A Theory of the Acquisition of Episodic Memory

Carlos Ramirez and Roger Cooley

University of Kent at Canterbury, Computing Laboratory,
Canterbury, Kent CT2 7NF, UK
{cr10, rec}@ukc.ac.uk

Abstract. Case-based reasoning (CBR) has been viewed by many as just a methodology for building systems, but the foundations of CBR are psychological theories. Dynamic Memory (Schank, 1982) was the first attempt to describe a theory for learning in computers and people, based on particular forms of data structures and processes, that nowadays are widely used in a variety of forms in CBR. In addition to being useful for system building, CBR provides a way of discussing a range of issues concerned with cognition. This focus on the practical uses of CBR has deflected attention from the need to develop further the underlying theory. In particular, the issue of knowledge acquisition, in not adequately handled by the existing theory. This paper discusses this theoretical weakness and then proposes an enhanced model of learning which is compatible with the CBR paradigm.

1 Introduction

In recent years, CBR has been gaining ground in the machine learning arena. Unfortunately, the interest has been mostly concentrated in categorisation tasks; several very successful CBR programs have been developed to date under this line of research; one example is PROTOS (Bareiss, 1989), an exemplar-based learner (see Gentner, 1989; Redmond, 1989) based on psychological theories of concept learning and classification (see Medin and Smith, 1984; Van Mechelen, *et al.*, 1993; Rosch, 1978). However, there are additional possibilities for learning within CBR (Schank, *et al.*, 1986; Burstain, 1986), and there are many avenues for research.

2 Acquisition of Events

One issue of CBR that should receive more attention is concerned with the acquisition of knowledge because little is actually known. There are only a few known theories on the acquisition of knowledge, and none of them are completely satisfactory (see below). Variations of schemata-like structures are widely used to represent acquired knowledge (e.g., *plans* by Abelson, 1973; *scripts* by Schank, 1975; *frames* by Minsky, 1975; *schemata* by Bobrow, 1975, and Rumelhart, 1980). Some theorists, working in cognitive and computer sciences, assume that some form of induction is used, but do not provide satisfactory accounts of it (either because the accounts are incomplete, too loose, or because more details need to be specified and proven). For example, Holyoak (1985) and Keane's (1988) accounts of schemata acquisition are limited to the creation of schemata by analogy; many other theorists remain suspiciously silent. Rumelhart (1980) elaborated one of the most complete accounts (see also Rumelhart and Norman, 1981) on schema acquisition. Rumelhart and Norman's account is based in three basic forms of schemata acquisition, which can be described as follows:

1. *Accretion* is the accumulation of 'memory traces' or 'traces of the comprehension process' upon having perceived some event or understood some text, into the repertoire of knowledge.
2. *Tuning* involves the elaboration and refinement of concepts in a schema through continued experience. There are three kinds of tuning: (a) systematic adjustment of variable constrains and default values, (b) concept generalisation, and (c) concept specialisation.
3. *Restructuring* involves the creation of new schemata either by induction (through the repetition of a spatio temporal configuration of schemata) or by analogy (mapping some aspects of an existing schema onto a novel situation, noticing differences and changing some of its attributes). This form involves the actual development of new concepts.

These accounts of schemata learning work well once a schema is discretionarily determined (already existent in memory), or elements or aspects of a schema are identified; but, what is involved in learning new schemata from scratch, i.e., when no similar schema is already in memory? The only form of learning that can deal with such a condition is schema induction. However, current schemata theories (as those mentioned above) have problems dealing properly with induction because they make no provision for recognising recurrent configurations for which a schema does not already exist in the system. Is this the reason why most theorists prefer to remain silent on this issue? Practitioners tend to implement some form of ad hoc or ill-defined method of induction when trying to tackle this situation, which sometimes works, but obviously, those are specific solutions to very limited domains. For example, a typical approach is to support the 'inductive' mechanism of a given system with some form of background knowledge or with training examples.

Dynamic memory theory (Schank, 1982) is the starting point of case-based reasoning, and is the foundation of this paradigm of cognition. In this theory, scripts are one of the main structures used to explain the organisation of episodic memory. However, other knowledge structures are also proposed, including *scenes, MOPs, Meta-MOPs*, and *TOPs*. The acquisition of knowledge is a more intricate process than is allowed for in plain schema theories. Dynamic memory is an elaborate theory, intertwining several cognitive processes. Such a theory inevitably leaves room for interpretation; more work is needed to articulate this paradigm. Furthermore, some theorists consider that dynamic memory theory is incomplete and underspecified (Eysenck and Keane, 1995). This paper tackles some of the problems encountered with dynamic memory as a learning theory.

3 Dynamic Memory Weaknesses

There are some problems concerning conceptual aspects of dynamic memory theory. Firstly, Schank argues that during the act of trying to understand an experience (event), we are inevitably reminded of similar events, because in order to recognise the closest previous experience, we have to retrieve related memory structures, sometimes closely related to the event at hand, sometimes only related by context. However, there is evidence (Seifert, *et al.*, 1986; Seifert and Hammond, 1989) that people do not always remember and utilise prior experiences that are only abstractly related to the current situation in such a "simple memory model of episode retrieval". **People frequently fail to recall specific memories at relevant times**, and even further, **people commonly fail to get reminded** of the closest or the most useful event when it is needed to solve a problem – specially novices. It seems that the determining factor in effective retrieval of events is the **quality of the original encoding**; and that additionally, agreat deal of inference is required to fully understand an experience containing abstract relations, required to improve the encoding. These findings are in line with previous predictions by Craik and Lockhart (1972), and Hyde and Jenkins (1973) (both studies in Eysenck and Keane, 1995), whom proposed that:

1. The level or depth of processing of a stimulus has substantial effects on its memorability.
2. Deeper levels of analysis produce more elaborate, longer lasting, and stronger memory traces than do shallow levels of analysis. Craik and Tulving's (1975) experiments suggest that elaboration of processing of some kind and the amount of elaboration are also important factors in determining long-term memory.

Another criticism of dynamic memory theory stems from Schank's proposition of "automatic reminding". Schank argues that during the act of processing an event, we are **inevitably reminded** of similar events. However, experimentation (Seifert *et al.*, 1985) reported that when subjects experience an event, they are not usually reminded of close events automatically. According with Seifert *et al.*'s experiments, it seems that **intentionality in recalling** is a required ingredient in the process of bringing up analogs from memory. *Intentionality* depends on subject's strategies and task difficulty.

4 An Enhanced Learning Model after Dynamic Memory

Due to limitations of space, it will be assumed that the reader has an understanding of the memory structures mentioned above (scripts, scenes, MOPs, Meta-MOPs, and TOPs; for details see [Ramirez, 1997a]). The theory that is presented below is based on dynamic memory theory (DMT); several modifications and enhancements have been carried out, the resultant theory is presented as follows:

(a) *Recognition and recall.* When a event is experienced, like <coming into a fast-food restaurant>, we try to recognise similar situations we have experienced in the past, by noticing some similarities with the current event. **Recognition** is a stage not considered in DMT at all, although many cognitive scientists (see Watkins and Gardiner, 1979, for a review; see also Tulving 1982, 1983) make a distinction here. The point is that a memories are encoded together with a context, and this context is relevant to the recognition process. Next to recognition comes the recalling of the best match, as proposed in DMT; however, it is important to notice that the effectiveness of the recalling process depends on individual strategies (e.g., which features of the event are observed–salient or distinctive features usually make the best indices or 'memory traces'; kinds of associations among elements of the events, etc.), and on the form of retention that was used for the encoding and storing (depth, elaboration, and distinctiveness). These two, "individual strategies" and "form of retention" are factors that Schank overlooked.

In more practical terms, if it is assumed that similar events are stored in a specific 'neighbourhood', then recognition means the localisation of that neighbourhood, taking advantage of common context. Recall is the process of retrieving the closest event.

(b) *Recollection and reminding.* During the process of recalling, we might be reminded of particular experiences, as pointed out in DMT, because the structures we use to process the new experience are the same structures we use to organise memories. However, Schank assumed that we are inevitably reminded of similar events, but evidence (see above) shows that reminding depends on intentionality–which is concerned with analogical strategies. What is remarkable here, is that memory structures for storage, and processing structures for analysis of inputs are the same ones. Therefore, it is not surprising that we may be "reminded" of similar events when processing a new one.

(c) *Reconstructing and Understanding.* Several cognitive processes are deeply intertwined in this theory: recalling and understanding are actually part of the same process. Understanding an event–been able to process an event accordingly to a expected outcome–begins when we start trying to recall previous similar memory events to the one at hand. Finding the 'right' one (i.e., the closest) means getting closer to the understanding of the experience. Schank makes an attractive remark that fits well at this point (1982, p.110): "A great deal of our ability to be creative and novel in our understanding is due to our ability to see connections between events and to draw parallels between events". This process of 'mapping events' is particularly interesting when it is done at the highest level (i.e., drawing analogies among TOPs or MOPs), because analogies can be done between domains or simply can be more significant in the same domain.

Therefore, we try to understand the current experience by reconstructing the recalled similar experience, or at least a significant part of it (the part that allows the understanding of the current part of the current event), by accessing the corresponding memory structures that organised it (i.e., scripts, scenes, or MOPs). An event is composed by sequences of situations–separable elements of the event–organised by those structures. If a close enough event does not exist in memory, then we may have to resort to foreign domain analogue events, by accessing TOPs; process that involves additional mechanisms. The above explanation of the understanding process may differ considerably from Schank's, since his presentation is of a more higher level, and is not well explained how recalled events are processed.

(d) *Expectations.* Once an event has been reconstructed, expectations about subsequent situations of the recalled event are automatically brought up. Therefore, it is possible to bring up situations, from the old event, that are likely to occur in the current one. This action can be used to *predict situations* as the current event progresses, that is, situations that still have not taken place, but that are part of the old event.

(e) *Expectation evaluation.* As the event progresses, some of the predicted situations may not take place (since the current event may differ from the recalled one); however, if most of the recalled expectations *match* the situations of the event at hand, then no modifications (or minor ones) to memory structures are carried out; clearly, very little or nothing is then learnt from the experience.

(f) *Explanation of expectation failures.* If some of the expectations (of situations) are not satisfied because the current experience differs too much from the old one, then the possibility of explaining those failures brings new opportunities for learning by modifying memory structures or creating new ones. Then, memory is organised in terms of explanations that are created to help to understand the differences between what is experienced and what is expected to experience. In DMT, Schank does not explain what it means for an experience to differ by "too much" from one stored in memory. What is proposed here is that those differences are concerned with aspects of beliefs, and hence, with confidence factors. The confidence factors are attached to the attributes of the schemata related to the events, and they are evaluated through the application of a similarity function. The confidence factors are modified on the basis of the frequency of use, and the effectiveness of the associated attributes, the higher the usage (provided that the outcome was positive), the higher confidence of the attribute.

(g) *Learning.* Having had an expectation failure, and having explained it, the individual is then in the position of modifying his memory structures in some way. But in what way? The question is not an easy one: it is not clear why every individual encodes his or her experiences differently. Schank again does not discuss this point. Here, it is suggested again that the beliefs of an individual are the grounds for his or her memory organisation, because memory modifications are determined by the explanations that an individual may provide as a response to encountering expectation failures during the processing of any event. As beliefs are non-concensual and have associated confidences, the most obvious implication is that every individual, although exposed to the same experience, will encode it differently. Thus, learning occurs when memory structures are modified, either by adding new structures when new experiences are encountered, or by changing old ones when similar experiences are met.

It is now possible to see how several cognitive processes are deeply intertwined: recalling, understanding, learning, and explaining can not be separated from each other because they are part of the same process. See Figure 1 for an illustration of the process. Schank makes a final interesting remark on understanding, he says that "we understand in terms of the structures that we have available, and those structures reflect how we have understood things in the past. Then, we see things in terms of what we have already experienced". This remark is an evident conclusion after points (c) and (g).

To conclude this paper, it should be mention that work is been carried out on the implementation of a CBR system applied to information retrieval. This is, in part, an evaluation of the theory proposed here (see Ramirez, 1997b, for details of the system). In particular, the elements of the system most strongly influenced by the theory are: recognition, recollection and reminding, and learning.

Acknowledgements

This work was supported by the University of Technology of Monterrey, Campus Queretaro (ITESM), and the National Council of Science and Technology of Mexico (CONACYT).

References

1. Abelson, R.P. (1973). Concepts for representing mundane reality in plans. In D. Bobrow and A. Collins (Eds.), Representation and Understanding: Studies in Cognitive Science. Academic Press.
2. Bareiss, R. (1989). Exemplar-Based Knowledge Acquisition: A Unified Approach to Concept Representation, Classification, and Learning. Academic Press.
3. Bobrow, D.G. (1975). Some principles of memory schemata. In D. Bobrow and A. Collins (Eds.), Representation and Understanding: Studies in Cognitive Science. Academic Press.
4. Burstain, M.H. (1986). Concept Formation by Incremental Analogical Reasoning and Debugging. Machine Learning: An Artificial Intelligence Approach, Vol. II, San Mateo, CA: Morgan Kaufmann.

5. Craik, F.I.M. and Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. Journal of Experimental Psychology: General, 104, 268-294.
6. Eysenck, M.W. and Keane, M.T. (1995). Cognitive Psychology. Hove, UK: Lawrence Erlbaum.
7. Gentner, D. (1989). The mechanisms of analogical learning. In S. Vosniadou and A. Ortony (Eds.), Similarity and analogical reasoning. Cambridge: Cambridge University Press.
8. Kolodner, J.L. (1993). Case-Based Reasoning. San Mateo, CA: Morgan Kaufmann.
9. Medin, D.L. and Smith, E.E. (1984). Concepts and concept formation. Annual Review of Psychology, 35, 113-138.
10. Minsky, M. (1975). A framework for representing knowledge. In P. Winston (Ed.), The psychology of computer vision. New York: McGraw-Hill.
11. Ramirez, C. (1997a). Schemata and Dynamic Memory Structures. Technical Report No 7-97, Computing Laboratory: University of Kent at Canterbury, UK.
12. Ramirez, C. (1997b). Enhancing Information Retrieval with Case-Based Reasoning. Submitted to the Third UK CaseBased Reasoning Workshop. Manchester, UK.
13. Redmond, M.A. (1989). Learning from other's experience: Creating cases from examples. In K. Hammond (Ed.), Proceedings: Case-Based Reasoning Workshop / DARPA, Pensacola Beach, Florida. San Mateo, CA: Morgan Kaufmann.
14. Rosch, E. (1978). Principles of categorisation. In E. Rosch and B.B. Lloyd (Eds.), Cognition and categorisation. Hillsdale, NJ: Lawrence Erlbaum.
15. Rumelhart, D.E. (1980). Schemata: The basic building blocks of cognition. In R. Spiro, B. Bruce, and B. Brewer (Eds.), Theoretical Issues in Reading Comprehension. Hillsdale, NJ: Lawrence Earlbaum.
16. Rumelhart, D.E. and Norman, D.A. (1981). Analogical Process in Learning. In J.R. Anderson (Ed.), Cognitive Skills and their Acquisition. Hillsdale, NJ: Lawrence Earlbaum.
17. Seifert, C.M., McKoon, G., Abelson, R.P., and Ratcliff, R. (1986). Memory connections between thematically-similar episodes. Journal of Experimental Psychology: Learning, Memory and Cognition, 12, 220-231.
18. Seifert, C.M. and Hammond, K. (1989). In Proceedings of CaseBased Reasoning Workshop, San Mateo, CA: Morgan Kaufmann.
19. Schank, R.C. (1975). The Structure of Episodes in Memory. In D. Bobrow and A. Collins (Eds.), Representation and Understanding: Studies in Cognitive Science. New York: Academic Press.
20. Schank, R.C. (1982). Dynamic Memory: A theory of reminding and learning in computers and people. Cambridge: Cambridge University Press.
21. Schank, R.C., and Abelson, R. (1977). Scripts, plans, goals and understanding: An enquiry into human knowledge structures. Hillsdale, NJ: Lawrence Erlbaum.
22. Schank, R.C., Collins, G., and Hunter, L. (1986). Transcending induction category formation in learning. The Behavioral and Brain Sciences, 9, 639-686.
23. Tulving, E. (1982). Synergistic ecphory in recall and recognition. Canadian Journal of Psychology, 36, 130-147.
24. Tulving, E. (1983). Elements of episodic memory. Oxford: Oxford University Press.
25. Van Mechelen, I., Michalski, R.S., Hampton, J.A., and Theuns, P. (1993). Concepts and categories. London: Academic Press.
26. Watkins, M.J. and Gardiner, J.M. (1979). An appreciation of generate-recognise theory of recall. Journal of Verbal Learning and Verbal Behavior, 18, 687-704.

This article was processed using the LaTeX macro package with LLNCS style