Schemata, Frames, and Dynamic Memory Structures

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Abstract

Acquisition of knowledge is fundamental to any theory of cognition. Schank's *dynamic memory theory* is the starting point of case-based reasoning, and is the foundations of this paradigm of cognition. *Schemata, frames,* and *scripts* are all knowledge structures of the same kind, but important differences between them exist and they are presented in this report. Schemata have played a mayor role in knowledge representation. Scripts are a form of schemata, and are one of the main structures used to explain the organisation of episodic memory in dynamic memory theory, jointly with other knowledge structures: *scenes, MOPs, meta-MOPs,* and *TOPs*. These structures and their organisation are explained in this report. Frames are another form of schemata, a more structured and modular one than scripts, devised to express daily aspects of the world in a practical way, and are widely used in AI programs. However, the theory of frames is incomplete in many respects. There are several theories of schemata, but they are too limited to account for a theory of the acquisition of knowledge. Acquisition of knowledge is a more intricate process than is allowed for, in plain schema theories. Dynamic memory offers new possibilities for explaining the acquisition of knowledge.

Keywords: Dynamic memory, schemata, frames, knowledge acquisition, learning

1 Introduction

Dynamic memory theory (Schank, 1982) is the starting point of case-based reasoning, and is the foundations of this paradigm of cognition. In this theory, *scripts*, which are a form of schemata structures (Bobrow , 1975; Rumelhart 1980), are one of the main structures used to explain the organisation of episodic memory, jointly with other knowledge structures proposed in the theory: *scenes*, *MOPs*, *Meta-MOPs*, and *TOPs*. However, the acquisition of knowledge is a more complex process than is allowed for in plain schema theories (Rumelhart, 1980; Bobrow, 1975). Dynamic memory, a elaborate theory intertwining several cognitive processes, opened new possibilities on this issue. However, dynamic memory theory is of a high conceptual level; therefore, inevitably it leaves room for interpretation. More work is needed in the articulation of this paradigm. On the other hand, frames are structured and functional representations devised to model daily aspects of the world in computers.

This report is a introduction to the memory structures presented in Schank's book—*Dynamic Memory*. The goal of this report is to present a simplified form of these memory structures and show how scripts are related to frames and schemata. This report is a complement to other papers written by the author, and it is also expected to be of use to others studying dynamic memory structures. For a review of other aspects of dynamic memory theory, see Ramirez et al. (1997).

2 Schemata

A schema is an organising structure for knowledge used to represent generic knowledge, and although during the years it has been represented in many different forms, it can be said that it is the most commonly used structure to represent complex knowledge organisation. Generally speaking, a schema is a structured group of concepts that can represent any kind of knowledge, from simple objects to complex knowledge about topics like medicine, history or physics.

Although the idea of a *schema* has a number of antecedents, it is not until the 1930's that it was properly coined by Sir Frederick Bartlett at Cambridge University. Bartlett (1932) was interested in how expectations play an critical role for people to remember and understand events in daily life. In the sixties, Piaget (1967) used schemata to understand changes in children's cognition. But it was in the seventies—when working on theories of memory—that the modern versions of schemata theories appeared: Schank's (1972) conceptual dependency theory, uses a form of schemata to represent relational concepts; Schank and Abelson (1977) proposed a form of schemata called *scripts*, which contain organised sequences of stereotypical actions; Bower et al. (1979) also experimented with a similar conception of *scripts*, and discussed the segmentation of them into low-level action sequences called *scenes*. In artificial intelligence, Minsky (1975) proposed another schemata-like structures, called *frames*. Frames are intended mainly for the representation of concepts, by grouping together sets of attributes, and then regrouping sets of frames in arbitrarily complex forms.

To summarise, many variations of schema-like structures have been devised under different names: *frames* by Minsky (1975), *scripts* by Schank (1975), *plans* by Abelson

(1973), *schemata* by Bobrow (1975) and Rumelhart (1980), and *units* by Bobrow and Winograd (1977).

3 Frames

Frames are an extension of the idea of representing concepts through semantic networks (Collins and Loftus, 1975). The main difference is that the concept of a frame is basically *functional* rather than *structural*. The frame representation scheme emphasises the object oriented function of the knowledge, whereas the network one stresses the structure of the knowledge in terms of relationships. Frames organise the knowledge that they represent according to the function of that knowledge. Hence, frames are structured, and modular representations, conceived in AI, from the necessity of having a *epistemologically adequate* representation (McCarthy, 1977); that is, a framework to model or express in computers, in a practical way, the facts concerned with daily aspects of the world. Put it in Minsky's words (1981, p.95):

> "It seems to me that the ingredients of most theories both in artificial intelligence and in psychology have been on the whole too minute, local, and unstructured to account—either practically or phenomenologically—for the effectiveness of common sense thought."

Although Minsky's theory of frames is "incomplete in many respects" (as himself pointed out), it is one of the first footings for the development of CBR (and a big contribution to knowledge representation, as a whole). Minsky (1981) presents the essence of the theory as follows:

> "When one encounters a new situation (or makes a substantial change to one's view of the present problem), one selects from memory a structure called a frame. This is a remembered framework to be adapted to fit reality by changing details as necessary.
>
> A frame is a data structure for representing a stereotyped situation, like been in a certain kind of room, or going to a child's birthday party."

A frame consist of a collection of knowledge *slots*, which contain the attributes associated with the represented concept or event (see Bayle, 1988) . Frames can have any number of slots, which contain the values (or the default values) of the attributes associated with the frame. Some of the information in a frame is also about how to use the frame, what to do if the expectations are realised (or not realised). Slots can have *procedures* (self-contained pieces of code) attached to them for the purpose of performing operations on the slot values when particular conditions (determined by the code contained in the procedure) are reached (like adding, modifying or removing slots or slot's values). Thus, frames represent declarative and procedural information in terms of knowledge represented and the expectations related to it. Some additional properties have been developed in modern computer frame systems, properties like inheritance and automatic activation of procedures through different mechanisms that 'fire' the procedures.

The character of frames suggests a hierarchical organisation of groups of frames, where different frames of a system can share the same slots. The frame-systems are linked, in turn, by an information retrieval network, which is in charge of dealing with situations where a retrieved frame cannot be made to fit the present event.

In Minsky (1981), it is possible to notice the influence received from the various psychological views of concepts. For example, the following paragraph (p.96) clearly describes how a frame-system supports the "Prototype" and the "Exemplar-Based" views of concepts:

> "A *frame* is a data-structure for representing a stereotyped situation, like been in a certain kind of room, or going to a child's birthday party. Attached to each frame are several kinds of information. Some of this information is about how to use the frame. Some is about what can one expect to happen next. Some is about what to do if this expectations are not confirmed.
>
> We can think of a frame as a network of nodes and relations. The top level frames are fixed and represent things that are always true about the supposed situation."

Then, the whole idea of a frame composed by any number of attributes (slots) is basically the essence of the "Attribute-Defining View", one of the classic approaches to concept representation (Eysenck and Keane, 1995). And finally, the idea that each slot can have attached pieces of code (procedures) concerning the use of the attribute, is a way to support the "Theory-Dependent View" of concepts.

Frames are an important integration of knowledge representation views into a pragmatic and effective framework. Unfortunately, Minsky did not proposed the processes involved in the use of the structures. Nevertheless, the frame theory had a strong influence in subsequent work on establishing some bases for the computational representation of schemata.

4 Scripts

Scripts can be considered as an extension of schemata, closely resembling frames. Schank and Abelson (1977) introduced these knowledge structures to explain how knowledge of complex event sequences is represented. Actually, scripts represent the common elements of similar events or experiences (such as been in certain kinds of rooms, or going to children's birthday parties, eating in restaurants or using information retrieval systems). Scripts are composed of hierarchically organised sub-scripts. Like schemata, scripts are a kind of normalised pieces of information where specific details of events are dropped out and the common features between similar experiences are retained. However, scripts usually contain elements that are not explicit when they are used, but work as default values of the missing elements of typical events. Schank and Abelson (1977) explain the point as follows:

> "People do not usually state all parts of a given thought that they are trying to communicate because the speaker tries to be brief and leaves out assumed or unessential information... The conceptual processor makes use of the unfilled slots to search for a given type of information in a sentence or a larger unit of discourse that will fill the needed slot."

Those elements of the script that function as default values can provide the necessary information to infer those parts of the event that are not usually explicit. For example, Schank (1982) says that in the experience of going to a new restaurant, it is not necessary to state that the customer pays for the dinner, since that element of the script already exist in a previous one, so the event can be understood by recalling a complete similar script.

5 DYNAMIC MEMORY THEORY

Dynamic Memory (Schank, 1982) is not a book on artificial intelligence, since there are not detailed descriptions of programs. It does not conform to standard conceptions of a psychology book because it does not report experiments. Neither is a book about linguistics because it principally deals with issues concerned with the representation and processing of memories, independently of the language spoken or the linguistic processes involved. Dynamic Memory theory is placed at the intersection of artificial intelligence, psychology and linguistics, then, this theory belongs to the recently created field, “Cognitive Science”.

Dynamic memory theory is concerned with the organisation of experiences in memory and the processes involved in the recollection, use, and modification of those memories, such that learning and intelligent behaviour can be produced from such a system of memories. Dynamic Memory is not a model for problem solving defined at the implementation level—as for instance the way SOAR (Laird et al., 1987) is—neither is a complete model of cognition. Besides, some problems have been identified in the theory (see Ramirez et al., 1997). Nevertheless, dynamic memory theory is central to CBR, it is the most important piece of research concerning the cognitive background of CBR.

Dynamic memory theory is computationally tractable, although, many variations on the implementation of the theory have been carried out. Schank’s graduate students, and colleagues (Schank, 1982; Kolodner, 1984, 1993; Lebowitz, 1986; Riesbeck and Schank, 1989) were the first to try computational implementations, producing programs such as FRUMP, SHRINK, CYRUS and IPP. These variations on the implementation are due to the fact that dynamic memory is a theory of high conceptual level, and is a very elaborate and somewhat convoluted theory, intertwining several cognitive processes; therefore, it leaves room for interpretation. On the other hand, it is a theory difficult to implement, because testing the ideas requires new methodological developments. For example, the way cases are acquired and processed is far from the way traditional knowledge-based systems acquire and processes its knowledge.

5.1 Memory Structures

In dynamic memory theory, *scripts*—a form of schemata—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*. These memory structures are the basis for the theory.

“Event” and “experience” are terms used all over the book in an interchangeable way; Schank uses those terms very loosely, but in general it can be said that they simply mean a noteworthy happening, like [going to a restaurant, having a physiotherapy session, paying a visit to a lawyer, or having an information retrieval session]. Sometimes Schank refers to an event as a part of an experience, but that practice will be avoided here. Events will be considered as full experiences, and they are always physical, objective, not subjective ones. The term "situation" or "element" will be used to refer to a separable part of an event. Then, it follows that a event is formed with a cluster of connected elements or situations. The memory structures that are at the core of the theory are described as follows:

Episodes are instances of repeated, similar events. An episode can also be called an experience, like a specific visit to a dentist, or a particular occasion going to a restaurant. For example, [business lunch at Mr Frog on the 2nd of May], and [that painful tooth extraction on last February, by Dr. Hardhand] are episodes.

Scripts are collections of specific situations, organised around common parts of similar episodes, i.e., a script is formed with common situations among similar episodes, built over time, by repeated encounters with those situations (see Fig. 1). Elements of those episodes that are identical are treated as a unit, a script, like [Doctor Jones' waiting room] script, or a standardised script [dentist's waiting room]. Schank also describes a script as "a set of expectations about what will happen in a give situation". This definition is much clearer after understanding the learning theory, which is presented below. Scripts are a extended version of schemata-like structures, used to explain how knowledge of complex event sequences is represented[1] .

Scenes are higher level knowledge structures, that organise a number of scripts, or parts of them (see fig. 1). Scenes are created by abstracting and generalising from multiple experiences. A scene is a general description of a setting and the activities in pursuit of a goal relevant to that setting; then, a scene is generally organised by context, the context of the relevant setting. Scenes are not directly related to the specifics of situations, so they capture generalities; scripts provide the specifics. For example, [waiting room] is a typical case of a scene formed by scripts embedded as standardisation of various general scripts; in this case, scripts about visiting different professional consultants (doctors, lawyers, financial advisors, etc.), or any other activity that have in common a similar procedure for [waiting room].

In terms of *cognitive economy*, scenes are of great value to the organisation of memories, by abstracting and capturing generalities (from scripts).

Memory Organisation Packets (MOPs) serve as organisers of scenes. MOPs organise events by controlling the sequence in which the scenes occur in the events. A MOP consists of a group of scenes directed toward the achievement of a goal. MOPs provide information about how a number of scenes are related to one another. A MOP always has a major scene whose goal is the essence or purpose of the events organised by the MOP. Another characteristic of MOPs is that they can be organised by other MOPs,

[1] Notice how *cognitive economy*, an important principle on the organisation of knowledge (see Collins and Quillan, 1969, for a study of content and organisation of knowledge), is achieved by identifying common elements among different episodes; and *informativeness*, by indexing the differences between similar episodes.

which provides great flexibility in building complex structures[2]. An example of a MOP is [MOP-Professional Office Visit], which would organise the normal sequence of scenes for use in processing a visit to a professional consultant (doctors, lawyers, financial advisors, etc.). A higher level MOP (for example [MOP-Health Protection], which would include scenes like [detect problem] and [find appropriate professional consultant]) could make use of another MOP, like [MOP-Professional Office Visit].

Meta-MOPs organise MOPs, but do not actually contain memories, as MOPs, meta-MOPs contain scenes, which in turn contain specific memories. Meta-MOPs work as a kind of template or plan by which MOPs in general are constructed. Meta-MOPs are formed with higher-level structures than scenes, they are formed with generalised scenes. A generalised scene is a decontextualised description of a setting and the activities in pursuit of a goal relevant to that setting. A generalised scene can be used to organise a experience without referring to specifics of the physical setting. For example the meta-MOP for a trip can be roughly described as follows:

mM-Trip = Plan + Get Resources + Make Arrangements + Preparatory Travel
+ Preparation + Primary Travel + Arrival + Do

Meta-MOPs can be used to construct MOPs, which organise scenes that conformed to its pattern. Then it follows that, mM-Trip can be used to construct for instance, [MOP-Airplane] as follows:

MOP-Airplane = Plan + Get Money + Call Travel Agency + Get Tickets +
Drive to Airport + Check In + Waiting Area + Boarding +
Flying + Deplaning + ...

Thematic Organisation Points (TOPs) are structures that capture similarities between situations that occur in different domains. TOPs contain knowledge about an abstract situation apart from any specific content, that is, TOPs are domain-independent. These structures account for our ability to use adages like “one stitch on time saves nine”, or to predict an outcome for a newly encountered situation.

All these knowledge structures make up a coherent cognitive model of episodic memory, but it should not be forgotten that although it seems to be a good, fairly satisfactory account, it was mostly devised through personal insights, by introspection, induced from a set of sample-experiences; although, some computer experimentation was carried out before, and during the elaboration of *Dynamic Memory*.

The trails behind dynamic memory structures come directly from Schank and Abelson’s (1977) work, when they proposed their ideas about memory organisation in the form of *scripts, plans, goals,* and *themes*. Since then, they have moved far beyond experimental psychology, simply because psychological techniques were well behind the level at which they were conceptualising. Later, experimental cognitive psychologists still were struggling to instrument scripts and plan structures (Bower et al., 1979), when

[2] Notice again, how this organisation provides a great deal of cognitive economy to the whole structure, and as in the previous two structures, this property—cognitive economy—is an intrinsic part of the theory, property that is widely achieved at all levels of the structure organisation.

Schank went even further with his ideas about memory organisation and learning, expressed in *Dynamic Memory: A theory of reminding and learning in computers and people*.

Schank's work is valuable because it opened new possibilities on knowledge acquisition, on one hand; and on the other, dynamic memory theory is the foundations of a recent new field of AI: case-base-reasoning.

6 CONCLUSIONS

In this report three widely used knowledge representation structures have been contrasted: schemata, frames and scripts. The later two being versions of the first; although there are important differences between them. Particular attention was paid to the theories that support frames and scripts. Minsky's theory of frames is incomplete and does not provide details of the processes involved in knowledge acquisition; However, frames are structured and modular representations that allow to model or express knowledge in computers, in a very practical way. Scripts are one of the various knowledge structures presented in dynamic memory theory. Schank's theory offers a more complete explanation of knowledge acquisition and the diverse cognitive process involved; however, the theory is a very high level one, and lacks operationalisation details, thus the theory leaves room for interpretation. Nevertheless, dynamic memory is the foundations of case-based reasoning, a recent, pulsating new field in AI.

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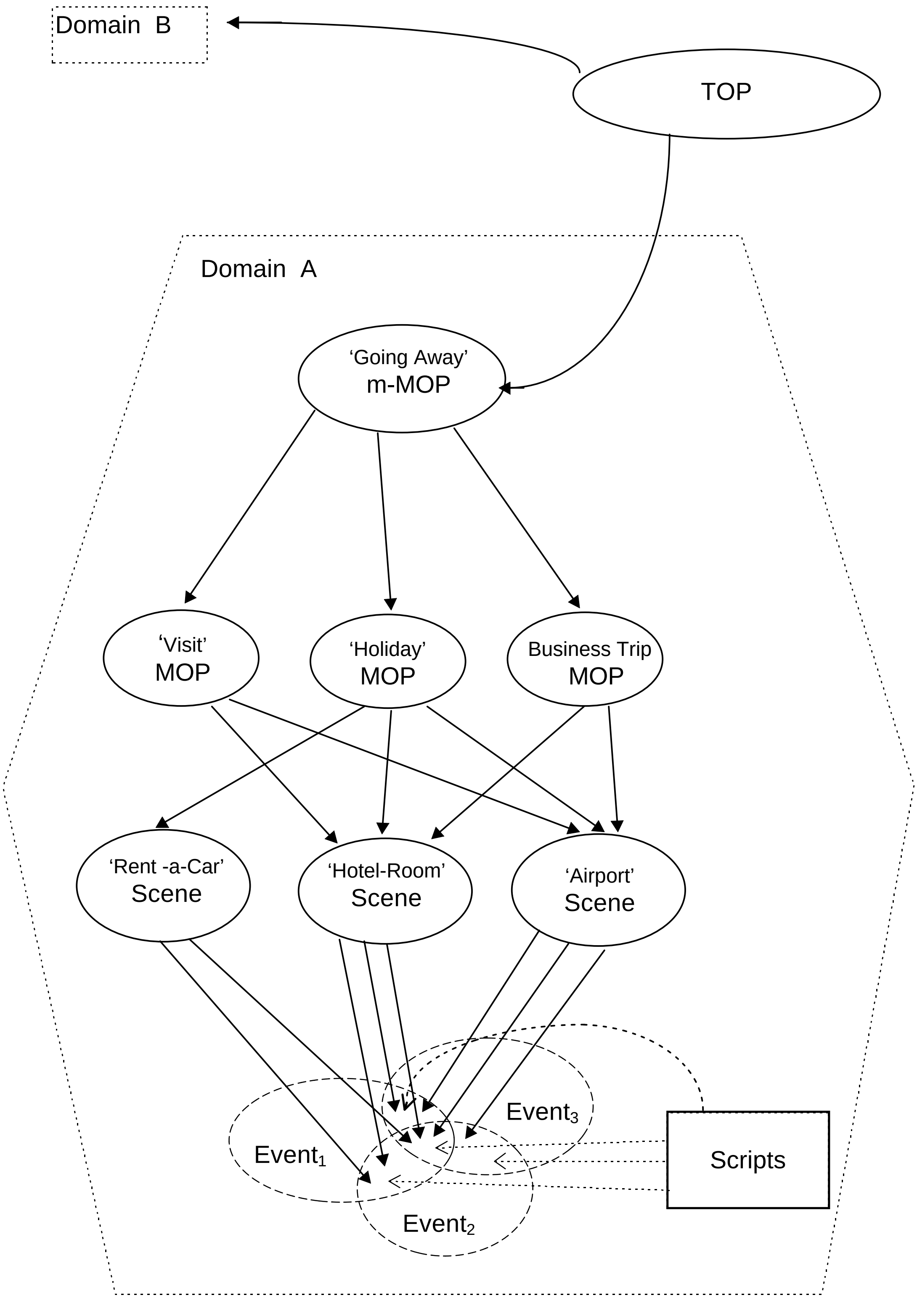

Figure 1. Dynamic Memory Theory - Memory Structures

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