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ASSOCIATIVE MEMORY-BASED REASONING: HOW TO REPRESENT AND RETRIEVE CASES

Boicho Kokinov

Institute of Mathematics
Bulgarian Academy of Sciences
Bl.T, Acad. G. Bonchev Street
Sofia 1113, Bulgaria

An attempt is made at investigating human reasoning from an uniform poir of view and a possible approach 'associative memory-based reasoning' is proposed. Deduction, induction and analogy are treated as slightly different manifestations of associative memory-based reasoning. The representation and the retrieval of problem solving cases is studied in greater detail.

1. INTRODUCTION.

Reasoning is an important process in recognition, problem solving, performing routine actions (e.g. walking), concept learning and all other cognitive tasks We shall examine reasoning only in the context of problem solving although sor of our conclusions may be applied to other cases as well.

It is widely accepted that deduction, induction and analogy are quite differer forms of reasoning and that is why they are studied separately. We believe tha from a computational point of view deduction, induction and analogy are only slightly different versions of an uniform reasoning process. We shall make an attempt at exploring this process and showing a possible way of reasoning in human problem solving that we call *associative aeaory-based reasoning.* Once again a special emphasis will be placed on the importance of experience for human thinking and for this reason we shall study in more detail the representation of cases. The crucial role of the retrieving process in reasoning will be revealed and this aspect of the reasoning process will be considered extensively.

Our considerations will be based on a computational model of human memory whic has been developed earlier [3,14,153. Knowledge representation in this model : *frave-based* and memory organization is based on an· *access network* which connects the frames. The retrieving mechanism is a form of *spreading activatio* combining both *directed and spontaneous retrieval* [15],

2. BACKGROUND.

Although the role of induction and analogy in problem solving was investigate by G. Polya and many others a long time ago, little research on inductive and analogical reasoning has been done in AI. Lately, the interest in thes phenomena has increased [13,20,213. Poetschke stated in [22] that if -fifth generation computers could reason deductively, then sixth generation computer should have the ability of inductive and analogical reasoning. The attention paid to analogy is comparatively little. Winston C27], Carbonell [4,5] as wel as other researchers made early attempts at building computational models of analogical reasoning. Many researchers have tried to formalize the notion of analogy using a purely syntactical approach. Centner C73, Haraguchi [10,11] an Poetschke [22] are representatives of this kind of approach. Melis and Melis [19] applied a semantic approach considering analogy as metainference. Hollan Holyoak et al [12] offered a pragmatic approach to induction and analogy. The insisted that Induction and analogy cannot be understood apart from goals and context and proposed a rule-based computational model of induction and analogy

Schank [24] paid more attention to the organization of memory and suggested a form of reasoning based on analogies with previous cases, a method called *case. based* reasoning. His ideas were further developed by Carbonell [4,5], Kolodne [16,17] and many other researchers [IB] exploring the role of experience anc memory in reasoning. Kolodner [16,17], Carbonell [5], Rau C23,24] and others paid special attention to the process of retrieving the appropriate informatio which is stored in memory. Kolodner proposed indexing new cases according to their differences from the general case whereas Carbonell suggested indexing them by the first steps in the corresponding reasoning process. Both approache have the shortcoming of static indexing, i.e. the way of retrieving the case is a priori fixed. Anderson Cl,2] proposed a *spreading activation* mechanism fo automatic retrieval of the relevant information, whereas Holland, Holypak et a C121 put forth a rule-based mechanism for directed spreading activation. Rau pointed out in [23] that there are two types of retrieval: forced and spontaneous. By carrying out a psychological experiment Walker and Kintsch [26 found out that knowledge retrieval has both an automatic and a strategic aspect. A model that incorporates the two types of retrieval processes from a uniform point of view can be found in CIS].

Gick and Holyoak [8,9] carried out psychological experiments to investigate the human ability for analogical reasoning in problem solving and to examine the types of problem similarity which facilitate reasoning by analogy. They have also studied the relationships between analogy reasoning and scheme induction.

Stanfill and Waltz [25] proposed a kind of *memory-based reasoning* which relies only on' a data base for old cases (considered as feature vectors) and presup poses no strong domain model, rules, etc. It is based on a dynamically compute metric between cases which helps finding the best match in the data base.

3. ASSOCIATIVE MEMORY-BASED REASONING.

Associative memory-based reasoning is a computational model of human reasonin in which the results of the reasoning process depend heavily on the content and the current state of memory. The contents of memory is a collection of interrelated descriptions of concepts, events, scripts, algorithms, etc. The state of the memory makes it possible to gain access to some descriptions (activates them) and renders others inaccessible.

In contrast with the memory-based reasoning proposed by Stanfill and Waltz [25 associative memory-based reasoning relies on the presence (availability) of general knowledge and domain models in memory. The candidate for the best matc is selected using a *dynamically computed metric* produced by the *associative mechanise* C3,15] which is a form of spreading activation. The resulting distance between the descriptions depends on their common features, the associative links between them or between their parts as well as on the overal

•tate of memory, **i.e.** on the context. This computation can be carried out in parallel in the human brain or on a parallel computer. Whether the selected candidate is really the best match is tested by a sequential mapping process.

Associative memory-based reasoning is a more general reasoning mechanism than case-based reasoning [24,17,63 because it uses previous cases as well as general algorithms if such are available. In contrast with case-based reasonin the candidate is not selected by a static indexing mechanism and a sequential retrieving process but by the parallel process described above. We propose the following'steps in associative memory-based reasoning (Fig. l)s

1. Encoding the problem, i.e. forming the description of the problem ·

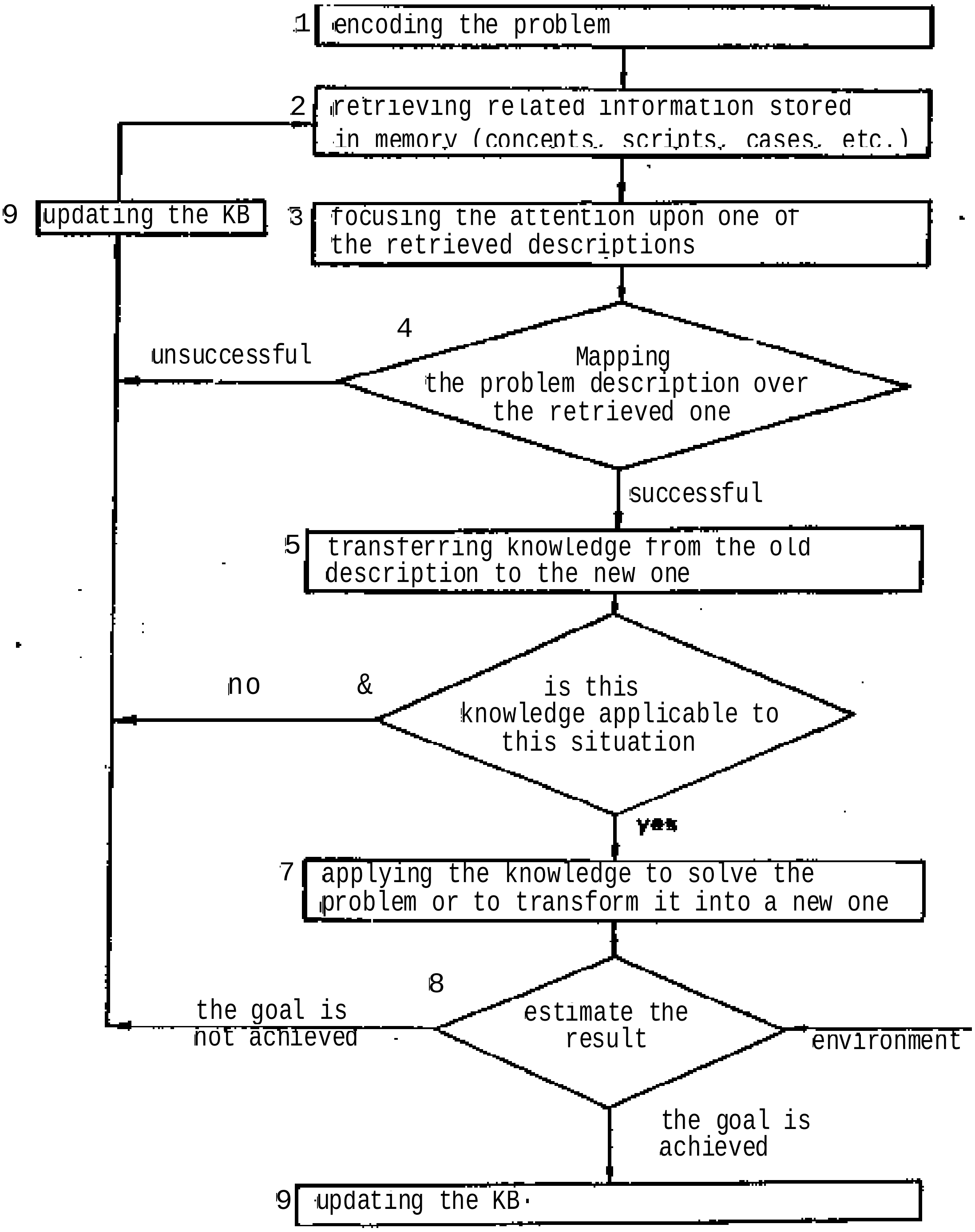

Figure 1.
Associative Memory-based Reasoning in Problem Solving.

recognition o-f circumstances, understanding or -formulating the goal.
2. Retrieving related information stored in memory, i.e. activating some descriptions of .concepts, events, classes of problems, particular cases algorithms, etc.
3. Focusing the attention on the most active description (the candidate for the best match)'.
4. Mapping the problem description over the retrieved one. In case of failure the mechanism updates the KB with traces of the failure and restarts the retrieving process in this new memory state.
5. Transferring knowledge from the old description to the new one, i.e. transferring some additional features, derivational strategies or problem solutions
6. Testing whether the transferred knowledge is applicable in the new situation, i.e. whether the addition»! feature· are really present (or at least not contradictory with the known features) and whether the recommended actions are really applicable.
7. Applying that knowledge to solve the problem or to transform it into a new one.
8. Estimating the result, i.e. testing whether the goal is achieved. If it is not, then another description is retrieved and the KB is updated.
9. Updating the KB - encoding the solution or the derivation step for future use, building up new links, changing weights of links, assigning blame or credit to some knowledge, induction of more general descriptions if possible.

Let us consider some examples of problem solving that would traditionally be classified as recall, deductive, inductive and analogical reasoning respectively (Table 1). We can view these as different manifestations of the same uniform associative memory-based reasoning process. Depending on the result of steps 2 and 3 we consider the following different cases»
1. If the candidate for the best match is a description of the same problem together with its solution or derivation of the solution, then the reasoning process is *recall* (e.g. ??, ?2 in Table 1).
2. If the candidate for the best match is a description of a class of problems

Type of lipping	Recall	Deduction	Induction	Analogy
	Al	Bl	Cl	O1
2 type A - > A'	P: Is Asiiov's book •The Gods Theiselves' interesting? C: I have read the book •The Gods Theiselves' and it Mas very interesting. A:Yes, it is interesting.	Pi Is Asiiov's book •The Gods Theiselves· interesting? C:Asiiov writes science-fiction. Science-fiction books are interesting. A:Yes, it is interesting.	P: Is Asiiov's book •The Gods Theiselves· interesting? Cil have read a chapter of 'the book In Aiazing Stories. It was very interesting. AsYes, it is interesting.	Pi Is Asiiov's book 'The Gods Thetselves* interesting? Cil have read Asiiov's book "I Robot' and it Mas very interesting. A:Yes, it is interesting.
	A2	82	C2	O2
4 type A --> ?- ? ! ? --> ?'	????? can you hold a hot tea-pot? E:There is. a tea-pot and a serviette on the table. C:Yesterday I took a hot tea-pot nith a serviette. A:Take it Nith a serviette.	PiHow can you hold a hot tea-pot? E:There is a tea-pot and a serviettt on the table. Cilf you Hint to take a hot pot take it Nith a piece of cloth. A:Take it Nith a serviette.	P:HoN can you hold hot pot? C:Yesterday I took a hot tea-pot Nith a serviette. A:Tike it Nith a piece of cloth.	PsHon can you hold a hot tea-pot? E:There is a tea-pot on the table. CiYesterday I took a hot coffee-pot with a serviette. A:Take it Nith a handkerchief.

Table 1.
Examples of associative memory-based reasoning.
P: problem, C: candidate for best match, E: environment, A: answer

to which the problem in hand belongs together with a) solution of the problems in the class (e.g. the formula for the solution of a quadratic equation, Bl an B2 in Table 1)| b) the derivation of solutions of «ach problem in that class (e.g. algorithm for solving a differential equation of a definite type), or c the rules for partial transformation of the problem (e.g. rules for an auxiliary construction in geometric problems or theorems applicable in the particular case, etc.) then we call this process *deductive reasoning.*

3. If the candidate for the best match is a description of a particular case of the problem in hand together with the solution of that problem (e.g. Cl and C2 in Table 1), or with the derivation of that solution then we call this process *inductive reasoning.*

4. If the candidate for the best match is a description of a similar problem together with its solution (e.g. Dl and D2 in Table 1) or with the derivation of that solution then we call this process *reasoning by analogy.*

5. If the candidate for the best match does not follow the description of the problem or if it does not contain any hints for the solution of the problem then the retrieving process is restarted in this new memory state to produce a better candidate.

4. CASE REPRESENTATION AND RETRIEVAL.

Associative memory-based problem solving as presented in the previous section relies on memory for past experience on problem solving and that is why it is important to investigate how to represent and retrieve problem-solving cases, generalized cases, general plans, etc.

We shall use a representation scheme proposed in C153. The primitives of this scheme are on the epistemological level and that is why we are free to choose appropriate conceptual primitives for problem cases and other notions. We propose to represent problems in terms of initial state, final state and restrictions, where the initial and final states are scenes, situations or events whereas restrictions are assertions on available resources, path constraints, etc. Plans can be represented in terms of their steps, i.e. elementary actions, and the relations between them.

Let us consider the following example. A few days ago a child had to solve the problem how to take a hot coffee-pot in his hand. The problem was too difficult for him and his mother told him to take a serviette first and then to take the hot coffee-pot with, the serviette. Now he must take a hot tea-pot in hand and there are no serviettes in the kitchen. The past problem is represented in Fig 2 and the plan for solving it in Fig. 3. The representation of the new problem is not shown here because it is slightly different from the one in Fig. 2. Analyzing the new problem now the child will notice that the difficulty arises from the need to satisfy a relation (such as the one described in G400) which states that the hot teapot must be in his hand. Starting from <hot, teapot, hand> and using the associative mechanism many of the descriptions (e.g. for cold, pot, coffee-pot, food) which are associatively linked with the active notions get into the working memory (WM). Starting from this state of WM and using the associative mechanism again different scenes (strategies) can enter the WM (e.g. cold teapot in hand; hot coffee-pot in hand etc.). In case the last description dominates the others and becomes the focus of attention (i.e the node G3 is in the focus) then it is possible by means of the associative link from G3 to G1000 to cause G1000 to become the focus - the plan for the solution of the old problem. Now the child has to transform the retrieved plan in order to apply it to the new situation. The problem is that there is no serviette. Then, starting from the serviette and its role in the plan (to cover something) the notion of the piece of cloth and later of something like a handkerchief can get into WM. So the child has solved the problem.

```
G1
instance-of: <problem>
slotl   type: part
        m-coref: initial state
        c-coref: 62
slot2   type: part
        m-coref: -final state
        c-coref: 63
        a-link: G1000

G100
instance-of: <coffee-pot>
slotl   type: relation
        m-coref: temperature
        c-coref: hot

G200
instance-of: <table>

G300
instance-of: <on>
slotl   type: part
        c-coref: (G2.slotl)
slot2   type: part
        c-coref: (G2.slot2)
```

```
G2
instance-oft <scene>
slotl   type: part
        c-coref: S100
slot2   type: part
        c-coref: 6200
slot3   type: relation
        m-coref: location
        c-coref? 6300

G400
instance-of: <in>
slotl   type: part
        c-coref: (63.slotl)
slot2   type: part
        c-corefi (G3.slot2)

G3
instance-of! <scene>
a-linki 61000
slotl   type: part
        c-corefi 6100
slot2   type: part
        c-coref? hand
slot3   type: relation
        m-coref! location
        c-coref: 6400
```

Figure 2.
Representation of the problem: "Take the hot coffee-pot in hand"

```
G1000
instance-of: <plan>
slotl   type: part
        m-coref: step
        c-coref: G1001
slot2   type: part
        m-coref: step
        c-coref: 61002
slot3   type: relation
        c-corefs 61003

G1003
instance-of: <enable>
slotl   type: part
        c-coref: (G1000.slotl)
slot2   type: part
        c-coref: <G1000.slot2)
```

```
G1001
instance-of; <take>
slotl   type: part
        m-corefi object .
        c-coref: serviette

G1002
instance-oft <take>
slotl   types part
        m-coref? object
        c-coref: (63.slotl)
slot2   type: part
        m-coref! instrument
        c-coref! (61001.slotl)
slot 3  typei relation
        c-coref! 61004

G1004
instance-of: <covered with>
slotl   type: part
        c-coref: (61002.slotl)
slot2   typei part
        c-coref: (61002.slot2)
```

Figure 3.
Representation of a plan for solving the problem displayed in Fig. 2

So it is evident that the associative memory-based reasoning depends, heavily c the associative and other links between descriptions, on the level of activation of different descriptions affected by many factors including the perceptual environment.

The process of problem solving is a chain of mental events such as encoding th problem, retrieving an old case, mapping between descriptions, failures, etc. Ideally all these events would be saved in memory and linked together with associative links. In fact only some of them are important and only these ar stored and linked for future use. In the above example only the description c the goal "to have something hot (a teapot) in hand" was linked to the plan description. That is why it is less prpbable for the plan to be triggered by the initial state "the hot teapot is on the table" which is a very usual situation. But with other problems it may be the case that the goal is an usua one and the initial state is not and therefore the solution (or derivation) will be linked to the latter. That is why we think that the way of linking experience together is pragmatically determined depending on the context, goals, emotions, etc., rather than being conceptually predefined.

5. EXPERIMENTS.

An implementation of these ideas is under development. It is written in Golde Common Lisp on an IBM PC/AT computer. The subject area is common-sense knowledge. There is an old version of the retrieval mechanism implemented in I LISP which was successfully experimented in a program for language understand- ing. Psychological experiments have also been planned and partially carriec out. A report on the results is forthcoming.

6. CONCLUSIONS.

An attempt is made at investigating human reasoning from an uniform point of view and one possible approach 'associative memory-based reasoning' is proposed. Deduction, induction and analogy are considered as slightly differen manifestations of associative' memory-based reasoning.

The mechanisms underlying associative memory-based reasoning are based on a computational model of human memory developed earlier and are considered as a way for exploring this model in the context of problem solving activities.

The ideas presented in this paper are a first sketch of the process of associative memory-based reasoning and only a few details of the retrieval ste are considered. All the steps in the reasoning process and especially the mapping step have to be studied in more detail. Problems concerning truth maintenance, confidence, etc. are to be explored.

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