Modeling Cued Recall and Memory Illusions as a Result of Structure Mapping

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Abstract

A model of cued recall is proposed. Its basic assumption is that processes of structural mapping and analogical transfer lie at the core of human cognition. Recall is viewed as a result of construction of a new episode, analogical to the old episode. The response items emerge from dynamic creation and competition of various hypotheses about what has happened. Thus, some psychological data about constructive nature of human memory are explained as resulting from constraints that are natural for the process of analogical mapping. Several simulations tested the model from different aspects. Finally, the role of connectedness of the episodes for the quality of their recall is explored in more details.

Keywords: Constructive memory; Analogy-making; Memory illusions; Cognitive modeling.

Introduction

During the last several decades experimental data have been accumulated in support of the phenomena of false, illusory memories (Bartlett, 1932, Deese, 1959, Loftus 1977, 1979, 2003, Roediger & McDermott, 1995, Schacter, 1995, 1999, Kokinov & Hirst, 2003). Ulrich Neisser (1967) proposed the constructive approach to human memory by analogy with the constructive approach to perception which was based on the phenomena of visual illusions. According to Neisser, recall is an active process of *interpreting* old memory traces, just as vision is viewed as an active process of interpreting visual information. Thus, recall includes a process of constructing and testing hypotheses about past events on the basis of various constraints and contextual information.

The problem is that there are very few computational models that account for illusory memories. The CHARM model (Metcalfe, 1990), the TODAM2 model (Murdock, 1995), and the Complementary Learning Systems (CLS) model (McClelland et al. 1995) are able to simulate the phenomena of blending of two similar episodes. However, all these models use in one way or another feature vector representations and are not sensitive to the structure of the episode. That is why they cannot account for the psychological data on blending of dissimilar episodes (Kokinov & Zareva, 2001) based on their structural similarity with a third episode.

Tulving (Tulving, & Watkins, 1973, Tulving, 1982) suggested that recall and recognition are processes of memory construction combining information from the encoded traces and the current environment (cues, questions, etc.). Kintsch (1988) working on text comprehension suggested similarly that information from memory and inferred elements are combined with the input while building the internal representation of the text. Following these traditions we have developed a model that postulates that *the specific mechanism for the constructive process of memory is analogy-making* (Kokinov, 1998; Kokinov & Petrov, 2001).

People usually think of analogy-making (Gentner, 1983, Falkenhainer et al., 1989, Hummel & Holyoak, 1997) as a slow, deliberated process of comparing structures from two domains. However, we assume that the basic mechanisms of analogy-making (such as structural mapping and transfer) may be very fast, unconscious, and parallel. Hofstadter and his colleges (Hofstadter, 1984, 1995, 2001) assume that analogical thinking lies at the core of human cognition and proposed several models of high-level vision, based on analogy-making. The DUAL architecture (Kokinov, 1994a) and the AMBR model (Kokinov, 1994b, Kokinov & Petrov, 2001) propose fast, parallel mechanisms of retrieval and mapping. Thus, analogy-making seems a promising basis for modeling various cognitive processes. The current model of memory recall is based on the DUAL architecture, inherits its mechanisms and provides few new ones, and is integrated with the other DUAL-based models like the AMBR model for high-level analogy making (Kokinov, & Petrov, 2001), the JUDGEMAP model for judgment on a scale (Petkov, 2006), and the RecMap model for visual recognition (Petkov, Shahbazyan, 2007).

This paper describes an attempt to further extend a model of memory that was capable of question answering and which simulated and predicted the dissimilar episode blending phenomenon (Grinberg & Kokinov, 2003). The problem with this model was that it required a detailed structural description of a specific question (e.g. “Where did the coffee cup break down”) and thus could not be used directly in simulation of a typical memory task such as “Please, recall the elements of the list of words that you studied two days ago in the lab”. This more general type of recall is less structured and we do not know in advance how many and what kind of elements we are looking for. We are trying to overcome this limitation in the current paper. We first briefly describe the mechanisms of the model and the results of several simulations and then compare them with psychological data obtained earlier (Kokinov, Petkov, Petrova, 2007).

The Model of Cued Recall

According to the current model the process of recall is a process of constructing a new ‘episode’ (the ‘episode’ of the current situation of recall), which is as similar as possible to a past episode that is referred to in the request for recall. Since recall is “constructing a new episode” the result could well be an episode that never happened. Thus the constructive nature of memory naturally falls out of this main assumption. In addition, since episodes are represented in DUAL as decentralized coalitions of agents and the agents are the building blocks of construction, it becomes quite natural and possible to use the “wrong blocks” and thus construct an episode with elements originating from various old episodes and thus blend them. However, the model is sensitive to the structure of the episodes, thus there are relatively small number of wrong recalls.

The main assumption of the model is that the process of constructing of this new episode can be basically viewed as a process of analogy-making. The representation of the question is a ‘target’; some mappings between the target and various distributed memory traces emerge; these mappings cause some transfers; and some of the transferred elements are hypothesized as possible recalls. Various structural constraints serve as justification for excitatory or inhibitory links among hypotheses and a constraint satisfaction network emerges. In this way the initially generate elements based on activation and the associations with the target, are then organized into a coherent structure by the structural constraints of analogy-making. Thus the model combines associative and structural constraints in modeling recall by constructing and testing hypotheses about past events.

Representation of the Target

Following the principles of the DUAL architecture memory is distributed and various pieces of information are interconnected into coalitions. Long-term memory (LTM) consists of a huge number of interconnected DUAL-agents without clear boundaries between episodes and between semantic and episodic knowledge. Each agent stands for very small piece of information (object, concept, relation, hypothesis, or a binding-node) and even relatively simple events are represented with large coalitions of agents.

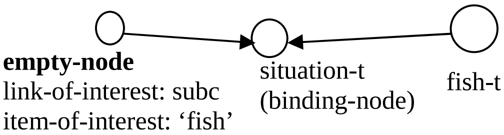

Figure 1. Representation of the target “List fish examples”.

Consider the following instruction “Recall as much as possible different types of fishes”. The target representation (Figure 1) involves a special “empty-node” together with a single new exemplar of a fish (*fish-t*), and a binding node for the current situation (*situation-t*). The role of the empty-node is to be mapped to various candidates for possible answers. All these mappings will be considered as hypotheses but only the winner hypotheses will be actually reported by the model. The empty-node keeps two additional pieces of information. The first one is the type of the important link – ‘*sub-class’*. This means that the question is for subclasses of fishes, not for parts or properties of fishes[1]. The second additional piece of information is, of course, the concept ‘*fish’*.

The exemplar of a fish, represented in a target serves an implementational purpose, not a conceptual one. The analogy should start from somewhere. The agent ‘fish-t’ will launch the first mappings, which in turn will be followed with transfers and more mappings.

Another agent in the representation of the target is the binding node, which brings together the elements of the current situation and makes it possible the system to recall later this situation “I recalled fishes”. There are links from the other agents to it, but there are only few opposite links.

The knowledge base is organized following the predicate structures of the items. For example, if the knowledge “fishes have gills” should be represented, the nodes for “fishes” and “gills” should be connected with a node for “have”. All predefined links – links between relations and their arguments, links from sub-classes to their super-classes, etc – have constant weights.

Spreading of activation

The relevance of each agent to the current context is represented with a real number - its activation level. The activation originates from the representations of the environment ant the goals of the system. It spreads among the network and the pattern of activation continuously reflects the changes of the context. The agents, which activation level exceeds a certain threshold, form the Working Memory (WM) (Cowan, 1999). Only the agents from the WM can perform some work and in addition, the more relevant a certain agent is, the faster it works.

Thus, the representation of the target is attached to a source of activation that spreads to some related concepts like animal, mammal, bird; also many concrete instances of animals; some concrete old situations with animals (for example, a zoo that my daughter and I visited last week). Together with the new situations some items very different from fishes can also be activated (for example, the ice-cream we eat with my daughter). However, because of a decay parameter in spreading activation mechanism, the volume of WM will stay relatively small.

Mapping and transfer

Each instance-agent that enters the WM emits a marker that spreads upwards to the class hierarchy with a speed, proportional to its activation level. When a marker from the target situation crosses a marker from the LTM, a

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[1] In the simulations the model was tested with questions of the type “Recall as much as possible objects from the picture we showed you yesterday”. Here the model looks for a concrete episode and the important link type is ‘*element-of*’.

hypothesis for correspondence between the two marker origins emerges. Then the transfer mechanism starts to copy the relations, in which the corresponding elements are involved. For example, suppose that the first memorized fish is one from the zoo that we have visited last week. The relations of this fish, together with their arguments, like the fishes from the neighbor aquarium; the next animals we have seen, etc, will be transferred to the current situation. (Note, most of these transferred elements will live a short time, but some of them possibly can become permanent and even after a week, I can remember something like this: “When I called to my mind the zoo from the previous day, I remembered for the ice-cream we eat”. The situation of visiting the zoo and the situation of remembering it are related but different).

Thus, a huge number of various related to each other memory traces become transferred in the current situation. Note, however, that this transfer is not un-limited. The main constraints for the transfer are two: a threshold for the activation level of the candidate (higher than the threshold for entering in the WM), and the structural connections of the candidate with the already mapped and transferred elements. Most of the isolated elements, which are not related with any relevant items, would be not transferred.

Hypotheses for recognition

For each transferred element, it should be considered whether this element is a reasonable candidate for an answer. If the system decides that the candidate can pass this filter, a hypothesis for recognition[2] between the candidate and the empty-node is created.

Following the principle for maximal flexibility the model assumes that rejections, instead of confirmations should be proved. For example, suppose that a certain ‘dolphin’ has been transferred to the target for recalling fishes. Instead of searching a direct sub-class link from the dolphin to ‘fish’, the system searches for direct reasons to reject the candidate. Such a reason can be a path between ‘dolphin’ and ‘fish’ through the class hierarchy, which path involves more abstract concepts. For example, ‘dolphin’ is ‘mammal’; ‘mammal’ is ‘animal’; ‘fish’ is also ‘animal’. This means that ‘dolphin’ cannot be a ‘fish’! However, sometimes it may happen that some elements from this path do not enter the WM, or enter it too late. Suppose that the link from ‘dolphin’ to ‘mammal’ is too weak. In this case it is possible ‘dolphin’ to pass the filter for creation of hypotheses for recognition. However, this happens rarely. Actually, it is a trade-off between the constraints enforced by the various mechanisms. If the link from ‘dolphin’ to ‘mammal’ is too weak, then why was the dolphin transferred? One possible answer is: because there are many relations, which are relevant to the fishes, and that involve dolphin – it swims, it lives in the ocean, it has fins, etc. Only the united pressure of many such relations can become sufficient to pass the filter of mapping and transfer.

Constraint satisfaction

So, various transferred items become hypothesized as reasonable answers. It is time the next filter – the filter for enough support and time – to play its role via the constraint satisfaction mechanism.

Two hypotheses support each other if their respective arguments are instances (or, respectively, parts) of one and the same agent. If there is a direct relation between two hypothesis’s arguments, then an excitatory link between the respective two hypotheses is created. An inhibitory link between two hypotheses is created when their respective elements are mapped to one and the same item.

In this way, dynamically, many excitatory and inhibitory connections between hypotheses emerge. The hypotheses compete with each other and when a certain one wins against its competitors, the following happen: (1) the model reports the respective item as an answer; (2) the hypothesis for recognition is replaced by a direct inst-of or part-of link from the respective item to the empty-node; (3) the respective hypothesis is excluded from competition. Thus, further on the hypothesis for the next promising item would win and so on. The system has a fixed time for its work. When the time is over, the collection of all winners is interpreted as an answer of the system.

Experimental Simulations

Three series of simulations were performed in order to test various aspects of the model. The first series tested whether the model is scalable. Both the volume of the episode of interest and the volume of the irrelevant part of the LTM are varied. The second simulation concentrates on the associative constraints, whereas the third one explores the structural ones. In fact, the third series of simulations explores the role of connectedness of the episodes for their recall and is a replication of a particular psychological experiment. Kokinov, Petkov, and Petrova (2007) presented the participants with series of pictures for memorizing the objects on them. Each of the series involved 12 pictures, and each of the pictures involved 3 objects. However, each object participated in three pictures and thus, the overall number of objects for each series was also 12. The first picture consisted of objects 1, 2, and 3. The second picture involved objects 2, 3, and 4, and so on. Finally, everything was turned as a circle – the 11th one involved objects 11, 12, and 1; the 12th picture involved objects 12, 1, and 2. Two different groups of people participated in two different conditions. In the ‘weakly connected’ condition, there were simply three unrelated objects on each picture, whereas in the ‘strongly related’ condition the objects were related in a meaningful but non-prototypical way[3]. After some time the

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[2] The name ‘hypothesis for recognition’ is inherited from the RecMap model for visual recognition (Petkov, Shahbazyan, 2007). The two models share the same basic principles and mechanisms.

[3] For example, a fire causes a cork of a bottle to launch out (first picture); the bottle is opened and the cork falls down on a chef’s hat (second picture), and so on.

authors gave to the participants a task for cued recall and found out that in the 'strongly related' condition people recall more correct items and produce less false memories.

All of the simulations were organized around a particular one (called 'connected 12' simulation). It was a representation of the 'strongly connected' task, given by Kokinov et al. to the participants. The knowledge base consisted of DUAL-agents that represented two series of 12 pictures and 12 objects in each series, organized in the same manner as in the psychological experiment. The LTM involved also separate concepts for each object. Assuming that the objects were very different, there was no single taxonomy among concepts but there were randomly chosen associative links. The knowledge base involved also some other examples of the concepts, related or not to some other elements (instances of other concepts), which potentially can be falsely reported by the system. Associative links were placed randomly among all instances.

The target was represented by an empty-node, the 'cue', a binding-node, and two more agents ('computer' and 'experiment') that represented the context of psychological experiment.

Thus, the first version of the knowledge base was the following one:

(1) **'Connected 12' base:** The agents from each picture are connected to each other with explicitly represented relations. Thus additional relations are created that connect respectively object 1 with object 2; object 2 with object 3, and so on; object 12 with object 1. All relations are instances of different concepts that are linked associatively but not taxonomically to each other.

The simulation was run 25 times, varying randomly the associative links and the opposite links (from concepts to some of their instances), thus simulating 25 different participants. The aggregated results from all simulations, together with the results from the psychological experiment are summarized in Table 1.

Simulation 1: Small and Large Memories

Two variants of the main base (1) were created to test the scalability of the model.

(2) **'Single connected 12' base:** There was only one single picture with 12 interconnected objects. Actually, this base can be seen as a representation of the simplest memory task of memorizing list of words.

(3) **'Large 12 connected' base:** The (1) base is enlarged by adding three times more elements – for each instance in base (1), which is not a part of any picture (i.e., its reporting will be considered as a memory intrusion), two more examples of the same concept are added.

Simulation 2: Far and Close Episodes

The base episode was modified in the following way:

(4) **'Zoo park' base:** The first base is replicated but some of the objects are replaced with instances of animals. Each series again consists of 12 pictures; each picture again consists of 3 objects; and each object again participates in three pictures, following the schema from (1). The difference is that six objects from the first series and six objects from the second series are replaced with animals. The animals participate in taxonomy and thus more activation would flow among them and more hypotheses for correspondence among different animals would emerge. In addition, some of the possible intruders (other instances of animals) are organized as a single episode – visiting a zoo.

The purpose of this simulation was to test the pure associative mechanisms, as well the role of various additional hypotheses for correspondence that emerge on the basis of the taxonomy of the animals.

Simulation 3: Connectedness of Episodes

A replication of the 'weak' condition of the experiment of Kokinov et al. (2007) was designed.

(5) **'Non connected 12' base:** It is the same as the first one (1), without the relations among the items.

Results and Discussion

The results of all simulations, together with the results from the psychological experiment were summarized in Table 1.

Table 1: Mean number of the real, blended, and constructed elements (up to 12) from the simulations, together with the experimental data (Kokinov, et al., 2007).

	real	**blend**	**constr.**
PsyExp strong connected	6.56		0.18
PsyExp weak connected	4.65		0.49
(1) Connected 12	6.47	3.26	0.53
(2) Single connected 12	7.68		1.32
(3) Large 12 connected	6.12	3.94	0.65
(4) Episode Zoo park	6.70[4]	4.45[5]	0.50[6]
(5) Non connected 12	2.24	0.96	1.06

Some of the simulations confirmed our expectations; some failed; and some provoked additional questions.

Comparing the results from simulation (1) to the results from simulations (2) and (3), we can conclude that *the model produces false memories* (like people do) and their relative number is not unrealistic huge; often *blends two episodes*; and *is scalable* (the performance do not degrade significantly with larger knowledge bases and larger episodes). When either of the episodes to recall or the irrelevant part of LTM increases, the percentage of the correct responses decreases and the amount of the constructed or blended items increases. However, these changes stay within reasonable limits because of the natural constraints on spreading activation mechanism which do not allow for drastic increase in the volume of WM. Independently of the number of the possible intruders the number of correct responses was about 6-7 items, whereas

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[4] Respectively 3.30 animals and 3.10 other elements.

[5] Respectively 2.50 animals and 1.95 other elements.

[6] Respectively 0.10 animals and 0.40 other elements.

the number of intruders never exceeded 5 items. Of course, the scalability of the model should be additionally tested.

The main result from the second simulation is also not surprising. If there are two similar bases both the correct and blended items increase a bit. This is because of the stronger associations between the episodes.

When we look closer into the details, however, something strange appears. We compared the number of real, blended, and constructed elements that were animals versus the respective real, blended, and constructed non-animals (see the footnotes bellow the table). The difference between the correctly responded animals and non-animals was smaller than we expected; whereas the same difference about constructed (but not blended) items was in a direction, opposite to our expectation. The reason was the following.

In the model there are two forces that sometimes work in opposite directions. On one hand, the spreading of activation makes the close associations of items for recall more plausible candidates for memory intruders. On the other hand, the natural for analogy-making constraint for one-to-one mapping causes the hypotheses for recognition, which involve mapped elements, to inhibit each other. For example, if a transferred ‘rabbit’ and a transferred ‘elephant’ are hypothesized as possible answers, it is highly probable that the two hypotheses will inhibit each other because the respective ‘rabbit’ and ‘elephant’ would be mapped to certain single mammal from the base.

It is difficult to distinguish the strength of an association between two items from the strength of their structural relatedness because they usually correlate. However, the property of the model to combine associative spreading of activation with the structurally constrained hypotheses creation can potentially produce novel predictions and can be used for further testing of the model.

The final, third simulation compared the results from strongly connected and weakly connected episodes. It successfully accounted for one part of the psychological data and failed to account for another part.

Just like the pattern of the psychological data, the model responded more correct items in the strongly connected episode case and produced more intruders in the weakly connected episode case. Thus, the model can be used for a possible explanation of the psychological data - both the associative and the structural mechanisms predict this result. The relations among the items increase the activation level of the correct elements and give them an advantage. On the other hand, these relations cause creation of direct excitatory links among the hypotheses for recognition that involve elements from the same base, and inhibitory with the rest.

The model, however, failed about the blended memories, i.e. the ones that come from the episode that shared the same context to the episode of interest. The reasons for this failure, from our point of view, are two. First, the representation of the episodes in the model is very poor. Actually, the episode that we call ‘weakly connected’ was represented as not connected at all. Probably people encode some spatial and semantic relations among items from the same picture. The second possible reason for the failure of the model was the implausible representation of the target. The ‘cue’, represented as the target, actually served associative purposes only and launched the first mappings only. As a result, the model produced an unrealistically high number of blended responses, more than people do.

From a certain point of view the two reasons are equivalent (or at least analogical). Both they are related to the poor representation of the relations among items either in the bases or in the target.

Conclusions

A new approach to modeling memory retrieval and illusory memories is proposed, namely, it is a result of the mechanisms that are basic for analogy-making. Thus, the process of cued recall is viewed as a process of active creation and competition of hypotheses about the past.

The associative mechanisms, typically used for modeling memory recall are integrated with structural ones. The role of the relations among the elements is emphasized.

The computational model is developed on the basis of this approach. The model does not exist in isolation but is integrated with models of seeming very different cognitive processes like analogy-making, judgment, and visual recognition and the same basic mechanisms underlie all models and thus some results emerge from mechanisms, designed for completely different purposes.

The ability of the model to recall episodic information was tested from different points of view via series of simulations. The scalability of the model was demonstrated. The results from semantically close or far bases are compared and analyzed. In this way novel questions emerge and new issues for investigation are opened.

The integration of associative and structural mechanisms makes the model capable of simulating the empirical data on blending of structurally similar but superficially dissimilar episodes. These results cannot be accounted for by pure associative models (Murdock, 1995, McClelland, McNaughton, & O’Reilly, 1995).

The role of connectedness of the episodes was explored in more details. The pattern of simulation results was compared to empirical data and in this way the model proposed possible explanations of the data from the psychological experiments.

We view the model as a first step in a large project for modeling various memory processes. Thus, some failures and weaknesses of the model were found in the simulations and were analyzed. In particular, the poor representation of the relations among elements from a certain episode produced extremely high number of blended items. This is going to be fixed by introducing more detailed representations of the episodes.

However, the approach, proposed seems promising and its further development may contribute to the understanding of the process of cued recall, as well as some seemingly different and unrelated cognitive processes.

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