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COPING WITH COMPLEXITY :

concepts and principles for a support system

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1. Introduction

It does not need to be argued that life in society today is more complex than it ever was. Through the new media of communication and transport our horizon has widened radically, and we have the possibility to interact with an ever growing array of people, of organizations, of media, of knowledge. Each of these systems may support us in solving existing problems, but together somehow they seem to create new problems of an unseen complexity.

Intuitively it appears that the easier systems can interact, the faster they will change, both individually and as a collective. The faster the evolution of the global system, the more difficult it becomes for the individual subsystems to remain adapted. This explains why so many people nowadays experience feelings of stress, of anxiety and meaninglessness. The changes are so rapid, and depend on so many factors, interacting in the most intricate ways, that it has become impossible to make predictions, except for the shortest time intervals. Everything appears uncertain and ambiguous. We cannot even take the time to think everything over, because in the meanwhile the problem we are reflecting about may have turned into a catastrophe. Illustrations of this difficulty are legion: AIDS, the threat of nuclear war, pollution, over-population...

Our biologically inherited constitution seems insufficiently prepared for living in an environment as complex as the present society. Handbooks on stress management emphasize again and again that the genetically determined "fight or flight" reaction is ill-adapted for coping with the problems we are confronted with in our every-day lifes. Yet we should ask the question whether our present environment is indeed more complex that that of prehistoric man. Perhaps the complexity is merely of a different kind? It can easily be argued that the tropical forest in which the apes, ancestors of man, have evolved, is an extremely complex system, consisting of a network of interacting biological and physical subsystems, which is constantly changing.

Yet you do not need the intelligence of a human being, nor even that of an ape, in order to adapt to such a complex environment. Indeed, even very simple creatures such as snails or worms manage to survive in these ever-changing surroundings. The environment as experienced by a snail (its "Umwelt") is clearly much less complex than that of man or ape.

The snail is adapted because it succeeds to reduce the global complexity by only attaching importance to those very simple phenomena which are directly relevant for its survival : heat and cold, moisture, food, light, ... The snail's sensitivity for these basic variables is due to its physiological organization, which has emerged through an evolutionary process characterized by variation and selection.

In the same way, we, as human beings, have inherited a number of mechanisms for distinguishing important phenomena, while ignoring or filtering out irrelevant details. This selective attention allows us to make sense of the very complex, ill-structured information we receive continously through our sensory organs. Yet we are completely unaware of this process of perceptual structuring and filtering, which is continuously taking place in our nervous system.

Some of the principles governing this process were uncovered by Gestalt psychology (Stadler & Kruse, 1989). The fundamental Gestalt law of "Prägnanz" states that a complex set of stimuli will be interpreted in such a way that the pattern which is extracted is the simplest possible. It is because of such basic physiological mechanisms that a human being is able to adapt to an environment bombarding him with complex stimuli.

Can we then maintain that our present environment is so much more complex than the environment of sensory stimuli (vision, hearing, touching, ...) provided by a natural biotope such as a tropical forest? Not in any absolute sense. The information provided by our present socio-cultural environment is simply different in kind : the data are symbolic rather than sensory. Our education has given us some tools for manipulating abstract, symbolic information (mainly verbal language and some rules of "rational" thought), but these are much less developed than the subtle and intricate mechanisms of perception. With an amplification of the communication media, however, comes an amplification of the amount of "symbolic stimuli" (sentences, texts, drawings, formulas, scientific concepts and models, cultural traditions, ...) we are to process, and hence the traditional methods for symbol processing become insufficient.

The new environment demands a new adaptation mechanism, allowing to reduce and manage complexity on a higher, more abstract level. The communication media (telephone, television, computer networks, printing press, ...) may have provided us with new sensory organs, but they have not yet provided us with the accompanying interfaces for processing the new information they produce. In order to cope with complexity we will then have to devise new support systems, functioning as a kind of externalized perceptual or cognitive systems, and thus extending the function of our inherited or learned complexity reducing procedures.

The present text will discuss some basic principles, partially inspired by Gestalt mechanisms, which may help us to design such support systems. Let us first shortly review how problems can be structured.

2. Problem Complexity and Distinction Systems

A problem can in general be defined as a *change* of situation desired by some actor, but such that the actor does not immediately know how to bring about this change. A situation is a relation between the actor and his environment, as experienced by the actor. The actor, by definition, is able to choose between several actions, leading to particular changes. An action can be either a primitive, physical act (e.g. walking, talking, or grasping), or the use of some tool or resource external to the actor (e.g. a hammer, a telephone, another actor, a firm, a social service...). The "tools" which are very broad in their scope of application, i.e. which can contribute in solving a large class of problems or help a large class of actors, may be called "support systems" (de Zeeuw, 1985). Problem-solving can then be defined as the selection and ordering of the actions or tools the actor can dispose of, in such a way that the resulting complex of actions (connected in sequence or in parallel) is able to produce the desired change (without simultaneously producing undesired changes).

The more varied the environment, the larger the variety of distinct actions the actor needs for controlling the situation. The larger the choice of simple actions, the larger the possibilities for combining these actions into action complexes. The growth of the number of action complexes in function of the growth of the number of primitive actions is extremely rapid (at least exponential). E.g. assume that there are 100 primitive actions, which are to be combined in a sequence of 10 subsequent actions. There are 100^{10} = 100,000,000,000,000,000,000 different possibilities. If we allow parallel combinations too, then the number of complexes becomes even larger. Here we encounter the problem of complexity : even for relatively short sequences the choice of an action sequence is very difficult, because a very large class of possible candidates is to be scanned in order to find an adequate one. Clearly it is practically impossible to examine each possibility separately in order to determine which one will solve the problem in the best way. This means that we need some method or plan to guide the decision-making.

Let us analyse in general how the complexity of the decision may be reduced. A problem as said is defined by a desired *change*, and a change can be defined as a *difference* between the initial situation and the final situation, when the problem is solved. In order to represent a difference we need some description of possible initial and final situations such that some features are present in the one situation and absent in the other one. Each "feature" represents a potential difference between two situations.

The relation between presence and absence of a feature, as experienced by the actor, may be called a *distinction* between the two situations. Let us look at some basic types of distinctions. Perhaps the simplest one is that between the presence and the absence of an object. An object which is present may or may not have a specific property, e.g. a certain colour, or a certain position. This determines another type of distinction. Properties can be predicated to objects and this determines atomic propositions. These can be combined by conjunction, disjunction, negation, ..., in order to form molecular propositions. The relation between a proposition and its negation determines a more abstract type of distinction. Other fundamental distinctions are those between past and present, between desired and not desired (Heylighen, 1987, 1988).

Assume now that we would have analysed the desired change, and thus have determined a list of differences (e.g. 10 differences) between initial and desired situation. In the ideal case each difference could be reduced by one action. In the previous example this would mean that for each of the 10 differences we would have to make a choice out of 100 possible actions, in order to find which of these actions would reduce the corresponding distinction. In total we would have to consider 10 x 100 = 1,000 different possibilities. Clearly an enormous reduction in problem complexity has taken place by assuming that the problem can be cut up in separate differences, corresponding to separate actions.

A further complexity reduction would occur if we did not have to test each action separately in order to see whether it is capable of reducing a particular difference, in other words if we would *know* the difference-reducing features of each action beforehand. Such knowledge might be formulated in condition-action rules of the form:

if difference *a* is to be reduced
then apply action *A*.

In the case of complete knowledge the number of possibilities to be explored would then be reduced to 1, a reduction in problem complexity by a factor 10^3. This reduction factor, however, is much smaller than the previous one of 10^{17}. (of course, this difference depends upon our previous assumptions about the number of actions and of differences).

In general, it would appear that the knowledge of condition-action rules would be less important than the more primitive "knowledge" of *how to make the adequate distinctions*. Indeed, "if ... then..." rules can only be formulated if the conditions for the application of the rule, and the corresponding actions, can be *distinguished*. It is with the analysis of this last type of knowledge that we will be concerned.

But which criterion will allow us to discriminate between adequate and inadequate distinctions? The difficulty to be surmounted is that there is in general no one-to-one correspondence between differences and actions : either more than one action will be needed in order to reduce a given difference, or more than one difference will be reduced by a given action.

The first problem may be resolved by combining several actions in a complex so that this complex would be sufficient to reduce just one specific difference. Such "macro-actions" may be constructed by grouping actions in sequences, or by arranging resources in "support systems".

The second problem is more serious, however, because it points to an interaction between different changes. It means that it is in general impossible to find an action which will reduce just one particular difference. The application of the action will have *side-effects*, i.e. it will produce undesired changes. In order to counteract those changes other actions will be needed. But these actions in general will also have side-effects. The danger is real that a situation arises in which every action applied to solve one subproblem will engender more than one new problem, so that the goal situation will move farther away with every attempt to approach it.

How can such complex interaction between actions be managed? The only general method seems to be that we would choose the distinguishing features in such a way that they would be as *independent* or *invariant* as possible. In fact the design of macro-actions mentioned above, can also be considered as the distinction of a system or "module" of connected actions, which is maximally invariant. This means that in the limit there would be at most one action (or complex of actions) which would be able to reduce a given difference; all other actions would leave the difference invariant.

The whole of interrelated distinctions (both determining "differences" between situations and "separable" action complexes) constitute a model or system, representing the problem domain as experienced or known by the actor. Such a distinction system may be called a *representation* (Heylighen, 1987, 1988). (remark that a representation thus defined is not a homomorphic image of "reality", but a subjective structuration of a complex problem situation). We will now discuss representations which satisfy the requirement of absolute distinction invariance.

3. Classical science and closed representations

The aim of classical science is to gain complete knowledge about a certain domain, so that all problems within this domain may be solved by a deterministic application of the available rules. This means that for each problem there would be a function or algorithm mapping the initial situation upon the desired final situation. Of course this ideal cannot be reached in practice. Yet it is helpful to study the theory which is closest to the deterministic ideal : classical mechanics.

The static (or kinematic) representation elements of classical mechanics (objects, predicates or properties, propositions, states, time, dynamical constraints, ...) may be considered as distinctions. Actions are represented as dynamical operators, mapping initial states upon new states. It can now be shown that all structural distinctions in the classical representation frame are invariant under all possible operators (Heylighen, 1987, 1988). The only things which change are the states. But even here the changes are constrained by the principle of causality : "equal causes have equal effects" which can also be formulated as "distinct initial states (causes) are mapped upon distinct final states (effects)". This means that in a certain sense all distinctions between states, determining the state space, are conserved. There is only a shift of "actuality", so that a state which was actual becomes potential, whereas a potential state becomes actual.

Classical representations may thus be characterized as maximally invariant distinction systems. This entails all the typical features of classical, mechanistic theories : determinism, reversibility, causality, absolute space and time, Boolean logic, perfect rationality, ... (Heylighen, 1987, 1988).

Although these features may appear very attractive, they have some major drawbacks. One is that even though all ambiguity and uncertainty is eliminated, the problem of complexity remains. The number of states and operators in classical mechanics is in general infinite. It is not sufficient to have deterministic algorithms for computing the solution of a problem if this algorithm may need an infinite time to produce the result. In practice one will attempt to cope with infinity by using higher level formalisms, such as analysis and geometry, but here the practically applicable procedures are limited to very simple cases. For example, it is still impossible to compute the evolution of a mechanical system consisting of more than two interacting objects (the so-called three-body problem).

A more serious drawback is that the assumption of absolute distinction invariance is clearly unrealistic if processes more complex than mechanical movement are considered. All phenomena where something qualitatively new emerges, e.g. thermodynamical self-organization, biological evolution, most cognitive processes, socio-cultural evolutions, ..., can be characterized by differentiation, i.e. the creation of new distinctions. Such phenomena simply cannot be represented within a classical theory.

This may be understood by noticing that a traditional scientific theory is *closed* : no knowledge (i.e. distinctions or rules) may be added to the theory, or taken out of it. Every information derivable with the theory is already (implicitly) present within the theory's postulates. Formally this may be explained by remarking that the set of operators in classical mechanics forms a group : the composition of operators is internal, associative, and it has neutral and inverse elements. In other words, any complex of actions from the group may be reduced to another action of the group, and this composed action may always be reversed by applying another action from the group, its inverse. Hence whatever you do, you always remain within the immediate neighbourhood of the point you started from. This "group" closure is formally equivalent with the requirement of absolute distinction invariance (Heylighen, 1987).

The fact that no extra data may be added to the framework leads to the requirement that the data on which the model is built be *as complete as possible.* The aim of classical science can indeed be formulated in this way : to construct a representation of the system under study, which is as complete as possible (a so-called canonical formulation, cfr. de Zeeuw, 1985). Once such a representation would be attained, we would no longer need the system in order to determine its behaviour : the model could *replace* the system. All possible problems could be solved by manipulating the model. Such a philosophy still governs much scientific research at present, even in recent areas such as artificial intelligence.

However, there are several reasons why such a complete model is in principle unreachable. First there are fundamental restrictions on the amount of information we can get about a system, as shown by the uncertainty principle in quantum mechanics, the second law in thermodynamics, and the Gödel theorem in mathematics. Second, and perhaps more practically, we must not forget that a model should be simpler than the system it represents. Otherwise the manipulation of the model would be as complex as the manipulation of the system, and hence nothing would be gained in problem-solving efficiency. Finally, even if these two limitations would not apply, the complete modelling of a realistically complex system would demand so much time and effort that the problem to be solved would either have disappeared spontaneously or turned into a catastrophe before the model would be finished. (in a certain sense, the three arguments listed here may be reduced to the same principle of the impossibility of self-representation, see Heylighen, 1987).

4. The structuring of open representations

We may then state that a practical problem representation should be *open*, i.e. it should be possible to introduce new data or structures (distinctions, rules) and to eliminate redundant or obsolete knowledge. In this way the representation would be adaptive, it would be able to learn or to discover new concepts. Moreover it should be possible to view the data at different levels of abstraction, i.e. with more or less detail, so that no more distinctions would have to be considered than necessary in order to solve the specific problem. But how can we achieve such a system?

One way to model an adaptive representation structure is by moving to a higher level of description, a *metarepresentational* level. The language or representation at this level would not speak about the concrete problem domain but about the possible representations of this problem domain, and the way they might be transformed (Heylighen, 1987, 1988). Such an approach is typical for Systems Theory and (second order) Cybernetics (cfr. Van Gigh, 1986). The representation of dynamical evolution typical of classical representations might now be applied at this metalevel. In principle it would suffice to represent all possible representation systems by points in the state space of the metasystem. A change of representation could then be modeled by a transformation in this space (cfr. Korf, 1980).

The difficulty with such an approach is that it remains very complex, since you should in principle be able to globally specify all potential representations, in order to represent the state space of the metarepresentational system. In practice only part of the representation will change at a given time, so only local transformations would be needed. Here we may introduce the principle of *default reasoning* : if there is no specific reason to doubt the adequacy of a rule or distinction used in the past, then by default this rule may be assumed to remain valid. This is another way of expressing the philosophical principle that you should be prepared to question any assumption, but that you cannot question all assumptions at once : the questioning of any particular assumption is only possible standing on a ground formed by stable knowledge. The cognitive principle of default reasoning might then formulated most generally as: a distinction or rule is assumed to be invariant, unless specified otherwise.

This leads us to characterize an open representation system as a system in which any part may be replaced, but in such a way that during a given change most of the other parts remain invariant. What we need to do now is to determine: a) which are the replaceable parts of a problem representation, and b) how a replacement takes place.

Let us begin with the second question. Any change or evolution may be described through the paradigm of *variation-and-selective-retention*. The variation of systems may be modeled as a (blind or random) recombination of subsystems, leading to a new assembly (cfr. Simon, 1962; Heylighen, 1988). If this assembly is in some way stable or adapted it will be selected, and hence "survive" as a new (sub)system. Otherwise it will fall apart and its parts will become available for new recombinations. The transition from temporary "assembly" to stable "system" may help us to answer the first question : what characterizes the parts or subsystems of a representation system which are stable enough to maintain most of the time?

The above argument about the stability of assemblies is used by Simon (1962) to motivate the prominence of "nearly decomposable" systems, i.e. systems consisting of subsystems which are only weakly coupled, and which are arranged in a part-whole hierarchy. Such approximately independent subsystems are usually called *modules*, and the fact that a complex system can be decomposed in such subsystems is called *modularity.* Seeking for modularity is about the only universal method for coping with complexity in computer science. It forms the base for paradigms such as structured programming, declarative knowledge representation and object-oriented systems.

Yet some things are lacking in the concept of "module". There does not seem to be a universal and explicit definition of a module. One of the defining features is that the application of a module should have no side-effects: the change produced by a module (or in a module) will only affect one, or a few, well-defined modules in the system, but the type of change depends on the particular representation system. Modules are usually viewed as (abstract) "objects", i.e. more or less "rigid" systems located in a finite region of (abstract) space, with a clear boundary separating inside from outside. The "modularization" of a system then corresponds to a *classification* or partitioning of the internal elements of the system into finite non-overlapping subsets, distinguished by invariant boundaries.

However there are other ways of analysing or structuring a complex system into relatively autonomous subsystems. For example, we might distinguish independent dimensions through a *factorization* of variables. The difference between classification and factorization may be likened to the difference between the statistical techniques of cluster analysis and factor analysis. A factorized dimension is clearly not restricted to a finite local region: it may extend infinitely. Moreover it does not seem to have anything like a topological boundary. Hence it does not correspond to a module.

It is clear then that in order to model the relatively invariant parts of a representation system we need a concept which is more general, and, if possible, better defined than the concept of module. For this we may go back to our analysis of classical representations. There it was argued that the invariance of distinctions corresponds to the closure of the system, but we wanted to exclude any global or absolute closure. This, however, does not exclude relative or partial closures of subsystems within a larger, open system. In this way distinctions would be only incompletely or locally invariant, yet stable enough to form the base of a well-structured, manageable system. But how can we define closure in a more general way?

5. Closure as general criterion for distinction invariance

The closure of a system can be defined as the *internal invariance* of a distinction (or distinction system) defining the system (Heylighen, 1989). Internal invariance means that the distinction is mapped upon itself during the application of transformations inherent in the system. Such a "transformation" is merely a different word for a subsystem, since each (sub)system can be viewed as a relation transforming input into output (cfr. Mesarovic & Takahara, 1975). The closure of an assembly of subsystems then signifies that the subsystems are connected (through their input and output) in such a way that some overall order, structure or organization may be distinguished, which is invariant under the dynamical processes generated by the interaction between the subsystems.

An example of such an organization is that of an algebraic group, discussed in the section on classical representations. Whatever the dynamics of the system, activating one transformation after another one, the resulting changes will always remain "within the system". A so-called *second order change* (cfr. Watzlawick et al., 1974), "jumping out of the system", is only possible if the group structure is broken up. A group could be a finite local system (e.g. the group of permutations of a finite subset), corresponding to a "module", or an infinite system (e.g. the group of translations in the *x*-direction in Euclidean space), corresponding to a "dimension".

The concept of a "closed" system is more general than that of a group, however. A group is merely a very clear example of the generic concept, because it combines several, more elementary types of closures: *transitive* or recursive closure (the internality of composition in a group), *cyclical* closure (the existence of inverse transformations), and *surjective* and *inverse surjective* closure (the bijectivity of group transformations) (Heylighen, 1989). The different combinations of these 4 basic closures define a wealth of closed structures, which are weaker than that of a group. For example, the combination of transitivity and cyclicity defines an equivalence relation. The combination of transitivity and non-cyclicity defines a partial order. The addition of surjectivity to this combination results in a tree structure or hierarchy; the further addition of inverse surjectivity defines a linear order (i.e basically a dimension). Complete cyclicity (i.e. symmetry) and non-transitivity define an orthogonality relation. The addition of surjective or inverse surjective closure leads to "orthogonally closed" classes. These form the base for orthocomplemented lattices and hence for Boolean algebras.

I do not want to exhaust all possible combinations of elementary closures and their corresponding mathematical structures here. I just want to argue (without at this stage being able to prove it formally) that all fundamental types of abstract order or organization which we use for the structuring of complex domains, such as hierarchies, symmetries, periodicities, dimensions, partitions, ..., can be generated by the recursive combination of extremely simple "closure" operations. Just like the "modules" in Simon's (1962) nearly decomposable systems can be arranged in higher order modules, which themselves may constitute even larger modules, ..., resulting in an unlimited hierarchy of ever larger or more complex systems, elementary closures too may be recursively combined forming higher-order closed systems, which themselves may form the building blocks of still higher order closed systems, ..., and so on, without limit.

The difference with modules is that closed systems should be viewed as *relations* rather than as objects. This means that they can be finite as well as infinite, linear as well as circular, oriented as well as non-oriented, topologically bounded as well as covering the whole space, ... Yet each "closed" relation determines one (or more) invariant distinction(s), so that its identity is unambiguously determinable, i.e. the "figure" can be separated from its "ground".

The difference between a closed, hence invariant, distinction and a variable distinction may be illustrated in the following way : consider a wall on the surface of the earth. Standing near the wall there seems to be a clear distinction between "this side" and "the other side" of the wall. However, if you follow the wall until the place where it ends, you will be able to walk to the other side without having to cross it. Hence the distinction is only local, relative or subjective, depending on the position from where you look at the wall. On the other hand, if the wall would form an uninterrupted, *closed* figure, e.g. a square or a circle, it would not have an ending, and you would follow the wall indefinitely without finding an opening to the other side. In this case the distinction between "this side" and "the other side" would be absolute or invariant. Hence "closing" a system can be seen as filling the gaps by adding the "missing elements".

Remark that a analogous invariant distinction would arise if the wall would extend in an infinite, straight line (this would correspond to a transitive closure rather than to a cyclical one). Hence closure, as I define it here, is more general than simply closing back upon itself in a "circular" or "self-referential" manner, as it it is often understood in second-order cybernetics (cfr. "organizational closure", Varela, 1979).

The closure concept is not only useful for characterizing the abstract order in scientific models, it can also be applied to the analysis of intuitive perceptual structuring. The perception of "figures" is determined by the Gestalt law of "Pragnänz", which states that out of the perceptual stimuli (visual, auditory, ...) those patterns will be abstracted which are as regular, simple, continuous, closed, symmetric, ... as possible (Stadler & Kruse, 1989). All these Gestalt qualities can be seen as special cases of the generic "relational closure" concept. This brings us back to the proposition formulated in the introduction, namely that we could learn much about complexity reduction by making the unconscious mechanisms of perception more explicit, thus allowing them to be generalized to more abstract information domains.

In practice the (discrete) physical stimuli as registered by the sensory organs do not form closed patterns themselves. The closure is in fact carried out by the cognitive system as a way of reducing the complexity of the percept, by filling in missing elements and filtering out unordered information (noise) so that only the invariant (i.e. meaningful) distinctions are enhanced and thus may come to the foreground. This may be understood through the default principle: unless there is reason to believe that the perceived figure is "objectively" incomplete, the cognitive system will assume that the lacking of certain data is due to noise or to inaccuracies of perception, so that the pattern should be viewed as closed, i.e. as an invariant distinction.

6. Conclusion : principles for the design of a support system

Let us conclude this discussion of possible mechanisms for coping with complexity by trying to integrate the different concepts and principles in the form a general method, to be implemented as a computer-based support system.

The first thing to do if we wish to tackle a complex problem domain is to collect knowledge. This knowledge may come from various sources: literature, experts, interviews, observation, one's own intuitive knowledge, databases, electronic media, ... The various "pieces" of collected knowledge (i.e. symbolic data or "sentences") should be made as explicit as possible, and may take the form of distinctions, rules, or (partial) representations. Because of the assumed complexity of the domain the knowledge will be heterogeneous, vague, uncertain, ambiguous, and sometimes even inconsistent. Moreover, since we assume that the representation we want to build will be incomplete and hence open, the knowledge will be continuously changed and updated.

The basic problem then will consist in *structuring* the knowledge, i.e. integrating, organizing, classifying, distinguishing, removing inconsistencies, filling in gaps, eliminating redundancies, abstracting away unnecessary details, letting implicit order emerge, constructing higher-order concepts and rules... The goal is to arrive at a representation which is as effective and efficient as possible in helping actors to solve the problems in its domain. Because of the openness this structuration will never be finished: we do not want to find a classical, closed representation. Instead we want the users to be able to change the representation, by introducing new knowledge, i.e. variety, or by questioning existing knowledge. Yet the system should remain as simple, as general and as transparent as possible.

In order to achieve this we need some meta-representation system (or a "generator of user languages") which would help the actor to structure the knowledge. First, it should encourage the user to formulate the "sentences" in the most general and explicit way, e.g. as distinctions and relations between distinctions. Such basic "subsystems" of the representations should then be (re)combined in various ways, creating a variety of temporary "assemblies". This recombination may require the opening up of (inappropriately) closed knowledge systems, i.e. the uncoupling of their rigidly connected parts, so that they may be put in contact with parts of different systems. The new assemblies which are closed according to formal criteria (such as transitivity, cyclicity, surjectivity, ... or a combination of these) may be kept as stable building blocks for new higher order combinations.

We must remark here that in general there will be several ways in which the same set of relations may lead to a closed system. So we will in general need additional, external selection criteria, which do not examine the internal invariance of a distinction, but its "external" usefulness as a tool for problem solving (e.g. its correspondence with actions, or goals). These additional criteria must be derived from the values driving the actor.

Assemblies which are partially or "almost" closed may be closed completely by filling in the gaps. This may be realized through the addition of new knowledge from the outside, or by internally "postulating" the existence of the missing elements (so that they could be generated by recursion). This process of completion is analogous to the perceptual "filling in" of incomplete figures. This means that its result can be ambiguous : different additions may lead to different closed figures or Gestalts. In this case a discontinuous Gestalt switch may occur.

The higher-order closure of patterns formed by already closed assemblies leads to a hierarchy of levels of abstraction or complexity. The number of invariant distinctions determined by a closed system will in general be much smaller than the number of distinctions determined by its subsystems before closure. The distinctions between subsystems are indeed "concealed" by the invariant distinctions determined by the global system (e.g. its boundary). Hence closure will in general diminish the number of "observable" distinctions and thus simplify the description. The higher the number of closures, the higher the level of abstraction, and hence the simpler the representation.

How could such a metarepresentational language be implemented? The most obvious tool (though not necessarily the only one) to achieve this would be a computer. In principle the closure operation could be programmed through production rules of the form : "**if** an assembly of distinction relations would have such and such properties, **then** it would be closed, and could be replaced by a new distinction with such and such properties". The new distinction would then be added together with the already present distinctions to a temporary memory or "message list". This updated message list could then be again subjected to the production rules to test whether one of them would fit, thus recursively generating new distinctions by closure. The main problem for the moment is how to represent the basic items in the temporary memory, i.e. distinction(relation)s, in such way that they could be easily manipulated by the computer, yet remain meaningful for the user, who must introduce external knowledge and apply internally structured knowledge.

Let us look at some existing computer support systems, incorporating part of the present requirements. "Classifier systems" (Holland et al., 1986) allow to develop adequate problem representations by the (random) recombination and selection of simple rules ("classifiers"), but the selection is purely external, determined by the problem-solving efficiency, not by any internal closure criterion. Hence there is no explicit way for constructing higher-order concepts, although implicitly some form of closure may develop spontaneously. The relatively low-order representation of the knowledge as classifiers makes it also difficult for the user to add new rules or to interpret the internally generated rules. Higher-order knowledge representation languages (based on objects, predicates, inferences, ...) are used in expert system shells, so that it is easier for the user to introduce new knowledge. A system like DEDUC (Hornung, 1982) moreover stimulates the user to rearrange and test the rules, so as to enhance the quality of the representation. However the system itself has no inherent learning mechanism. The same remark can be made about other systems, such as outliners (e.g. More or ThinkThank), hypermedia (e.g. HyperCard) and conversational systems (Pask & Gregory, 1986), which require less well-structured knowledge, and which propose various mechanisms for the ordering and recombination of concepts. However, the more detailed, structuring work must still be done by the user, since the system provides only little guidance in making closures.

The challenge for the present method for structuring complex problem or knowledge domains, based on the closure concept, would then consist in the construction of a system which would be more general, more user-friendly and more effective than these existing support systems.

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