The Anticipatory Nature of Representations

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Since the beginning of AI, *intelligence* was conceived as the capacity to solve a problem by working on internal representations of problems, i.e. by acting upon "images" or "mental models" with simulated actions ("reasoning"), before acting in the world. Successively, the concept of "representations" has been attacked in many ways. Recently, many converging evidences in psychology and neurobiology indicate a crucial role of anticipatory representations for many cognitive functionalities such as visual attention[1] and motor control[9]. As suggested by the discovery of mirror neurons[8], representations are mainly action-oriented and deeply based on the motor apparatus. Barsalou[2] and Grush[4] try to provide unitary accounts of these phenomena and anticipatory functionalities now begin to be explored from a computational point of view[9,5].

We think that by *conceiving representations as mainly anticipatory* it is possible to *reframe many of the central claims of AI*. In fact, the ability that characterizes and defines a "true mind", as opposed to a merely adaptive systems, is that of building representations of the non-existent, of what is not currently (yet) "true" or perceivable. A real mental activity begins when the organism is able to endogenously (i.e. not as the consequence of current perceptual stimuli) produce an internal perceptual representation of the world ("simulation" of perception)[3]. For example, the organism can generate the internal "image" for matching it against perceptual inputs while actively searching for a given object or stimulus while exploring the environment; or it can use it as prediction of the stimulus that will probably arrive, and match its predictions against actual stimuli, and be confirmed, disconfirmed, or surprised. But it can also form mental representations of the current word to work on it, modifying this representations for virtually "exploring" possible actions, events, results: "what will happen if…?"; or maintain concurrent representations, such as motor plans, and select among them. Expectations are not only representations: they can have motivational, axiological, or deontic nature; saying us not only how the world is, was, will be; but how the world *should* be, how the organism would like the world to be. Anticipatory representations can thus be used as *goals* driving the behavior. This is what mind really is: *conceiving and desiring what is not there*: the presupposition for hallucinations, delirium, desires, and utopias.

We aim at providing a *unitary account of the role of anticipation in many cognitive functionalities*, including sensorimotor interaction with the environment, attention, planning and goal selection; and to *integrate them into an unitary architectures*. Anticipatory representations offer two advantages: 1) they make it possible to build up more and more complex functionalities exploiting less complex ones (e.g., off-line planning exploiting on-line planning); 2) even if they are used for detatching from reality (as in visual imagery, or in planning), they are fully grounded: they are acquired in the past experience (e.g. with supervised learning[9]) and can be compared with actual stimuli. **Fig. 1** shows our model for an *oculo-motor coordination* system in which many concurrent *perceptual* and *motor schemas* control a camera and a gripper[6,5]. In the framework of the EU funded project MindRACES (FP6-511931), this model is being used for realizing a system that has to pick-up with its gripper insects having different sizes, velocity and trajectories on the basis of visual input.

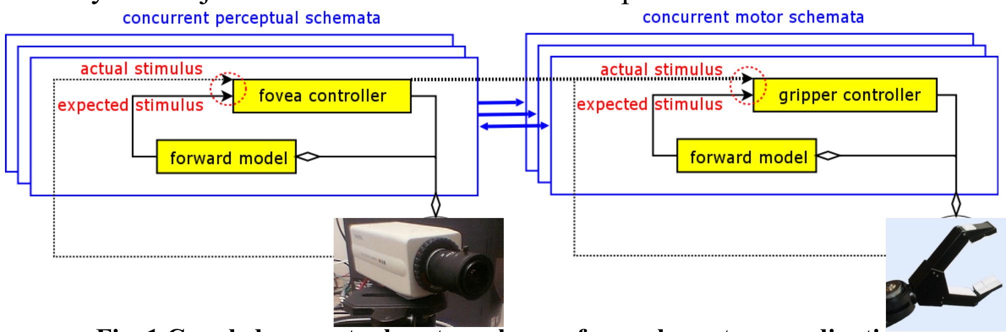

Fig. 1 Coupled perceptual-motor schemas for oculo-motor coordination

In our systems, anticipation has five main roles: 1) *Action control*: in the case of perceptual schemas, this means orienting the fovea towards relevant inputs (e.g., relevant colors and trajectories); in the case of the motor schemas, this means selecting the most appropriate gripper action (e.g., specialized for quick or slow, big or small insects). Moreover, some perceptual and motor schemas are *coupled*: active perceptual schemas specialized in tracking some trajectories or colors pre-activate motor schemas for picking related insects and vice versa. 2) *Decision*: *many competing motor plans are generated and maintained* for the same or for different targets, and choice depends on *predictive accuracy*. Schemas predicting better are selected: the rationale is that schemas predicting well are "well attuned" with the current course of events[9]; prediction is an evaluation of schemas efficacy. 3) *Replacing the actual input* if sensors are unavailable or unreliable. 4) *Compensating time delays*. 5) *Erasing the auto-generated input* (e.g., for avoiding to consider as target the own moving gripper).

The anticipatory representations provided by the forward models (e.g. implemented using fuzzy logic or neural networks) offer also a bridge for more complex functionalities such as *offline planning*: possible outcomes of events can be simulated and compared offline by exploiting the same machinery involved in online visual and motor planning, but without sending commands to the effectors. During this operation the expected stimuli replace actual ones and serve as inputs for chaining the schemas. This offers two more advantages: 1) "detatching" the representations from the sensorimotor loop by setting up *hierarchies of schemas* representing abstract concepts; 2) *using goal states,* and not current stimuli*, for the selection of action*.

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