Chapter 7

Innovation and the Operation of THOUGHTSTICKER

1. INTRODUCTION

"Innovation" is used to denote a *process* without commitment to its originality or creative value. Innovation is distinct from learning insofar as it involves the existence of two or more P-Individuals (recognised by the existence of two or more simultaneous aims, or *foci of attention*) that are subsequently coalesced, at the moment of innovation, into one. If the P-Individuals are cognitive organisations in separate human brains, their distinction is in general guaranteed, and their coalescing is signified by an agreement over the common meaning of the topics under discussion. If the P-Individuals are compiled and executed in the same human brain, there is (under propitiously chosen circumstances) an alternation between many aim and one aim behaviours.

1.1. Although the theoretical notions are quite generally applicable, the investigations have so far been confined to the process of course assembly. This limitation is a mixed blessing. On the credit side of the balance, it is possible to recognise configurations in a conversational domain (representing the thesis which is evolving throughout course assembly). On the debit side, there is no means of telling in terms of *content* whether a topic is innovated or recalled. In either case, there is a memory-computation which refers to concepts existing in a repertoire. These concepts are recomputed or reconstructed (like repetitions of the "Indian Ghost" story in Bartlett's (1932) classic study. If the reconstructions are accurate enough, they may constitute recall (of the "Indian

Ghost" story, or equally well of previously known facts).

In terms of content alone, the reconstruction is seldom entirely veridical. It contains fresh elements or fresh combinations of existing elements. On a broader front, consider the "recall" of historical facts (assuming only they are not merely rote learned for repetition, parrot-fashion). Is this recall an innovation or a reconstruction? Does the respondent delve into his repertoire *for the facts* or does he use his repertoire for computing the solution to a historical problem (a gap where some event "must" have occurred, for example, a mode of transport that "must" have existed).

Perhaps the respondent invents a leader because he is told about a movement. Perhaps he recalls "Napolean". Perhaps the respondent "invents" the use of carts and carriages (counterfactually) because the Aztecs were a highly organised civilisation. Perhaps he recalls the passages from Von Hagen (1962) arguing that wheels, though used on children's toys, were never recognised by the Aztecs as mechanically useful. Given that, he may either invent or look up the litter (like a sedan chair) as the conveyance these people must have used. It seems likely that both activities accompany the mental operation, though one or other may be dominant at a particular instant. The whole business of scoring tests and examinations for divergent and convergent thinking is plagued by such ambiguities, which remain so long as content is emphasised.

1.2. From the present point of view, all the mental operations of course assembly are many faceted, and no attempt will be made to distinguish the "recall" of a topic and the "invention" of a topic. Indifference on this score is legitimate until the originality and value of invention come under discussion. Until that juncture the essential distinction is wrought in terms of process alone; whether one focus of attention is involved (which is learning), or whether several foci of attention are involved but coalesced in the process (which is innovation). So far as content is concerned, both learning and innovation have components of recall and invention, often in roughly equal measure.

2. INFORMAL DISCUSSION

If two subject matter experts are engaged in natural language dialogue, expounding a thesis to an interrogator or analyst (as they do during the informal course assembly process described in the first monograph), it is frequently possible to observe incidents that look like innovation and are by hypothesis indicative of innovation.

To illustrate the argument, suppose the thesis bears on the subject matter of energy conversion. Prior to the incident the following configuration exists. One expert is concerned with a subthesis; for example, the notion of heat engines, such as steam engines, that use a temperature difference to harness energy for doing mechanical work. The other expert is concerned with some other subthesis; for example, the "obviously" (to the already knowledgeable) converse case of a refrigerator or a heat pump in which mechanical work is done to maintain a temperature difference. The experts' subtheses generally range over wide and quite different interpretations. For instance, the steam engine subthesis ranges over historical technology, Newcommen and Cawley pumps, Watts mining pumps, marine engines, piston engines in tramp steamers, piston driven railway engines, and Parson's Turbine. The refrigerator subthesis ranges over domestic refrigerators, ice cream carts as improvident users of Freon, ice boxes, and heat exchangers in ecologically desirable dwellings.

It should be evident from these examples that an interpretation means, in this context, a "natural language interpretation". Although it is true that most of the examplars do correspond to an existing or historical actuality, it is certainly not always true that they have the generality they are credited with in the subthesis. For example, though an early Watts steam engine (using atmospheric pressure to drive the piston beam down upon condensing steam) is an instance of steam engines in general, it does not, unless explicated at some depth, illustrate the principles of expansion (piston) engines or the need to employ many stage expansion. Quite possibly, the machine is only mentioned (as a historically existent example of a steam engine) rather than described in sufficient detail to explain what steam engines (this one included) really are. This fact is not at odds with the regulation carried out by the interrogator/analyst to ensure learnability and memorability if the exemplars in question do have a limited explanatory power and are, within the limts of a part of the subthesis, legitimately derived.

2.1. Observable Mechanisms

From time to time, the experts, who ultimately are both anxious to delineate a thesis upon energy conversion, feel impelled to explain one subthesis in terms of the other. This is an empirical fact. The innovation originates in the ensuing interlocution which typically includes the following kinds of transaction between the participants (henceforward called Expert 1 and Expert 2, for Subthesis 1 and Subthesis 2 respectively), all of whom are monitored by and interact with the interrogator/analyst as he makes certain that the learnability/memorability conditions are satisfied.

2.1.1. Expert 1 makes an hypothesis about the explanations and derivations given by Expert 2 of all or some of the topics in Subthesis 2; vice versa, Expert 2 makes a personal hypothesis regarding the explanations and derivations of Expert 1, in respect of Subthesis 1.

2.1.2. On the basis of these hypotheses, Expert 1 builds up the explanations and derivations, he believes Expert 2 would have built up for Subthesis 1, and Expert 2 builds up a similar set of postulated explanations and derivations which he believes Expert 1 would have used in delineating Subthesis 2.

2.1.3. If possible, Expert 1 and Expert 2 reach mutual agreement in respect of their interpretations of each others subtheses: a process involving variations to be discussed in Sections 2.2., 2.3. and 2.5.

Insofar as their endeavour is successful, the experts establish a common meaning (in the sense of Chapter 4, Section 9) which is inscribed as an analogy relation in the thesis; the analogy holding between some or all the topics which make up Subthesis 1 and Subthesis 2.

2.1.3.1. The hypothesis building which is performed in Section 2.1.1. may be, to a greater or lesser extent, accomplished before the interlocution. (This in no way means it does not occur; merely, that our linear account of the matter is oversimplified; taken as conceded throughout.) It *is* performed before the current interlocution whenever, as is mandatory in systematic course assembly, the thesis (and thus its subtheses as parts) is displayed in a developing entailment mesh.

2.1.3.2. The hypothesis building which goes on (Section 2.1.2.) above may also be accomplished to some extent before the current interlocution. It *is* accomplished beforehand insofar as there are mutually agreed parts of the entire thesis. These, if they exist, are inscriptions of a common meaning and are analogy relations strictly between subtheses previously constructed by Expert 1 and by Expert 2, respectively. It is sometimes maintained that previously agreed parts of a thesis (as produced by a course team of experts, for example) constitute areas of consensus. This contention is accepted only if consensus is given the coherence based connotation discussed in Chapter 4, Section 7. If consensus is supposed to mean that Expert 1 and Expert 2 (or the body of experts in the course team) solemnly vote upon the nature and inclusion of topics, we deny that any learnable and memorable thesis can be output in this manner. Even if voting or the like is introduced as a procedure, it is quite artificial (it may serve an administrative purpose, but it does not bear directly upon the process under scrutiny).

2.1.4. The matching operation of Section 2.1.3. is precisely the operation described in Chapter 4, Section 8; namely, a coherence agreement is reached regarding a syntactic topic or set of topics such that all interpretations of the topic (those of Expert 1 and Expert 2 in this case) are isomorphic (semantic agreement between the experts). Generally we also require that the interpretations are represented at this stage in the process as models in a common (though lumped) modelling facility. Either this requirement must be introduced or some other means employed for matching verbal interpretations as isomorphic or not.

2.1.5. Assume, as before, that the experts have subtheses headed by "Heat Engine" (HE) and "Refrigerator or heat pump" (RP) and that matching starts in respect to this head topic. To some numinous person, it is obvious that Expert 1 (heat engines) can see a refrigerator as a kind of heat engine, and vice versa, that Expert

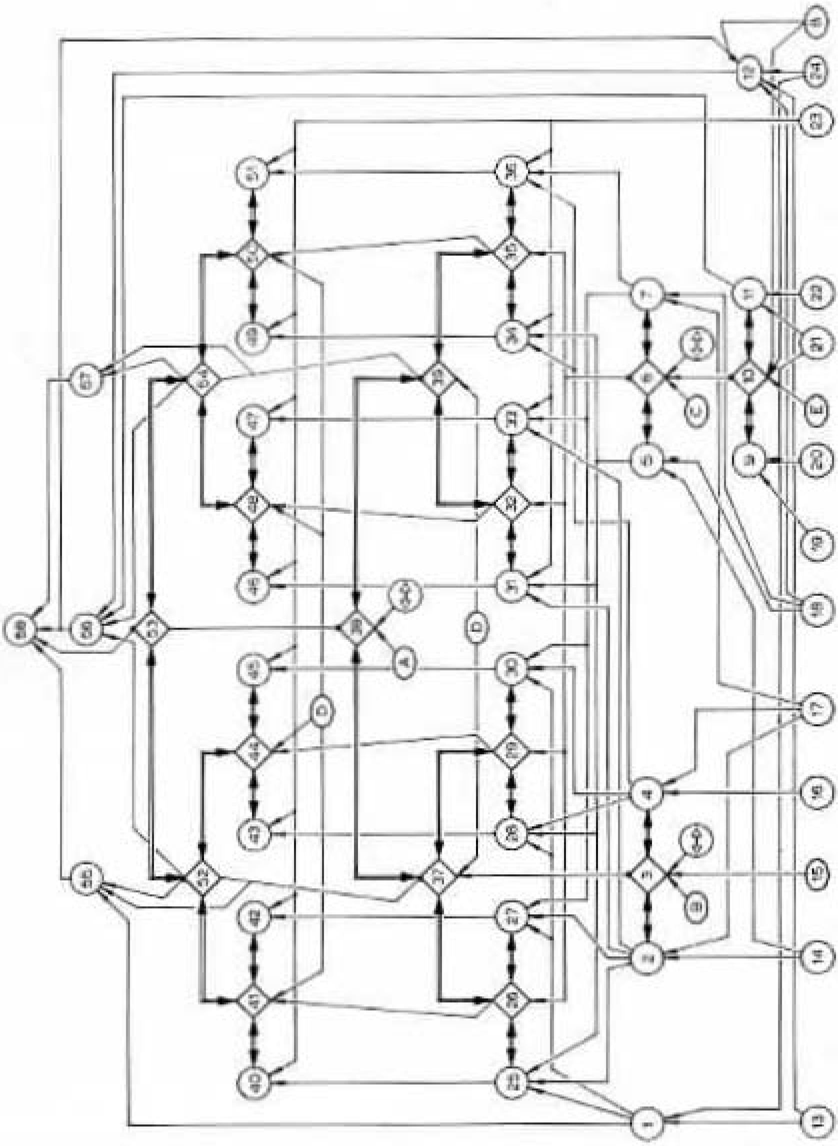

Fig. 7.1. Fragment (between $\frac{1}{2}$ and $\frac{1}{4}$) of a thesis on "Heat Engines". Topics directly concerned with the inversion "temperature difference into mechanical work output" and "mechanical work done to maintain temperature difference" enter thesis chiefly at the analogical relation of node 38 and are not shown. Other topics are listed on the adjacent page with the analogy relation first. The remaining topics are listed in detail apart from the central core (25—36 and 40—51) where they are tabulated under visually clear descriptor values.

Analogies
53, 58: "Temp. Diff. in"/"work out" (left): "Work in"/"Temp. Diff. out" (right)
52, 57, 37, 39, 3: Piston/volume operated cycles (left)
Impeller/turbine operated cycles (right).
41, 44, 48, 50, 28, 29, 32, 35, 6: systems losing working fluid though retaining heat content stored by fluid (left) and systems preserving working fluid (by condensing device or the like) on right.
10: storage on heat in working fluid (left) and storage of mechanical energy (right).
In grouped analogy relations the similarity is identical; the difference depends upon the contexts that are related.

Other Topics
1. Temperature difference/conversion/work done
2. Piston heat exchanger
3. Turbine heat exchanger
5. Working fluid discarded if heat extracted
7. Working fluid in a closed system
8. Degree of organisation
9. Heat storage medium (state change also explained)
11. Storage by inertial medium
12. Temperature as mean kinetic energy and/or level of organisation (potential)
13. Pressure/volume
14. Change of volume/force
15. Cyclic operation
16. Change of pressure/velocity
17. Thermally insulated enclosure
18. Loss
19. Specific/latent/heat
20. Fluid as storage medium (in one state/in liquid/gaseous states)
21. Velocity/force
22. Momentum/mass/inertia
23. Repeated application of energetic transformation
24. Heat (thermal energy)
55. Temperature difference/work output of heat engine
56. Composition of heat pump (refrigerator) with heat engine (possible if energy supplied, impossibility of perpetual motion in mechanical system)
57. Work input/temperature difference output of heat pump
58. Efficiency of a heat engine

Descriptors (determined by an analogical relation): A. "Systems that convert temperature difference into mechanical work" (+) or "work to produce and maintain a temperature difference" (—). B. "Piston Impulsion" (+) "Turbine Impulsion" (—). C. "Lose fluid" (+) "Retain Fluid" (—). D. "Iterated System" (Double or Multiple Expansion) (—) "Simple System" (+). E. "Storage heat" (+) "Storage of Mechanical Energy" (—).

25: A, +; B, +; C, +; D, + (For example, simple steam engine, losing steam)
27: A, +; B, +; C, —; D, + (For example, simple condenser engine)
28: A, +; B, —; C, +; D, + (For example, simple outlet turbine)
30: A, +; B, —; C, —; D, + (For example, simple condensing turbine)
31: A, —; B, +; C, +; D, + (For example, refrigerator losing fluid, e.g., "Freon")
33: A, —; B, +; C, —; D, + (For example, refrigerator with "absorber" fitted)
34: A, —; B, —; C, +; D, + (For example, impelled refrigeration plant)
36: A, —; B, —; C, —; D, + (For example, impelled refrigeration plant recondensing "Freon")

40: A, +; B, +; C, +; D, —
42: A, +; B, +; C, —; D, —
43: A, +; B, —; C, +; D, —
45: A, +; B, —; C, —; D, —
46: A, —; B, +; C, +; D, —
47: A, —; B, +; C, —; D, —
49: A, —; B, —; C, +; D, —
51: A, —; B, —; C, —; D, —

[All the examples as given above, except that engine or heat pump operation is iterated to provide a multiple expansion or multiple compression machine which extracts more heat at given temperature difference for doing work or (within limits) vice versa.]

The "syntactic" descriptor, "depth," is vertical displacement from the head topic 58 (efficiency of a heat engine). Almost any semantic descriptors may be added; for example, "Marine engines" or "Properties of matter" or "Making up for lost heat".

2 can see a heat engine as a kind of refrigerator; the topics are surely not identical, but there is a very substantial isomorphism between their interpretations. However, the joint requirement (imposed by the course assembly system) that a topic is an explanation and not simply a mentioning or classification of named entities means that the analogy relation (referenced as "Heat Exchange Work Cycle" or HWC) has a syntactic or formal component, which represents the similarity between topic HE and topic RP, and a semantic component, representing the difference by virtue of which HE (heat engine) and RP (refrigerator, heat pump) are definitely not *identical.*

2.1.6. The difference component of an analogy relation either is, or is based upon, one or more semantic descriptors which are stipulated and agreed by the experts. The agreement in this respect may be given many different names as an indefinite number of descriptors could be mustered to establish the required distinction. One distinction made by real experts working upon this subject matter was tag named "*converse*" meaning that the following discrimination can be made. "Heat engines use thermal energy available because of a temperature difference to do mechanical work; *conversely* refrigerators or heat pumps use mechanical work in order to maintain a temperature difference between the energy of two different regions (for example, the ice compartment and the room)." This distinction is shown in Fig. 7.1, alongside several others: the distinction "piston/turbine" proper to an analogy "conversion mechanisms" (CM), and "impeller/volume change" proper to an analogy "circulation of the working fluid" (CWF).

Now, although the agreed semantic distinction, or the descriptor on which it is founded, can be chosen from an indefinite number of possibilities, the choise is *not* unrestricted. The chosen descriptor must serve to discriminate the cases HE and RP under whatever the experts have agreed to be the similarity which is shared by HE and RP. In respect of this syntactic agreement the observed instances are divisible into two quite different categories. These categories amount to the *limiting common meaning agreement* of Chapters 4 and 6 (models are placed in register without the need to modify their formal structure) and the *general common meaning agreement* in which models are placed in register as a result of a formal restructuring.

2.1.7. Agreements of the first kind are rare. One of them is shown in Fig. 7.2. The analogy relation (HWC) is supported by a strict isomorphism; in Rapaport's (1972) terms, this is a "mathematical isomorphism". It is modelled by concurrently executing models for HE and RP, each in its own universe of compilation and interpretation, with the proper couplings or correspondes established. It might also be modelled in a distinct (mathematical) universe, but the isomorphism itself (represented in Fig. 7.2 by "⇔") belongs to none of these universes; it belongs to the universe of nodes standing for topics.

This isomorphism is valid but has a limited range of application, which in turn restricts the meaning attached to the semantic distinction labelled "converse". To see this, notice that most experts (including the pair under discussion) would deny the possibility of perpetual motion obtained by running RP to secure the temperature difference required for the operation of HE and running HE to provide the mechanical work simultaneously needed for the operation of RP. If the terms "temperature" and "mechanical work" and "heat energy" which contribute to the meaning of "converse" are firmed up, it becomes evident that this construction is disallowed.

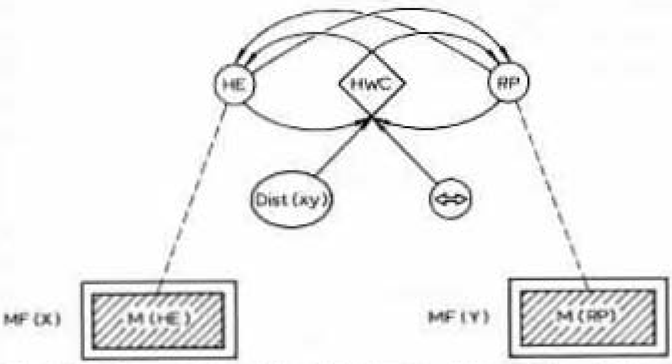

Fig. 7.2. Proposed (and limited) isomorphic analogy between "Heat Engine" (HE) and "Refrigerator Heat Pump" (RP). Models are constructed in distinct and a-priori-independent modelling facilities, *MF*(X) and *MF*(Y). Isomorphism is shown as the operator ⇔. Dist(x, y) is the predicate or set of predicates, distinguishing the universes X and Y.

2.1.8. The other (general) kind of agreement is exemplified by Fig. 7.3, constructed by a different pair of experts. So far as they are concerned the syntactic communality of HE and RP depends upon a construction called "generalised heat work machine" (GHWM), and as the name suggests, this is a generalisation of HE and RP. The most elegant and familiar representation of GHWM is Brillouin's (1953, 1965) information theoretic development of Carnot's cycle. It explicitly involves the notion of "orderliness" of a system (officially negentropy or "disorderliness" for entropy); it also involves the idea of temperature as "noise" perturbing the

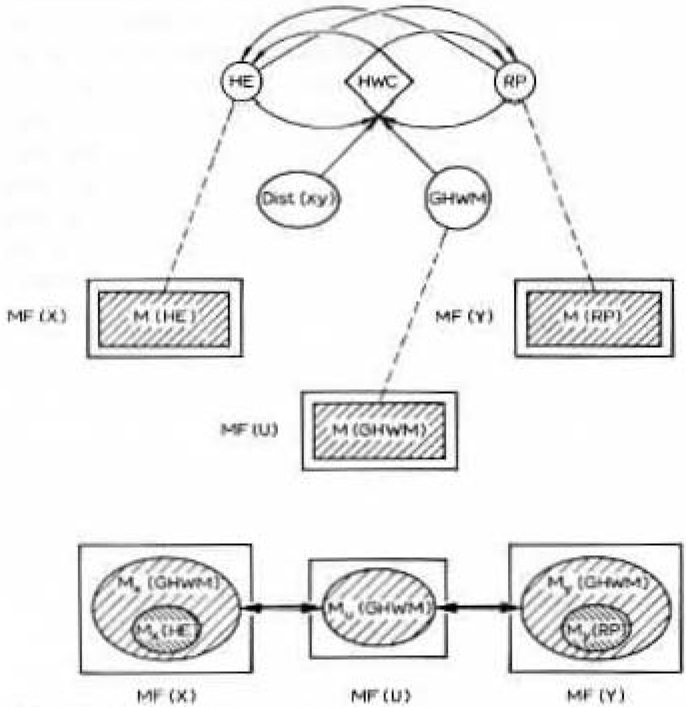

Fig. 7.3. (Above) A generalisation (GHWM) based analogy, connecting topics, HE and RP. Models for all of the topics are constructed in distinct modelling facilities shown as *MF*(X), *MF*(Y), and *MF*(U). (Below) As noted in Chapter 10, a useful material analogy has a further property; namely, specialised model M_x(GHWM) exists in *MF*(X). A specialised model M_y(GHWM) exists in M_Y. M_X(GHWM) and M_Y(GHWM) are isomorphic. M(HE) and M(RP) are not isomorphic, but M(HE) is a subsystem of M_X(GHWM) and M(RP) is a subsystem of M_Y(GHWM).

transmission of negentropy ≙ information; also of temperature difference as a "noise" gradient. Viewed overall, the operation of a reversible GHWM means that a quantity of entropy is transferred over a temperature difference.

GHWM is an entropy exchange system. It can be modelled in a *distinct* universe of compilation and interpretation and appears as a topic (GHWM) in Fig. 7.3 (above); since the interrogator/analyst insists that *if* the analogy relation is supported by a generalisation rather than an isomorphism ⇔, then the generalisation itself is modelled as a topic in a Lumped Modelling Facility. Now, say HE is modelled in *MF*(X), RP is modelled in *MF*(Y), and GHWM is modelled in *MF*(U). The analogy relation HWC depends upon the fact that GHWM (in U) can be specialised as a heat engine to yield GHWM in X or specialised as a refrigerator to yield GHWM in Y, and that HE in X is part of GHWM in X and HE in Y is part of GHWM in Y. For notice, in X, GHWM is not the same as HE, though both are the same kind of system; similarly, GHWM in Y is not the same as RP in Y, though both are the same kind of system. GHWM is both more sophisticated than HE or RP and more generalised. If the symbol ⇒ stands for "restriction under the constraints of a modelling facility," the situation is summarised in Fig. 7.3 (below).

There is an isomorphism between generalised systems, one realised in the universe of HE and one realised in the universe of RP, and the analogy relation HWC between HE and RP hinges upon *this* isomorphism (shown in the diagram). Further, *this* isomorphism is compatible with any meaning ascribed to the semantic distinction "converse" throughout the entire thesis (which ramifies, incidentally, over energy conversion in open systems, such as living organisms and some chemical reactions, as well as topics to do with elementary thermodynamics).

The act of producing HWC (between HE and RP) supported by a generalised topic (GHWM) will be regarded as a paradigm for innovation. The act of recognising that HE and RP are related by an analogy based upon ⇔ is also regarded as a valid innovation, but as the limiting case of innovation.

2.2. Origins of Innovation

Where did the innovation come from? Our hypothesis in the matter was stated in Chapter 4. It is a consequence of the syntactical generative capabilities that are responsible for producing explanations of heat engines (in $\mathcal{L}_1$ for Expert 1) and refrigerators (in $\mathcal{L}_2$ for Expert 2), conjoined with the requirement of establishing isomorphism.

In particular, there is no need to invoke randomness (presumably, randomness could account for anything) as several theorists propose. Nor it it necessary to invoke prior knowledge of special thermodynamic constructs; we have used accepted names like "Carnot's Cycle" for ease of exposition and because this innovation has also been invented (by someone other than Expert 1 and Expert 2). But, as the argument is intended, HWC is not a regurgitation of some previously well-entrenched concept, it is the result of an $\mathcal{L}_1$ and $\mathcal{L}_2$ production sequence. True $\mathcal{L}_1$ and $\mathcal{L}_2$ are relevant to thermodynamics; they are means of generating "thermodynamic" concepts, but we suppose that the production "Carnot's Cycle" was not previously familiar, at any rate in the context of this subject matter.

In short, the innovation arises from an interaction between P-Individuals (here, between Expert 1 and Expert 2) when a common meaning is constructed. If a common meaning is established, then fresh semantic descriptors are agreed between the P-Individuals (here, the distinction "converse"). The common meaning not only produces an isomorphism, HWC, between models interpreted in universes distinguished semantically as having a positive (+) value of "converse" and a negative (−) value of "converse" but also a further syntactical construction, GHWM, which is modelled (as Model GHWM) in a further universe on which the value of "converse" is * (either undetermined or altogether irrelevant).

2.3. Rearrangements and Revisions Due to Innovation

Recall the further learnability/memorability condition imposed by the interrogator/analyst; namely, that any topic which is instated as part of a conversational domain must be such that other than primitive topics used in its derivation can be derived from the topic in question.

2.4. General Qualification

In order to satisfy these conditions, it may be necessary to revise the subordinates of any topic which is introduced. The entire network, at this stage, has only a tentative status and is open to revision (for example, refinement of topic U in Fig. 7.4).

2.5. Innovation as a Catalytic Agent

Innovation of GWHM and HWC leads to two further kinds of mental activity: one kind engenders a fresh innovation which is often subsequently consolidated; the other is a constructive (though not strictly innovative) act called extrapolation.

2.5.1. Given HWC, it is possible to ask "how" or "why" questions based upon the enquiry, "Since there is a refrigerator that uses no moving parts (the absorption refrigerator in Fig. 7.5), is there a steam engine that uses no moving parts which is not currently exhibited?" The reply to this enquiry is either citation of some conjunct of descriptor values that specifies a cell which currently contains no topic or a denial that such a machine exists.

An affirmative reply is countered by the question, "How does the machine you describe work?" (This is answered by an explanation which, the interrogator analyst will insist, is also derived.) Here the initial reply is affirmative (an historically valid exemplar is the Savery Mining pump invented around 1680 or 1690), and the explanation of its operation (sucking water up a shaft due to the condensation of steam) involves the idea of a valvelike device together with alternating vacuum chambers to implement a cyclic hydraulic process. But, we emphasise, the requisite idea could be invented de novo and has been invented by more than one expert unfamiliar with mining history.

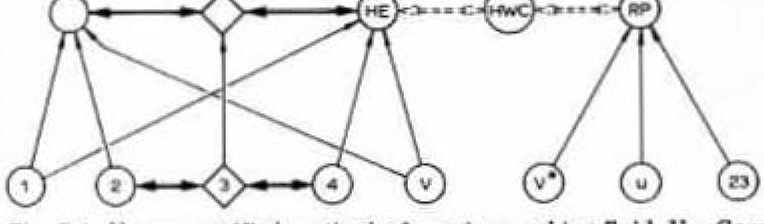

Fig. 7.4. U = unspecified method of moving working fluid. V = Conservation of stored heat (EXPERT 1). V* = Conservation of stored head (EXPERT 2).

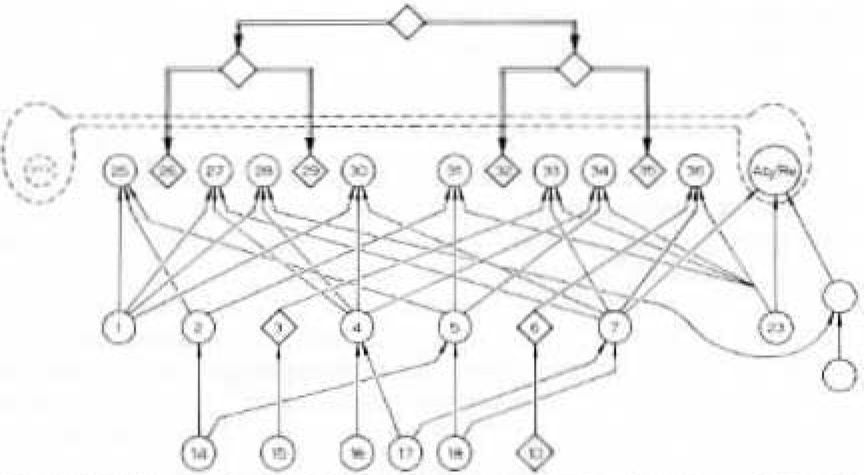

Fig. 7.5. Filling empty descriptor value cells. Proposing derivation of topic to fill empty cell in a descriptor. Since refrigerator Ab/Re has no moving parts, is there any heat engine also having no moving parts? An affirmative reply is possible and one possibility, mentioned in the text, is the Savery and Newcommen mining pump.

A negative reply is countered by the question, "Why not?" This is again answered by an explanation, instated as a topic qualifying all derivations that lead to the analogy. To quote an example culled from later in the thesis, "Since mechanical energy can be converted entirely into heat energy, is there a means for converting heat energy entirely into mechanical energy?" The "why" question emerging from a negative reply to this enquiry is the qualifier, "because there are grades of energy and some irreversible transformations in a closed system". The qualifier refers immediately to the topic "thermal efficiency" which has, at this stage, been introduced and qualifies, either directly or indirectly, nearly all of the topics superordinate in the derivation to GHWM.

2.5.2. These questioning transactions are underpinned by the metatheoretic idea that knowledge is symmetrical; the existence of an isomorphic analogy between two topics implies the existence of isomorphic analogies between symmetrically related topics. Since the proposal is a suggestion or permission rather than a directive, the existence of the companion topic can be denied. Justification of a denial asserts a local complement; namely, a complement with respect to the set of hypothetical symmetrically related topics. The underpinning idea is callled "epistemic symmetry" for reference later (Fig. 7.6).

2.5.3. Call a topic which is reapplied (that is, which makes an appearance in the pruned entailment mesh as the precursor of more than one topic, as in Fig. 7.7) a *principle*. If there is a "principle" it is possible to ask, "What is the result of applying this principle to the freshly constructed topic GWHM?" provided only that the universe of GWHM contains (in the slightly esoteric sense of "may be projected onto") the universe of interpretation of the principle. Similarly, if GWHM is a principle, it is legitimate to ask, "What is the result of applying GWHM to any topic with universe of interpretation that is, or is a projection of, the universe of interpretation of GWHM?"

2.5.4. The idea of generating such (hypothetical) topics, the existence of which may be affirmed or denied by the expert, is called "extrapolation of principles" for later reference.

2.5.5. Extrapolation of principles is illustrated in Fig. 7.8. The principle is composition of thermal or mechanical systems (CS) in order to extract work in several stages (for example, the multiple expansion tramp steamer engine) and is used in the derivation of a topic called "thermal efficiency" (TE).

Extrapolation of this principle (CS) with respect to GHWM proposes the composition of HE with RP; namely, a device, x, that does work in order to maintain a temperature difference and a device, y, that obtains work from this temperature difference. As a first stage construction, this composition is valid though not especially useful. The further composition, whereby y supplies the work to drive device x (and x, as before, provides the temperature difference needed to drive y) is a putative perceptual motion machine. In any veridial thesis (this one included), its existence is denied, and the denial qualifies or augments both the topic "thermal efficiency" (TE) and the topic "reversibility of transformations" (RT).

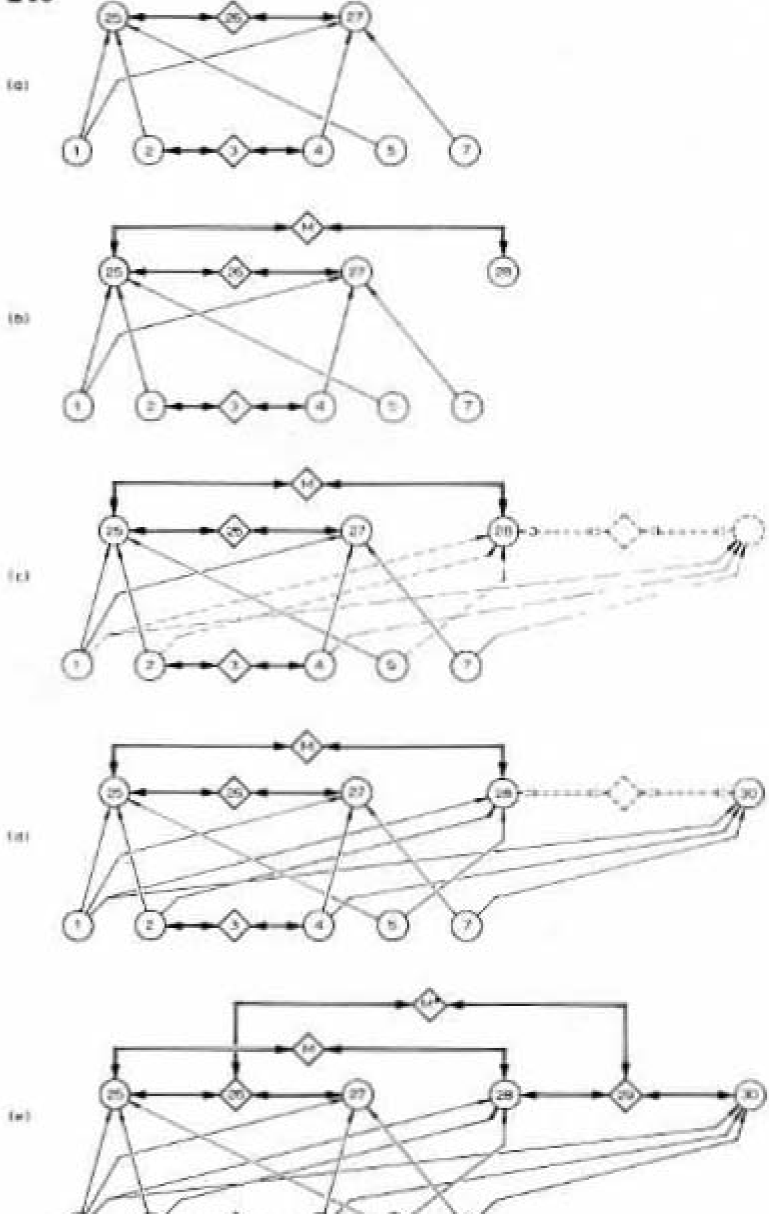

Fig. 7.6. Epistemic Symmetry. (a) Initial condition. (b) Expert builds topic 28 (a turbine which discards all its working fluid) and asserts an analogy relation M between topic 28 and topic 25 (a piston engine that also discards all its working fluid). (c) Analogy instated. (d) By epistemic symmetry substructure and further analogy relation proposed. (e) The proposal instated.

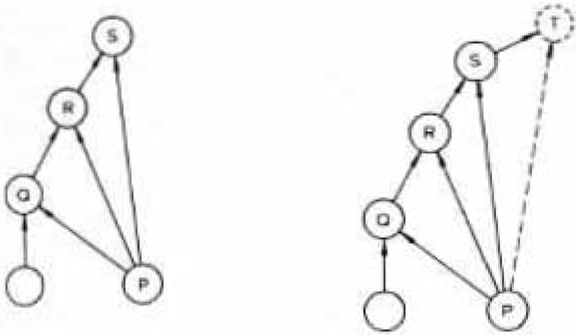

Fig. 7.7. Principles. *Topic* P is used in constructing *topics* Q, R, and S. Thus P is a "Principle".

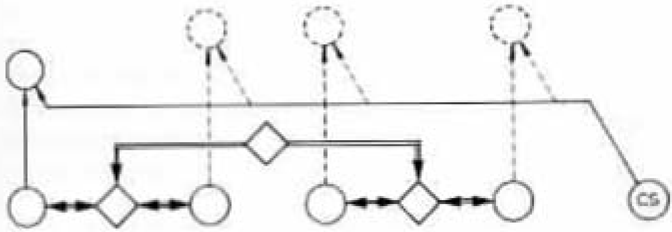

Fig. 7.8. "Extrapolation of Principles".

3. INNOVATION AND COUNTERFACTUALITY

Probably the most powerful and commonly used instrument for major innovation is a combination of extrapolation of principles and the application of epistemic symmetry. Industrial creativity certainly thrives upon this package of operations whether in technical invention (the telephone, the railway, the hovercraft, most semiconductors, the majority of clever chemical syntheses, the television receiver) or in scientific advance (Maxwell's equations, Plank's quantum theory, Einstein's relativity). So, judging from a consensus of commentators, does social innovation. There is little doubt that development in the visual and the dramatic arts stems frequently from this origin.

That is, an extrapolation, E, takes place with respect of a structure rooted in universe X which is analogous to a derivation rooted in universe Y. It is essential to recognise that the constraints upon X (its character as a universe of compilation and interpretation) are determined by the primitive topics in X; similarly, the constraints upon Y are determined by the primitive topics in Y.

If E can be realised or modelled in X (that is, a processor satisfying symmetric) extrapolation, F, is legitimate over Y, and may be realised or modelled in Y, with E isomorph to F.

This may literally be the case (Kirchoff's equations for a resistive network are isomorphic to a packing function for rectangular shapes, applied by March and Steadman (1971) to achitectural design). More often F cannot be modelled in Y, but both E and F belong to a generalisation G (modelled, say, in universe U), and G can be modelled isomorphically in X and Y as well as U (the hovercraft, for example).

However, if neither an isomorphic analogy nor a generalisation based analogy exist, then the construction using extrapolation and epistemic symmetry leads to a counterfactuality which is open to various contextually legitimate interpretations.

3.1. A Case of Counterfactual Inference

A convincing and quickly appreciated example of counterfactuality is given in an elegant construction due to Kallikourdis. It is based upon the well-known "impossible object" shown in Fig. 7.9. This figure may be viewed against many perspectives (for any of which the following comments are quite valid): one of these perspectives is the three-dimensional coordinate geometry of triangles, composed of line segments meeting at points in Euclidean space.

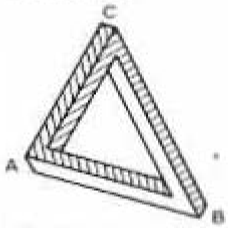

Fig. 7.9. Impossible object (from Penrose, L.S. and R. (1958). "Impossible Objects," *British Journal of Psychology* 49: 31—45).

An entailment structure, E, for a body of knowledge about joining line segments, is on the left hand side of Fig. 7.10 interpreted in a universe X. The structure E comprises nodes 1 to 9 in the entailment structure. The models are shown graphically (to understand the topics it would be necessary to build the explanatory models), and the structure and its primitives a, b, c determine the constraints upon X, i.e., the kind of universe that X is. An extrapolation of E accomodating triangles contains other nodes conjoined, together with E, and called E*.

On the right hand of Fig. 7.10 is a construction, F, for realisable properties of rectangular slabs joined with their faces at right angles. The constructions which can be modelled are shown graphically; and this entailment structure and its primitive topics (A, B, C) determine a universe Y.

The structures E, F, are related by a collection of isomorphisms, shown shaded, carrying lines into blocks, and it may be postulated (since E as we have it determines X, and F as we have it determines Y) that $X \Leftrightarrow Y$, or generally, that X, Y are constructions in three-dimensional Euclidian space; an ordinary and perceptual point of view.

Now consider the following operations. By extrapolation of E in X, a further derivation yields E*. If E* exists, then by epistemic symmetry from E* the "impossible object" (IO) is postulated as an hypothetical "block triangle". Specifically, the hypothesis is that (IO) could be derived from the (internal) analogy or through an extrapolative derivation (both shown dotted). Here is a perceptually obvious form of counterfactuality, since (IO) cannot be so derived unless some or all of the primitives of F are modified, thus altering the character of Y. The price paid for such a modification is that the existing isomorphic analogies between X and Y are falsified.

3.2. Resolutions and Interpretations

(1) Hypothesis (IO) (impossible object) is falsified with respect to the universe $X \Leftrightarrow Y$.

(2) I may imagine the impossible object (since it is perversely derivable), provided my brain is an L-Processor able to accommodate a generalisation G in universe U (such that a model of G exists in X and Y). But I cannot understand (IO), because I cannot

build an explanatory model in a processor that is constrained by $X \Leftrightarrow Y$.

(3) Rephrasing (2), the impossible object is unknowable, though it may be appreciated as an hypothesis.

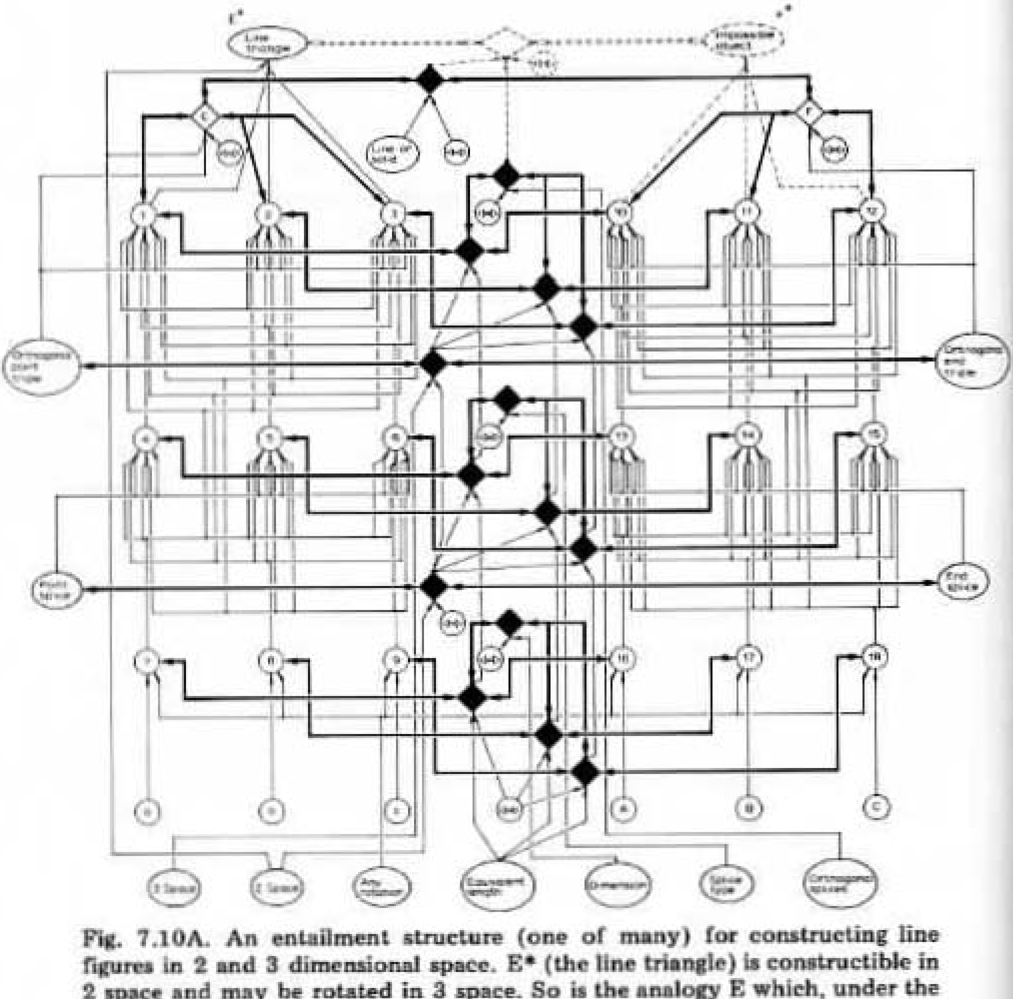

Fig. 7.10A. An entailment structure (one of many) for constructing line figures in 2 and 3 dimensional space. E* (the line triangle) is constructible in 2 space and may be rotated in 3 space. So is the analogy E which, under the distinction between solid rectangles and lines, tallies with the analogy F, realisable in 3 space generally as a discontinuous transformation. However, F* is not constructible as an object. Hence, the "Null" analogy between E* and the "imaginary" or "impossible" F* is denied.

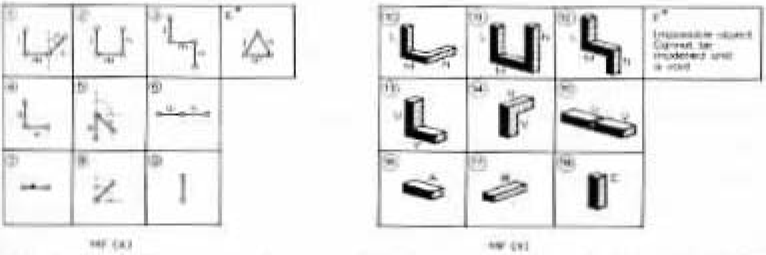

Fig. 7.10B. Representative models in a modelling facility *MF*(X), for line geometry constructions (each figure being rotated), and in a modelling facility *MF*(Y) for assembled and rectangular block geometry: a, b, c = lines; u, v = any pair of a, b, c; ℓ, m, n = any triple of a, b, c. Similarly, A, B, C = rectangular blocks; U, V = any pair of A, B, C; L, M, N = any triple of A, B, C.

(4) Conversely, if my brain is not an L-Processor with the capabilities mooted in (2), then I cannot even imagine the impossible object.

(5) Just as the Necker Cube Illusion (previous monograph) may be perceived as an oscillation between an inward facing and an outward facing image seen at one instant and the next, so the impossible object may be conceived as an oscillation between derivation structures holding tenure at one instant and the next.

If a generalisation G, exists in U to comprehend F* and G*, then this is a hybrid and forms a stable configuration of alternating perspectives.

4. THE INTEGRITY OF P-INDIVIDUALS AND OF PERSPECTIVES

A fresh slant upon the remarks in the last section is obtained by taking in earnest the contention that distinct theses are entertained by different people. The prerequisites for bridging the gap between talk about innovations, illusion figures, etc., and the (present) talk about persons, perspectives, and the like, are as follows:

If the topics in a cyclic and consistent entailment structure (for example, E or F in Fig. 7.10) are realised as a series of concepts and memories compiled and undergoing execution in an L-Processor, then the result is a viable P-Individual; that is, a replicating and stable system of beliefs.

The constraints imposed upon the L-Processor in order that the system shall be compiled are determined by the primitive topics in the entailment structure.

The analogies between two or more entailment structures (each of which contains at least one analogy relation) represent agreements; there are agreements between distinct. P-Individuals, insofar as certain agreements proposed by extrapolation and epistemic symmetry are also counterfactual, giving rise to the denials or instabilities discussed in Section 3.2. Observe that we are at this stage in the discussion taking the verbalisation, "any analogy relation is a petrified agreement," quite seriously; that is, we contemplate its converse, that "an agreement between P-Individuals may be generated by transforming an (appropriate) analogy into the concepts and memories which realise it as dynamic entities". To do so gives substance to the notion that a thesis is necessarily personalised by the person or school of thought originally responsible for its synthesis and exposition.

Now turn to the "pending" remark in Chapter 6, Section 7, where (in the context of "conversation breeding") it was maintained that certain replicative events connected with reaching interpersonal (inter P-Individual) agreement gave rise to generating fresh universes of compilation and interpretation.

The conundrum is, "How can such distinction (α_u, α_v or β_x, β_y) arise inside one L-Processor? "There is no problem if the P-Individuals are associated with spatially distinct L-Processors.

In that connection, recall that the constraints upon an L-Processor, which go alongside distinctions between universes of compilation and interpretation, are determined by the primitive concepts (namely, those corresponding to the primitive topics in a representative entailment structure), and note that such a distinction is not different in kind from the distinction between X and Y, the universes of Section 3.

The situation called the counterfactuality of one thesis in the context of another thesis is precisely the situation which puts teeth into the fission α_u, α_v or β_x, β_y. The characteristic of conversation breeding, "not all agreements (seen as analogy relations if preferred) are possible, " implies the necessity of mooting within one L-Processor (α or β as the case may be) a distinct universe of complication and interpretation; just as the counterfactuality of Section 3 leads either to denial or to the generation of modified universes to accomodate E* and F*, or finally, to a hybrid generalised system G (the "generalisation").

More profoundly, ask why P-Individuals are distinct at all; why people do have definite perspectives, fields of attention, or roles to characterise different replicable systems of beliefs. As a special case, these P-Individuals may be executed in spatially distinct L-Processors with distinct a priori characteristics. In general, the reason is simply that given the characteristics and capabilities of one L-Processor, there are limits imposed by compatibility; that E may be executed with F, or even E* with F, but E* is incompatible with F*, and in any one such system, this extension of the corresponding P-Individual is lethal (unless, of course, G exists to resolve the disparity).

The crunch comes at the point in the argument where topics are to be realised as concepts, and aggregates of topics are to be realised as P-Individuals responsible for generating a thesis containing these topics.

At the moment, the only means of performing this transformation is to ask a student to learn and believe in the thesis. But this is not an end to the matter. As a refinement of this procedure, choose a specially talented kind of student, a professional actor. Ask him to learn and enact and live the part of the progenitor of this thesis. The proposition is not absurd, but it is clear that the actor has greater demands than students have, by and large. He requires not only a thesis specification but a *characterisation*, a personalised thesis. Obviously, such a thing can be provided in principle (authors write plays as well as textbooks), and an embryonic form of characterisation is described in Chapter 10. Moreover in Chapter 11 we set the stage (in one of many ways, perhaps) for the representation of actors, not only of the characters they become.

5. EXPERIMENTAL STUDIES

The phenomena discussed in the previous sections are typical of those reported by other research workers in this field. They also tally quite well with records of introspection on the part of inventors, artists, and mathematicians. Since the examples cited come from a two person situation dedicated to course assembly, a peculiarly "objective" record is left of the "subjective" transformations; namely, the evolving entailment mesh for the entire thesis. Because of that, the innovative process is better controlled than usual and perhaps, as a detrimental side effect, somewhat impoverished. We hypothesise (in line with the construction of Fig. 6.4) that the same processes take place within one human being when he accommodates (or functions as) two P-Individuals, and further propose that a fission of this kind is an invariable concomitant of innovation.

It is natural to ask whether there is an operating system used for course assembly like the EXTEND Program of the previous monograph, in which the innovative phenomena peculiar to one human being can be exteriorised as bits of behaviour. EXTEND itself is inadequate; the one-aim-at-once restriction puts it out of court. There is now an operating system, the THOUGHTSTICKER of Chapter 6, Section 1, in which many aim (and many P-Individual) transactions can take place. Pilot trials show that these transactions do take place, and moreover, are very similar to those described in the informal discussion.

THOUGHTSTICKER serves several purposes. (a) It is a course assembly system and provides realistic aid either to a subject matter expert, in the thoroughgoing sense of somebody well versed in a field, or to an innovator, who is not so knowledgeable, but has a genuine thesis he wishes to develop. (b) The system acts as an "epistemological laboratory". It exteriorises the way in which the expert (under either of these connotations) sets about coming to know. (c) The system is not entirely neutral and embodies not only checking routines but heuristics intended to provoke invention. Hence, THOUGHTSTICKER also has a tutorial function. Insofar as the principles it incorporates are regarded as valid, it teaches the user some of the arts of knowing, thinking, or (maybe, though we are not yet in a position to claim it, positively) innovation.

5.1. Overall Organisation

The basic idea behind THOUGHTSTICKER is as follows. The user makes a model in a modelling facility which consists in several components or subsystems. He sets about the job of delineating and describing a thesis regarding the nature and operation of the model, and thus operates in a course assembly mode with respect to this model or collection of models. This amounts to a *cognitive modelling operation* (as contrasted with the initial *concrete modelling operation*), and in order to exteriorise the process, he is furnished with a *cognitive modelling facility* which we call a *construction grid*. As a result of propounding his thesis about the original concrete model(s) and describing the thesis, he may from time to time be impelled to enlarge the original *concrete model* or to build fresh *concrete models* for topics in the thesis which have no referent. Unlike course assembly, there is no fixed directionality imposed upon the production of concrete and cognitive models; the same description ultimately gives a semantic interpretation to both.

Several embellishments are needed to foster the many aim transactons that are believed to underlie genuine innovation.

There must be disjoint (or many headed) substructures in the developing network of derivations, the thesis representations. Crucially, each substructure must have models that are compiled and interpreted in distinct universes, so that several components are mandatory in the Lumped Modelling Facility. These distinct components will give rise to subtheses that are related by analogical topics with descriptors that act as distinguishing predicates holding the models apart. Moreover, it is necessary to encourage the production of further distinctions of this kind as course assembly (thesis building, cognitive model making) proceeds and as a network is developed on the construction grid.

To accomodate this requirement, it is convenient to specify an initial condition in which there are several disjoint substructures (representing an existing thesis about the original concrete models) to begin with. The concrete model for each substructure exists in a distinct component *MF*(X), *MF*(Y) ... of the Lumped Modelling Facility *MF*. The set of disjoint substructures (henceforward, the *starting set*) is obtained by denuding an existing thesis; that is, by deleting all analogy relations and obscuring descriptors.

This expedient guarantees that the many aim operation is possible and may be exteriorised.

Typically, the user contemplates topics in disjoint substructures of the starting set and instates an analogy relation between them; either one of the analogies removed when the original thesis (unknown to the user) was *denuded* or an entirely different analogy.

In addition, the user may instate topics representing behaviours of models that *he* has built in *MF*(X) or *MF*(Y) over and above the models for topics in the starting set; and, of course, he can establish analogy relations between the fresh topics.

Neither this nor any other (known) expedient will guarantee that many aim operation *does* take place, though we shall later introduce heuristics which *encourage* many aim operation.

In order to perpetuate many aim operation (if it is in vogue), there must be a (practically) indefinite supply of spare modelling facilities which will be indexed *MF*(z); the first z_0 of these are occupied by the models for topics in the initial (disjoint) substructures, and the remainder ($z_{max} - z_0$) are spare modelling facilities mustered as required by the user (once committed, they cease to be spare).

Since many aim operation has the effect of constructing analogy relations between topics that are differently interpreted (and consequently modelled in different *MF*(z) of *MF*), the grid used to represent the thesis has to be laminated. Each lamina, labelled *CG*(0), *CG*(1), ... represents a region of analogy relations (Chapter 2), and the original equipment was reminiscent of a cake stand in an old fashioned tea shop (or maybe a railway station buffet). These points are summarised in Fig. 7.11 which shows the several construction grids (one to each region) as layers with the starting set of substructures in Region 0. This arrangement is inconvenient and the current implementation of THOUGHTSTICKER uses a computer controlled graphic display. However, regions and other structural features are preserved both as visual devices and as part of the (computer embodied) data structure.

To each universe of compilation and interpretation there is a distinct component *MF*(z) (an a-priori-independent processor) which is part of the Lumped Modelling Facility (z_0 of the available components being occupied by concrete models for topics that are parts of the starting substructures). For many purposes where the users *ability* to make a model after the event can be taken for granted, the physical existence of these processors is unimportant, but the logical independence of universes of interpretation is essential and is maintained.

Transformations typical of cognitive modelling, and some concrete modelling also, are shown as A, B, C, D, E, F, in Fig. 7.11. The cognitive model, a developing entailment mesh, is realised by

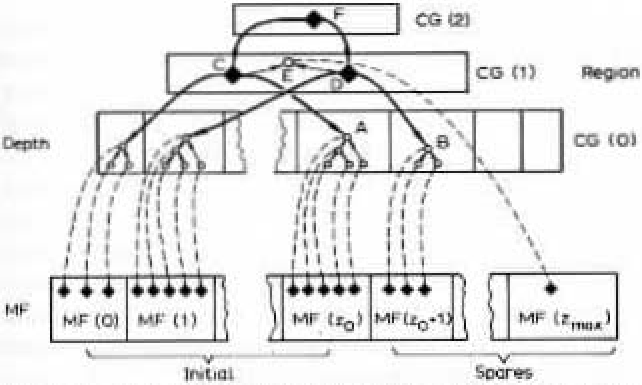

Fig. 7.11. Indication of main features in the construction process. The user has: (i) extrapolated (A) as cognitive model and a concrete model in $MF(z_0)$; (iii) stated a distinct subthesis and the cognitive model (B) with concrete models in $MF(z_0 + 1)$; (iii) has also constructed an analogy relation (C) between topics present at the outset in the starting substructures; and (iv) has made a further analogy (D) between an initial head topic and the head of his novel subthesis. *Topic* (E) is an entailment relation between the analogies (C) and (D) which is modelled in $MF(z_{max})$. Finally, (F) is an analogy relation between the analogy relations (C), (D).

mounting electronic units, which (Chapter 8) stand for topic or analogy relation nodes, on the perspex grids and connecting them together with various links representing simple entailments and analogical dependencies.

Rather simple and visually obvious construction rules apply to the placement and interconnection of the units (these rules are described in Chapter 8). The units themselves contain most of the equipment needed to ensure that the rules are obeyed, and a mechanism for signalling that a unit is either *active* or instated as a node representing a topic.

Apart from this, the main constraint upon the user's construction is as follows: If node i and node j are instated as representing *topic* i and *topic* j, if the user places a unit to represent node k (of *topic* k) on the grid, and if he derives *topic* k (by links or connections) from *topic* i and *topic* j, then he is required to show by construction how *topic* i and *topic* j can be derived from *topic* k (together with other instated topics perhaps). This weak cyclicity condition is checked before instatement is affirmed. * If node k

* As in Chapter 8, more stringent conditions may be used.

represents an analogy relation, then this purely syntactic requirement is modified; instatement depends upon describing the topics related by the analogy so that the descriptor names employed form the distinguishing semantic predicate, Dist, of the proposed analogy relation.

Coexistence of more than one-aim-at-once is signified either by the user stating two (or more) aims under two or more heads (for example, the heads of the disjoint starting structures, which make up one path leading to creation of the analogical transformation C of Fig. 7.11), or by the user marking an existing topic as aim and simultaneously instating a fresh unit. In general, there is more than one aim if there are two or more active markers u, v (either aims or freshly instated units), such that u is not in the entailment set of v (EntSet v) and v is not in the entailment set of u (EntSet u). This condition is quite easily detected, though its occurrence, as noted before, can only be encouraged not guaranteed.

Once the many aim operation is initiated, the resolution of the many aims to form a common meaning agreement (which we believe to be an innovation) is handled by the many person heuristics already discussed in Chapter 6, Section 4 and 5). Here, of course, there is only one user (in general, though THOUGHTSTICKER may be operated with several users also). The trick is to detect a certain kind of many aim situation and to consider the one user with two aims (or more, say, node i and node j) as two P-Individuals (A_1, A_2) or participants $\langle A_1, \alpha \rangle$, $\langle A_2, \alpha \rangle$, such that A_1 aims for node i, and A_2 for node j. The "certain kind" of many aim configuration is a configuration in which there exists distinctive descriptions of node i and node j; that is (as later), the user has assigned descriptors with real (+, —) values on *topic* i which have * (irrelevant) value on *topic* j, and vice versa, has assigned descriptors with real (+, —) values on *topic* j that have * (irrelevant) value on *topic* i. Under these circumstances, if node i and node j are aims, the user, regarded as $\langle A_1, \alpha \rangle$, $\langle A_2, \alpha \rangle$, is in the position of the participants $\langle A_1, \alpha \rangle$, $\langle A_2, \beta \rangle$ of Chapter 6. The user can be asked to agree about the disparity "with himself" or to reach agreement between "his own perspectives" (A_1, A_2) by the exchange grid process, i.e., to adjust the descriptors so that they come into accord (Chapter 6).

Such an agreement, if reached, is a resolution; in practice, resolution is achieved by instating an analogy relation between *topic* i and *topic* j together with additional descriptors having *values* (+, −) of *topic* i and *topic* j, the *names* of which are the distinguishing predicate Dist of the analogy relation. This newly created analogy relation is, as stressed often, the ossification of an agreement, an inscription in the mesh of a resolution act.

If no agreement is possible, the the result of disagreement is inscribed as a conditional analogy (a special kind of analogy denial which represents the coexistence in the same mesh of rival and, at the moment, incompatible subtheses).

Since there is only one mesh and it is accessible to A_1 and A_2 (both A_1 and A_2 are executed in the same brain, α), there is no point in duplicating the representation. We cannot exteriorise and capture all of the agreement process. However, much of it is captured in the revision of descriptor values, the production of a fresh analogy relation, and the addition of descriptor(s) (like those produced in the "exchange grid" process of Chapter 6) which form its distinguishing predicate(s). But, just as we cannot *guarantee* many aim operation, neither can we guarantee distinctive descriptions; only encourage them.

Thus, the heuristic embodied in THOUGHTSTICKER (henceforward the B heuristic) is many faceted. For each node instated, B must require a cyclic derivation and check it. B must pick up some one aim situations and elicit descriptions; it must pick up many aim situations and encourage resolution to yield further descriptions; it must incite the user to many aim operation.

The B heuristic is governed by an executive that continually checks these conditions shown in Fig. 7.12 and sets the proper routines in motion. If there is no aim, it musters routines to procure an aim; if there is only one aim, it musters routines to procure many aim operation. If several aims exist, each one of them is interpreted as the aim of a distinct participant, and resolution is tantamount to agreement between these "participants".

5.2. Data Bank

Quite possibly, the arrangements so far outlined (and refined in the sequel) would serve the purposes of a genuine subject matter expert who has a thesis firmly in mind. If not (and even for the

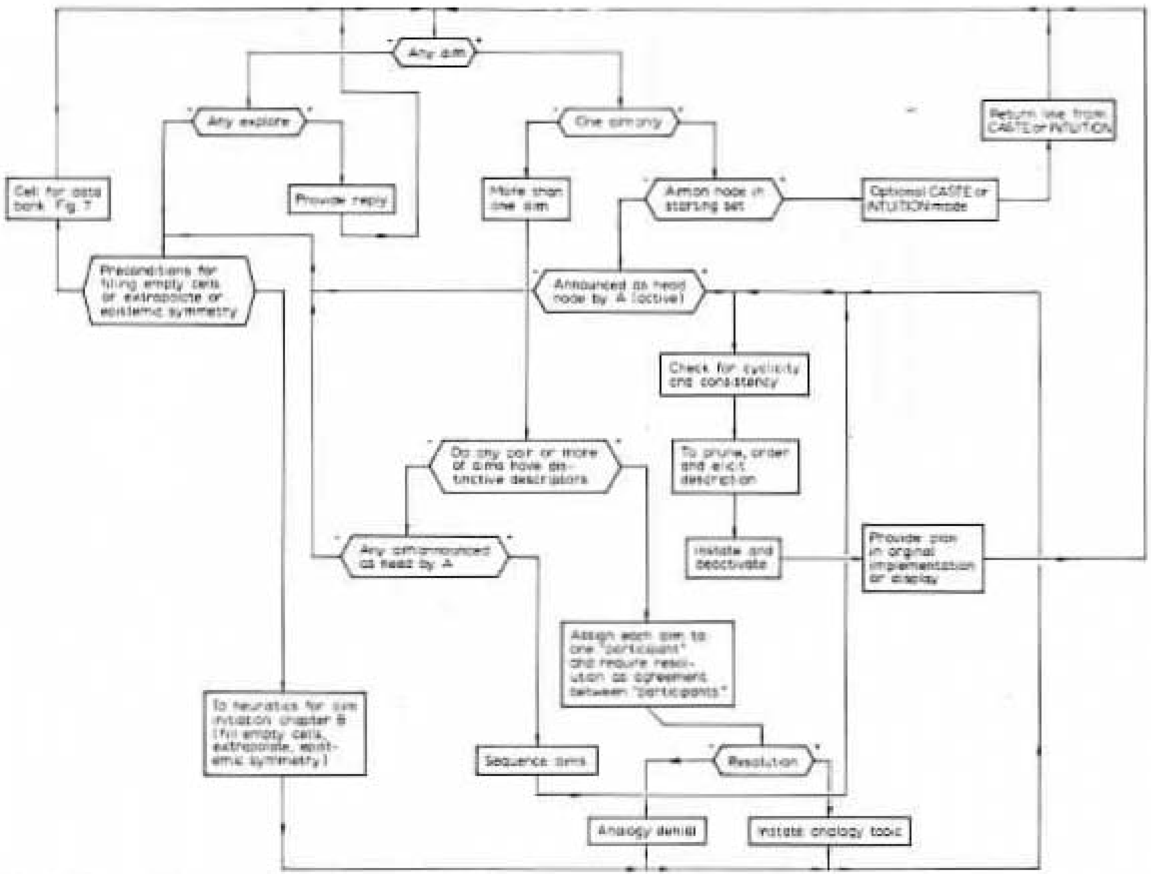

Fig. 7.12. Outline of operating cycle or executive routine.

majority of titular subject matter experts), it is necessary to augment the system by a forcing input of information over and above the information obtainable by executing the original set of concrete models (those attached to the starting set of substructures).

The augmentation is not so peripheral as it seems to be and soon comes into focus as an essential feature of THOUGHTSTICKER. In practice, the forcing input is provided from a data bank, and the data bank consists in an arbitrarily indexed set of computer controlled channels each able to act as a source of information. Channels in the data bank can either be explored (using explore transactions), or failing any activity on the part of a user, information is automatically delivered after an appropriate delay by a scanning routine that is designed to maximise novelty and also revisit channels in which the user has previously shown an interest. At this stage, the channel indices do not form part of the description scheme proper; they are tag names having no semantic interpretation. The information conveyed may even be irrelevant to the user's thesis (though relevance is desirable). If the data channels are relevant, then they become described in due course by the user in his own terms, and this personal meaning replaces the initially assigned index names.

It is often possible to choose the channels so that they have a sensible chance of relevance. For example, THOUGHTSTICKER may operate in the environment of *energy conservation*. If so the starting set of substructures is obtained by denuding the entailment structure of Fig. 7.1, i.e. by removing analogy relations and eliminating the semantic descriptors. Under these conditions, it makes sense to specify data channels as the packs of exemplary material available to a student through explore transactions in a *standard* operating system (CASTE or INTUITION). But it is important to notice that the relevance of this material and the semantic interpretation of the energy conservation topics belong to some other subject matter expert, not a user of THOUGHTSTICKER. Just as the user can piece together the Spartan minded fragments of the original thesis as he likes (by constructing analogy relations between some of them), so also, he may give an entirely different semantic interpretation to the topics (and thus use different descriptions and assign their values as he likes).

5.3. Description Eliciting

Whatever entailment mesh the user builds up on the construction grids as his cognitive model, its topics must be described. The description eliciting routine, discussed in Chapter 2, is used for this purpose (the ordering of the grid laminae to correspond to analogical depth). It is augmented by one additional trick: the *channels* are treated on a par with topics, insofar as any descriptor specified on the topics in the mesh is also assigned values over the set of channels in the data bank.

In order to display the description to the user, each locus in the construction grid (Fig. 7.11) is associated with a pair of light emitting diodes (LEDs) one red and the other green. These are used by the B heuristic to convey information to the user about the values he has previously assigned to descriptors or logical combinations of descriptors (subsets of descriptor values). Further, each cell in the construction grid (Fig. 7.11) is allocated one "attention lamp". The attention lamps are used by the B heuristic for proposing constructions. They are employed in particular as pointers in transactions which encourage many aim operation (based on "epistemic symmetry" and "extrapolation of principles," the gambits exemplified in Section 2).

5.4. Tidying Up the Cognitive Model or Mesh

Suppose the users have somehow been spurred into constructive activity, that he builds up a mesh or network (as a cognitive model) on the construction grids. It is fairly evident that the whole thing is liable to degenerate into an appalling mess. Enforcing the discipline needed to avoid this result would be certain to inhibit free use of the facilities. That, in turn, defeats the object of the system, which is to exteriorise such subtle and transient mental operations as "entertaining several perspectives" (tagged by several aims) and "resolving the differences of perspective by common meaning agreement". The problem is significant, if only because the discipline required to obtain an ordered mesh which can be input to the description eliciting routine of Chapter 2, is very stringent.

5.5. Cycle of Operations

The tidying up operations needed to keep order are simply a combination, in sequence, of the pruning, ordering and depth numbering routines of Chapter 2, executed with respect to any head node specified at a point of resolution. These programs are executed as part of the cycle outlined in Fig. 7.12 (the executive routine).

Using the older implementation with physically distinct construction grids, it is only possible to output a plan of the revised and sorted entailment mesh. The user is required to follow this plan, dismantle his construction, and rearrange it. The recently implemented system performs this chore (within limits) on the user's behalf and displays the result.