Memorising Remembrances in Computational Modelling of Interrupted Activities

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Abstract

In an experimentation whose objective is to model the interruptions phenomenon and its impact on tasks achievement, we show that in some cases, such as a temporarily interrupted realisation of tiramisu recipe, the ACT-R approach cannot offer a model that is highly close to the usual human behaviour. We emphasize the incapacity of an ACT-R model to reproduce correctly the recall of information in a temporal context and we propose an alternative theory which uses additional knowledge structures that are inspired from the human memory.

Introduction

One of the greatest challenges for man has been to understand himself. By the past, a multitude of theories was proposed to model the mind and the behaviour that it dictates, but these theories were originally devoid of operating implementations. Nowadays, computational technology has progressed to the point that partial, if not full, implementations of a mental model can be constructed. ACT-R (Anderson, 1993; Anderson & Lebiere, 1998; Anderson et al., 2004) is a computational cognitive theory that allows modellers to develop simulations of human behaviour. Over 100 ACT-R models have been published to date on topics ranging from visual attention to arithmetic and from playing backgammon to make scientific discoveries. This track record, covering such a wild variety of applications and cognitive phenomena, implies that the ACT-R architecture offers a fair approximation of human cognitive ability.

In this research project we have been interested on the computational modelling of the behaviour during a task achievement suspended by an interruption phenomenon and its impact on the task accomplishment. Interruptions are part of everyday experiences including food preparation. Cooking is a cognitively demanding task delimited by definite beginning and ending stages. This manner of *arranging food* to make it suitable for eating involves a specific task sequence of a script from memory or from a written recipe. Several studies (see for example, Kreifeldt & McCarthy (1981), Bailey et al. (2000) and Cutrell et al. (2001) for more details) reveal that interruptions may negatively affect the person's state and performance –the recall of information associated with recent actions is problematic, especially when one is prone to be distracted or interrupted. For instance, Zijsltra et al. (1999) show that the occurrence of interruptions may affect the action plan to achieve the original defined goal. Interruption can be observed in practice. They can also be evoked, simulated and studied under controlled conditions in a laboratory setting. In this paper, we show that in some cases, such as a momentarily interrupted recipe realisation, the ACT-R approach cannot offer a model that faithfully reproduces the usual human behaviour. More precisely, we highlight the incapacity of the theory to reproduce correctly the recall of information in a temporal context, we emphasize in particular the ACT-R failure in memorising remembrances and we propose an alternative theory which uses additional knowledge structures that are inspired from the human memory.

The remainder of the article is organised as follows. First, we briefly present the ACT-R approach by stressing on the knowledge representation aspect. Next, the experiment and the related results are described. Finally, our alternative theory is introduced.

The Knowledge in ACT-R

The ACT-R theory has been based on a great number of studies in experimental psychology and has a great success as a cognitive modelling approach. As mentioned, it allows expressing a wide range of phenomena such as the acquisition and transfer of particular types of knowledge. The basic architecture of ACT-R consists of a set of modules, each devoted to processing different kind of information. Coordination in the behaviour of these modules is achieved through a central production system. Knowledge of the long-term memory is divided into two distinct categories: declarative knowledge and procedural knowledge. The former is composed of elements having descriptive nature and called *chunks* (Miller, 1956). A chunk must be an instance of a chunk type which defines the chunk attributes whose values are specified when declaring the chunk. Communication between the various modules is done via buffers. In each buffer, it is permitted to deposit and/or to recuperate only a chunk at a time. The acquisition of new declarative knowledge is made by stimuli interpretation of the environment or by calling procedural knowledge. The later are production rules that manipulate declarative knowledge. Each production has a *"conditions → actions"* representation. Whereas *conditions* specify the necessary buffers contents to fire up the rule, *actions* (i) detail facts to add to buffers after achieving the rule or (ii) modify the value of one or several chunk attributes in a buffer. In ACT-R, the procedural knowledge is acquired in situations of *learning by acting*. Novel knowledge is initially stored in declarative form and then, with the frequency of activation during the learning process, this knowledge will be compiled, generalized in rules and will be finally treated as procedures. Thus, every capability is decomposable in minimal elements which are learned by doing. In this sense, learning consists in compiling several particular cases in a general production rule and to practice with it for automation. For instance, complex task realisation, such as the LISP programming, corresponds to sequences of hundreds of production rules learned independently.

The Tiramisu Experiment

In an experimentation whose objective is to model the interruptions phenomenon and its impact on tasks achievement, we show that in some cases, such as the realisation of tiramisu recipe, the ACT-R approach cannot offer a model that accurately imitates the natural human behaviour. In general, an interruption is an event which causes the suspension of an activity for a lapse of time and which can have consequences on the correct realisation of the stopped task. For example, Tran & Mynatt (2003) observed, when studying the interruptions phenomenon and its consequences in culinary activities, that several subjects added only half of the necessary quantity of an ingredient, others doubled the quantity of another one, etc.

Abstractly, the tiramisu recipe realisation consists of well-ordered layers of ingredients – placing twice the set <*mascarpone cream mixed with egg yolk and sugar, cocoa powder mixed with grated chocolate, lady fingers biscuit dipped in espresso coffee and brandy, cocoa powder mixed with grated chocolate*> and adding the set <*mascarpone cream mixed with egg yolk and sugar, cocoa powder mixed with grated chocolate, sugar*> (see figure 1–part a). The experiment supposes that the cook (i) initially has these four ingredients mixtures ready to employ and (ii) uses an opaque baking dish that allows noticing only the last added layer. A first type of frequent faults due to an interruption (for example, a telephone call during the preparation of the recipe) is the erroneous layers order. In fact, a problem emerges when continuing (after interrupting) the task and the last placed ingredient (the only observable among all) is <*cocoa powder mixed with grated chocolate*> (see figure 1–part b). As in this case three possibilities are to be considered (adding <*lady fingers biscuit dipped in espresso coffee and brandy*>, adding <*mascarpone cream mixed with egg yolk and sugar*>, or adding <*sugar*>), an error risk is highly probable in a lapse of memory situation and if there is no information about what it has been done before. A second kind of errors results in being confused about the number of sets already placed and/or those remaining to place without necessarily being mistaken on the mixtures order. For example, duplicating more than twice or adding only once the set <*mascarpone cream mixed with egg yolk and sugar, cocoa powder mixed with grated chocolate, lady fingers biscuit dipped in espresso coffee and brandy, cocoa powder mixed with grated chocolate*>.

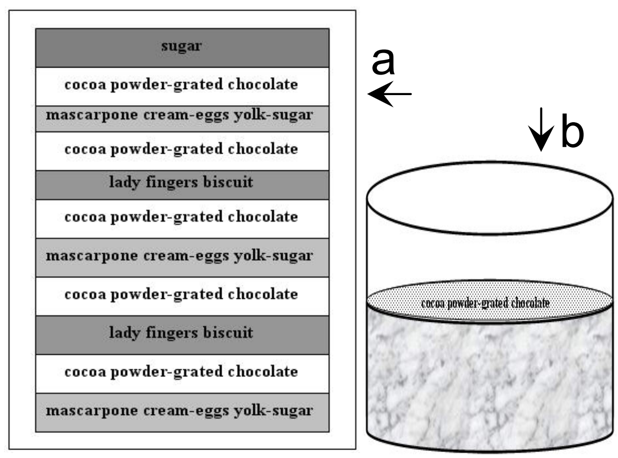

Figure 1 : well-ordered layers of ingredients (part a) and an example of problems (part b).

To model the tiramisu recipe preparation, we have defined various types of chunks. A first set of chunks contains information allowing to know the number of the <*mascarpone cream mixed with egg yolk and sugar*> ingredients already placed in the baking dish. A second set of chunks memorises the last mixture placed before the <*cocoa powder mixed with grated chocolate*> ingredient. To cause a fault due to an interruption, the simulation is stopped (at a given time chosen randomly) and the model was forced to compute some arithmetical calculus (during few seconds) to return again to the tiramisu suspended realisation. Experimental tests show that the model was unable to *remember* the last chunk used before the interruption. In fact, the chunk which is always reminded was the one having the greatest activation value. According to the ACT-R theory, the activation of a chunk reflects (i) its general usefulness in the past and (ii) its relevance to the current context (Anderson et al., 2004). This activation is given by equation (1) :

$$A_i = B_i + \sum_j W_j S_{ji} \qquad (1)$$

where B_i is the base-level activation of the chunk *i*, W_j reflect the attentional weighting of the elements that are part of the current goal, and S_{ji} are the strengths of association from the elements *j* to chunk *i.* The activation of a chunk controls both its probability of being retrieved and its speed of retrieval. In this sense, it is impossible to recover a given chunk according to its occurrence in time. Only the activation law determines which chunk will be recovered. Since the time impact on the calculation of the B_i factor decreases rapidly, after an interruption the number of use of a chunk becomes the most decisive feature that affect its recall. This induces abnormal behaviours of our model, especially in the situation where the last placed only observable ingredient after the interruption was <*cocoa powder mixed with grated chocolate*>. In theory, to decide what to do next, the model must recall a chunk that memorise the last added ingredient. In practice, the recovered chunk will not be the one desired –the chunk recalled was that used for deciding to lay <*cocoa powder mixed with grated chocolate*> in the previous step (prior to the occurred interruption) and as it has already been utilised, this increases its activation value. The further an inappropriate chunk is reminded, the more its activation augments. Gradually, this chunk becomes the only remembered one. For example, if it specifies that the last ingredient is <*mascarpone cream mixed with egg yolk and sugar*> this will result in placing an infinite sequence of <*cocoa powder mixed with grated chocolate*> followed by <*lady fingers biscuit dipped in espresso coffee and brand*>.

To resolve the mentioned problem, it was indispensable to enrich the defined chunks with additional slots. For example, adding the slot "*is-last-created*" to chunks of the type "*last-ingredient*" to permits to the model to retain the last ingredient placed before the <*cocoa powder mixed with grated chocolate*> mixture. The "*is-last-created*" slot values are exclusively booleans. However, this proposed solution, even if it demonstrates efficiency in memorising ultimate steps done before interruptions, cannot translate a right use of the human cognitive structures –by handling boolean parameters, the model behaves and reasons rather like a machine than like a human being.

An Alternative Theory

The experiment of the simulation of the tiramisu realisation shows that our ACT-R based model cannot memorise particular events in a temporal context. Particularly, it cannot remember last remembers. For example, what it has just placed before adding <*cocoa powder mixed with grated chocolate*>, last operation before the caused interruption. Even if it is possible to simulate a *memory of events* by distinguishing between various occurrences of the same chunk (by defining several instances of this declarative knowledge entity), to establish the relation between each occurrence and the context in which it was created and handled remains a missing advantage of the model. By encoding each event in a suitable structure, it would be possible (i) to find it later by scanning the structure and (ii) to recreate all the context characteristics to which it was attached. i.e., the intention or the need leading to the event creation, means used to satisfy (or try to satisfy) this need and the generated consequences.

We propose an alternative theory in which the distinction between semantic and procedural knowledge is mainly based on the criteria of the ACT-R theory. However, this *new* model takes into account an additional component of the declarative memory – the episodic memory, a structure which is characterised by the capacity to encode information about lived facts and to preserve temporal relations allowing reconstruction of previously experienced events (Neely, 1989; Tulving, 1983). Humphreys (1989), for instance, affirms that cognitive models which do not make a distinction between *declarative* and *episodic* cannot distinguish various occurrences of the same element of knowledge[1].

The proposed approach subdivides procedural knowledge in two main categories: primitive procedures and complex procedures. Executions of the first are seen as atomic actions. Those of the last can be done by sequences of actions which satisfy scripts of goals. Each one of those actions results from a primitive or complex procedure execution; and each one of those goals is perceived as an intention of the cognitive system. The episode representation is based on instantiation of goals. These are seen as generic statements retrieved from semantic memory. In other words, the episodic knowledge is organised according to goals. Each episode specifies a goal that translates a learner interest and gives a sense to the underlying events and actions. If the goal realisation requires the execution of a complex procedure,

[1] To fill this gap, ACT-R permits to create several instances of the same chunk type in order to indirectly simulate the existence of an episodic memory. However, this form of memory does not have an explicit structure –the notion of episode is nonexistent.

formed by a set of "n" actions, then the goal will be composed of "n" subgoals whose realisation will be stored in "n" sub-episodes. Thus, executions of procedures are encoded in episodic memory where each goal realisation is encoded in an episode. In this way, the episodic knowledge reflects experiences details during the lived activities and the related temporal relations allowing the reconstruction of previously lived events as well as the time and context in which they took place.

As for chunks, episodes are characterised by a set of slots: (1) "*Identifier*" is a unique number randomly generated by the system, (2) "*Time*" indicates the time at which the episode occurred, (3) "*Goal-Episode*" points to the goal identifier and to those of the handled cognitions, (4) "*Procedure-Episode*" contains a reference to the selected procedure, (5) cognition obtained by the application of the chosen procedure is stored in "*Result*", (6) "*Super-Episode*" and (7) "*Sub-Episodes*" contain links to the inner and the outer hierarchical episode, (8) "*Status*" takes a qualitative value (success, failure, on standby or aborted) according to the status of the current episode; and finally, (9) "*Cost*" comprises an estimated cost of the procedure usage.

Identifier	*EP#7*
Time	*1075929453695*
Goal-Episode	*(G_stack_lady fingers <lady fingers biscuit dipped in ...>)*
Procedure-Episode	*P_stack_lady fingers*
Result	*new_step (<lady fingers biscuit dipped in espresso coffee ...>)*
Status	*success*
Super_Episode	*EP_Do_Triramisu*
Sub-Episodes	*Null*
Cost	*1*

Table 1 : Example of an episode content

Instead of recovering a chunk which will undoubtedly be the one having the greatest value of activation and which is not certainly the one that the model wishes to obtain, the latter consults the episode of the second last event (which occurred before inserting <*cocoa powder mixed with grated chocolate*> and having as "Time" slot the nearest value to the most recent recorded one). Recuperating in that episode the goal instance in the slot "*Goal-Episode*" (for example the goal [*G_stack_lady fingers*], seen in Table 1) enable the model to remind what occurred before the interruption. i.e., layering <*lady fingers biscuit dipped in espresso coffee and brandy*> before <*cocoa powder mixed with grated chocolate*>. In this way, the model can search any time in its memory to seek indices to help it to remember any lived episode. Nevertheless, if an episode is relatively far in time, this requires that it would be less *accessible* by the model than the more recent episodes. In this sense, we think that it is necessary to take into account an *equation of remembrance* which may be inspired from the activation law of ACT-R. This takes part of our future work.

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