A developmental perspective on memory-centred cognition for social interaction

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Memory is generally implemented as a discrete module in systems where a learning mechanism has central importance. This memory module is thus matched to the particular learning algorithm chosen in terms of structure and format, whilst allowing the general property of having past experience influence current processing. For example, in the Soar cognitive architecture, an episodic memory module has been added to the existing cognitive architecture (Nuxoll and Laird 2007). This module periodically stores a snapshot of all of the information held in the common processing workspace (so-called working memory) at a given time, where a snapshot can be recalled into the workspace in its entirety at a later time. As such, the implementation of episodic memory is tied to the type of processing performed by the cognitive architecture (in this case symbolic processing).

The proposal made in this paper is that using memory as the starting point, rather than the learning mechanism, allows a different perspective that enables an alternative approach to developmental cognitive robotics. Consideration may then be made of how memory constrains and structures learning, rather than the reverse.

Evidence from the domain of neuroscience supports such a memory-centred approach. It has been proposed that cooperative interaction of distributed networks of neurons (i.e. the substrate of memory) throughout the cortex underlies the functionality associated with cognition (Fuster 1997; McIntosh 2000). These networks are dynamic and overlapping, responsive and adaptive to the context in which they operate. Memory thus has a particular type of structure, which may be described as being fundamentally associative network-like, upon which all other functionality is based. It may also then be considered to be fundamentally process-based, where the process of association is a central aspect. This structure imposes constraints on what can be learned, how this is learned, and how this influences (or even is responsible for generating) ongoing behaviour.

The application of this concept to developmental cognitive robotics thus leads to a reinterpretation of the cognitive architecture, and how learning and development takes place. Rather than considering the traditional problem of what structures and functions are responsible for the development of a particular behaviour, the problem becomes a question of what memory processes must be present *a priori* such that this behaviour may develop, given the presence of ongoing interaction. In this way, the focus is on how memory structure underlies the generation and development of behaviour, without committing to a specific task environment.

In subscribing to this process-based view of memory, the requirement for a constructivist development becomes clear, due to the necessity of continuous interactions (both within the memory structure, and between the agent and its environment) in the acquisition and adaptation of the memory structure. On this basis, learning should not be considered to be a process of optimisation, rather it should be considered to be the adaptation of the memory structure in response to changing conditions and context.

There are two aspects to the perspective shift that this developmental view on memory entails for cognitive robotics, one concerns the conceptualisation of memory and the other how this view of memory function entails an alternative perspective on the ontogenetic adaptation of behaviour. In this distributed, network view memory is not clearly separable in terms of either structure or function from on-going cognitive processing. Fuster describes the necessity for a shift in focus from "'systems of memory', to the memory of systems" (1997 p.451). By extension, this perspective has implications for how we think about the construction of cognitive systems. Memory being fully embedded within cortical processing entails that mnemonic systems are subject to developmental process and such development will be similarly integrated with that of cortical function.

However, in robotics memory systems are still very often conceptualised as modular storage units functioning as adjuncts to learning mechanisms. In such systems the function of memory is to act as a repository for learning e.g. enabling the storage of learned perception-action correspondences. In biological systems the functions of memory are evidently more complex, and episodic memory can provide a useful example of the benefits of a developmental view. According to Tulving's (2002) definition of episodic memory entails the recall of events in a specific spatio-temporal context accompanied by autonoetic consciousness i.e. an explicit awareness that the events are located in the past and a 'feeling' of remembering (Trinkler et al., 2006; Clayton et al., 2007a). By this definition episodic memory is a uniquely human attribute there being no way to prove conscious experience of recall in other species. However in neuroethology an alternative, behavioural definition has been advanced retaining the spatio-temporal component of episodic recall but dispensing with the requirement for autonoetic consciousness (Clayton el al., 1998; 2007b).

By this definition a number of species demonstrate behaviour requiring episodic-like memory for example food-caching in Western Scrub Jays and mate guarding in Meadow voles (Clayton et al., 2001), generalist brood parasitic in Brown-headed Cowbirds (Miller et al 2006) and alliance formation in primates (Tomasello and Call, 1997). In these very diverse settings spatio-temporal encoding and recall of events (what, where and when information) underpins the animal's ability to function in a complex social environment. Similarly, in the context of human behaviour episodic memory i.e. the capacity to recall what happened, where and with whom, is a requirement for non-trivial social interaction.

Taking memory processes as a source of constraint for functional development, can enable a more a mechanistic, process driven approach to task decomposition and the understanding of 'what develops' in the acquisition of new behaviour. For example, in food-caching the individual is required to hid food items that decay at variable rates from conspecifics and to retrieve items before they spoil. A traditional learning driven approach to the food-caching problem begins with definition of the task environment and selection of a learning mechanism to learn the right mapping between task and behaviour.

If the same problem is addressed from the perspective of memory then the task of keeping track of what was hidden where and when, becomes a matter of encoding perceptual states that, through processes of adaptation, are recalled as cues for behaviour (with cues here consisting in network states). Thus, learning can be understood to function as adaptive process rather than optimisation of behaviour. Memory thus acts the primary source of constraint for adaptation rather than an explicit task environment or pressure for particular behaviour.

ALIZ-E (Adaptive Strategies for Sustainable Long-term Social Interaction) is a project aiming to explore the implementation of meaningful, temporally extended social interactions between humans and robots. A core component of the systems devised to supply this functionality will be episodic memory allowing the robot to recall prior encounters with a user and to adapt its behaviour on the basis of previous events. The commitment to a developmental memory-centred approach allows episodic memory to be considered as part of an integrated system, rather than a discrete component. Episodic memory is thus fundamentally linked to the cognitive system as a whole, enabling it to play a central part in the on-going development of interactive behaviour.

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