learns in any way about the conversational domain, then his learning amounts to a series of *DB/PB understandings*, so that he may be characterised as a P-Individual in this domain.

(2) It furnishes assistance, by augmenting the student's repertoire and the computing facilities of his brain, qua L-Processor, so that within limits a student can act as a P-Individual in this domain.

Function (1) is sufficiently explained by Table 5.1. To make a convincing case for (2), it is necessary to retrieve the detailed transaction types of the previous monograph, and this is done in Table 1.2.

If the student is versatile (the *DB* and *PB* competence profile of Table 5.3), no assistance is needed, even though it is at hand. If his competence profile is *PB* not *DB* (Table 5.3), then the operating system guided by the entailment structure carries out external *DB* operations that are surrogates for those which could otherwise be executed by the student. If his competence profile is *DB* not *PB* (Table 5.3), then it externally furnishes surrogate *PB* operations. Finally, if the student is neither *DB* nor *PB* (Table 5.3), the operating system literally tells the student what to do (there is some rather shaky evidence for a positive transfer effect).

Now, as external observers, we can quantify the student's competence in a taciturn (8.1(b)) sense insofar as the student does function as a P-Individual only if he receives a (measurable) amount of help from the operating system, that is, to this extent only is it possible to make a firm demarcation between the row categories of Table 5.3 (low and high adicity, *PC*: local and global).

Little can be said of the student column categorised as neither *DB* nor *PB*, since he may or may not act as a P-Individual in the conversational domain.

Students having the *DB* not *PB* competence profile fall quite definitely into holist *GDB* behaviour if they are *PC* characterised as global (high adicity) learners and into serialist *GPB* behaviour if they are *PC* characterised as local (low adicity) learners. The *PB* not *DB* competence profile is similarly dichotomised (*GPB* and *LPB*) in terms of the demonstrative assistance they need in order to satisfy *understanding* (condition 12 of Table 5.1).

Finally, having the competence profile *DB* and *PB*, versatile students are not unambiguously distinguished in terms of *PC* competence since they do not need assistance. These students do exhibit a learning strategy which is either holist or serialist in form, and this suggests that their *PC* competence favours global or local processing. The trouble is that cognitive fixity, which is a predictable consequence of *DB/PB* organisation, would lead on its own account to a clearcut demarcation or distinction in learning strategies, so that the observed dichotomisation of behaviours may be (and probably is) due to this effect rather than a processor bias that renders students only able to learn in one way or the other. These arguments are summarised in Table 5.3 and gain support from the studies of Chapter 2, where the operating system is abraded either by relacing the *understanding* condition, or by withdrawing the potentially available assistance.

To summarise the matter: If the demand for explanation is replaced by a correct response criterion (multiple choice questions), then some students (*DB* not *PB*, on this or other grounds) are liable to "globetrotting" defects which are characteristically either discursive (*GDB*) or normally channeled (*LPB*) while other students are unaffected (*PB* not *DB* or versatile). If the entailment structure is abraded and descriptive data is withdrawn, some students evidence the defect of "improvidence" (*PB* not *DB*, on this or other grounds) but are not as seriously affected. Finally, there are some students (all of those acting like "neither *DB* nor *PB*" in an operating system, perhaps others also) who seem able to learn very little unless given a specific and phased sequence of instructions; in fact, unless they are conditioned by one of the less exciting kinds of behaviour shaping.

9. PARADOXICAL FEATURES OF THE COMPETENCE RESULTS

If the objects of observation in 8.1(a) and 8.1(b) are lumped together, many common observations appear paradoxical. For example, it is queer to remark that a student (the lumped entity) deliberately adopts a mismatched learning strategy, i.e., his disposition does not tally with his competence. But the existence of this divergence is a strong result.

It is equally difficult to comprehend the Jekyl and Hyde demeanour of many students which leads them to learn and think in one way of academic subjects and in another way of the rest (manifest as the curiously strong serialistic disposition induced apparently by institutional training and often running contrary to competence, either in test or practice). The data referenced in Chapter 3 give only a mild mannered expression to the facts which, once aired, turn out to be part of conventional wisdom. These students have not only different styles, dispositions and learning strategies, but different personalities; they live in different realities; they deploy the external data storage in their environment (files, book arrangements, recall cues) quite differently with one persona and the other. Only if they are versatile do they function in each role with comparable efficiency.

Both of these phenomena are marked enough and important enough to take in earnest, and both are paradoxical, unless the convenience of viewing the student as a lumped entity is discarded. Any trenchant explanation must make some distinction akin to 8.1(a) and 8.1(b), and this particular way of carving the cake does at least dispel the air of mystery.

For the student, qua P-Individual is formulated to place connation on a par with cognition; viewed thus, as a language oriented system, he may have a will or disposition to do what he cannot do effectively; further, it is not unreasonable to suppose that more than one P-Individual inhabits the same brain. Regarding the processor which is said to have a certain *PC* competence, it could be just one brain or it could, more realistically, be considered as the total environment encountered in each area of activity, institutional and extra curricular. To a large and significant extent, this environment is structured individually (for example, by arrangements of external data and recall from storage). The processor which is *PC* competent includes all of these structures, as well as the more obvious augmentation provided by masters and peers.

10. ANALOGICAL TRANSFORMATIONS

The *DB* and *PB* and *PC* distinction permits the prediction of mental transformations, involving analogy learning. Recalling the discussion of analogy in Chapter 4, $\underline{\mathrm{Proc}}^0\mathrm{i}$ is a compiled program:

$$\underline{\mathrm{Proc}}^0\mathrm{i} \triangleq \langle \underline{\mathrm{Prog}}\ \mathrm{p}, \underline{\mathrm{Inter}}\ \mathrm{x} \rangle.$$

PB acts upon both components, Prog and Inter, of $\underline{\mathrm{Proc}}^0$.

DB acts upon interpreted relations (sets in some internal universe X, Y, U). Since the distinguishing predicate of an analogy is itself a relation, $\underline{\mathrm{Dist}}(\mathrm{x}, \mathrm{y})$ which is *given externally*, DB may act upon it as one argument and perform a transformation

$$DB(\mathrm{R}_i, \underline{\mathrm{Dist}}(\mathrm{x}, \mathrm{y})) \Rightarrow \mathrm{R}_j = \underline{\mathrm{Ex}}(\underline{\mathrm{Proc}}^0\mathrm{j})$$

where, in the simplest case, *DB* realises isomorphism so that $\mathrm{R}_i \Leftrightarrow \mathrm{R}_j$; that is, if R_i is interpreted in X, its form is copied into Y. At this stage, Prog p in $\underline{\mathrm{Proc}}^0\mathrm{i}$ may be given a different interpretation, that is:

$$PB(\underline{\mathrm{Proc}}^0\mathrm{i}, \mathrm{R}_j) \Rightarrow \underline{\mathrm{Proc}}^0\mathrm{j} = \langle \underline{\mathrm{Prog}}\ \mathrm{p}, \underline{\mathrm{Inter}}\ \mathrm{y} \rangle.$$

Moreover, if $\underline{\mathrm{Dist}}(\mathrm{x}, \mathrm{y})$ is given externally, R_i and R_j need not be isomorphic, providing the type of morphism is properly spelled out.

Conversely, if R_i and R_j are given externally and the analogy relation is said to be an isomorphism by some external agent or specification, it is possible to write a transformation like

$$DB(R_i, R_j) \rightarrow \underline{\mathrm{Dist}}(x, y)$$
$$PB(\underline{\mathrm{Proc}}^0 i, R_j, \underline{\mathrm{Dist}}(x, y)) \Rightarrow \underline{\mathrm{Proc}}^0 j.$$

These transformations may be countenanced within the compass of one P-Individual (generally in any "One-aim-at-once" or "one focus of attention" experiment) because external information is furnished which stipulates that X and Y are distinct universes united by the analogy relation. As a result, distinct compilation and interpretation sets may be reserved in the brain (generally in L-Processor storage), and the computation may go on uniformly, apart from the distinctions thus stipulated. X and Y, so united, have comparable internal representations. In fact, one meaning of P-Individual is a set of processes that are not independent and are able to interact because a dependency exists (equisignificantly stated as "uniform computation" and "synchronicity").

The one-aim-at-once condition is fairly innocuous in the context of learning where what may be known and done is spelled out (in a conversational domain, for example). However, the one-aim-at-once restriction imposes very serious constraints upon the unguided generation of analogy relations (for example, generalisation based analogies) and upon the production of interesting novelty.

11. INNOVATION AND GENERALISATION BASED ANALOGY RELATIONS

Let us focus the discussion upon analogy relations that straddle two or more a-priori-independent universes of compilation and interpretation.

The act of learning as analogy, when the distinguishing predicate $\underline{\mathrm{Dist}}(x, y)$ is externally delineated by information from an entailment structure or any other source, differs fundamentally from the act of creating the analogy relation *de novo*, when the distinguishing predicate is invented. In the previous monograph, without special emphasis upon analogies, this act figured as "predication". Our key point is that learning an analogy can go on in a cognitive system is informationally closed, apart from the specificity injected by way of guidance. The process need involve no more than an application of *DB* and *PB* operations already in the repertoire, and much the same comment applies to other than analogical syntactic derivations; for example, forming new rules or concepts by iterating or combining those that exist.

In contrast, creating an analogy relation between two or more universes calls for the construction of a semantic predicate, Dist(x, y). Any cognitive system able to perform this feat must be informationally open, and the sort of openness considered amounts to the juxtaposition and (partial) coalescence of two (or more) systems which have distinct and a-priori-independent "internal representations" — one a "representation" of X, and one of Y.

This state of affairs is captured in Gergely and Nemeti's argument, as it is sketched in Chapter 4, and this slant upon their argument is developed in Chapter 6. From a psychological point of view, the events in question may be characterised as the juxtaposition and partial coalescence of two or more a priori asynchronous and independent P-Individuals; or as the coexistence and subsequent integration of two or more aim topics; or as a division of attention between two or more topics (whether or not the two foci of attention are externalised and objectified as aim selections).

Before depicting this important process, it will be prudent to press home an already made distinction between "many goal" situations (of the sort encountered in quite ordinary holistic learning) and the very different class of "many aim" situations pertinent to the immediate issue. Subsection 11.1 is a digression intended to serve this purpose; the main line of argument is resumed in Section 11.2.

11.1. Diversity Under One-Aim-at-Once

One characterisation of a serialist student in a strict conversation is that he has an aim topic (his maximal focus of attention, the most distant topic he appreciates) and only *one* goal that he chooses to learn about, the one member of his legitimate workset. In contrast, a holist student appreciates a topic well in advance, he aims for it, and his workset includes several subordinate topics which he has chosen as goals to learn about.

We often cannot (and need not) discriminate the possibilities that a holist student deals with the goal topics simultaneously "in parallel" and the possibility that he scans them in an order of his own choice, usually leaving one topic before it is fully learned, dealing with another, and returning later on to the original. The crucial feature is that in either kind of holism, the topics in work-set are considered in the context of the aim topic and that the exteriorised behaviours are synchronised with respect to aim behaviour and each other. Scanning is just as good a synchronisation as a parallel approach, and there are grounds for believing that apparent simultaneity (even in the case when an analogy R_k is explained by the simultaneous execution of M_i and M_j) is really a complex and probably variable topic scan.

Unequivocally, the serialist's exteriorised behaviour is also synchronised with respect to the aim topic. The behaviour in this case is literally sequential.

Under one aim circumstances, observations are made of one, and only one, P-Individual; for example, using the expedients described in the previous monograph. It will be recalled that a strict conversation (amongst other things, a means for securing one-aim-at-once) is defined as a P-Individual in its own right. Although this P-Individual may have factors that are also P-Individuals, they are synchronised under execution and, in that sense, are dependent. The conversation manifest at an interface is *the* P-Individual actually observed. As before, the locus of *this* P-Individual in the conversational domain is the current aim topic; this is a more precise way of stating the commonplace dictum that a student, qua sentient cognitive system, is located at his focus of attention and is thereby identified.

11.2. Many Aim Systems

It has been argued that nothing essentially novel (or, at any rate, no predicative or semantic novelty) can arise until there are two or more aims (alias two or more a priori asynchronous and independent P-Individuals). In the sequel, it is assumed that the two P-Individuals (which may be executed in one brain or several) address their attention to, and formally aim for, two topics with relations R_i and R_j respectively, which are interpreted in a-priori-independent universes (X and Y, respectively). However, the two P-Individuals are in a position to interact and may wholly or partially coalesce, losing some or all of their independence. A creative act, such as the production of an analogy relation, comes about due to their interaction, and this interaction may be of two different-sounding but essentially similar kinds: (a) By a linguistic exchange, as in Chapter 4, or (b) As the concurrent and interactive execution of procedures in each P-Individual. Of these, (a) is a perspective proper to "language oriented" systems, as distinguished in Section 5, and (b) is a perspective proper to "taciturn" systems.

For conformity with the rest of this chapter, it is desirable to express the joint analogical transformation in the form

$$DB(R_i, R_j) \Rightarrow R_k$$
$$PB(\underline{\text{Proc}}^0 i, \underline{\text{Proc}}^0 j, R_k) \Rightarrow \underline{\text{Proc}}^0 k$$

As it stands, the form is unacceptable, because the *DB* and *PB* operations are defined as acting within one mental repertoire. By edict, R_i and R_j do not, at the instant concerned, have a uniform internal representation. (R_i is interpreted in X and R_j in Y; $\text{Proc}^0 i$ and $\underline{\text{Proc}}^0 j$ operate within repertoires that are, at this stage, still independent.) On the other hand, if interaction can take place (clearly it *can* if the P-Individuals are executed in the same brain, and interaction has been posited anyhow), then the expression is not nonsensical, simply non standard. In order to indicate that transformations of this type do not have the same meaning as the standard *DB* and *PB* transformations, they are distinguished by adjoining an asterisk: thus

$$DB^*(R_i, R_j) \Rightarrow R_k$$
$$PB^*(\underline{\text{Proc}}^0 i, \underline{\text{Proc}}^0 j, R_k) \Rightarrow \underline{\text{Proc}}^0 k$$

Regarded from the language oriented perspective, these expressions represent linguistic transactions whereby one P-Individual is able to describe and manipulate the descriptions and operations used by the other P-Individual, and of course vice versa. The conversation can be realised either by providing a metalanguage to accommodate these transactions or by enriching L so that it can express interpersonal hypotheses as well as hypotheses which refer directly to topics.

From the taciturn perspective, the asterisk marked expressions mean that all operations (*DB*, *PB*, or Proc) are executed, perhaps concurrently, in a distributed L-Processor.