Context-Sensitivity of Human Memory: Episode Connectivity and Its Influence on Memory Reconstruction

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Abstract. This paper is testing a DUAL-based model of memory. The model assumes decentralized representation of episodes as a coalition of agents and analogical transfer processes as the basis for memory reconstruction of our past. It is a model of active reconstruction thereby allowing memory insertions and blending of episodes. The experiment explores the role of the degree of internal connectivity of the coalition representing the episode on the outcome of the reconstruction process. It demonstrates that the more the links between the elements of the episode are, the higher the number of details we recall, and the lesser the intruded elements and the context influence.

Keywords: Cognitive Science, Psychology, Cognitive Modeling, Episodic Memory, Context effects.

1 Introduction

Even though human memory has been studied for more than 100 years now, we still do not have a clear understanding of how it works. There are two main metaphors for human memory used over this century (and the millenniums before that): the *storehouse* metaphor and the *paleontologist* metaphor. According to the first metaphor human memory is a “storage” where “memory traces” are “collected” and later on “retrieved”. According to the second metaphor human memory is an active process of “constructing the past” (Neisser, 1967) – that is why this approach is also called “constructivist approach” (Bartlett, 1932, Schacter, 1995, 1999, Kokinov, Hirst, 2003). These two metaphors are still being in use and are still the basis of the main accounts of human memory.

In this paper we will discuss the possible mechanisms underlying episodic memory, i.e. memory for events, instances, and experiences. There are a number of models of episodic memory that can be classified according to two factors: whether they are more or less abstract (mathematical models, computational symbolic models, or biologically-oriented connectionist models) and whether they follow the storehouse or the paleontologist metaphor. There is a correlation between these two dimensions and as a rule the mathematical and symbolic models of memory are predominantly based on the storehouse metaphor, while the connectionist models tend to be more of a constructivist type, but this is not necessarily the case.

B. Kokinov et al. (Eds.): CONTEXT 2007, LNAI 4635, pp. 317–329, 2007.

In the short review that follows two important characteristics will be taken into account: the capabilities of the models to *explain false, illusory memories* (Deese, 1959, Loftus 1977, 1979, 2003, Roediger & McDermott, 1995, Schacter, 1995, 1999, Kokinov & Hirst, 2003), i.e. to explain not only the successfully recalled events, and the failure to recall some details, but also the cases of inserting elements in the recalled events that have never happened, as well as blending of two or more different episodes; and the capabilities of the models to *explain context-sensitivity of human memory* (Davies & Thomson, 1988, Smith, 1988), i.e. the tendency to recall an event easier when in the same environment or in the same internal state than in a changed environment or state; to recognize a face easier when the person is in the same setting, dressed the same way, doing the same activities, etc.; to recall different aspects of an event depending on the specific context of recall.

There are many models of episodic memory. These include the SAM model (Raaijmakers & Shiffrin, 1981), the REM model (Shiffrin, & Steyvers, 1997), the MINERVA2 model (Hintzman, 1984, 1986, 1988), the CHARM model (Metcalfe, 1982, 1985, 1990), the TODAM2 model (Murdock, 1982, 1983, 1993, 1995), the Complementary Learning Systems (CLS) model (McClelland, McNaughton, & O'Reilly, 1995, Norman, & O'Reilly, 2003), the ACT-R model (Anderson, 1993, Anderson & Lebiere, 1998). These models have been successfully used to account for various aspects of memory for list of words both in recognition and recall tasks. We are, however, interested in explaining the recall of complex episodes.

Except for the ACT-R model, all other models share a basic assumption which is that "memory traces" are represented by feature vectors. This is fine when lists of words has to be remembered, however, it becomes problematic when memorizing real-world episodes which include not only items and features, but also relations between the objects and participants. The relational information becomes even more important when analogy-making is involved (Gentner, 1983) and episodes are often used for transferring knowledge from old to new situations. ACT-R uses structured representations (chunks) and thus allows for representing this relational information. One may argue that the associative information in the "memory images" of SAM is relational in nature, and this is certainly true, but it is a very specific case and cannot be used for representing complex relational knowledge about the episodes.

Most of these models would account for the known context effects. Incorporating environmental information in the feature vector (or the chunk) and trying to find the best match to the retrieval cue (which may involve environmental features as well) results in a context-sensitive recall and/or recognition. In this way they account for the fact that people recall some words from the lists in one context, but not in others. Most of them, however, will not be able to account for context sensitive event recall, i.e. for the fact that different aspects of the episode might be reported on different occasions. This is because retrieval of an episode is all-or-non phenomenon according to these models – either the models finds the corresponding vector or not. Some models fix this problem by postulating a stochastic process by which some of the features in the feature vector might be unsuccessfully recovered or randomly changed during the recall and thus reproduced wrongly. Basically these models tend to ignore this issue since they were designed for explaining memory for word rather than for complex episodes.

It would be even more difficult for most models to explain false, illusory memory since most of them are based on the storehouse paradigm. Still some of these models explicitly attack this issue. Thus, for example, the CHARM model has been used to simulate some of Loftus' (Loftus 1977, 1979, 2003, Loftus et al, 1995) experimental results showing that human memory blends two similar events. TODAM2 should also be able to simulate these results since it is very similar in nature – both models assume that all memory traces are transformed (e.g. by convolution) and added to a single LTM vector. In this way the interference between two similar vectors results in blending between them. The CLS model (McClelland, 1995) has also been able to simulate blending of simple sentences which is even more interesting since the blending is produced at retrieval, i.e. it is constructed.

The next section describes a model of human episodic memory that was designed in order to face all these challenges: to be able to represent complex relational structure, to explain the constructive nature of human memory, and to account for its context sensitivity.

2 DUAL-Based Model of Episodic Memory

DUAL is a general cognitive architecture (Kokinov, 1994b, 1994c) developed in order to provide an integrated platform for building models of various cognitive processes that will interact with each other. Several models have been built so far on its bases: the AMBR model of analogy-making and memory (Kokinov, 1988, 1994a, Kokinov & Petrov, 2001, Grinberg & Kokinov, 2003), the JUDGEMAP model of judgment (Kokinov, Hristova, Petkov, 2004, Petkov, 2006), the PEAN model of perception (Nestor, Kokinov, 2004) and the newest integrated model of analogy and perception (Petkov, et al., 2007).

DUAL is a multi-agent system that combines the connectionist and symbolic approaches at the micro level. Each DUAL-based system consists of a big number of simple micro-agents each of which is hybrid. The symbolic part of the micro-agent represents a small piece of knowledge – a separate aspect of a proposition, of an episode or a concept, and its connectionist part represents the level of relevance of that piece of knowledge to the current context. In this way knowledge is represented by symbol structures in a decentralized fashion – knowledge is distributed over coalitions of agents. On the other hand, context and relevance are represented by the pattern of activation over the entire set of micro-agents.

Long term memory (LTM) corresponds to the whole set of micro-agents, while working memory (WM) corresponds to the set of micro-agent that are activated above a certain threshold at a given moment of time. Only the agents which are in WM are performing symbolic operations. Moreover, the speed of their symbolic processing depends on their activation level, thus the more active the agents are the faster they process the information and therefore have greater influence on the computational process. Cognitive processes are emerging in DUAL as a result of the local interactions among the micro-agents. There is no central control on the processes. Everything emerges from the message exchanges between simple micro-agents.

Episodes are represented by coalitions of agents, i.e. agents that are linked together and exchange activation supporting each other. Each agent in the coalition represents either an aspect of the episode (an object, a person, a feature) or a relations between aspects of the episode (relation between two persons or objects, an action performed by someone, etc.). The agent representing an object can be linked to the agent representing its feature and vice versa, the agent representing a relation is linked to the agents representing its arguments, etc. In this way the coalition is a kind of subnetwork of the network of the knowledge represented in LTM. Some coalitions are loosely connected since there are not many links between the agents (either there are few relations among the objects in the scene, or they were not encoded). These coalitions are quite vulnerable, i.e. it could easily happen that only few elements of the coalition are activated (and the activation cannot spread to the rest of the coalition because of the few links within it) and thus the cognitive model will spontaneously recall only a few aspects of the episode. On the other hand, some coalitions consist of strongly interconnected agents and these coalitions will be quite robust – as soon as some agents are activated all other members of the coalition become active as well because of the numerous excitatory links (Figure 1).

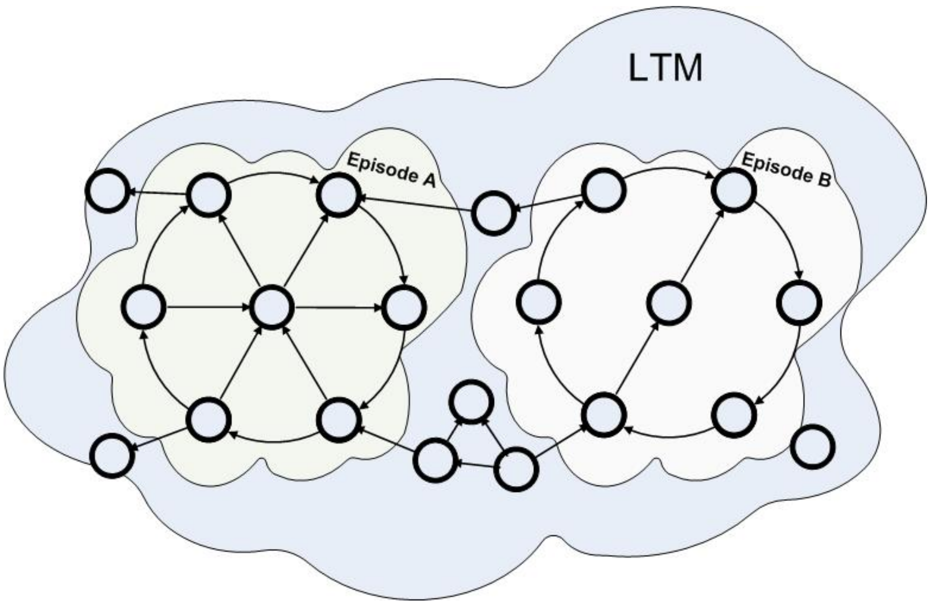

Fig. 1. Episodes are represented as coalitions of interconnected agents in LTM. Some episodes are robust (e.g. Episode A in this picture) – they consist of highly interconnected agents, while others are vulnerable (e.g. Episode B in this picture) – they consist of loosely connected agents.

The events and situations are represented in a hierarchical order. Thus, suppose for example, that several sets of pictures are presented at the computer screen during a psychological experiment. The participation in the experiment will be represented as an episode and each set of pictures will be represented as a sub-episode. In turn, each concrete picture is a sub-episode of the sub-episode, etc.

Recall is modeled in two ways in DUAL. Spontaneous free recall is a result of simple spreading activation. Activation starts from agents representing the immediately perceived aspects of the environment (connected to the INPUT node) and the goals of the system (connected to the GOAL node). The result of the spreading activation entirely depends on the initial activation (residual from some priming task and perceptual) and the pattern of connectivity. Cued recall is modeled as a kind of superficial analogy being sought. The probe is considered as a target and the AMBR analogy-making mechanisms are responsible for finding the closest base, and for the mapping and transfer processes. The model simulated blending of dissimilar episodes (Grinberg & Kokinov, 2003) which was a very surprising result. No other model or theory has ever claimed that dissimilar episodes can be blended. Taken as a strong prediction of the model, it has been experimentally tested and confirmed (Kokinov & Zareva, 2001, Zareva & Kokinov, 2003).

A number of other predictions fall out of the model. Consider the two coalitions presented in Figure 2. They represent the same objects participating in the two episodes. In the first case there are a number of relations between the objects thus connecting them into a strong and robust coalition, while in the second case there are no relations between the objects and they are bound together into a coalition only by the fact that all of them were present at the same place – in the lab. This second coalition will be weaker and more vulnerable. What are the consequences of this difference?

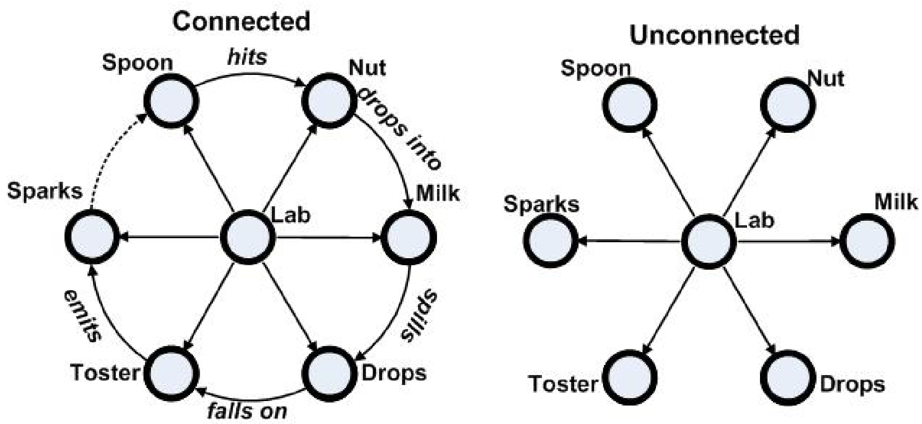

Fig. 2. An example of strongly connected and weakly connected coalition. In the strongly connected version there are relations between each two objects in the scene, while in the weakly connected version there are no relations among the objects (except for the spatial relations which are not depicted).

Predictions

Firstly, the first episode should be expected to be easier for recall: when activating some of the elements of the coalition the activation will spread easily to the rest and most of them will be activated as well. Therefore we should expect more elements of the episode to be reported.

Secondly, it would be easier for intruders from other episodes to be integrated into the weak coalition than into the robust one, since in the robust coalition all elements will be highly active because of the strong links among them and they will easily win the competition with the potential intruders, while in a weak coalition the intruders may easily become more active and win over its own members. Therefore less constructed illusory elements should be expected in the case of strong coalition than in the case of a weak one.

Finally, context effects should be stronger in the second case, since the coalition is unstable and even a single unrelated cue can change the activation levels and thus produce a bias towards the recall of associatively related elements of the episode.

4 Psychological Experiment: Testing the Model's Prediction

The experiment described in this section tests the predictions of the DUAL-based model of episodic memory by designing strongly connected and weakly connected episodes and testing the effect of the connectedness on various variables.

4.1 Method

Design. The experiment has a 2x2 mixed design. The independent variables are connectedness (with two levels – strongly connected version and weakly connected version of the stimuli) and context (with two different contexts for each stimulus set).

The connectedness conditions were randomly assigned to each subject for each stimulus material. Thus a single person participated in different conditions for different stimuli. The data were treated as repeated measurements with one within-subject factor – connectivity. The context factor was a between groups factor.

There are several dependent variables: the number of correctly recalled objects from each group of pictures (from each episode); the number of constructed (invented) objects that were actually not present in the pictures but were "recalled" by the participants; the order of recalled objects; and the distance of the recalled objects from the context stimulus and the degree of context influence.

Procedure. The procedure was very simple. The participants had to look at the computer screen where a series of pictures were presented for 3 seconds each. They were asked to remember the objects in each picture since they will have to recall them later on. There was a short training session in which they learnt what an object is – in order to eliminate parts of objects and their properties and relations from the list of to be remembered and recalled things. We asked them to focus on the objects only.

Then they participated in another experiment for 15 minutes in which they had to evaluate the length of line segments on a 7 point scale. This is a distracter task, which aims to shift their attention to a different field in order to be sure that they cannot hold the pictures or objects in their WM. So, if after that they would be able to recall some objects they should come from LTM.

The third session was a cued recall test. On a sheet of paper the participants had to write the list of objects they remember from the corresponding group. The first element of the group was present on the answer sheet and served as a cue for the rest of the group.

Fig. 3. Examples of the stimulus material: (left column) the strongly connected version, and (right column) the weakly connected version

Stimuli. Three sets of pictures have been used each of them consisting of 12 pictures. On each picture there are three objects, and each object is repeated on three pictures. Thus in each set of 12 pictures which is considered as an episode in our case, there are 12 different objects altogether. Each such set of 12 objects is presented in either a strongly connected version, or in a weakly connected one.

In the weakly connected version (see the right column in Figure 3) simply the three objects were not related in any meaningful way on the screen. In the strongly connected version (see the left column in Figure 3) the three objects interact in a meaningful way. The scenes were designed not to evoke schematic knowledge (prototypical events) thus the relations were quite strange and could not be used to predict what will happen next. The purpose of these relations was to make the representation of the episode a closed connected chain of objects and in this way to become a strong coalition.

The context stimuli were designed to be associatively linked to one of the objects in the corresponding set of pictures (Figure 4). Thus for example the "gift" is associatively linked to the "bottle of champagne", while the "bread" is associatively linked to "toaster". The idea is that presenting the context element "gift" the participants will be more likely to recall those elements that are associatively linked to it, and its neighbors, than when presented with "bread". This manipulation was designed to study the fine context effects on the content of the recalled episodes.

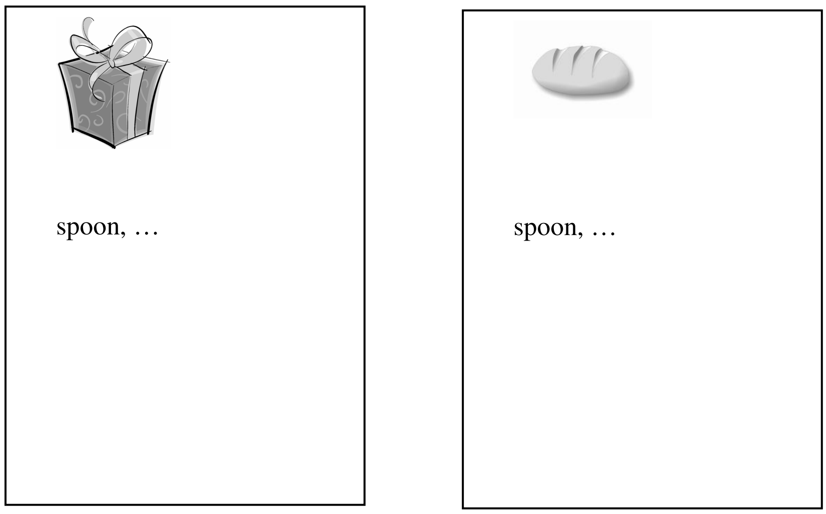

Fig. 4. Examples of the answer forms containing pictures of the context stimuli: gift and bread, together with the cue

Participants. 48 students from the New Bulgarian University participated in the experiment. Each of them participated in both the strongly connected and weakly connected condition, but each of them participated in only one context condition for each picture set.

4.2 Results

The data were aggregated for each participant and each condition (averaged over the items, i.e. over groups of objects to be remembered) and thus we obtained two measurements for each of them: for strongly connected and weakly connected episodes.

Thus repeated measurements ANOVA revealed a significant main effect of connectedness on the number of correctly recalled objects ($F(1, 47) = 36.483$, $p<0.001$) – Figure 5.

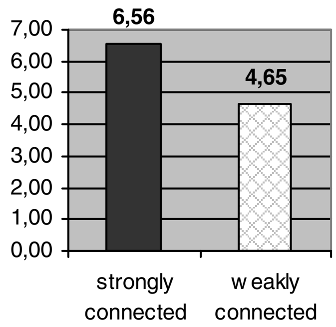

Fig. 5. Mean number of correctly recalled elements of the episode depending on the connectedness of the episode (out of 12 objects)

The main effect of connectedness on the number of falsely constructed elements of the episode (illusory memory) was also significant ($F(1, 47) = 5.905$, $p=0.019$) – see Figure 6.

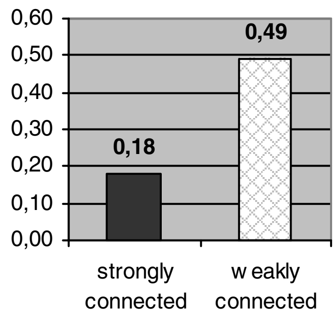

Fig. 6. Mean number of constructed (inserted illusory) elements of the episode depending on the connectedness of the episode

The next step was to analyze the main effect of connectedness on context influence. Context influence was measured in the following way: for each recalled element and for each of the two contexts 10 independent judges rated on a 7 point scale how closely associated the listed element and the context element are. In this way we obtained an average associative distance between each generated word and the context element. Then we calculated the difference between the two distances and called it context influence. The bigger this difference is the higher the context influence is, i.e. in the two different contexts subjects generated very different elements – one close to context 1 and the other to context 2. If the difference would be zero, then subjects would have generated the very same list of elements, or elements that are equally close to both contexts. It turned out that the main effect of connectedness on context influence is marginally significant ($F(1, 45) = 3.484$, $p=0.068$) and the context influence is higher in the case of weakly connected episodes.

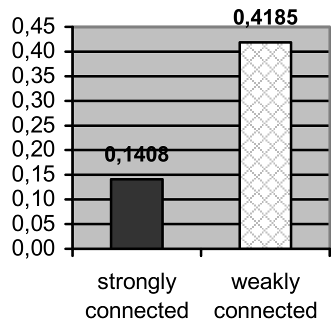

Fig. 7. How connectedness moderates context influence? Average context influence in the case of strongly connected episodes and weakly connected episodes

Finally, the order of recall of the episode elements was analyzed. A new variable was introduced which is called “distance in steps” – this is a measure of how many steps there are between the previously recalled and the currently recalled element if we follow the order of presentation of the objects in the initial slides. If the participants exactly follow the order of initial presentation the average distance in steps for their recall list will be 1. Of course, this is not the case. However, the participants in the strongly connected episodes group were following significantly more closely the initial order of presentation ($F(1, 43) = 10.431$, $p=0.002$). This is because they can use the represented causal relations between the elements as a way of traversing the episode, while in the weakly connected episodes this is impossible.

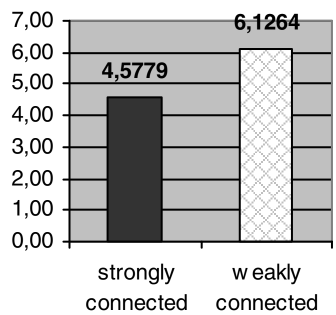

Fig. 8. Strongly connected episodes tend to be recalled to a greater degree in the same order as presented than the weakly connected episodes

4 Conclusions

All of the predictions of the DUAL-based model of memory were confirmed (in one case only marginally). Strongly connected episodes make the recall easier – participants recall a bigger number of correct objects, a smaller number of incorrect (inserted) objects and they tend to recall them more closely following the order of presentation of the objects. At the same time strongly connected episodes are less influenced by context, while weakly connected episodes tend to be recalled in a context-dependent manner (the content of the episode is changing with context).

This is only a first step in a long journey. A number of additional questions arise out of this experiment. Although we tried to push away the schematic knowledge from this experiment by designing strange, unconventional situations, we can still not be sure that schematic knowledge has not been involved to certain degree. One way to explore this further would be to explicitly manipulate the degree of conventionality of the relations between the objects. Highly conventional relations are expected to chunk the whole episode into a single whole and thus make it much easier to remember, they should contribute to higher number of correct recalls, but also a higher number of false (illusory) recalls if a prototypical object is missing from the presented situation. And also context effects should be smaller or even nonexistent with prototypical situations.

The DUAL-based model of episodic memory presented here allows for a much more detailed analysis of the content of the episode representation, especially of the internal structure of the episode. Most models of memory ignore this structure, but as we see from the experimental data, the structure plays an important role for successful recall, for the specific content we recall, and is characteristic for the degree of constructivist illusions and context influence imposed on recall.

Acknowledgments. This work is supported by the Project ANALOGY: Humans – the Analogy-Making Species, financed by the FP6 NEST Programme of the European Commission.(Contr. No 029088).

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