AI Assignment 9

1. [Introduction](http://mydy.dypatil.edu/rait/mod/url/view.php?id=39391)

Until now the theory of problem-solving (e.g. Newell and Simon, 1972) has mainly emphasized the *search*of solutions within a problem space. From this viewpoint, problem-solving capability (i.e. intelligence) should be seen as the possession of adequate *heuristics*, which allow to make the search more efficient. This view presupposes that the search space is explicit and well-structured, i.e. that at each decision point there is a well-defined set of operators (or problem states to be generated) from which the most promising can be chosen according to some heuristic rule.

This approach is typically applied in "game" situations (e.g. chess) and "toy" problems (e.g. the tower of Hanoi problem), where the possible "moves" are fixed by predetermined rules. As we all know, games and toys are primarily used by children (and adults) to learn about the world by *playing*, i.e. by performing simulations of actions so that the result of these actions can be explored without being confronted with the complexities and dangers of the real world. In this sense we have learned a lot about problem-solving and about intelligence by constructing computer models of how to play games or how to manipulate toys.

However, this does not mean that we are able to build models of how to cope with the real world. Recently, the awareness has been growing in AI that, in order to get insight into practical intelligence, we need to build autonomous agents (e.g. robots) capable of directly interacting with a real environment. However, in order to experiment efficiently with such systems we should simultaneously develop a *theory*of problem-solving in complex, ill-structured environments. The present paper proposes the outline of a research project, aimed at the construction of such a theory.

First, we should attempt to define an "ill-structured problem environment". It can be characterized, first, by the presence of a "problem", i.e. a situation which is to be changed in some way; second, by the absence of the structure needed for efficient search : well-defined goal(s), problem-states, operators, constraints, heuristic criteria ... In a more radical formulation : when confronted with such a problem, we know that something is to be done, we do not want the situation to evolve on its own, but we do not know what to change, how to change it, or what the result of the change should be like.

 Some examples of ill-structured problems may show the practical applicability of the theory we are looking for. The management of a large socio-economic system (e.g. a firm, an organization or a state) is clearly a very complex problem (cfr. Dörner & Reither, 1978; Dörner et al., 1983) : it is in general not at all clear which goals are to be pursued, which means are available, or which information is relevant. The availability of communication and information technology will in general only increase the complexity of decision-making. Indeed, existing computer systems are only capable of solving well-structured problems. In this way they will merely increase the available information and hence the possibilities for choice, without reducing the ill-structuredness of the situation. Another example is research : the development of scientific theories is clearly an ill-structured problem domain. The *discovery*of new concepts or models is basically a process of building simple structures out of the available data, which are often inconsistent, ambiguous, vague and changeful.

 Clearly, the first thing to be done in order to solve an ill-structured problem is to *formulate* it in a well-structured way, i.e. to describe explicitly the initial situation which is to be changed, the goal which is to be achieved, the problem-space which is to explored, the operators which are to be used, ... Such a well-structured formulation is traditionally called a *representation* of the problem (cfr. Amarel, 1967; Burghgraeve, 1976; Korf, 1980; Heylighen, 1986). A representation of how to build such representations may then be called a *metarepresentation* (Heylighen, 1987a,b). Once we know how to construct (and transform) representations of ill-structured problem domains, we can simply apply the existing knowledge about search through problem spaces in order to be able to solve all types of problems. We will now propose a conceptual framework for the analysis of representations.

2. Representations as Distinction Systems. 

In order to begin our study, we must analyse the object of the study : representation. A representation can always be considered as a system, i.e. an organized, goal-directed whole of interrelated elements. The goal or function of a representation is to structure the field of experience of the intelligent *agent* using the representation, in such a way that the agent can search efficiently for solutions when confronted with a problematic *situation*, which is to be changed.The second question to be asked then is : what are its elements ? The elements we are looking for are primitive structurations of the problem environment as experienced by the agent.

The simplest form or structure we can imagine is a *distinction* (Spencer-Brown, 1969). A distinction can be defined as the process (or its result) of discriminating between a class of phenomena and the complement of that class (i.e. all the phenomena which do not fit into the class). As such a distinction structures the universe of all experienced phenomena in two parts. Such a part which is distinguished from its complement or background will hereafter be called an *indication* (Spencer-Brown, 1969). If more than one distinction is applied the structure becomes more complex, and the number of potential indications increases, depending on the number of distinctions and the way they are interrelated.

In contrast to Spencer-Brown (1969), we will not assume any general axioms for distinctions. In particular we will not assume that the complement of the complement a' of an indication a is again the same indication (law of double negation) : (a')' = a . This means that we do not suppose distinctions to be symmetric : the complement or negation a' of an indication a has not necessarily the same status as a. However, if this symmetry property is assumed, together with a related axiom about conjunctions (or disjunctions) of distinctions (the law of idempotence, cfr. Heylighen, 1987a), it can be shown that a set of distinctions gets a Boolean algebra structure, isomorphic to the algebra of classes in set theory or to the algebra of propositions in logic (Spencer-Brown, 1969).

How do distinctions determine problem-solving efficiency ? Clearly, to formulate a problem you need to make a minimum number of distinctions. At least you should be able to distinguish the situation to be changed from the situation corresponding to a satisfying problem-solution. Furthermore, in order to be able to search for a solution you should distinguish different problem-states, which can be reached by distinct operators. The more general you want your representation to be, i.e. the more potential problems you want to be able to solve, the more distinctions you must make.

However, more distinctions means more states, more operators, more decision points, hence more search to be carried out. Clearly, in order to minimize search you must minimize the number of distinctions. This means that for a computationally tractable representation of a real problem domain most phenomena must remain "indistinguishable" (cfr. Hobbs, 1985). In the terminology of (Heylighen, 1987a) : different phenomena are "assimilated" to the same class, which is "distinguished" from other classes.

Assimilation and distinction necessarily go together : the number of potentially distinguishable phenomena in the universe can be considered to be infinite, the number of actual distinctions used for solving a problem in the real world must be finite. Which finite set of distinctions is selected from this infinite set will depend upon the problem domain. The problem of problem-formulation could hence provisionally be formulated as : how to determine the optimal (i.e. minimal, yet large enough to cover all relevant solution paths) set of distinctions for a particular problem domain ?

 However, a representation is not just a set of distinctions, it is a *system*. This means that we must first look for the properties of and relations between distinctions, in order to understand how they are organized towards the fulfillment of their function. The structural units of a representation can be described in a hierarchy of levels, ordered from the more "subjective", agent-determined structures, to the more "objective", situation-determined structures (see fig. 1) :

 1) a problem is determined first by the autonomous agent, whose ultimate aim is survival; 2) in order to survive the agent must specify more concrete goals or values, which represent classes of situations for which the long-term survival is more probable, and which can be reached by a sequence of actions (cfr. Heylighen, 1988); 3) to attain these goals the system must dispose of a set of operators (also called "(production) rules"), representing possible actions changing the situation; 4) the operators have arguments, which may be called problem-states, and which represent distinguished situations; 5) the states can be analysed as compound logical propositions, consisting of primitive propositions formed according to the Predicate (object) scheme; a predicate may be conceived as a class of phenomena ; 6) an object to which this predicate is attributed corresponds then to an instantiation of that class; 7) finally, the objects and predicates perceived by the agent depend upon the physical stimuli received from the external (or internal) situation of the agent, i.e. by its environment.

Each of these units can be interpreted as a particular type of distinction : 1) the distinction between survival (i.e. maintenance of the identity or self-environment boundary, cfr. Heylighen, 1988) and destruction of the agent; 2) the distinction between "better" situations and "worse" situations. In the General Problem Solver (GPS; Newell & Simon, 1972) these distinctions are called "differences" between goal and non-goal states. The number of such "differences" can then be used as a basic evaluation criterion for states, allowing "hill-climbing" search heuristics; 3) the distinction between the situation before and after the operator has been applied. Clearly, if these situations cannot be distinguished, the operator is meaningless. In GPS these "distinctions" are coupled to the previous ones by a matrix, connecting a list of operators to a list of differences by specifying whether a particular operators is able to reduce a particular difference between the initial state and the state to be attained; 4) propositions describing potential situations form a Boolean algebra which can be interpreted as an algebra of distinctions (Spencer-Brown, 1969). The basic distinction here is that between a proposition and its negation; 5) as we already pointed out, a predicate corresponds to a class, and a class is the result of a distinction between phenomena; 6) an object on the other hand, arises when a stable "form" or "system" is distinguished from its "background" or "environment"; 7) sensory stimuli, finally, are the result of a differential excitation of elmentary receptors (e.g. nerve cells), creating a distinction between "activated" and "non-activated" receptors.

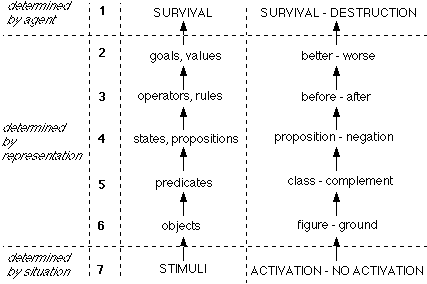


Figure 1 : hierarchy of representation levels and their corresponding distinction levels