"It's a poor sort of memory that only works backwards"
Anticipation as the Essence of Cognition

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Prospection — the capacity to anticipate the future — is the hallmark attribute of cognition. It lies at the heart of the other core characteristics of a cognitive agent: autonomy, perception, action, learning, and adaptation [1, 2]. It facilitates autonomy and the ability to cope with adversarial conditions by allowing the agent to prepare to act. It is also involved in constitutive autonomy [3, 4, 5], predictively adjusting internal system processes through allostasis [6, 7]. It facilitates perception through expectation-driven attentional processes [8, 9]. Attention, in turn, facilitates predictive control of, e.g., gaze [10, 9], and the prediction of the consequences of actions [11]. In general, anticipation is central to action since "actions are goal-directed and are guided by prospection" [12, 13, 14]: a cognitive agent continually anticipates the need to act and it anticipates the outcome of those actions [15]. Prospection also lies at the heart of learning, for learned models are used in both for prediction and explanation. Finally, adaptivity arises in cognitive agents when the learned models fail to produce accurate or reliable predictions.

So, how is prospection effected? There is emerging consensus that internal simulation plays a key role in such prospectively-guided goal-directed action [16, 17, 18]. However, there is less agreement, at least in the cognitive architecture literature, about the manner in which internal simulation is accomplished. Some cognitive architectures opt for an explicit module in the architecture (e.g. [19, 20, 21]) while in others it is a covert mode of the whole cognitive system whereby internal simulation is effected by the same sub-systems as those responsible for sensorimotor-mediated action but using covert, internally-generated endogenous sensorimotor signals rather than exogenous sensorimotor signals (e.g. [22, 23, 24] and also see [16, 25]).

Internal simulation goes beyond prospective guidance of action. Theory of mind [26], the process whereby a cognitive agent takes a perspective on the actions, intentions, and goals of another agent, is a canonical example of the crucial role that anticipation plays in cognition. Again, internal simulation mechanisms may facilitate this by recruiting motor representations, not on the basis of internally-generated goals, but on the basis of the observations of the actions of other agents [18], in a manner that is consistent with the mirror neuron system [27].

Internal simulation involves mental construction of an imagined alternative perspective [28], allowing the agent to pre-experience its future in a process sometimes referred to as *episodic future thinking* [29] in which the agent projects itself forward in time when it forms a goal, creates a mental image of itself acting out the event, and then episodically pre-experiences the unfolding of a plan to achieve that goal. This highlights the importance of personal episodic experience in anticipating the future [30].

Episodic memory is one of two forms of declarative memory, the other being semantic memory [31, 32]. Episodic memory refers to specific instances in the agent's experience while semantic memory refers to general knowledge about the agent's world (which may be independent of the agent's specific experiences). Episodic memory has an explicit spatial and temporal context and this temporal sequencing is the only element of structure in episodic memory. Significantly, episodic memory is a constructive process [33]: each time an event is assimilated into episodic memory, past episodes are reconstructed but they are reconstructed a little differently each time. This is a key characteristic for enabling internal simulation. It forms the basis for the constructive episodic simulation hypothesis [28, 34, 35, 36] whereby episodic memory facilitates the simulation of multiple yet-to-be-experienced futures. This provides the flexibility necessary to pre-experience previously unexperienced futures, perhaps inaccurately, as in the case of hedonic experiences [37].

We tend to think of memory as being focussed on reliable recollections of the past but episodic memory allows you to re-experience your past and pre-experience your future. Truly, "It's a poor sort of memory that only works backwards" [38], to which one might add "It's a poor sort of memory that only remembers what has happened" [39].

Internal simulation is not confined to the anticipation of future episodic states of the cognitive agent. As we have already noted, it is also concerned with anticipating future actions, both those of the cognitive agent itself and those of other agents. Here, procedural memory comes into play. Procedural memory can be characterized as memory of "knowing how", rather than "knowing that" [40]. Action-directed internal simulation involves three different types of anticipation: implicit, internal, and external [41]. Implicit anticipation involves the prediction of motor commands from perceptions (which may have been simulated in a previous phase of internal simulation). Internal anticipation involves the prediction of the proprioceptive consequences of carrying out an action, i.e. the effect of an action on the agent's own body. External anticipation involves the prediction of the consequences for external objects and other agents of carrying out an action.

The sensorimotor associations involved in internal simulation requires both episodic memory and procedural memory. Usually, a clear distinction is maintained between episodic memory and procedural memory. However, the two may be bound more closely in joint perceptuo-motor representations, e.g. Ideo-motor Theory [42], Theory of Event Coding [43], and joint episodic-procedural memory [17].

But what of semantic memory? Semantic memory "is the memory necessary for the use of language. It is a mental thesaurus, organized knowledge a person possesses about words and other verbal symbols, their meaning and referents, about relations among them, and about rules, formulas, and algorithms for the manipulation of the symbols, concepts, and relations." [31], p. 386. Recently, Schacter et al. [44], writing about the advances in our understanding of the role of memory in future thinking, highlighted that episodic memory and episodic future thinking can be modulated by semantic memory. This opens up an intriguing possibility: that language might be used both to express a desired goal and recruit episodic memory in constructing internally-simulated intermediate and final goal states which drive the internal simulation of the actions required to achieve these goals. This presents us with an attractive prospect for the design of cognitive architectures: a concrete way of binding semantic, episodic, and procedural memory together, operating forwards in time to anticipate the future and prepare the cognitive agent to act effectively when interacting with the world it inhabits.

The prospect becomes even more appealing when you consider the recent advances in the integration of vision and language through deep learning [45], which might allow (a) the synthesis of intermediate and final goal state images based on language-based descriptions, e.g. [46], and (b) the generation of language-based descriptions of predicted visual outcomes states, e.g. [47]. Such a scenario for anticipation modulated by language would be inherently more flexible than present approaches to internal simulation which tend to depend of concatenation of inverse and forward models of sensorimotor contingencies, e.g. [22], or networks of instances of episodic and procedural memories, e.g. [17].

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