Solve Memory to Solve Cognition

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***Abstract*—The foundations of cognition and cognitive behaviour are consistently proposed to be built upon the capability to predict (at various levels of abstraction). For autonomous cognitive agents, this implicitly assumes a foundational role for memory, as a mechanism by which prior experience can be brought to bear in the service of present and future behaviour. In this contribution, this idea is extended to propose that an active process of memory provides the substrate for cognitive processing, particularly when considering it as fundamentally associative and from a developmental perspective. It is in this context that the claim is made that in order to solve the question of *cognition*, the role and function of *memory* must be fully resolved.**

I. Prediction, Cognition, and Memory

There are a range of competencies that are involved in cognition: an ongoing challenge is to identify common functional and organisational principles of operation. This will facilitate both the understanding of natural cognition (particularly that of humans), and the creation of synthetic artefacts that can be of use to individuals and society. One such principle is that of prediction [1], prospection [2], or indeed simulation [3], as being fundamental to cognition. A further requirement is the need to incorporate an account of development [4] as a means of an individual to gain cognitive competencies through experience (of the physical and social world), rather than *a priori* programming.

It is suggested that one common dependency of these principles is a requirement for memory. At this point, the definition of memory provided is only in the broadest sense: i.e. memory is a process that acquires information through experience in the service of current and future behaviour [5]. While broad, it nevertheless commits to a fundamental function/role for memory in behaviour [6]. It is on this basis that the remainder of this contribution is focused: taking memory as fundamental, how can it be characterised such that it serves cognition (and the development thereof)?

In one particular perspective grounded in neuropsychological data, emphasis is placed on the associative and network nature of memory. This is apparent in the "Network Memory" framework for example [7], which proposes a hierarchical and heterarchical organisation of overlapping distributed associative networks that that formed through experience, and whose reactivation gives rise to the dynamics that instantiate cognition [8]. Such a perspective is not unusual, e.g. [1], despite the apparent contradiction to multi-system accounts of memory organisation, e.g. [9], [10], with it being also consistent with more purely theoretical considerations, e.g. [11], that emphasise the dynamical process properties of memory over passive information storage.

By taking on this interpretation of memory, a more refined process definition memory may be ventured: memory is a distributed associative structure that is created through experience (the formation associations), and which forms the substrate for activation dynamics (through externally driven activity, and internal reactivation) that gives rise to cognitive processing [12], [5]. The creation of structure through experience is consistent with developmental accounts, and enforce the consideration of not only interaction with the environment, but also the social context of the learning agent (if human-like cognition is to be considered). Previous explorations have suggested how this framework can be used (in principle) to account for human-level cognitive competencies within a memory-centred cognitive architecture [13], although there remain many gaps in this account that require addressing before it can be considered definitive.

II. Application and Implications

Following this definition, take for example the role that such a memory-centred cognitive architecture could play in facilitating social robot behaviour, as a prototypical example of a cognitive competence that needs to be fulfilled. It is uncontroversial to suggest that humans incrementally acquire social skills (though perhaps based on some inherently present mechanisms) over time and through development. The role of memory within this is therefore also not controversial, particularly when skills such as intent prediction (based on prior experience) are also considered [14]. Using an associative network that learns from the behaviour of the interaction partner [15], following the use of simple associative learning in [16], it has been found that a degree of behavioural alignment between a child and a robot is observed within real-time interactions - an effect readily seen in human-human interactions. While only a basic illustration of human-like competence, this nevertheless demonstrates the importance of memory for social HRI [17], and thus establishes associativity as a candidate foundational mechanism for a social cognitive architecture. Similarly, with associativity being considered sufficient for generating predictions as noted above, and prediction/anticipation being considered essential for sociality in terms of supporting coordination [18], then such an account of memory remains consistent.

An alternative implementation using similar principles of associativity and interactive learning has been applied to a range of embodied and developmental psychology models related to language. The Epigenetic Robotics Architecture (ERA) [19] emphasises associative learning, and is instantiated through linked self-organising maps (SOM), arranged through a "hub" SOM that learns from body posture. This structure, learning from a blank initial state, can provide an account of how aspects of language can extend cognitive processing [20], and of how word learning in infants is mediated by body posture [21]. In each of these examples, the computational instantiation of ERA is the same, but the functionality observed differs based on the interaction context of the experiment. Given the fundamentally associative nature of the learning process, this is consistent with the memory-centred account of social human-robot interaction competence described above.

In many principled but low-level approaches – including the those systems based on the developmental systems paradigm, as subscribed to here – there is often a gap between the theoretical consistency and the complexity of the applied resulting system, with simplified (or rather constrained) problems typically targeted. While the memory-centred approach advocated here suffers similarly, the range of applications outlined in the previous paragraphs cover a number of aspects of "higher level" (indeed, human-level) cognition that go beyond the typical domains for low-level associative systems. The efforts described here remain relatively sparse and currently lack a computational integration into a single coherent system that existing psychologically-derived cognitive architectures (such as SOAR, ACT-R, etc) attempt. Nevertheless, there appears to be a convergence of principles of operation that the present work seeks to extend: cognition founded on formation and manipulation of memory, and memory as associative and developmental. At the least, what is proposed here is a re-framing of the problem: not to look at cognition from the perspective of the 'computation' or the behavioural outcome as is typical, but rather to re-evaluate the problem from the perspective of memory.

III. The Sufficiency of an Account of Memory

The outcome of this discussion is a commitment to a fundamentally associative structure of memory, with this maintaining consistency with the developmental perspective, and as illustrated through the social human-robot interaction and language examples. The outline described in this abstract points to a framework within which the relationship between memory and cognition can be understood, although there remain a number of open questions that need to be resolved, such as reconciliation with empirical evidence supporting the multi-systems organisation of memory, e.g. [10], and the interplay of memory with non-memory mechanisms underlying cognition (such as affective processes, e.g. [22]). Nevertheless, the proposal is that even these aspects could be approached from the perspective of memory. In all, this leads to the view that in order to 'solve' cognition, the problem of memory must be fully resolved. Indeed, the suggestion of the present contribution goes beyond this: that a full account of memory may be *sufficient* to provide an account of cognition.

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