Modelling and Simulation Methodology
in the Artificial Intelligence Era
M.S. Elzas, T.I. Ören and B.P. Zeigler (Editors)

Chapter IV.3

KNOWLEDGE SEEKING IN VARIABLE STRUCTURE MODELS

P.Hogeweg & B.Hesper
BIOINFORMATICA
Padualaan 8
de Uithof, Utrecht
the Netherlands

Systems with a variable structure are often modelled in terms of models with a fixed structure. We will argue that such fixed structure models are conceptually inefficient at best, and (worse) tend to "beg the question" concerning the system.
We review modelling methodologies in which the variable structure of the system is represented as the variable structure of the model: MIRROR modelling methodology, with an emphasis on the role of knowledge seeking (by OBSERVERs) in such models.
We will illustrate our ideas with several, still primitive, examples of MIRROR models which, we hope, will contribute to our understanding of the use of knowledge seeking processes in science.

1. INTRODUCTION

1.1 On the need of knowledge seeking in models, or Modelling sensu strictu vs studying Paradigm Systems

Most verbalisations and formalisations of the concept modelling presuppose a "real" system which the model system should mimic. Such a "real" system is conceived by Zeigler (1976,1984) as a database of potential observations. In his conceptualisation the real system can be thought of as being represented by a "base model", i.e. the hypothetical system which produces exactly the same set of observations as the real system. However, neither the set of potential observations nor the base model are known. Therefore at any one time the "working" model represents the base model only relative to an explicitly defined experimental frame, i.e. a set of input/output relations which the system should mimic. Likewise, Klir (1984) recognises an "observation channel", and Wymore (1984) a set of feasible test items. The "real" system and the model are supposed to produce similar input/output relations when studied through the appropriately similar experimental frame. Thus although it is recognised that modelling is a "multifacetted process" (Zeigler 1984) in which a variety of alternative experimental frames are employed (which are partly defined in a feedback process from model studies employing other experimental frames (Elzas 1984)) at any one time a model is studied with a fixed structure (system specification) in which the potential observables are predefined and incorporated in the model as observational entities.

However "modelling" in the exploratory phases of science is often done without pinpointing the real system (i.e. a source of potential observations) which the model should (partially) mimic. Instead modelling serves the important purpose of defining sets of coherent observations. In such cases the modelling process starts with defining 'paradigm systems', i.e. interesting relations and/or properties of model entities and proceeds by studying what observables /observations can be generated by these relations/properties. Finally a search in the "real" universe will be undertaken to find out whether such a set of observables is applicable in that universe and if so to recognise these observables as a coherent set. This pathway of scientific modelling can be illustrated with well known examples: (1) The fact that observables are generated by models and are only secondarily sought in the "real" universe is clearly true for Black Holes. (2) A prototype of previously observed observables which unexpectedly were shown to form a coherent set are planet trajectories and apples falling from trees.

In this paper we are concerned with studying paradigm systems. Because no apriori behavior of a target system is chosen, knowledge seeking in the model, and therewith the generation of new observables (not represented in the model as observational entities) is of utmost importance.

1.2 On the need of variable structure models

The need for variable structure models arises simply from the fact that
1. Some systems do have a variable structure; imposing a fixed structure then leads to
    a. redefinition of the system, or
    b. including "quiescent entities" and zero interactions, to simulate variable structure (compare cellular automata (which only can be specified assuming quiescent states), and partially decoupling in random nets (Kaufman 1969) (which make these fixed structures de facto variable structure)),
2. We may be interested in how a (relatively) static entity structure arises from the behavior of autonomous entities

Both these cases are often true in bioinformatic studies: If we represent biotic systems in terms of their information processing entities we obtain variable structure systems, and the most outstanding question in bioinformatics is how autonomous entities (like molecules, cell, organisms) form relatively stable structures (like cells organisms ecosystems) without assuming global control.

2. FIXED-STRUCTURE VS VARIABLE STRUCTURE MODELS

2.1 Implicit global control

Fixed structure model formalisms are all those formalisms in which the model consists of a fixed set of entities (modules, subsystems) which interact each with a fixed subset of the other entities all through the existence of the model. All classical model formalisms (e.g. differential equations, difference equations, cellular automata, and also DEVS, etc.) fall into this class. Not withstanding their superficial localness (being built up out of simple interacting subsystems) such systems are inherently global in the sense that:
1. The subsystems represent global properties of the system. This is because of the requirement of a fixed set of subsystems: in many systems only global properties are definable in such an invariant way. For example many biological models are defined for this reason in terms of populations (of organisms, cells or molecules) instead of in terms of individuals: the

latter form a varying collection, whereas the former remain the same entity (possibly with value zero).
2. The model system is defined as a "whole": the subsystems may not preserve their identity (model interpretation) except as part of the whole.

In variable structure models the set of entities constituting the system is variable (in number, types and properties) and the interaction between the entities change in time (neccesarily so because of the changing set of entities). Such models can comply much more to local characteristics than fixed structure models because:
1. the model entities can represent "individuals", i.e. the basic information processing entities of the system to be modelled;
2. the model entities are defined so as to be self-sufficient: they pursue their own purposes, they gather their own information and they establish, maintain and abolish relations with other entities on the basis of their local experiences. Thus the model entities can exist in different environments and still maintain their model interpretation. The system as a whole is not explicitly represented in the model.

Besides the distinction between fixed structure- and variable structure models there is the distinction between models with a global timing regime (incorporating the world-view that "everything is changing all the time") and models with a local timing regime(incorporating ultimately the world view: "once in a while something interesting is happening somewhere in the system", (see below)). (Note that this does not imply that an implicit global time does not exist in models with a local timing regime). We have shown previously that implicit global control through a global timing regime can impose unwarranted structure in otherwise locally defined systems (Hogeweg 1980).

The two distinctions run parallel in the sense that local time is required in variable structure models, whereas both timing regimes are possible in fixed structure models.

2.2 Knowledge incorporated

The knowledge incorporated in fixed structure models is the invariant relation it embodies, and the concepts (i.e. entities and entity structure) which allow for such an invariant relation. (One should be aware that the class of invariant relations used in (fixed structure) systems models is wider than that used in mathematical context, e.g. switches are allowed.) The knowledge to be gained from such models is about the state-changes compatible with the invariant relation. This knowledge can be gained easily: the relevant concepts are apriori defined and the stated values have only to be recorded.

The knowledge incorporated in variable structure models concerns the information processing properties of the entities under consideration. The (ultimate) knowledge to be gained from such models concerns the patterns of interactions which result from the simultaneous occurrence of the information processing entities under consideration. One such pattern can be an invariant relation such as incorporated a priori in fixed interaction models. However not only invariant relations are of interest, may be even more important is knowledge concerning 'interesting' events, i.e. events which redirect the system from one configuration to the next. The knowledge sought in variable structure models is much harder to obtain then the (different) knowledge sought in fixed structure systems because new concepts are to be formed to express the patterns of interaction, whereas in fixed structure models the concepts are given (i.e. are identical to those represented in the model) and the patterns of interaction are fixed.

The role in science of both types of models is also different. Fixed structure models are implemented to test the invariant relation and to predict the state of the system: they are indeed employed most often in "applied" science. Variable structure models can be implemented in the exploratory phases of scientific enterprise and aid in the process of pattern discovery and concept formation.

3. MIRROR MODELLING

MIRROR modelling represents our attempt to provide the concepts and tools (implemented in MIRSYS) to make variable structure modelling feasible (Hogeweg & Hesper 1979,19811,b,1983,1985a,b; Hogeweg 1985). The name MIRROR modelling is chosen with "through the looking glass" in mind: our variable structure models should be "as large as life and twice as natural" and should "reflect our reflections" (recursively). A summary of the concepts of MIRROR modelling in the form of the most important requirements and the resulting structure follows.

3.1 Autonomous entities

The basic units should be autonomous entities ('individuals') which possess their own information processing capabilities. This directs us in the direction of the "Process" view modelling formalism or to object oriented modelling/programming, as used in AI. Because of the variable structure, and the knowledge aquistiion properites of entities, the entities should preserve their structure during the simulation, and not be only entities in an abstract formulation which lose their identity during runtime (as e.g. in SIMSCRIPT).

Individuals should be selfsufficient, i.e. they should not need the active cooperation of other individuals to satisfy their informatic needs (Hogeweg & Hesper 1985b). For example a predator should not need a "here I am" message from a prey to find it.

Autonomy and selfsuffiency do not imply that the individuals are independent. On the contrary their behavior is highly determined by the varying interactions in which they are involved (refer to the TODO principle in the example section). Indeed MIRROR preeminently implements Simon's paradigm about the ant (and human): "an ant viewed as a behaving system is quite simple, the apparent complexity of its behavior in time is largely a reflection of the environment in which it finds itself; a human ...... etc." (Simon(1969)).

In MIRSYS individuals are INTERLISP functions which posses an indirect reference to their own local program pointer (the ME pointer). Through this pointer the entire calling environment of the individual can be accesses, i.e. individuals can inspect the parameters etc. of other individuals of which they know the local ME pointer (i.e. of which they have a YOU pointer). Note that the calling environment (i.e. the 'knowable' individual) changes dependent on the state (behavior) of that individual. Note also that an individual can not automatically assess all parameters of other individuals of which they have a YOU pointer: they need in addition knowledge of how to decode the information (i.e. they need the appropriate senses). In this way individuals can have the required autonomy and selfsufficiency without violating the localness requirements (see also section 3.5).

3.2 Variable interactions

Interactions between individuals can be established in one of the following ways:
1. knowledge incorporated a priori (= fixed structure)
2. Ancestry based: an individual inherits its interactions from the individual which generates it. Various forms of ancestry based variable structure systems are quite common, e.g. context sensitive grammars, L-systems, but also the "hire/fire" ancestry based variable structure model of Zeigler (chapter IV.1) Our PATCHes (which subdivide SPACEs) employ an ancestry based divide/merge variable structure regime comparable to the above mentioned "hire/fire" regime in the sense that PATCHes are generated at need (see below).
3. Proximity based. For this purpose the individuals should be embedded in (one or more) space(s) and change their location in these spaces. This mode of establishing interactions generates more truely variable structured systems than the previous one: e.g. prediction of the interactions is usually not possible. MIRROR models mostly use proximity based interactions. The spatial structure employed is discussed in the next section.
4. Based on common relations (e.g. A knows B and C and establishes a direct interaction between B and C). Such an interaction is implemented in MIRROR through DEMONs (see below).

3.3 The MIRROR universe

The MIRROR universe consists primarily of SPACEs and DWELLERs. DWELLERs are embedded in SPACEs so that they can establish interactions on the basis of proximity. Note that the definition of proximity is not necesarily the same for every DWELLER although all are subjected to the same SPACE topology: proximity depends on the senses of the DWELLERs, e.g. the proximity definition may include viewing direction, different distances etc. The behavior definition of DWELLERs often includes movements through space which implies that the proximity relations change.
SPACEs are themselves of variable structure. They can be subdivided in PATCHes. PATCHes form a hierarchical structure subdividing SPACEs. New PATCHes are generated if necessary for the DWELLERs (e.g. the SPACE is extended by a new PATCH at the root of the hierarchy when a DWELLER moves into hitherto unoccupied (hence non-existing) regions, and PATCHes at the leaves of the hierarchy subdivide if they contain a very large number of DWELLERs). The interaction of PATCHes is ancestry based.

Moreover SPACEs can be generated and deleted during runtime. Like the PATCH structure the interactions of new SPACEs are ancestry based: SPACEs are associated with DWELLERs (which themselves dwell in some other SPACE) as their SKINSPACE. SKINSPACEs can be used in many different ways. They can harbor for example parasites on the animals which are modelled in SPACESPACE. Alternatively a DWELLER can built up its 'worldview' in its SKINSPACE in the form of a (dynamic) configuration of (interacting) DWELLERs (i.e. the SKINSPACE serves as mental space). In both cases the configuration of DWELLERs in the SKINSPACE of a DWELLER is generated by- and will influence the latter DWELLERs behavior. The MIRROR universe is initiated with at least one SPACE (which often represents physical space and is called SPACESPACE). Fig 1 represents the general structure of a MIRROR universe.

3.4 Interesting events

Every event oriented description should confine itself to some extent to 'interesting events'; otherwise it runs into Achilles and the turtle problems (by introducing 'passing the halfway mark' as event, so many

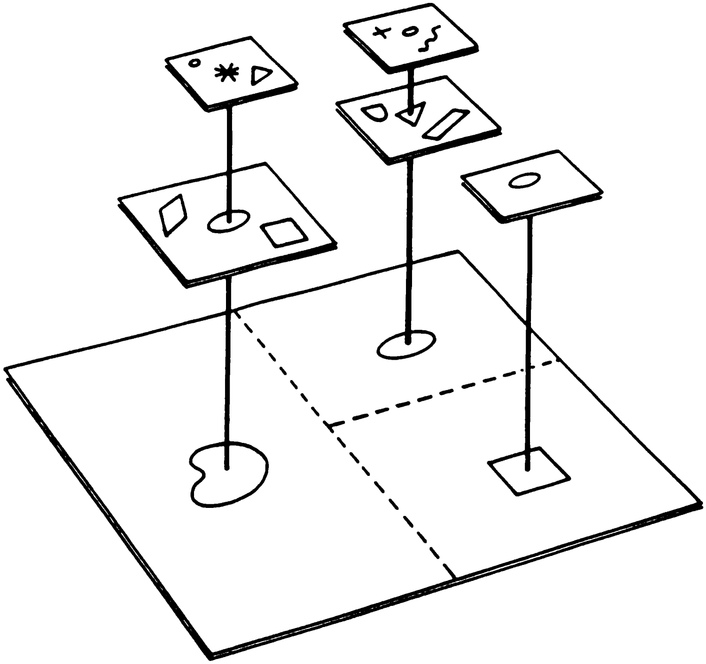

Fig. 1. Sketch of MIRROR universe which consist of SPACEs (sub divided in PATCHe in which DWELLERs (of different types) dwell. Each DWELLER may possess a SKINSPACE in which, again DWELLERs dwell.

events happen that time is effectively stopped; the paradox derives from talking about never after stopping time). We define 'interesting' events as those events which redirect the system from its expected behavior, i.e. interesting events are those events which should happen explicitely in order to know what happens in future. Which events are interesting depends on the composition of the universe, not only on single individuals. Therefore the requirements of autonomous, selfsufficient individuals on one hand and confining events to interesting events on the other hand are in conflict. This conflict can (in principle) be resolved in MIRROR by using its variable structure and knowledge seeking capabilities and the 'shadow world' (see below). The reasoning is as follows (Hogeweg & Hesper 1981b):

1. Interesting events are those events which redirect the system away from its expected course of behavior
2. The purpose of modelling is to generate and refine expectancies about the behavior of the system
3. Such expectancies should not only refer to the system as a 'whole' but in particular to partial processes (e.g. temporarily decoupled subsystems)
4. Expectancies can be formed by MIRROR entities by monitoring the behavior of the system (MIRROR entities need such capabilities anyway) and can be used to confine the events to interesting events by changing the structur of the system, by replacing (for the time being) the original entities b

entities which only incorporate the interesting transitions.
5. Expectancies are (by definition) generally wrong when interesting events occur. Thus the system should be able to fall back on its original definition, i.e. the specification before restructuring on the basis of expectancies.

This course of restructuring the model is undertaken by DWARFs (which hoard their "treasure" (knowledge base) of expectancies and make tools out of them to confine the system to interesting events). DWARFs are part of the 'shadow world'.

3.5 The shadow world

The shadow world is inhabited by DEMONs and DWARFs (and WIZARDs and SENTINELs) These are locally defined, autonomous, selfsufficient entities as are the "real world" MIRROR entities. They embody the universal properties of the MIRROR universe under consideration without violating its autonomy requirements. They accomplish the ultimate purpose of modelling itself: embodying expectancies and generating interesting events. This has always been their role in stories as well.

4. KNOWLEDGE SEEKING IN MIRROR UNIVERSES

In a MIRROR universe three types of entities are defininED to communicate what is happening in the MIRROR universe to the outside, i.e.
RECORDERs
REPORTERs
OBSERVERs

RECORDERs are the simplest. They just record the value of a variable which is defined in the MIRROR universe, or the events in which a certain entit is involved. They do not do any information processing to accumulate this information; they only output it in a reasonable form. They produce for example a protocol of the behavior of a certain entity or record all interactions of a special type. RECORDERs are all that is needed in fixed structure models. They do not suffice in variable structure models. They tend to produce bulky and irrelevant output.

REPORTERs report on global properties of the system, i.e. properties which do not occur in the model definition, but can be gathered fairly easily. Information processing is, however needed to obtain this information. Often reporters are sent into the system to report on the state of the system using those concepts which would constitute the primary entities in a fixed structure model representing a similar system.

OBSERVERs (Hogeweg & Hesper 1981a) are the most versatile: they "observe". They find interesting phenomena and tell about them in terms appropriate to the situation, i.e. their information is context dependent. Thus they are not defined in terms of what to observe, but in terms of how to observe and possess some criteria of interestingness. Interesting in MIRROR worlds are, as mentioned, patterns of interaction and the resulting differentiation between otherwise similar individuals. Such patterns have as interesting features both the individuals conforming to the pattern as those which do not conform to the pattern.
OBSERVERs can use the information gathered by RECORDERs, and they profit from the focus on interesting events caused by the DWARFs. They can also make use of the concepts formed by other OBSERVERs to evaluate their own concepts and to focus attention on interesting features.
So far only relatively simple OBSERVERs have been implemented. The most

powerful of them make use of non-supervised pattern analysis procedures, in particular cluster analysis.

Cluster analysis is routinely used in science for concept formation. Some methods (e.g. agglomerative clustering with minimal mean sum of squares as clustering criterion, Ward 1963) are very powerful filters to find consistent patterns, even if the pattern is weak. By its space dilating properties this method finds detailed patterns in those parts of the state space in which much information is available, i.e. it focusses attention on those parts, and, by taking a coarser view of other parts, the method pinpoints exceptional cases (Hogeweg 1976, Hogeweg & Hesper 1981).

The validity of cluster analysis and the generated clusters should not be sought in statistical properties (its power is to provide context dependent information), nor in the ability to recover a priori well defined concepts (compare Michalski & Stepp (1984), who reintroduced cluster analysis in AI context, but modified, to conform to apriori notions about classes). Instead the validity lies in the interpretability (e.g. consistency, local order preservation, (partial) coincidence with other known concepts etc.) of the label information of the extensively defined classes (Hogeweg & Hesper 1981). Thus cluster analysis can (slightly) redefine apriori notions so as to give rise to consistent patterns (see e.g. Van Honk & Hogeweg 1981, Mastenbroek et al 1984), which would not be found otherwise.

In MIRROR worlds OBSERVERs using cluster analysis can for example be used to find groups of individuals which do interact with a similar group of other individuals, using as primary information a record of all interactions (of a certain type). If the groups of individuals selected in this way remain the same during some time, interesting information about the structuring of the interactions is found: later changes in this pattern are very interesting events!
These groups of individuals can be lumped in a next step of pattern seeking processes. The groups become even more interesting if the same groups can be found in other characteristics of the individuals under consideration (e.g. their SKINSPACE configuration). Moreover supervised pattern analysis techniques can be used to characterise the groups, to find typical and exceptional cases etc.
Examples of the use of such OBSERVERs are given in the next section.

More sophisticated OBSERVERs should be able to trace the interesting events which lead to such patterns and tell stories about how it all came about.

Note that OBSERVERs are not alien entities in a MIRROR universe: DWELLERs and DWARFs also gather knowledge. The difference between OBSERVERs and those other entities is that observers do not leave traces in the environment and do not change the structure of the system: they only observe. In addition OBSERVERs establish relations with other OBSERVERs REPORTERs and RECORDERs on the basis not of proximity in SPACESPACE but on proximity in 'knowledge'space.

5. EXAMPLES OF MIRROR MODELS

The examples given aim to demonstrate:
1.the need for variable structure models
2. the complex structures that can be generated by relatively simple variable structure models
3.the need for knowledge seeking in such models
4.how knowledge can be incorporated in biotic systems as 'side effect' of other concerns

5.1 Social structure of bumble bee colonies, or how do Bumble bees know when the season ends?

Bumble bees are truly social insects somewhat more primitive then honey bees. Only the queens survive the winter and start a "solitary" life in spring. They build a nest, lay eggs,forage etc. Later the worker offspring take over all duties except egglaying. At the end of the season the workers, however, "rebel", the queen is thrown off the nest and some of the workers start laying unfertilised (=drone) eggs, and the last eggs laid by the queen are reared so as to produce not workers but new queens. By timing the rebellion (and therewith the switch to the production of generative offspring) at the appropriate time (i.e. as late as possible, but early enough to get the generative offspring "off the line"), ergonomic optimality of the nest as a whole can be achieved (Oster 1976, Oster & Wilson 1978). The question is how the appropriate "collaboration" (i.c. rebellion) is achieved without introducing some global control mechanism, or introducing a prepattern like a change in the environment (experimentally the switch occurs at the appropriate time in a constant environment) or senility of the queen (experiments show that old queens still can "manage" young nests).

This is obviously a variable structure system: the number of individual bees (the relevant information processing entities) increases from 1 to about 500. Moreover they interact with each other in various ways. This interaction seems, moreover, to cause a differentiation between initial identical workers: some lay eggs at the end of the season and others do not. Van Honk and Hogeweg (1981) have shown that in experimental nests the dominance interactions between bees and the laying of eggs are related.

Simulating this system as a fixed structure system would require either lumping bees in apriori defined compartments and defining transitions between these compartments (which would beg the question of how the differentiation comes about and which factors influence the nest composition) or including not yet born individuals as quiescent entities and accepting a tremendous overhead in (the selection of) interactions (all bees interacting but many interactions amounting to nothing).

In contrast, the variable structure MIRROR model is very simple (Hogeweg & Hesper 1983,1985). The universe consists of the nestSPACE, in which the bees dwell. The interactions between bees are regulated by proximity in nest space (which is simply subdivided in the PATCHes CENTER, PERIPHERY, POT (i.e. the honey pot in which food is stored) and OUTSIDE; proximity is in this case determined by random drawing in the PATCH in which a bee is). On interaction the BUMBLEs simply do what there is to do (we call this the TODO principle) with the type of entity they meet: they feed larvae, dominate (or are dominated by) adults etc. When hungry (this is signaled by a DEMON which monitors the amount of food not yet digested or given to larvae) they go to POT; when they find POT empty they go foraging. In this way, what the BUMBLEs do depends on the composition of the nest, but no global control whatever is included.

The dominance interaction causes the differentiation in the MIRROR universe. When DOM is a numerical value representing the dominace of an individual, this interaction (called DODOM) is defined as:

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1.Display of the current DOM value of each of the bees
2.Determining who wins:
      if $rand(0,1) < DOMi/(DOMi + DOMj)$ then $k=1$ (i wins)
                                           else $k=0$ (j wins)
3.Updating of the DOM values:
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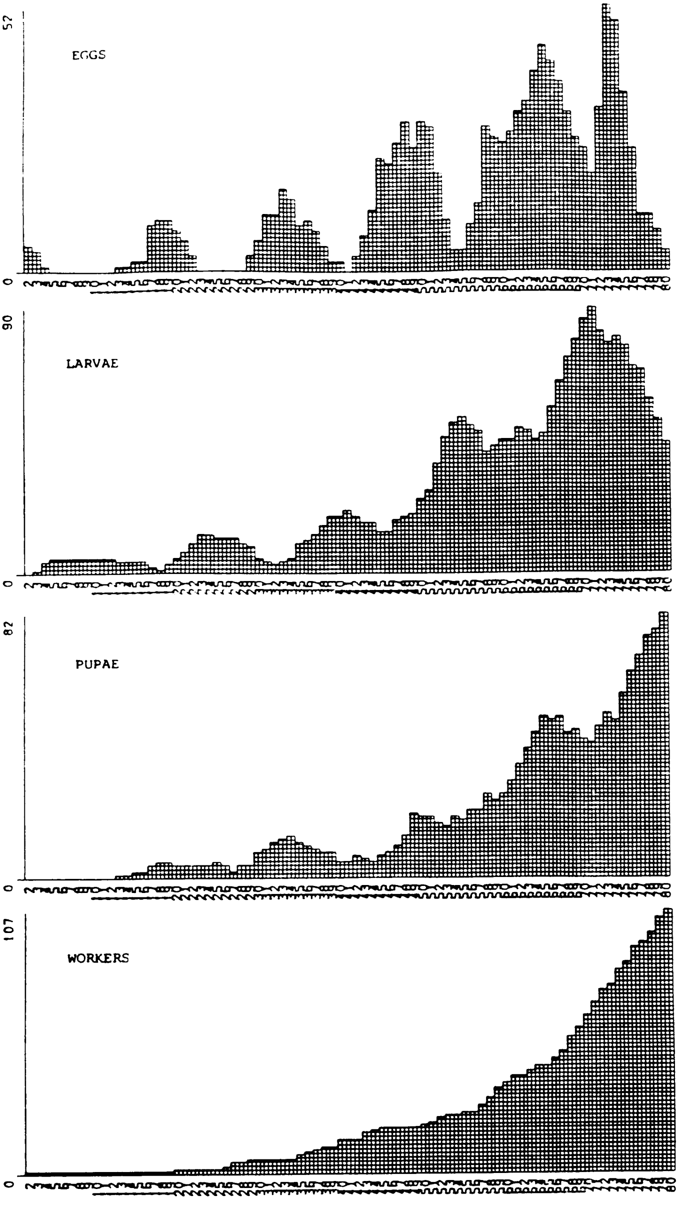

Fig. 2.

Population structure of a (simulated) Bumble Bee nest through time. Horizontal axis: time in days. Vertical axis: number of eggs, larvae, pupae and workers respectively.

DOMj = DOMj - (k-DOMi/(DOMi + DOMj))
This updating causes an "expected win" to generate little change and an unexpected one a big change: DODOM is a form of ritualised dominance behavior. We think that such a ritualised dominance behavior underlies much social organisation.

We have shown (Hogeweg & Hesper 1983,1985) that the so defined MIRROR world generates all the social complexities of a bumble bee colony known so far. In fact it generated several behavior patterns which we did not know existed in bumble bee colonies but which were confirmed by experimental studies later.
However to find this out we needed all our information gathering entities: RECORDERs, REPORTERs and OBSERVERs.
RECORDERs provided us with basic protocols similar to those gathered by experimenters (in our case van Honk (see Van Honk 1981, van Honk & Hogeweg 1981, and Van Doorn (see Van Doorn & Heringa 1985): i.e. a recording of all pairwise interactions (and who wins) and sometimes protocols of the behavior of individual bees.
REPORTERs provided us with an overview of the nest composition in terms of population numbers of the various developmental stages (eggs, larvae pupae, workers, newqueens and drones, see fig 2). It shows that the population structure shows the same uneven composition as is the case in experimental nests.
OBSERVERs were used to observe the differentiation of workers (as a result of differential interaction patterns). Using cluster analysis on the interaction data gathered by the RECORDERs they recognized elite workers and common workers as well as a transition group. The behavior of these groups was similar to that observed by van HONK & Hogeweg (who used cluster analysis to find the groups) although in fast growing nests the groups were less stable then the ones observed by them. Later Van Doorn found that this is also the case in experimental nests (van Doorn & Heringa 1985).

A very striking property of the MIRROR bumble bee nests was the fact that the switch from worker to generative offspring production occurred at a fixed time, was caused by the interaction pattern in the nest, but was independent of growth rate of the nest (Hogeweg & Hesper 1985). Although the time of the switch (=killing of the queen) is of course easily recordable, the timing could only be understood in relation to the dynamics of the elite vs the common worker group as elucidated by the OBSERVER: In fast growing nests the elite was much less elite then in slow growing nests where the elite resembles the queen closely at the end of the nest development.

We conclude that knowledge about the duration of the season is incorporated in the DODOM interaction in combination with the TODO of bumble bees. By coding in this way this knowledge is preserved notwithstanding variations in climate or individual idiosyncrasies of the bees (Hogeweg & Hesper 1985).

5.2 SKINNIES: their world view and personal aquaintances

In contrast to the previous example (which can be considered as either modelling s.s. of Bumble bee colonies or as defining a TODO/DODOM paradigm system in the context of bumble bee population dynamics and maintenance behavior) the present example is a pure paradigm study: SKINNIES are not supposed to represent any real world object. Instead SKINNIES were defined as a minimal informatic system in which the DODOM/TODO principle operates and in which the individuals know each other personally.

Knowing each other personally only makes sense when relevant information

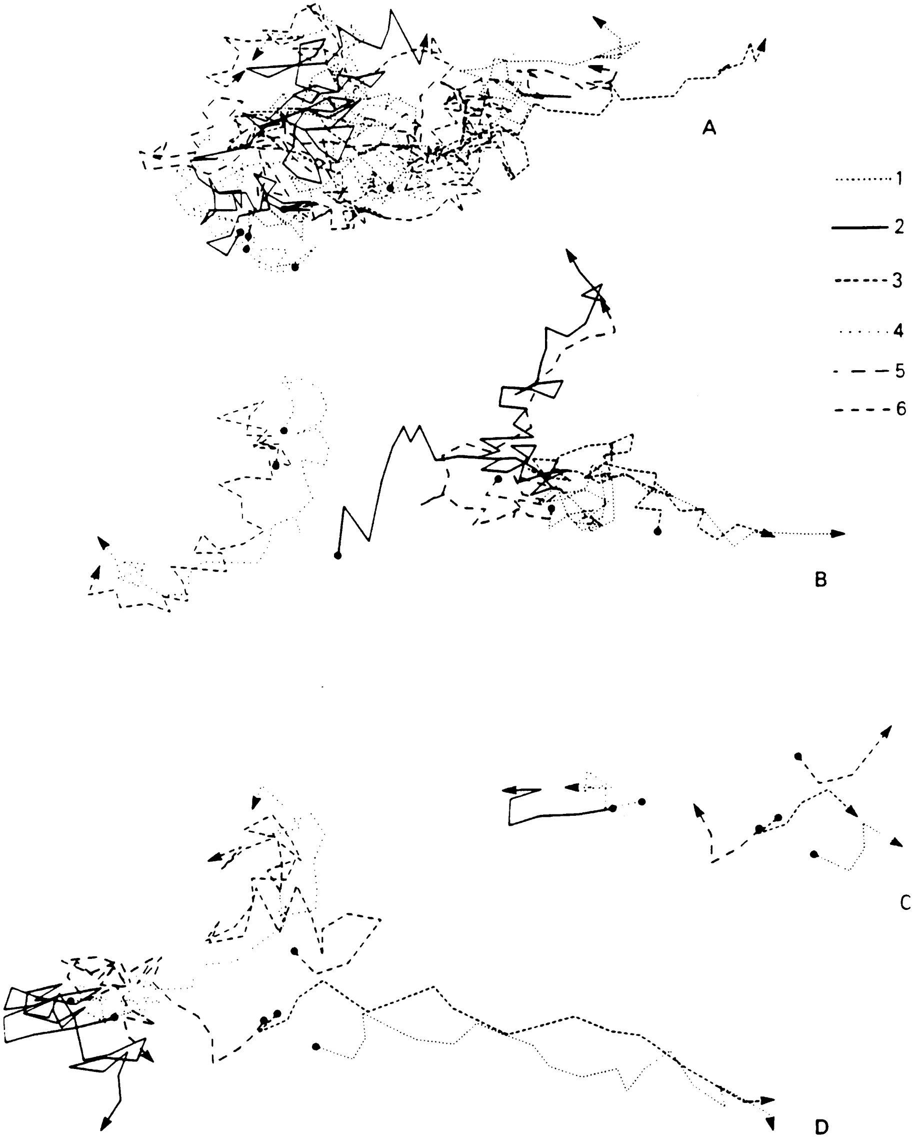

Fig. 3. Paths of SKINNIES.

3a. Period 0-70: the SKINNIES, who started their life with an undifferentiated "world view", initially stay roughly together and move back and forth in an unstructured manner.

3b. Period 70-120: Pairs of SKINNIES split off and move away together. When such pairs meet again, or

3c. When the SKINNIES are reinitiated in a random configuration they quarrel bu

3d. Walk off in the same pairs again.

cannot be sensed directly on encounter. Indeed bumble bees do not seem to know each other personnally but the DOM value seems to be directly sensible as pheromone (= chemicals used for communication between animals) composition and concentration. In SKINNIES the DOM value is supposed not to be sensible, in fact it does not exist as such (see below). On encounter SKINNIES however recognise each other and refer to the internal representation of the other SKINNY in their SKINSPACE to access its (assumed) relative DOM value. In this most simple case the internal representation of the SKINNY only constitutes its DOM value (i.e. its location in a one dimensional SKINSPACE).
DODOM operates both in SKINSPACE and in SPACESPACE. In SKINSPACE it is defined identically to DODOM in the bumble bees, i.e. direct sensing of the mutual DOM values, determining who wins by random drawing and the relative dominances and finally updating of both dominances in accordance with the probability of the outcome of the interaction (see previous section). In SPACESPACE DODOM is defined similarly but:

1. The display of dominance is the relative dominance in each of the SKINSPACEs, i.e.
    Di=DOMi/(DOMi+DOMj) in SKINSPACE of SKINNYi
    Dj is defined similarly in the SKINSPACE of SKINNYj
(Note that in MIRSYS no absolute indices i and j exist but that each individual refers to "me" and "you")

2. The winning is defied as before but using Di and Dj

3. The updating happens in SKINSPACE It is based on who wins in SPACESPACE and the expectancies available in the SKINSPACE under consideration (Note that this is the only possible interpretation of "expected" in this context), i.e. is identical to the SKINSPACE updating described above.

Thus a straight forward generalisation of the DODOM interaction is achieved.
TODO is defined very rudimentarily as yet. It only includes some spatial behavior associated with the DODOM interaction. On encounter of another SKINNY (a SKINNY is obliged to react if anybody is nearer then a certain distance (compare the critical distance known of many animals) it first performs a DODOM in its SKINSPACE. If it looses this imagined interaction it moves away. If it wins it displays its relative dominance (which not withstanding its winning may be relatively low) to the other and a DODOM in SPACESPACE takes place. If it wins it moves towards its opponent, if it looses it moves away. The only extra assumption in the SKINNY paradigm is that they are gregarious: if they are too far from other SKINNIES they move towards them.
The so defined SKINNIES show interesting behavior. If they all start with an equal "world view" (i.e. with the same configuration in SKINSPACE, i.e. with an equal estimate of all dominances which are in addition assumed initially equal) they first stay roughly together moving back and forth without covering much distance (see fig 3a). After some time, however, pairs of SKINNIES split off from the rest and start making "mileage" (fig 3b). When such pairs meet each other later on (the SPACESPACE is toroidal) there is some quarrelling but sooner or later they move apart again, forming the original ("harmonious") pairs (fig 3c,d). (this is not always the case but there is a clear preference for the old pairs). This differential coupling between SKINNIES is, of course easily observable when their movemements are displayed. However, why on earth (in SPACE) do SKINNIES form such "friendships"?
OBSERVERs found an answer:

On clustering SKINSPACE configurations the same pairs are formed as those walking off in SPACESPACE (fig 4). Apparently such pairs build up a similar "worldview" (because they see the same). Having the same worldview they behave similarly towards "foreigners" and so stay together (they bounce of in the same direction in SPACESPACE). Note that the SKINNIES forming pairs are by no means the same: they only agree about their mutual dominance. OBSERVERs also observed that if individuals are characterised by how they are represented in the SKINSPACE of other individuals a (stable) dominance hierarchy was recognised (fig 5)

These results are intriguing. Clearly SKINNIES have severe shortcomings as representations of organisms: their TODO is only social and does not contain any maintenance constraints. This fact is probably responsible for the counterintuitive phenomenon (not often observed in animals) that dominant SKINNIES follow submissive ones.
Nevertheless we think that the worldview, spatial configuration, alliance relationships displayed by the SKINNIES under influence of DODOM interactions are observables interesting enough to try to use them in studying groups of animals, e.g. monkeys.

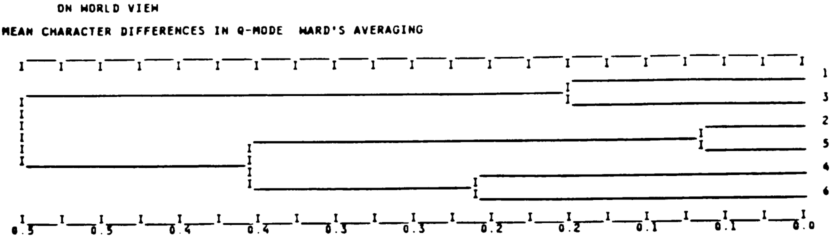

Fig. 4.

Clustering the SKINNIES on the basis of the configuration of DWELLERs (representing the SKINNIES) in their SKINSPACE (i.e. on their world view) at time=200. The pairs of SKINNIES emerge which walked off together (see fig. 3).

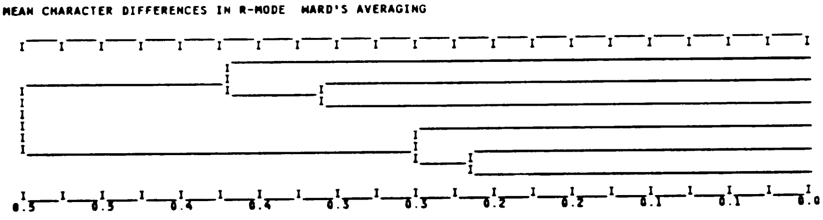

Fig. 5.

Clustering the SKINNIES on the basis of the location of their representations in the SKINSPACES of other SKINNIES (i.e. on the others estimate) at time=200: a dominance pattern emerges: SKINNIES 1, 2, 6 are dominant ones and 3, 4, 5 are submissive ones. The latter tend to be in front when the SKINNIES walk in pairs (see fig. 3).

6. EPILOGUE

Most modelling and simulation studies and most AI work is strongly "supervised": desired behavior of the systems is predefined (as input/output relations. as solution to problems, as correct diagnosis, as conforming to behavior of experts etc.). In contrast our work on knowledge seeking in (variable structured) paradigm systems is strongly non-supervised and aims at discovering new observebles, entities, concepts and relations. Likewise, the work of e.g. Lenat (Lenat 1975,1984; Davis & Lenat 1981, in the the program called AM) aims at discovering new concepts (at least new for the program; no concepts new to mankind were discovered so far), in his case the concepts of number theory given elementary set theoretic concepts (the program discovered for example the concept prime number). There are several similarities between his approach and ours although these similar structures may appear at different levels in the two cases.
1. Both emphasize the use of paradigm systems. Studying paradigm systems is an a priori goal in our approach whereas AM invents (in its simple universe of numbers) paradigm systems in order to have material to find patterns.
2. Both are variable structured individual oriented systems. The individuals communicate via a common environment (the MIRROR universe, the knowledge base).
3. Both are scheduling events (time axis in MIRROR, agenda in AM).
4. Both relate concepts via their extensive definitions (individuals to which they apply in MIRROR, numbers to which they apply or which they generate in AM)
5. Both use similar general heuristics, e.g. find extreme cases, find typical cases etc.)
6. Both use criteria for "interestingness" (e.g. an definition of "interesting" as concepts which share a similar extensive definitions is used in both systems).

Important differences stem from the fact that:
1. in MIRROR knowledge is sought in an autonomously changing universe, whereas in AM numbers are numbers and only what we know about them changes. Therefore AM seeks only invariant relations whereas we seek semi-invariant relations and the interesting events changing the structure of the system
2. comparison of numbers is easy (they are the same or different) whereas the comparison of individuals or relations are more difficult (we need the concept 'similar' and non-supervised pattern detection methods)
3. communication in AM is unlimited (the entire universe (=knowledge base) is accessible to all modules) whereas in MIRROR the MIRROR universe consists potentially of many (possibly imcompatible) worlds (SPACEs). The latter is certainly the case in socio- or ecosystems and we think it is true also in epistemic systems (which we simplistically circumscribe as 'insight seeking' systems).

Finally we note that the most exciting possibilities for merging modelling methods and AI methods is in employing variable structured modelling in modelling epistemic processes (the ultimate goal of AI). After all not all our thought is of the form of an inference machine. A rather large amount has the form of interesting event simulation: stories reflect such epistemic processes. Likewise we think that a knowledge representation in the form of sequences of interesting events instead of in the form of invariant relations would enhance science.

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