ASSOCIATIVE MEMORY-BASED REASONING: SOME EXPERIMENTAL RESULTS

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ABSTRACT

Deduction, induction and analogy are considered as slightly different manifestations of one and the same reasoning process. A model of this reasoning process called associative memory-based reasoning is proposed. A computer simulation demonstrates that deduction, induction and analogy in problem solving could be performed by a single mechanism which combines the neural network approach with symbol level processing. Psychological experiments on priming effects in problem solving tasks have been carried out in order to test the hypothesis about the uniformity of human reasoning. In particular it has been shown that there are priming effects in all three cases (deduction, induction and analogy) and these priming effects decrease in the course of time which corresponds to the model's predictions based on the retrieval mechanism. The computer simulation demonstrates the same type of priming effects as observed in the psychological experiments.

1. INTRODUCTION.

The tradition of exploring deduction, induction and analogy in AI is to study them separately and to propose different models for them. Contrary to that we believe that there is a uniform underlying reasoning process of which deduction, induction and analogy are only slightly different manifestations. A model of this process in the context of problem solving has been proposed in [11]. This model has been called associative memory-based reasoning (AMBR).

The associative memory-based reasoning model will be reviewed in section 2. The retrieval step will be discussed in more detail.

Psychological experiments have been carried out in order to explore the common features of deduction, induction and analogy and thus to test the hypothesis about the uniformity of human reasoning. The experiments also test the model's predictions about the results of the retrieval step. The experiments will be described in section 3.

A computer implementation of associative memory-based reasoning has been developed. The results from the computer simulation are discussed in section 4.

2. ASSOCIATIVE MEMORY-BASED REASONING: An Overview

AMBR was proposed in [11]. It is composed of a set of processes running sequentially or in parallel: *retrieving, mapping, transferring, evaluation* and *updating processes*. Depending on the results of the retrieval process and the correspondence between the descriptions established during the mapping process, we can view the reasoning process as deduction, induction or analogy. Burstein and Collins [3] similarly conclude, after analyzing a large set of protocols, that "the kind of knowledge retrieved from memory drives the particular line of inference produced.".

AMBR is based on a hybrid architecture put forth in [10,12]. This architecture of cognition combines a frame-like representation scheme with a spreading activation mechanism (called in our model associative mechanism) implemented as a neural network. In this way we exploit the advantages of theories both at the symbol and subsymbol levels. In contrast with Anderson's ACT* model [1] we do not separate declarative from procedural knowledge and, since a frame-like representation scheme is used, the domain of application of spreading activation is extended over procedural knowledge as well. Both types of spreading activation, automatic and directed, exist in AMBR versus automatic only in ACT*. Finally, reasoning in ACT* is rule-based whereas rules and other general knowledge as well as particular case descriptions are used in AMBR.

Unlike case-based reasoning [4,5,14] (with a sequential retrieval process relying on a static indexing mechanism), in AMBR we have a parallel and continuous retrieval process depending both on the static links and the current memory state. Besides previous cases, AMBR uses general knowledge about a class of problems and general algorithms as well.

AMBR differs from memory-based reasoning (Stanfill and Waltz, [17]) in that it relies on the availability of general knowledge and domain models in memory. It uses a sophisticated frame-like representation and a complex mapping process.

2.1. Memory Organization

Our memory model includes *long term memory (LTM)*, *working memory (WM)* and *focus* (of attention), where WM is the active part of LTM, and the focus is the most active element of WM. LTM is considered as a network of nodes and weighted links. The nodes correspond to frame-like descriptions of objects, concepts, events or plans. The links correspond to semantic relations as well as to arbitrary associations. The nodes have variable levels of activation. All nodes whose level of activation is above their threshold t_i form WM. The focus is the only node which can be consciously processed. A more detailed description of the representation scheme and memory organization can be found in [12].

2.2. Associative Mechanism

The associative mechanism runs in parallel with all other processes and in this way influence their work. It changes the activity of the nodes which is critical for all processes working on these nodes. The associative mechanism plays the role of a retrieval mechanism as well. It can be considered as a form of spreading activation [1,2]. Its detailed description in the terms of PDP models [16] can be found in [13]. There are two slightly different versions of the associative mechanism: directed and automatic.

Directed spreading activation is performed when some information has to be obtained from a node referred to by the focus. This is done by directing the activation via the corresponding semantic link. It usually has the maximum strength of 1 and therefore the node pointed to by the link will receive the same activation as the focus and thus become the new focus.

Automatic spreading activation is performed continuously and in parallel with all other processes in memory. Each node in working memory passes over its activity to all of its neighbours proportionally to the strength of the corresponding link.

2.3. Reasoning in Problem Solving

AMBR is started when a problem description is in the focus. The retrieval process ends with a new memory state, i.e. a new collection of nodes in WM and a new focus. Then a mapping process between the old (O) and the new (N) focus is started. The mapping aims to establish a correspondence between the slots of the problem description (O) and the retrieved one (N). The result from the mapping between O and N heavily depends on the activity of the other nodes in WM. The established mapping is extended by the transferring process and tested by the evaluation process, i.e. some knowledge from O is transferred and eventually applied in the new situation N.

Now we shall concentrate only on the retrieval step which is performed by means of the associative mechanism described above. The results of the retrieval step will depend on the input (problem description and concrete wording) as well as on the memory state, i.e. which nodes are active at the moment (as a result of previous input or reasoning processes). The prediction made is that there has to be a priming effect on reasoning in problem solving task and that this priming activity has to decrease in the course of time.

3. PSYCHOLOGICAL EXPERIMENTS

Psychological experiments are performed in order to test our two main hypotheses:

- ***first*, that deduction, induction and analogy are performed by a single uniform reasoning mechanism;**
- ***second*, that the retrieval step in this reasoning process is accomplished by a spreading activation mechanism.**

The spreading activation hypothesis is usually tested by priming experiments. Most of the experiments of this kind are performed with low level tasks (lexical decision, items recognition, word completion, etc.). We have shown priming effects in a question-answering (fact retrieval) task with an experiment described in [12].

The experiments to be described here are carried out in order to explore the existence of ***priming effects in a high level task like problem solving.*** Gick and Holyoak [7,8] have performed some experiments on analogical problem solving, but they concentrate more on the mapping process rather than on the retrieving one (the subjects usually received hints to apply a given analogy to the problem). But as Holland, Holyoak et. al.[9] pointed out, "for an autonomous problem solver the most difficult step in the use of analogy is likely to be the retrieval of a plausible source".

According to our second hypothesis, we expect that the activation of some specific knowledge before giving the problem to the subjects will influence the way of solving the problem or the success/failure ratio. Moreover, we expect this priming effect to decrease in the course of time.

Considering the first hypothesis, we expect that the same priming effect should be observed in all three cases: deduction (Experiment I), induction (Experiment II) and reasoning by analogy (Experiment III).

3.1. Experiment I.
Priming Effects on Deductive Reasoning

3.1.1. Method

Subjects. The subjects were 385 pupils from 15 to 17 years old. They participated in the experiment without pay.

Materials. The subjects had to solve mathematical problems that belonged to well-known classes, applying well-known general methods in a deductive manner.

The target problem was: "Prove the identity: $\sqrt{7 + \sqrt{24}} - \sqrt{7 - \sqrt{24}} = 2$ "

The priming problem was: "Reduce the expression $\sqrt{6 + \sqrt{20}}$ "

The distractor problems were ones from geometry.

The target problem could be solved in at least two ways, well-known by the pupils beforehand:

- squaring both sides of the identity
- reducing the expressions under the radicals, e.g. $7 + \sqrt{24} = 1 + 6 + 2\sqrt{6} = (1 + \sqrt{6})^2$

We suppose that the priming problem activates the knowledge needed to solve the target problem in the second way.

Procedure. Subjects were tested in groups of 15 to 25 people. They had to solve about 10 problems, each of them in a restricted time period. The problem descriptions were written on a blackboard one by one - after the time for solving a given problem was up, the blackboard was cleaned and the next problem was written on it. Subjects were not aware of our classification of problems as target, priming and distractor ones. The experimenter presented the solution of the priming problem to the subjects in order to ensure that all of them will use one and the same method and thus activate the same general knowledge. The solutions of some of the distractor problems were also presented to the subjects so that the priming problem would not stand out among the rest. Subjects wrote down the solutions of the problems keeping trace of all attempts and errors. The statistics made in this experiment reflects the number of subjects trying to solve the problem in one and the same way but does not reflect the number of correct solutions of the problems.

Design. There were three conditions in the experiment:

- control condition - subjects solved only distractor and target problems;
- near priming condition - subjects solved the priming problem immediately before the target one;
- far priming condition - subjects solved the priming problem, after that two distractor problems (8 min) and then the target problem.

The measured variable is the number of subjects solving the target problem in each particular way.

3.1.2. Results.

The number of subjects that solved the target problem in a certain way under each condition is given in Table 1. The differences between the results in every two conditions are significant at the 1% level measured by the X^2 (chi square) criterion. Although almost all subjects have solved the target problem "by squaring" under the control condition, the experiment demonstrates a clear priming effect which decreases slowly. There are both near and far priming effects but they are significantly different.

ways\conditions	control	near prime	far prime
solved by squaring	71	43	54
solved by reducing	7	91	57
unable to solve	13	15	34

Table 1
Results from Experiment I.
X^2=69.04 (control - near), X^2=40.52 (control - far)
X^2=16.37 (near - far)

3.2. Experiment II.
Priming Effects on Inductive Reasoning (Generalization)

3.2.1. Method

Subjects. Subjects were 422 pupils from 15 to 17 years old participating in the experiment without pay.

Materials. Subjects had to solve about 10 problems.

The target problem was Clement's "spring coils" problem: Imagine a spring with a weight hung on it; if the original spring is replaced with one made of the same kind of wire, with the same number of coils, but with coils twice as wide in diameter, will the spring now stretch more, less, or the same amount under the same weight, and why?

The priming problem I was: There are two rods made of one and the same material with the same width and profile but with different lengths. Each rod is fixed horizontally by one of its ends and a weight (the same for both rods) is hung at the other end. Which rod will bend more?

The priming problem II was: There are two single-coil springs made of one and the same kind of wire but with different diameters of the coils. Which coil will stretch more under one and the same weight?

The distractor problems were mathematical and physical ones.

The solution of the bending rod problem is well known by pupils. Subjects have no general knowledge to solve the target problem in a deductive way, but they are able to generalize the solution of the bending rod problem to a solution of the target problem in an inductive way (i.e. the rod need not be straight). We expect that the priming problem will activate the required knowledge and in this way facilitate the solving of the target problem.

It might be questionable if the target is solved by generalization of the bending rod problem or it is used as a base for analogy. (This shows that the boundaries between analogy and generalization are not always quite distinct.) Because of the fact that the protocols from the experiment were not always clear enough to make this distinction, we repeated the experiment (with other subjects) with the priming problem II, where the target problem is obviously a generalization of the priming problem with respect of the number of coils. (According to Clement [6] this case cannot be considered as analogy.)

Procedure. The procedure is the same as in Experiment I.

Design. There were three conditions in the experiment:

- control condition - subjects solved only distractor and target problems;
- near priming condition I - subjects solved the priming problem I just before the target one;

- near priming condition II - subjects solved the priming problem II just before the target one;
- far priming condition I - subjects solved the priming problem I, after that two distractor problems (4 min) and then the target problem.
- far priming condition II - subjects solved the priming problem II, after that two distractor problems (4 min) and then the target problem.

The measured variable is the number of subjects answering the target problem in each possible way.

3.2.2. Results.

The number of subjects who answered the target problem in a certain way under each condition is given in Table 2. Both near and far priming conditions are significantly different from the control condition at the 1% level measured by the X^2 criterion.

The difference between the results under near and far priming conditions has not been found to be statistically significant but there is a tendency towards decreasing the priming effect. We think that the priming effect is not significantly decreased in this case because of the short time period between the priming and test phase (4 min).

answers	control	near I	far I	near II	far II
more	22	82	70	58	64
equal	6	3	4	5	3
less	23	30	30	6	16

Table 2
Results from Experiment II.
X^2=13.94 (control - near I), X^2=9.34 (control - far I)
X^2=24.1 (control - near II), X^2=16.04 (control - far II)
X^2=5.39 (near I - far I), X^2=4.09 (near II - far II)

3.3. Experiment III.
Priming Effects on Reasoning by Analogy

3.3.1. Method

Subjects. The subjects were 344 pupils from 15 to 17 years old participating in the experiment without pay.

Materials. Subjects had to solve about 10 problems.

The target problem was: Imagine you are in a forest by a river and you want to boil an egg. You have only a knife, an axe and a match-box. You have no containers of any kind. You could cut a vessel of wood but it would burn in the fire. How would you boil your egg?

The priming problem was: How can you make tea in a glass?

The distractor problems were mathematical and physical ones.

Subjects have no general knowledge for solving the target problem in a deductive way; they do not know any particular case of this situation either. All of them, however, have experience in using immersion heaters (i.e. they know the solution of the priming problem) and could try to find an analogy (to heat stones or the knife or the axe and to put it in the water). We expect that the priming problem activates the knowledge about immersion heater and thus facilitates the analogy.

Procedure. The procedure was the same as in Experiment I. The experimenter presented the solution of the priming problem to the subjects in order to ensure that all of them will focus on the same particular experience (case).

Design. There were four conditions in the experiment:

- control condition - subjects solved only distractor and target problems;
- near-1 condition - subjects solved the priming problem just before the target one; the experimenter presented the solution with the words: "By an immersion heater".
- near-2 condition - subjects solved the priming problem just before the target one; the experimenter presented the solution with the words: "We heat the water by an immersion heater.".
- far condition - subjects solved the priming problem, after that eight distractor problems (24 min) and then the target problem.

The measured variable is the successes/failures ratio in solving the target problem.

3.3.2. Results

The number of subjects that successfully solved the target problem under each condition is given in Table 3. The differences between the results in control and in both near priming conditions are significant at the 5% and 1% level respectively, measured by the X^2 criterion. There are no significant differences between the control and the far condition. We think that there is no far priming effect because of the long time period between the priming and the test phase (24 min).

results\conditions	control	near-1	near-2	far
success	7	31	71	7
failure	34	54	90	50

Table 3.
Results of Experiment III.
X^2=4.94 (control - near-1),X^2=10.07 (control - near-2)
X^2=0.45 (control - far),X^2=10.18 (near-1 - far),
X^2=18.55 (near-2 - far)

3.4. Discussion

The experiments reported here have shown that **1) there is a priming effect in all three cases (deduction, induction and analogy); 2) this priming effect decreases in the course of time** (with no statistical significance in the induction case) and **3) it decreases slowly and there is still a priming effect after solving some distractor problems (for 4 to 8 min).** Experiment III has demonstrated a tendency (without statistical significance) that different wordings of the priming solution can influence the solving of the target problem differently. All these results substantiate our second hypothesis that the retrieving step is performed by a spreading activation mechanism.

Recently a retrieval theory [15] has been proposed which assumes that the prime and the target are combined at retrieval into a compound cue that is used to access memory and in this way some priming effects can be accounted for as well. We think, however, that it will be more difficult to explain the far priming effects demonstrated in our experiments with the help of that theory. The priming effects demonstrated in low level tasks are indeed short term effects. In our opinion this is due to the fact that in these experiments only single nodes are activated by the preliminary setting (e.g. only one or two words). In more complex experiments like the ones reported here a large part of the network is activated and the activation pattern is more stable and that is why the activation of the nodes decreases more slowly (the nodes activate each other mutually).

The experimental results reported here also substantiate our first hypothesis that deduction, induction and analogy are performed by a single uniform mechanism because the effects demonstrated in all three experiments are the same.

4. COMPUTER SIMULATION

A computer implementation of associative memory-based reasoning is developed [13]. It is done in Common Lisp. It simulates human problem solving in the area used in Experiment III (cooking and boiling water, eggs, etc. in the kitchen or in the forest). The simulation system demonstrates that AMBR is capable of problem solving in a deductive, inductive and analogical way as well as some of the priming effects found in our experiments. For example, without preliminary activation of any knowledge the system failed in solving the target problem in Experiment III, but after preliminary activation of the case of preparing tea by an immersion heater in a glass, the system found a possible solution - using a hot knife, if the stone description is also activated beforehand than the generated by the system solution is "using a hot stone". A detailed description of the simulation experiments will be presented in another paper.

5. CONCLUSIONS

Two hypotheses underlying associative memory-based reasoning have been discussed and some experimental support for these hypotheses has been obtained.

Both **near priming effect** (immediately after the priming) and **far priming effect** (4 to 8 min after priming) **on problem solving in high level tasks** have been demonstrated. It has also been shown that the **priming effect decreases in the course of time.** This is considered as a support for the spreading activation hypothesis, which needs further testing. Psychological experiments are planned to explore the causes for the priming effects: we would like to contrast the hypothesis of the residual activation after the priming phase with the hypothesis of the creation of associative links during the priming phase. The decreasing of the priming effect in the course of time substantiates the first hypothesis but nevertheless we would like to explore the differences further by giving two different primes to the subjects in order to check if there will be interference between the priming effects.

The experiments on deductive, inductive and analogical problem solving have demonstrated the same behavioural phenomena which is considered as a support for the hypothesis that there is a single uniform reasoning mechanism.

The simulation results have shown that it is possible to produce deductive, inductive and analogical reasoning by the AMBR mechanism and that the demonstrated priming effects are similar to that in the performed psychological experiments.

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