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DECISION: FOUNDATION AND PRACTICE

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Decision: (L. decidere) A cutting away, a separation, the making of a distinction.

"Human knowledge and human power meet in one; for where the cause is not known the effect cannot be produced. Nature to be commanded must be obeyed; and that which in contemplation is as the cause is in operation as the rule" (Bacon, Novum Organum Book 1, III)

Contents

1 PREAMBLE

In these notes I have attempted to bring together in uneasy synthesis several strands of my own studies. They are confluent but it would be premature to present them as an integral whole. They are best regarded scaffolding for an architecture of decision - taken with other contributions and the discussion of this conference, they may yield further glimpses of the structures for which we are all striving.

The key points made here are:

1.1 Foundational

(1.1.1) That the problems of a science of decision are truly foundational and impinge strongly on the foundational problems of a range of other sciences.

(1.1.2) That different approaches and answers to the problems are not only possible but also vital to progress. There is no unitary foundation for a theory of decision and the differing pre-suppositions of disparate approaches each generate their own dialectical tensions that lead to the synthesis of key theories.

(1.1.3) Attempts to reduce the variety of approaches to a unified theory are essentially doomed to failure, and yet are not to be discouraged since they themselves reflect important preceonceptions at a meta-theoretic level that are a further important source of conflict and progress.

1.2 Practical

(1.2.1) The significance of the advent of low-cost digital computers providing through interactive graphic interfaces the capabilities of "man-machine symbiosis" and the "amplification of intelligence" is of fundamental importance to the development of decision theories and systems.

(1.2.2) Popper's "3 worlds" model is very useful in determining the essential role of the computer. It provides a new dynamic for world 3 (the world of statements in themselves, of books and libraries) just as did steam, internal combustion and jet engines for world 1 (the world of physical objects).

(1.2.3) Man-machine symbiosis will only come to fruition when all the factors are right, technological, psychological and conceptual. The next few years will see the technology required become available in primitive, but usable, form. The concepts necessary are currently only in nascent form and their development cannot take place except through actual experimentation and experience.

1.3 Technical

(1.3.1) Klir's "epistemological hierarchy", of "source", "data", "generative", "structure" and "meta", systems provides a useful framework in which to anaiyse the onotological pre-suppositions necessary to decision systems.

(1.3.2) The epistemological problem can thereafter be 'solved' in a very general sense in terms of an "admissible space" of models derived from orderings of complexity on models and approximation on the relation between models and data.

(1.3.3) Analogy between systems may be analysed formally in a category-theoretic framework. This analysis may be used to allow new systems to be explored by analogy with known systems.

(1.3.4) The Wittgensteinian argument that if I know something then I know all its consequences is false psychologically. The computer, however, as a "consequence-generator" is a tool to provide this facility - to make us aware of the consequences of our pre-suppositions, axioms and hypotheses. In this sense computer systems can provide 'completion' of the human thought process.

(1.3.5) The concept of a 'database' may be generalized to include a very wide class of systems for the acquisition, storage and manipulation of information. The role of a database in man-machine symbiosis is to provide a "possible world" simulation from which to derive consequences of actions.

2 FOUNDATIONS

The study of decision is central to systems technology in that it requires foundational access to all the key system sciences: sociology, psychology, linguistics, philosophy, computation, statistics, logic,..... Not only is each of these individual sciences stretched to its limits through the requirements of the study of decision, but also the inter-disciplinary combinations required generate what are effectively new sciences such as computational logic, philosophical linguistics, artificial intelligence, and so on.

The key significance of decision is that it involves action and hence also interaction with the world, with an environment. This is why I term the study of decision a "systems technology" - the circumstantial purification possible (and necessary) in a science becomes clearly artificial in the context of decision. 'Pure decision' is a myth in practice and a syntactic contrivance in theory - we decide only in order to act - we do not know what it is to make a decision except as we may see it lead to action, and we evaluate that decision in terms of its effects on action, and the effects of action on the world.

This key role played by action and its evaluation means that concepts of value are intrinsic to decision and its study. If we are not concerned about the outcomes of action then we have no basis for decision. The minimum structure with which we can express our concern is at least some relation of preference, forcing the display of some degree of committment. Neutrality is inconsistent with decision.

Having commenced with a polemic that emphasizes the central role of decision as a systems technology, I will now switch to the converse view that emphasizes the foundational role of decision at the heart of all the sciences. We cannot have knowledge acquisition without decision. There is the decision to make a distinction and define a domain about which to acquire information. There is the decision to use certain observational methods and terminology. There is the decision to use certain bases of explanation. There is the decision that a particular explanation best fits the observations. There is the decision that further data gathering is necessary to secure agreement as to the explanation.

And so on. Decision is at the heart of every science and decisions have to be made at every stage in the generation of the knowledge that is that science. Yet these decisions are outside the sciences that they generate. They form a meta-science with its own structure of decisions. And so on ad infinitum. We have iteration, recursion, and also paradox in that what appeared to be the foundations of decision also have decision at their foundations.

If this line of argument is accepted what conclusions may we draw ? Certainly that no single-aspect, or single-level approach to the study of decision can possibly capture more than a small part of its overall complexity and dynamics. Also that a unified model of decision is impossible in a strict sense since we have essential circularity - to study decision we have to break into a dynamic process of which the study itself is part - the only possible model of decision is decision itself.

2.1 Three Positions

The argument becomes most pointed if we summarize it in terms of the "rule of natural numbers" - that zero, one and infinity are the only numbers that can arise in nature. All three possibilities have been proposed in terms of models of decision:

[ZERO] There is no foundation for decision.

This has been the sceptical position throughout the ages, leading in its most extreme forms to total nihilism. The first clear statement of nihilist scepticism is attributed to Gorgias, but probably pre-dating him and many times re-discovered. Gorgias held:

(1) Nothing exists;

(2) Even if something did exist it could not be known;

(3) Even if were known this knowledge could not be communicated.

Hume is the best-known proponent of scepticism in recent times but new defences of the position are being published to the present day (Unger 1975). The clearest, and most convincing, statement of the sceptical position is still that of the Roman philosopher Sextus Empiricus in his "Outlines of Pyrrhonism" (trans. Bury 1933), who discusses a form of non-nihilist scepticism originating with Pyrrho of Ellis but substantially developed by many subsequent philosophers into a methodology of thought and decision based on the "suspension of judgement". Pyrrhonists based their suspension on some 10 rules which seem fresh and cogent today, e.g. the necessary of regression ad infinitum in any form of explanation not based on dogmatism.

It is easy to dismiss the [ZERO] hypothesis as being absurd and offensive to common-sense - Hume has often been villified but never answered:

"To refute him has been, ever since he wrote, a favourite pastime among metaphysicians. For my part, I find none of their refutations convincing; nevertheless, I cannot but hope that something less sceptical than Hume's system may be discoverable." (Russell 1946 Ch.XVII)

"I found Hume's refutation of inductive inference clear and conclusive." (Popper 1963 Ch.1 IV)

Popper's reply to Hume is based not on answer but acceptance - he re-establishes an empiricist epistemology on the possibility of "laws" being falsified but accepts the Humean position that they cannot be verified:

"we must regard all laws or theories as hypothetical or conjectural; that is, as guesses" (Popper 1972 Ch.1 6.)

Popper's reply exemplifies the dialectical significance of scepticism. Whilst the sceptical position itself it seems to offer only disillusionment, that we:

"sit down in forlorn Scepticism" because we have departed "from sense and instinct to follow the light of a superior Principle" and "a thousand scruples spring up in our minds concerning those things which before we seemed fully to comprehend" (Berkeley 1710 1.)

and Russell terms Hume's scepticism:

"the bankruptcy of eighteenth century reasonableness" (Russell 1946 p.645)

- it is, however, this same dissolution of illusion, the ripping of the veil of maya, the dynamic bankruptcy that leaves us with all false currency spent and only new beginnings before us, that is the vital force of scepticism as a genesis for knowledge.

Popper answered scepticism with a new basis for the acquisition of knowledge. Descartes re-discovered scepticism as the tool of ultimate doubt that removes all but the essence of reality. Sartre continues in the Cartesian tradition with his emphasis on "neantisation" (usually translated as "nihilation") as the force behind the transcendent upsurge of consciousness that makes knowledge possible. As Catalano remarks in his commentary on "L'Etre et Neant" (Satre 1943):

"when I ask, 'What is a tree ?' I remove, or negate, the tree from the totality of nature in order to question it as a distinct entity. Also, when I question the nature of a tree, I must have a certain 'distance' within myself that allows the tree to reveal itself to me. It is this 'nothingness' within myself that both separates the tree as this thing within nature and allows me to be aware of the tree. It is this break with a causal series, which would tie being in with being in a fullness of being, that is the nothingness within man and the source of nothingness within the world." (Catalano 1974 p.66)

I could develop and exemplify this line of argument further but enough has been said here to illustrate the role of what Margaret Wiley (1966) has termed "Creative Scepticism" (and illustrates with literary examples as well as those from Eastern and Western philosophy). It is not the nihilist scepticism of Gorgias that became the dogmatic scepticism of later many later philosphers - this is self-defeating because the positive affirmation of non-existence is itself subject to scepticism. It is rather the Pyrrhonism propounded by Sextus Empiricus that suspends belief, searches out opposites, quests for truth through balance rather than dogma, and holds the manner of quest itself subject to doubt at the very moment that truth appears to have been found.

In practical decision-making the [ZERO] hypothesis has a key role in allowing us to break out of self-consistent systems that somehow do not work or, more insidiously, that do work but not as well as they could. In general it is the "tried and trusted" rule which generates the biggest explosion of novelty under the fuse of doubt - it is the "strong point" of an argument that yields most under a sceptical attack. We should doubt that which we find most efficacious, and disbelieve that which seems most obvious.

In this day and age Kuhn's (1970) "normal science" proceeds at such a rapid pace that the consequences of an argument, its verification through a wealth of exemplars, and its practical utilization through implementation in systems, are as good as over once begun. We consolidate innovation to form dogma at a pace that allows little scope for contemplative imagination - the circle is no longer open than it is complete again. With the advent of the computer this tendency becomes amplified since computers are generally programmed to be the ultimate dogmatist, propounding incessantly and without variation those dogmas that have been set into them through software. Bremmerman, Rogson and Salaff

(1965) has shown that the fortuitous processes of evolution cannot be used to break out of such algorithmic dogma. It is active scepticism that must, in Popper's words:

"replace routine more and more by a critical approach" (Popper 1974a)

and somehow we have to find ways to embed it in our decision-making systems.

[ONE] There is <u>one</u> correct foundation for decision.

The [ONE] hypothesis has its dynamics and its dangers fully equal to those of [ZERO]. The great significance of existence hypotheses and existence proofs and the key role they play in mathematics is always something of a surprise to those who meet it for the first time. To go from knowing nothing about A to knowing that A exists may seem a very small step on the path to those who wish to know what A actually <u>is</u>. However, an existence proof is often sufficient in its own right to lead to a derivation of the properties of A and even a construction of A itself.

The line of argument involved is of the form:

(i) A exists.

(ii) Any A must P.

(iii) B does P.

(iv) No other entity does P.

(v) Hence B is A.

It is interesting to note that the obvious temptation to put this into symbolic logic in the form of the classical predicate calculus must be resisted. This is because step (ii) is not adequately captured by the statement:

(ii') $\forall A\ P(A)$

since we have the standard result:

$$\forall A\ P(A) \supset \exists A\ P(A)$$

that is, (ii') pre-supposes (i), whereas (ii) itself is intended to be independent of the truth of (i). We can state that "all unicorns have horns" without having claimed that "a unicorn exists". It is clearly desirable that this pattern of reasoning be adequately formalized, and Schock (1968) has given a very clear exposition of the problems involved and some of the solutions developed. The incapacity to express arguments about existence is one of the major defects of the classical predicate calculus.

Returning to the argument sequence stated above, we can see that its significance lies in the fact that given only that A exists, and that A has the property P, we may find out under some circumstances precisely what A actually is. Somehow the necessity of existence of A has generated a complete ontology of A. The danger is that a false hypothesis of existence can lead through a weak and obvious property to a strong ontological result. The strength of such fallacious reasoning is that the existence hypothesis itself appears to have little content - certainly too little to be responsible for that of the result derived from it.

The classic example of the mis-application of the argument above is:

(I) There esists a largest positive integer.

(II) The square of any integer is greater than or equal to it. The square of the largest integer cannot be greater than it so that it must be equal to it.

(III) 1 squared equals 1.

(IV) No other positive integer squared equals itself.

(V) Hence the largest positive integer is 1.

Only the first step, (I) the existence hypothesis, is false in this line of argument. From the supposition that a largest positive integer exists we have managed to determine precisely what it must be.

Note also the key role of step (iv). In the example given step (IV) may be proved explicitly. However the [ONE] hypothesis gives us both existence and unicity without any further requirement for proof - steps (i) and (iv) in the argument are available for free. Essentially, the [ONE] hypothesis says that if we can find an agreed property that A must have to be called A and we can then find an actual entity B that has that property, then there is no need to perform any further tests of B to verify that it is A, not any need to look for alternatives to B to falsify that it is A. Without further activity we may say that B necessarily is A.

The [ONE] pre-supposition often turns up in technical literature as an assumption of the existence of a <u>unique optimum solution</u> to a problem, e.g. "We will determine the best linear classifier in this decision space". There may be no such best entity because the decision criterion cannot be uniformly satisfied, and even if there is one it may not be unique. These various possibilities show up as an ambiguity in the use of the word "optimum":

Def: Opt1 - an optimum solution is one such that no other is better;

Def: Opt2 - an optimum solution is one that is better than all others;

Def: Opt3 - an optimum solution is one that is better or equal to any other.

The three definitions coincide under conditions of unicity but not necessarily otherwise. To differentiate between them we have to enlarge our vocabulary and call Opt1 "admissible" (Gaines 1977) rather than optimum - the key factor being that the non-existence of better solutions may be due to incomparability. Opt2 would be called a "unique optimum", leaving Opt3 as the correct precisiation of "optimum" (reading "correct" here as "agreed by convention" since any of these definitions may be taken as precisifying the colloquial term "optimum").

In the control literature lack of appreciation of these distinctions has several time resulted in the publication of extensions to the Pontryagin maximum principle which purport to show that it is applicable to discontinuous decision spaces also. Such forms of "discrete maximum principle" are however incorrect with the "proofs" incorporating tacit assumptions of false results that do not carry over to the discrete case. One of the most powerful features of continuity is the well-ordering it establishes in solution neighbourhoods, and this is what allows Pontryagin's formulation but no discrete equivalent.

Categorial adjunctions may be seen as arising essentially through the unicity of a pair of reciprocal functors. The Goguen/Arbib/Ehrig behaviour/structure adjunction (Gaines 1978a) encompassing a wide range of system 'identification' schemes is dependent on the existence of a unique structure ascribable to an observed behaviour. Attempts to determine a similar adjunction for stochastic systems were doomed to failure because no comparable unique solution was definable. However, the meta-systemic move to define the 'solution' in terms of the "admissible space" of structures (Gaines 1977) has allowed Ralescu (1977) to express behaviour/structure transformations in the stochastic and fuzzy cases as adjunctions because the "admissible space" is itself unique.

It is the pre-supposition of [ONE] that most often leads to fruitless searches for solutions that result in the conclusion that "the problem is insufficiently well-defined". What we mean by "well-defined" seems to be the existence of a unique solution. However, it should be clear that problems can be 'solved' in some sense without necessitating unicity of solution, and thus that some problems may be solved even though they are "ill-defined". Indeed, requiring them to be precisified to a state of well-definition in this sense may destroy the essence of the problem.

However, although one may point to the problems that [ONE] causes, one should not be blind to its virtues. In particular cases, the defence of a false theory against a powerful attack on its strong points can generate precisely the environment in which new ideas are generated. Certainly many good ideas are not developed as early as they might be because their originators drop them prematurely, only to see others re-generate them later and show that superficial weaknesses overlay great strength. Defending weak positions is often infinitely more rewarding than buttressing up strong ones - as Kenneth Boulding (1964) has noted one must be "willing to make a fool of oneself".

In the general case also, [ONE] has its virtues - even if we are dis-satisfied with all existent theories and prepared to defend none, it is the belief that there is [ONE] that keeps us looking - the "unified field theory" for gravitational and electromagnetic forces, an organic basis for schizophrenia, controlled energy from thermonuclear reactions, and so on - all of them unsolved problems but where the belief that a solution exists makes them inspirations of major fields of endeavour.

[INFINITY] There are an <u>indefinite</u> <u>variety</u> of foundations for decision.

This pluralist hypothesis is that which best summarizes actual decision-making practice. The decisions of everyday life are usually highly over-determined and skill in practical decision-making comes from the ability to balance and make most effective use a variety of bases for decision. This is not necessarily a problem of multi-criteria, but most often one of multiple information sources each of which, in theory, provides sufficient information for decision.

A good example of this is the long-standing controversy over distance perception, "What are the cues that people use in determining the distance of an object ?". Experimenter X claims that phenomenon A is the prime determinant and demonstrates this by removing all cues but A - sure enough distance perception remains and is highly accurate. Experimenter Y claims that phenomenon B is the prime determinant and demonstrates this by removing all cues but B - sure enough distance perception remains and is highly accurate. Sooner or later, after the most refined experimental designs to ensure that no cues of type B are slipping in to confound those of type A, or vice versa, it is realized that not only are A and B each individually completely adequate distance cues, but the people subconsciously switch from one to another depending on which is available. At this point the excitement of controversy dies down, perhaps even the scientific research (the [ONE] hypothesis is highly important as a social dynamic !), and a few patient researchers are left determining all the different, interchangeable, bases for distance perception (Gibson 1950).

The real problem, once a pluralist basis for some aspect of practical decision-making is found, it to determine how the many different bases for decision are brought together to determine a single decision when more than one is available, i.e. how is over-determination resolved ? This is a difficult point which is often missed - [INFINITY] seems to lack the dialectical strength of both [ZERO] and [ONE] because it allows for all possibilities and hence does not bring them into essential conflict. In terms of explanation this may be so - your explanation is consistent and adequate, so is mine - we are both good fellows who do not need to fight but can revel in mutual self-satisfaction. However, in terms of explanation even, a meta-problem immediately arises as to how two explanations can account for a single phenomena: are they ordered in that one can be derived from the other, but not vice versa ?; are they unrelated ? - in which case is there a deeper underlying explanation from which both may be derived ?; and so on. One of the rules of the scientific game is that, like acausality, plurality is not allowed except as a matter of short-term expediency.

In terms of decision, there is no rule of the game that says that a plurality of bases is not allowed. Moreover, there is no rule either that says that these bases cannot conflict - generally they do - over-determination in a precise theory leads to multiple values for essentially single-valued variables and hence conflict, paradox, and, if the rules of the theory are precisely applied, a total breakdown of the basis for decision. In distance perception the possibility of such conflicts between the multiple bases of perception leads to "optical illusions" (Gregory 1970). The related phenomenon of "reasoning illusions" in practical reasoning is neglected in work on formal logic because the classical predicate calculus has the formula:

$$P \,\&\, \sim P \supset Q$$

i.e., that a breakdown of the law of contradiction may be used to derive any conclusion, and hence there is nothing that can be usefully said about this (in the same way that nothing can be said about existence). However, in practical reasoning we seem able to avoid the Wittgensteinian trap of knowing all the consequences of our premises (I would suggest by using a more appropriate logic rather than just by not working out all possibilities), and the mechanisms for conflict resolution are a key component of our systems of practical reasoning.

Thus [INFINITY] does have its own means of generating dialectical conflict and it is the most subtle and important of all. We have to accept as a basis for practical reasoning that multiple accounts of equal standing will arise and can be in conflict. Decision-making under uncertainty is usually seen as leading to under-determination, but in practice it most often leads to over-determination. Conflict resolution because we are over-provided with conflicting advice is far more prevalent than the other forms of conflict where we have too little.

2.2 Role of Foundations

I have dramatized the foundations of decision because they are worthy of it. If we are unaware of the seething conflicts below any theories, methodologies and practical schemes that we erect then we are not only guilty of that false peace of mind that stems from ignorance, but we are also missing out on that major element of choice that comes through conflict. If there are different pre-suppositions possible even at a truly foundational level, all of which are of equal merit (in the sense that they can be defended one against the other), then we have freedom of action in moving between them. It is our choice to be sceptical, to defend a unifying theory, to give equal status to mutually contradictory schemes.

The realization of the extent of choice enables them to be taken lightly. Practical decision is sometimes a game against nature but most often a game against other decision-makers, and real games are most often "won" by changing the rules. Even in the 'hot-war' against nature itself, the rules under which we play are of our own contrivance - it was the decision to consider the 'impossible' concept of "action-at-a-distance" that enabled Isaac Newton to forecast the motions of apples and planets - it was the decision to place Mach's eyes in the 'impossible' vehicle of a photon that forced Albert Einstein to distort the 'certain' constancies of space.

If this seems more a prescription for rhetoric than for decision-science then so be it - if rhetoric were not so neglected a science the powerful analogy by which the whole of science is seen as the "persuasion of nature" would be more often used. In decision this becomes more than an analogy because it is the "persuasion of the world" through action that is the key to decision.

In summary, this section has pointed to two key dialectical conflicts in the foundations of decision. In terms of the form of argument outlined in (i) to (v) above, there is first a conflict over step (i), existence: the Gorgian sceptic denies it; the [ONE] and [INFINITY] hypotheses both affirm it; the Pyrrhonian sceptic transcends all of them by suspending judgement. The [ONE] and [INFINITY] hypotheses themselves come into conflict over step (iv), unicity - this is the classic conflict between the tendency to unify and that to disintegrate.

In any system of decision that we build all of these dialectical possibilities will be present, and in good systems they will be explicitly present. The greater the awareness that we have of them, the more control we have over the possible choices they give, the more versatile and powerful the decision system will be.

In the following sections, I will give some practical and some theoretical approaches to decision systems that have such versatility and breadth of approach as key objectives.

3 THE ROLE OF THE COMPUTER

The digital computer cannot be regarded as just a tool for work on decision. The tool is itself so significant that it will change our whole approach to both the theory and practice of decision. I say "will change" because the potential of the computer is far from being realized. As a 'stand-alone' calculation system it is already powerful and important. As a closely coupled complement to the mind of man, however, it generates a new kind of creature whose capabilities are yet beyond our imagination. Currently we are able to add the data-processing power of the computer to thought processes of man. At the next stage we shall effectively multiply the two together and generate a quantity with new dimensions.

In these notes I shall not duplicate the two papers:

"Man-computer communications: what next ?" (Gaines 1978d)

"Minicomputers in business applications in the next decade" (Gaines 1978b)

which are available. The first of these papers highlights informally the current trends in man-machine symbiosis emphasizing the role of the computer as a tool for the emancipation of cognition. The second details recent developments in low-cost interactive computer systems that are beginning to allow this to take place. That is, the first paper develops the principles of close man-computer interaction, and the second shows the current state-of-the-art of the relevant technology. The overall message is that we do not yet have either the communications interfaces, particularly voice-interaction, or the communications software, particularly 'world' models, that are necessary for full man-computer symbiosis. However, the message is also that we are moving rapidly in the right direction - raw processing power in small machines, colour graphic displays at low cost, and a variety of basic software modules to provide easy access to the power of the machine - these are already available to allow the individual to share some of his load in intellectual tasks with the computer. To a large extent we are already 'imagination-limited' - the "personal computer" can do far more for us now than is at all evident in current applications.

However, the lag of applications behind hardware/software technology is comparatively short - good systems have only been available for the last 3 years and the price is only now beginning to hit levels that are attractive to the 'non-professional' user (non-computer-professional, that is - many key first-time users are professionals in their own areas, doctors, accountants, clinicians). A pattern of use for the personal computer in the home and office is emerging from the dozen small business and hobbies magazines and journals now extant: text processing for correspondence and document production is one major application; tax returns for personal and business purposes another; there are also developments in "planning" packages that optimize delivery schedules, etc.

The most important feature of current forms of personal computing is that they are enabling key individuals to increase their own speed and flexibility of operation by decreasing their dependence on the availability and skills of others. It is the supporting services of a secretarial, clerical, acoounting, information-retrieval, nature that are being taken over by the personal computer. We seemed to have been entering an era of essential team-work where individual "acts of creation" were possible only through a mediating network of supporting staff. The personal computer is already changing this and the potential for further change is very great indeed. "Each man his own Leonardo" is now a realizable slogan in human terms - the 'team' is still there and still necessary but it is the 'record' of pooled human skill within the computer that forms the rest of the team not the people themselves.

3.1 Computers in World 3

In attempting to come to grips with the problem of understanding the new opportunities that computers create, I have found Popper's "3 worlds" model (Popper 1968) of great value. In his autobiography he introduces it (Popper 1974a p.143) by quoting Bolzano's notion of "truths in themselves" in contradistinction to "those thought processes by which a man may...grasp truths", proposing that:

> "thoughts in the sense of contents or statements in themselves and thoughts in the sense of thought processes belong to two entirely different 'worlds'."

and making the three-fold distinction:

> "If we call the world of 'things' - of physical objects - the <u>first world</u> and the world of subjective experience the <u>second world</u> we may call the world of statements in themselves the <u>third world</u> (...world 3)." (Popper 1974a p.144)

Popper notes:

> "I regard books and journals and letters as typically third-world objects, especially if they develop and discuss a theory." (Popper 1974 p.145)

and stresses the key role of world 3 in the development of human "civilisation", giving two gedanken experiments on the destruction of civilization to illustrate the status of world 3:

> "(1) all machines and tools are destroyed, also all our memories of science and technology, including our subjective knowledge of machines and tools, and how to use them. But <u>libraries and our capacity to learn from them</u> survive...our world civilization may be restored...from the World 3 that survives"

> "(2) in addition <u>all libraries are destroyed</u> ...men would be reduced to the barbarism of primitive man in early prehistory, and civilization could be restored only by the same slow and painful process that has characterized the story of man through Paleolithic times" (Popper 1968 p.334)

Popper emphasizes the distinct ontological status of world 3:

> "I regard the third world as being essentially the product of the human mind. It is we who create third-world objects. That these objects have their own inherent or autonomous laws which create unintended and unforeseeable consequences is only an instance (although a very interesting one) of a more general rule, the rule that all our actions have such consequences." (Popper 1974a p.148)

It seems to me that the computer provides a new dynamic for world 3 just as did the harnessing of energy in world 1. It brings world 3 into the demesne of man just as did the steam, internal combustion, and jet engines, world 1. That is we can move about in, conquer, control and fabricate to our needs the lands and materials of world 3 using computers in a way that makes our previous efforts, all but a few, look feeble. Those few we shall shall look back upon in wonder as we do the construction in world 1 of the Egyptian pyramids, equalled in world 3 by Greek philosophy. However, such 'impossible' achievements prior to the harnessing of inhuman energy and inhuman intellect will be surpassed in achievement, if not in wonder, through our control of mechanisms that give us control of the worlds in which they exist: the energetic engines of world 1 and the informatic engines of world 3.

The role of computers in world 3 can be seen most clearly by contrasting information within a library with that in a computer database. The library itself is passive, waiting for scholars and technicians to tap its stored information, but powerless to process that information in any way, to classify it, extend it, and correlate it, except through human mediation. The database contains the same information as the library but may also itself be active through processes that interact with that information without necessary human mediation, sifting through the stored data structures, analysing and comparing information, and building new structures to enhance and extend those already present. The library is like a museum of preserved flowers, a static record of unchanging knowledge, whereas the database can be a living garden subject to growth and evolution, changing even as we study it.

The contrast becomes most pointed if we look at the exceptions that prove the rule. Librarianship is the art of preserving the static garden and also of cultivating it as much as is possible by preparing indexes, concordances, and so on, and also making it maximally available and attractive to scholars who will cross-pollinate and extend it - a good library is one where much effort is put into overcoming its intrinsic stasis. On the other hand, current databases are going through that usual stage of computer-based systems where they are designed primarily to mimic that which exists, the static library. Research on inference-based "knowledge structures" in artificial intelligence research is moving in the right direction, but we still have a long way to go before the potential of the computer database begins to be realized (Gaines 1978c).

However, the important thing is that the potential exists and that we have mechnisms capable of doing routinely and on a large scale what good librarians and scholars are currently only able to do with difficulty and on a small scale. Speeding up the processes of scholarship will have the same effect on world 3 that speeding up the processes of transport has had on world 1. Our physical world is a very different place from that of 100 years ago - we are able to take actions in it that disregard boundaries of size and distance because we have, to a very large extent, conquered both. A similar phenomenon has taken place in world 2 where modern communication techniques allow us to share subjective experiences through film and television - to live out vicariously the pleasures and horrors of the lives of others without actually doing so. Popper has pointed to the independent existence and impact of world 3 even as a static store - the ideas of Plato, Hume, Hitler and the Beatles, are active today in so much as they reach into world 2 and germinate in the minds of men. How much more active they will become as world 3 itself becomes energized with its own power sources such that the small energies of world 2 are able to control far greater powers in world 3 as they do in world 1. Power has its dangers - we may yet destroy world 1 and there are no doubt similar possibilities in world 3 - but danger is a necessary face of humanity and the last aspect of any world that should make us wish to avoid it.

3.2 The First Faltering Steps

The next section outlines some of the technical developments necessary to exploit the potential of computers for the conquest of world 3. However, it is interesting first to review briefly how this might come about and where the first steps are being taken. I commenced this section by emphasizing the role of the personal computer and in the long term this is the key to the next stage of development. Personal computers provide a bridge from world 2 into world 3 that the previous generation of centralized off-line machines did not. It will be the growing demands for this bridgehead to be be strengthened and extended that will lead us into new territories.

There are several uses of computers already that seem to me to point the way:

David Mulhall's (1977) use of data-processing in the treatment of disturbed inter-personal relationships is a clear example of the role of the computer in the "emancipation of cognition" to use Habermas' (1968 p.308) apt terminology. The graphical presentation of the social consequences of actions and interactions has proved to be both acceptable and effective. By seeing the world 2 situation that they have created for themselves in world 3 terms individuals are able to make changes through their own choice and decision. This is far removed from the "technical cognitive" approach of aversion therapy that treats people as objects in world 1.

Laurie Thomas and Mildred Shaw's work on the interactive construction and analysis of repertory grids (Shaw & Thomas 1978, Shaw 1978) again puts into the hands of the individual, and groups of individuals, a tool by which they may construct a world 3 model of their own views of worlds 1, 2 or 3. This is a particularly exciting development because it takes Kelley's (1955) insight into the world 2 nature of all our knowledge and applies it flexibly, but uniformly and rigorously, to that knowledge, whatever its source or content: the "Focus" system and its variants can be used to model and externalize (in world 3) the personal and group knowledge that we have (in world 2) of the physical world (world 1), inter-personal relations (in world 2) or scientific constructs (in world 3).

Systems that successfully anlalyse and encode professional skills and make them available to others less skilled are also pre-cursors of those which will conquer world 3. Mycin (Shortliffe 1976) is currently an outstanding example, but its success has lead to this area of development becoming one of major activity and we may expect to see more and more general systems for encoding and activating professional knowledge skills become available.

These examples are all ones whereby world 3 is built out of the material of world 2 and hence may be a world of fantasy just as easy as one of reality, i.e. the computer is not itself directly interacting with world 1. Popper himself notes the role of such fantasy in world 3:

"Even theories, products of our intellect, result from the criticism of myths, which are products of our imagination: they would not be possible without myths; nor would criticism be possible without the distinction between fact or fiction, or truth and falsity. This is why myths or fictions should not be excluded from the third world. So we are led to include art and, in fact, all human products into which we have injected some of our ideas, and which incorporate the result of criticism, in a sense wider than a merely intellectual one." (Popper 1974a p.155)

It is this acquisition and processing of 'knowledge' by computer systems through interaction with world 2 that I would rate as having the most immediate importance and potential rather than any direct interaction with world 1. It is only after substantial developments in the computational structures necessary to fully interface with world 2 that we shall be able to fabricate systems that can be comparable to ourselves in having independent and meaningful access directly to world 1. That is, we shall build companions and colleagues long before we build robots, and the robots we eventually build will be nothing like those we currently envision since the conquest or world 3 will change our entire relationship with world 1.

I have blurred the distinction between the individual and the group in the above discussion and feel that this distinction will become increasingly blurred. World 3 has always been the creation of many minds and modern communications equipment may be seen as amplifying our capabilities to form 'group minds'. The computer takes this a step further in allowing us to communicate not just with passive records of the state of an individual's mind but with an active process that replicates the activities of his mind. However, the effect of this on individuals is to enhance their individualism not erode it - by being freed from dependence on the availability of others (i.e. their physical presence, attention, interest, co-operation, etc.) we are able to operate more effectively ourselves. We shall never be, nor ever wish to be, freed from our dependence as such on others - world 3 is the sum total of all our acts of creation, but once created it exists independently of us - the computer provides the means to faithfully record and make available far more of world 3, both its passive and active natures, than has any previous technology.

4 SOME TECHNIQUES

Part 2 of this paper has explored foundations and part 3 practical tools for decision science and applications. In this final section I shall outline a few of the techniques that have the potential to make fundamental changes to the basis of decision. This section is illustrative rather than comprehensive - it is here that we now have most work to do, but also the opportunities to do it.

Again I shall not duplicate presentations already available:

"Analogy categories, virtual machines and structured programming" (Gaines 1975)

"System identification, approximation and complexity" (Gaines 1977)

"General systems identification - fundamentals and results" (Gaines 1978a)

"Foundations of fuzzy reasoning" (Gaines 1977)

"Nonstandard logics for database systems" (Gaines 1978c)

The first paper presents a formal analysis of analogies between systems in category-theoretic terms. The second and third papers present a review and up-to-date account of work on general system identification. The fourth paper presents a foundational account of uncertain reasoning, the necessity for its formalization, and the relationship between fuzzy and probabilistic accounts. The fifth paper presents the state-of-the-art of modern database systems, illustrates fundamental defects in the structures currently available, and suggests ways in which these may be remedied.

The following are brief notes on these topics.

4.1 Klir's Epistemological Hierarchy

I have found George Klir's (1976) notion of an epistemological hierarchy a very useful one in analysing, classifying, and developing techniques for decision systems. This is shown in Figure 1:

META-META SYSTEM, ETC.

META SYSTEM

STRUCTURE SYSTEM

GENERATIVE SYSTEM

DATA SYSTEM

SOURCE SYSTEM

Figure 1 Klir's Epistemological Hierarchy

This would be more fairly termed an ontological hierarchy since it represents the levels at which pre-suppositional decisions must be made before the epistemological process itself can begin.

The lowest level, of source systems, is effectively one of data definition wherby the way in which our experience of the world will be described is defined and agreed. The next level in the hierarchy is one of data systems, effectively one of system observation whereby our actual experience of some system is described in terms of the agreed domain of discourse at level zero. The next level is one of generative systems effectively one of a model for the system of which the experience is reported at the level below. The level above this is one of structure systems effectively one at which the models themselves are seen to have internal structure and hence to be analysable in other terms. The first meta level will be one at which this form of model analysis is itself seen as part of a class of possible approaches to model analysis, and so on.

This hierarchy is very useful in studying techniques for system analyis and clarifying debates in the literature on epistemology where apparent conflicts are often due to confusion between levels. In scientific work we usually appear to take the lowest level for granted, assuming that our vocabularly is already standardized and accepted. However, this is the level of phenomenological and existential debate, and it is not unreasonable to feel "dread" at the responsibility for ruthlessly encoding experience in languages which one knows lose the major part of its content and superimpose their own pre-conceptions upon it.

It is determining the relationship between data systems and generative systems that constitutes the epistemological problem of system identification, and this is a task well-suited to the patient power of the computer. This particular problem can be resolved in a very general sense that draws together much of the literature on modelling, identification, pattern recognition, etc., and the basis for this is outlined in the next section.

4.2 Identification, Complexity and Approximation

Let E be a set of possible exemplars of system behaviour, e.g. the set of all possible patterns on a grid, or the set of all possible strings of input/output behaviour of an automaton. Let i: $I \rightarrowtail E$ be a sub-object monomorphism from an 'index-set' I to E that represents the 'observed', or 'classified', sub-set of E. Let b: $I \rightarrow V$ be a mapping from I to a 'truth-set' V which represent possible observational assignments of values to elements of E. Goguen (1974) calls such a mapping a 'V-set' with I as carrier, and V will normally be some ordered algebraic structure such as a lattice, or the interval [0,1] with max/min, add/multiply, or logical operations (Gaines & Kohout 1976). For example, V might be a set of possible pattern classes, or V might be the interval [0,1] with the mapping b corresponding to the observed relative frequencies of the exemplars in E. I have previously termed b the (observed) "behaviour" of a system, and taken the problem of system identification to be one of inferring a "model" that accounts for b in some well-defined way.

Let M be a set of mappings from E to V such that any $m \in M$ represents a possible 'model' of behaviours such as b. Figure 2 shows the mappings under consideration and it is apparent that a basic view of the problem would be to require m to be an extension of b from the sub-object of E, I, to the whole of E, so that: im=b.

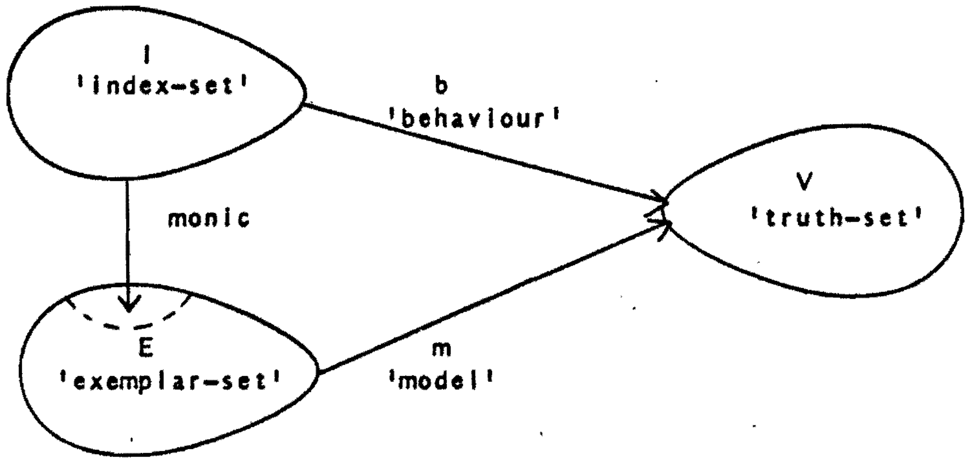

Figure 2 Modelling as Extension of a Mapping

Consider this to be the requirement for the moment, that m should be chosen such that im=b, and consider the situation where many m satisfy the requirement. How do we select amongst the many possible extensions of b ? In particular situations, we will usually have some criterion that, ceteris paribus, allows us to select one model as being preferable to another, e.g. that it has the least 'parameters', or the least 'states', or some other Ockham's razor type of criterion. In general, all such criteria can be subsumed under the requirement that there is some pre-order on M, $\leq$, such that the lesser models in the pre-order are intrinsically preferred to those greater, i.e. if $m,n \in M$ are two models that are both valid extensions of some behaviour b, and $m \leq n$, then we will not prefer n to m as a model of b. This preference order is not necessarily of Ockham's razor type, for example it could be one based on elegance or the party-line, but it is so often one of simplicity it is convenient to use this terminology and say that if $m \leq n$ then n is not 'simpler' than m. There has been a great deal of discussion in the philosophical literature (Bunge 1963, Kemeny 1953, Sober 1975) of our justification for preferring 'simpler' models in a variety of circumstances, but for present purposes any underlying rationale does not matter.

At this stage our formulation of the problem of system identification might seem complete - "out of all models that are valid extensions of the observed behaviour chose the simplest". However, whilst this is a reasonable formulation for the deterministic case where the behavioural mapping b is well-defined and should be precisely extended, it is not an adequate formulation of the non-deterministic case. For example, if b represents an observed distribution of behaviour of a stochastic system then determining a model that precisely generates the observed relative frequencies is a number-theoretic problem whose solution has little relevance to actual requirements. What we really want is a model that approximates the observed frequencies to an extent that residual differences between behaviour and model are statistically insignificant. Equally, if b represents a given 'degree of membership' assigned to the possible behaviours of a fuzzy system, then what we require is a model that places the same fuzzy restriction on behaviour within a reasonable tolerance. In general, we do not require m to be an exact extension of b but rather a reasonable approximation to such an extension - the diagram of Figure 2 need not commute, only 'almost commute'.

In a particular situation one will have highly specific concepts of what one means by 'almost commutes', i.e. to what extent Im approximates b. However, in general the key notion is again one of order, that it should be possible to say that one model is a better, or worse, approximation to b than is another. To do this one needs to define there to be a mapping from the set of behaviours, to the set of pre-orders on models, Ord_M, $f: B \rightarrow Ord_M$, such that if $\leq_b$ is the image of b under f, then, for $m,n \in M$, $m \leq_b n$ means that n is not a better approximation to b than m is.

Having defined the pre-orders of simplicity and approximation, we are in a position to define a solution to the identification problem in terms of their product, $\leq^*_b$, defined as:

$$\forall m,n \in M, \quad m \leq^*_b n \Leftrightarrow \quad m \leq n \text{ and } m \leq_b n$$

i.e. $m \leq^*_b n$ if and only if n is both neither simpler nor a better approximation to b than m. The minimal elements in this order are all admissible solutions to the identification problem because they cannot be bettered in simplicity without worsening the approximation, and they cannot be bettered in approximation without worsening the simplicity. They form the admissible subspace of models determined by b, $M_b \subset M$, such that:

$$M_b \equiv \{m: \forall n \in M, \; n \leq^*_b n \Leftrightarrow m \leq^*_b n\}$$

i.e. if any model is better than one in M. then it is equivalent to it.

One interesting side-effect of requiring the diagram of Figure 2 only to 'almost-commute' is that the expression of the problem may now be simplified by the artifice of extending the set V with an additional element representing 'unknown', or 'unobserved', assignments to elements of E. This removes the need for the sub-object monomorphism i, which is now subsumed into the semantics of the approximation ordering $\leq_b$ in that models that differ only in their assignments of values to elements of E to which b assigns the 'unknown' assignment must be equivalent in approximation. 'Don't-care' assignments clearly also have the same semantics.

This formulation of system modelling may be used to draw a number of important conclusions about the actual implementation of identification systems:

First, consider the set M of possible models. It is clear that the selection of M alone is but a small step in setting up the modelling problem. The simplicity ordering over the models must also be specified and variation of this affects the solution to the problem as much as does that of the choice of the models themselves. For example, even the basic class of finite automata may be ordered by number of states, number of links between states, or by some more complex function that takes into account hierarchical structure, etc. Zeigler (1976) has given several examples of such order relations on automata and we have found that varying among them has a very profound effect in practical modelling situations, both on the speed of computation and the solutions found.

Secondly, consider the set E the set of possible exemplars. The 'language' in which these are described is arbitrary and can be varied without affecting the essential modelling problem. However, it is clear that changes in E will be reflected by changes in the admissible sub-set of models, not only in the trivial sense that the models themselves must change to reflect the variations in E, but also in that the simplicity ordering on models must also change if the situation is to remain invariant. This is unlikely to be so since this ordering will generally be derived from intensional, extra-linguistic, considerations. Variations in the language in which exemplars are described and in the class of models and simplicity orderings are outside the framework of the modelling situation and yet can have a very profound effect on it. I have previously suggested that, whilst the process of modelling described here is very Carnapian in its search for the models best confirmed by the observed behaviour, the great significance of changes in the actual terms of reference of the modelling process itself corresponds to Kuhnian "scientific revolutions" - changes in the underying concepts and assumptions on which the modelling itself is based.

Thirdly, the implementation of a modelling scheme once the various ordered sets required have been defined is basically simple. One needs only an algorithm that generates possible models in order of decreasing simplicity. As each m is generated it is checked against b for its position in the approximation order. If this is is worse than that of simpler models previously found the model is rejected, but otherwise it is added to the admissible set. The key trick here is the derivation of a production algorithm for models for complete enumeration of models of decreasing simplicity, and Wharton (1977) has recently given some techniques for doing this for very wide classes of models.

Fourthly, the measures of approximation used are clearly very significant and it is interesting that these seem to have a high degree of problem independence, largely because the set V is basically problem independent, a classification, or a distribution, or a fuzzy restriction. For example, consider V to be the interval [0,1] with the mappings b and m giving normalized relative frequency distributions. A suitable measure of approximation between b and m is then one that has a minimum when . e E, me=be (neglecting now the sub-object mapping i), and varies above this minimum to the extent that they differ. Examples of such measures are:

$$SE = \sum_{e \in E} (me-be)^2 \qquad (1)$$

$$CE = \sum_{e \in E} (me-be)^2/me \qquad (2)$$

$$LE = \sum_{e \in E} -be \ \ln(me) \qquad (3)$$

Measure (1) is a standard least-mean-squares test used extensively in the literature on modelling and pattern recogntion, and by de Finetti (1972) as the foundation for his theory of probability. Measure (2) is the chi-square statistic used as a statistical test of similarity of distributions and by Maryanski and Booth (1977) in their grammatical inference scheme. Measure (3) is a Gibb's function giving rise to a Shannon entropy measure that has been widely used in grammatical inference and in Savage's foundations of subjective probability (1970). Pearl (1978) has pulled together these and other such functions into a single economic model of such approximation.

Fifthly, the determination of the admissible set is often not in itself the final solution to a modelling problem. Pattern recognition, system indentification, etc., are generally carried out for a purpose, to give us a basis for decision, and we have to decide which model to actually use out of the admissible set. Often this will involve action to obtain further data on further exemplars to provide for better discrimination between admissible models. Clearly this can itself conflict with the use of the models giving rise to a 'two-armed bandit' form of problem (Witten 1976). In terms of the formulation here it may well be appropriate to change the measures of approximation to ones of 'achievement' when the overall task of the system is action rather than prediction, i.e. to set up a pragmatic epistemology in which 'truth' is evaluated in terms of 'usefulness'.

Finally, these last remarks highlight the extent to which the order relations of simplicity and approximation are an operational definition of our axiology. I have stressed that no epistemology can be free of arbitrary ontological decisions, and I will emphasize also that it cannot be free of axiological ones either. We take on a great deal of responsibility in our decisions as to both ontological and axiological pre-suppositions before we even begin to acquire the information for action.

The implementation of modelling schema based on the framework of simplicity and approximation outlined here seems to be an excellent task to allocate to a computer. The machine can take over the routine drudgery of "normal science", effectively using a Carnapian paradigm of incremental confirmation of hypotheses. Clearly, there is nothing within the framework I have proposed that allows the "revolutionary" components of epistemological advance to be automated. This is one of the roles for man in complementing the computer. When the modelling process seems to be going badly then we intervene to make changes in the space of models, simplicity ordering, approximation measures, etc. This will be possible and effective to the extent that these are expressed in a mutually comprehensible form to man and machine.

4.3 The Relation of Analogy

The concept of there being an analogy between two systems such that one can "reason by analogy" and make statements about one system based on knowledge about the other is very important to any form of decision system. It is the analogy of a system at time t to itself at time t' that is crucial to our being able to acquire knowledge at all. It is the analogy of one person to another that gives us the concept of a human race and a science of psychology. Korzybski (1958) has emphasized the semantic problems of the concept of "identity", and it is clear that in practice this is an abstraction for there being an ultimate level of analogy.

Whilst there have been many studies of the role of analogy in science (Hesse 1966, Leatherdale 1974) and it forms a major component of "plausible reasoning" (Polya 1954), there appears to have been little attempt to formalize it systematically. In Gaines (1968) I introduced a category-theoretic formulation of what we mean by an analogue computer and in Gaines (1975) extended it to systems in general.

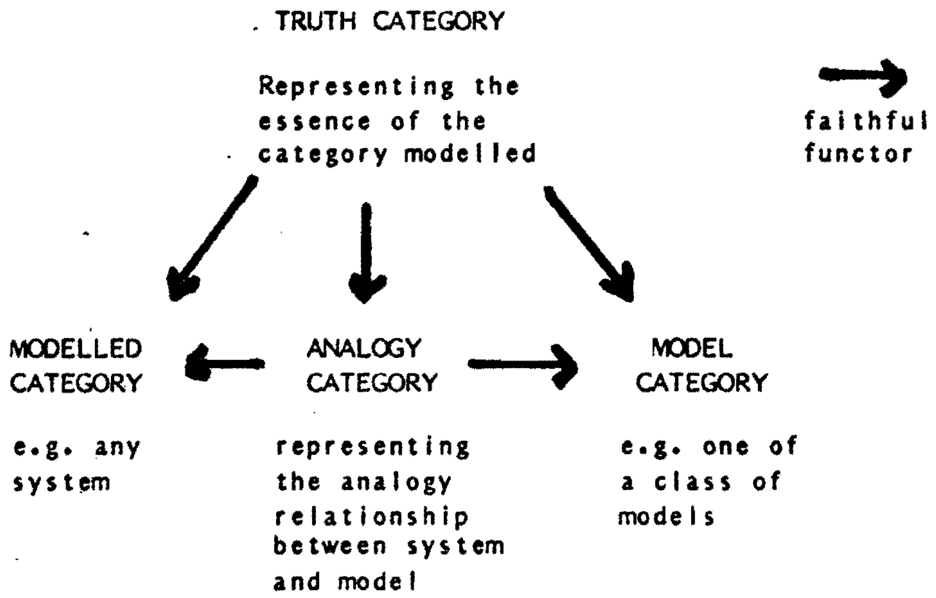

Figure 3 The Analogy Category Between A System and Its Model

The basis of this formalization of analogy is shown in Figure 3: the "category to be modelled" and the "model category" are such that there is no functor of interest from one to the other, i.e. both contain 'structure' that the other does not; however, there is an "analogy category" that maps into both model, and modelled, categories through faithful functors and hence represents mutual structure; there are many such possible analogy categories and to ensure that they are non-trivial it is necessary to introduce a "truth-category" such that the diagram of Figure 3 commutes; all possible analogy categories satisfying Figure 3 then form a semi-lattice.

Gaines (1975) gives 3 postulates on which to base a theory of analogy:

I A system can be represented by a category.

II A truth category having a faithful functor to each of a category and its model can adequately represent all that we mean by a "correct", or "significant", or "adequate", or "true", analogy.

III The semi-lattice ordering of analogy categories represents what we mean by one analogy being "more comprehensive", "closer", or "more detailed", than another.

This theory is attractive in being operational - it is possible to compute the entire semi-lattice of analogies between any two systems. However, the computation gives rise to a combinatorial explosion in all but the most trivial cases, and this again seems the type of task ideally suited to a computer. In practice it will not be the calculation of the analogy structure between to well-defined systems that is of importance, but the exploration of an ill-defined system using the analogy between it and a known system.

4.4 The Logic of Decision

All of the techniques outlined in this section involve the use of a variety on standard and non-standard logics and the manipulation of logical structures, theorem-proving, etc. As we refine a science of decision these logics are formalized to sets of axioms and rules of inference that enable us to derive all deductive consequences of statements in appropriate formal languages. However, we find in practice that such a 'logical science of decision' falters at an early and trivial stage - trivial in that it has nothing to do with the content of the facts and theories being used but only with the syntax of the logics. We, unaided, are unable to cope with the task of formal deduction to all but a virtually trivial extent.

Thus, for a person, to know a proposition is not to know all its consequences - we do not "know" in the sense that Wittgenstein defines:

> "If I know an object I also know all its possible occurrences in states of affairs. (Every one of these possibilities must be part of the nature of the object.) A new possibility cannot be discovered later." (Wittgenstein, Tractatus 2.0123)

Even if such "knowing" is physically impossible, it is clearly important that the potential is there - that given a proposition, x, and a body of propositions, A, we should be able to determine of any proposition, y, in the deductive closure of A under some logic, whether x implies y, y implies x, neither, or both.

The role of the computer in providing the deductive reasoning power to expand human "knowing" to the Wittgenstieian ideal is one of the most important aspects of man-machine symbiosis. For major areas of logic, such as the varieties of modal logic, it is claimed that we are already at this stage:

> "The formal techniques to be used are essentially mechanical. Proving theorems within a given system of logic involves following a straightforward mechnical procedure with paper and pencil that could as well be done by computer." (Snyder 1971 p.12)

However, despite advances in theorem-proving for many-valued and modal logics (Gaines & Kohout 1977) we have not yet done as Snyder suggests. There seems to be no reason why we should not do so in the near future, however, and set up "possible world" simulations of the consequence structures of major sets of real-world premises.

The significance of this is world 3 terms is illustrated by Popper in his demonstration that the currently encoded part of world 3 (which he terms world 3.1) is transcended by the consequence structure that may be generated from it:

> "world 3 transcends essentially its own encoded section. There are lots of

examples, but I will take a simple one. There can be no more than a finite number of numbers in world 3.1. Neither a library nor a human brain incorporates an infinite series of natural numbers. But world 3 possesses the lot, because of the theorem (or axiom): every number has a successor." (Popper 1974b p.1050)

In emphasizing the logical role of the computer in man-machine symbiosis we must not lose sight of the converse role essentially provided by man. The lack of rigorous foundations to any theory of decision, and the necessary lack of the possibility of such foundations, means that any system based on a logical approach to the expansion of knowledge is inherently restricted and bound ultimately to fail. The human component of a man-machine symbiosis complements the machine part by providing the possibility of meta-systemic branches and deviations from the programmed system. If particular "deviations" prove valuable then they will be programmed into the repertoire of the machine, but it seems reasonable to conjecture that whatever the level of formalization and rigour there will be a meta-level at which the human component provides necessary informality resulting in lack of rigour and the possibility of acts of creation. The human component breaks the 'closure' of the machine. Between man and conputer there is a battle of imcompletion and completion - for man completion is intellectual death - for the computer incompletion is intolerable ignorance.

4.5 The Database as a General System

Database systems originated as mechanisms for storing and retrieving information and their later development has largely concentrated on immediate commercial requirements (Nolan 1973). Currently a wide range of practical and cost-effective systems are in use, and there have been notable successes in more advanced applications involving natural language interaction with commercial databases by naive users. There are however severe limitations in the extension of databases into practical "management information systems" due to the rigidity of the data-structures imposed by current implementations and the system-theoretic concepts that underly them. Recently there have been a variety of attempts to liberalize the underlying logical structure of database systems to allow a wider range of more realistic data structures to be encompassed. Gaines 1978c illustrates the practical need for such extensions, surveys recent developments, gives examples of how a variety of classical logical and systemic problems arise in database systems, and shows the underlying structure common to a wide variety of extensions.

Codd's (1970) relational formulation of databases was the first step in the direction developed here, in that it greatly generalized and made far more flexible the forms of data structure and retrieval specification allowed. However, available implementations of databases are in terms of "hard", static, deterministic relations, whereas in real-world applications data is often imprecise, inherently dynamic and non-deterministic. In recent years there has been a range of developments concerned with representing and using data that can only be analysed in these "softer" terms. Some of the work has been explicitly concerned with database systems, but much of it, whilst highly relevant, has been in other application areas.

Gaines (1978c) develops a systemic account of databases that relates their dynamics to topological automata theory and enables normalization to be viewed as a constraint on the category of database automata. Within this framework the extension of databases to "softer" structures may be seen as the introduction of nonstandard logical structures. Some of the real-world defects of standard relational databases are shown to correspond to the occurrence of paradoxes in the corresponding logics. This paper also discusses the roles of modal, multi-valued and fuzzy logics in databases and a common computational framework for their representation in relational databases is outlined.

I believe this concept of a "database" generalized as above is quite fundamental to system and decision theory. All the classical system-theoretic constructs which we use, dynamical systems, automata, etc., are special cases of the general "database". The "possible worlds" treatent of logical structures that has proved so fruitful in giving firm foundations to a variety of non-classical logics may be regarded as using a "database" model. The database model itself seems to be a natural tool with which to investigate practical reasoning (Zadeh 1978b) of a fuzzy (Gaines 1976) or possibilistic (Zadeh 1978a) nature. If we see the role of the computer in man-machine symbiosis to provide a generalized database facility allowing man to aggregate information and from it explore possible worlds then this is probably as far as we yet can, or need, to see. Currently, as Gaines (1978c) shows, we are far from this possibility - however, the technology exists, many developments are underway, and tomorrow may see the potential of man-machine symbiosis become actualized.

5 CONCLUSIONS

After section 2 it would be foolish to attempt to draw conclusions about decision itself. In terms of the study of decision however, there is a clear prescription not to place one's trust in foundations - certainly not to become over-enthusiastic about optimizing particular approaches based on particular foundations. Robustness, rather than optimality, is what we have to seek - robustness not just against uncertainty in our data but also against essential uncertainties in the foundations of the subject itself.

Robustness in many key structures comes from disparate entities working together in a complementary fashion to enhance the other's strengths and eradicate the other's weaknesses: the combination of iron and concrete to form ferro-concrete is of just this nature. This world 1 example has its parallel in world 3 through the combination of man and computer. We do not yet know how to weld these two together. We cannot yet foresee the properties of the new system that we shall have created. We, as individuals, will probably never comprehend its use, since that level of comprehension will only be open to the new creature, the creation of symbiosis, itself.

In the near future, it is the movement towards operationalism, towards the embedding of theories in an applicable form within the computer, that has most to offer us. The basic concepts of ontology, epistemology, axiology, and their associated logical calculi, may now be actualized as effective algorithms. These will give us access to systems of plausible reasoning that extend and complement our own.

The scope for innovation in the operation of the mind itself is now limitless - as closing parentheses let me quote again one who mastered all 3 worlds as much as was possible in his time:

> "It would be unsound fancy and self-contradictory to expect that things which have never yet been done can be done except by means that have never yet been tried." (Bacon, Novum Organum Book 1, VI)

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