Artificial cognition in neurorobotics for limb movement and manipulation

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The challenge

Nature has provided living beings with cognitive skills for interacting properly with their environment to ensure their survival. In this sense *cognition* can be defined as the set of mental abilities permitting the decision-making based on the processing of perceived and acquired information. Among these cognitive abilities the main ones, as understanding, learning and memory, are the subjects of theoretic and experimental scientific disciplines. The importance of our comprehension about cognition lays on the wide social application of this knowledge, especially in the field of robotics. In a near future the robots will be an essential part of our life, but in order to get their natural and smooth integration in our society it is desirable that their mental processes are similar to our brain mechanisms. The neurorobotics is focused on developing artificial cognition inspired by the nervous system of animals and humans to provide robots with mental abilities similar to those exhibited by living beings. This challenge will ensure that robots can interact with our world (and with us) in an efficient, versatile, and robust way, naturally facing complex tasks that demand a proper combination of movement, navigation, and manipulation.

The problem

The main context of cognition (both in biology and robotics) is the interaction with the real world.

- *How does our brain understand a situation?*

  During the last decades Neuroscience has revealed the main brain mechanisms involved in the understanding of *static* (i.e. time-invariant) environments, e.g. a maze. In brief, there exist different neuronal populations that code distinct spatial attributes of the environment, as the subject's position (place cells), the location of obstacles (boundary cells), the metric of the space (grid cells), etc., creating an internal representation of the environment called the *cognitive map*. The relationships among these features allow the brain to *understand* the perceived environment: 'where am I?', 'where is the closest obstacle?', 'which is the free path?'.

- *Where is the difficulty?*

  Our reality is essentially *dynamic*, i.e. time-changing. If we consider a dynamic situation as a set of consecutive static environments (as a movie composed of static frames) the amount of information to be processed could increase explosively. However our brain constantly deals with complex dynamic situations in a fast, reliable and robust way. Therefore it is required a

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novel paradigm in brain information processing dealing with the big amount of information contained on the time dimension.

- *How can it be solved?*

Recently our group has proposed a novel paradigm of information processing in the brain called *Prediction for CompAction* or PCA, based on a generalization of the biological concept of cognitive map named *compact cognitive map*. Prediction for CompAction paradigm is illustrated in figure 1 and transforms a perceived dynamic situation (e.g. a pedestrian walking in front of us) into a static abstract representation, the compact cognitive map, where the time is compacted by extracting the critical events (possible collisions with the pedestrian) and projecting them into the map. The compact cognitive map contains the essential information required to deal with the dynamic situation, in Fig. 1, how to navigate with no collisions with the pedestrian, i.e. where and when collisions can occur and pathways for safe navigation.

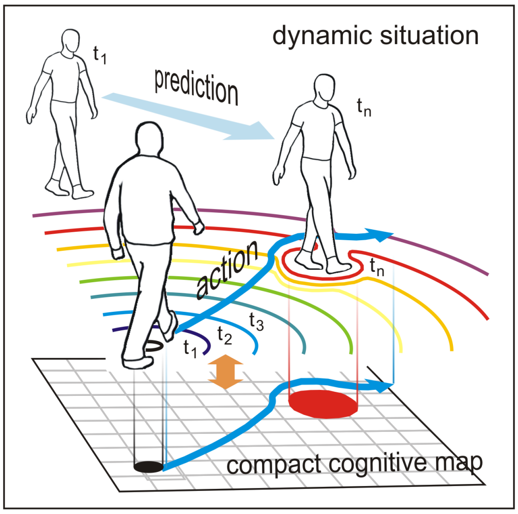

Figure 1. *Prediction-for-CompAction paradigm for cognition*. The cognitive subject (dark black line) predicts the movement of a pedestrian (light black line) and simultaneously simulates its own possible actions (coloured curves denote possible agent's positions at different times). Coincidences of its possible actions with the predicted pedestrian's movements form a static effective obstacle (red area) leading to the *compact cognitive map*. Avoidance of this static obstacle following routes contained in the map ensures collision-free walking.

Prediction for CompAction is a natural framework for cognition where understanding, learning and memory emerge in a unified way from a unique dynamic flux of information (Fig. 2). PCA has been implemented in an artificial proto-cerebrum and successfully applied to robot navigation in dynamic situations.

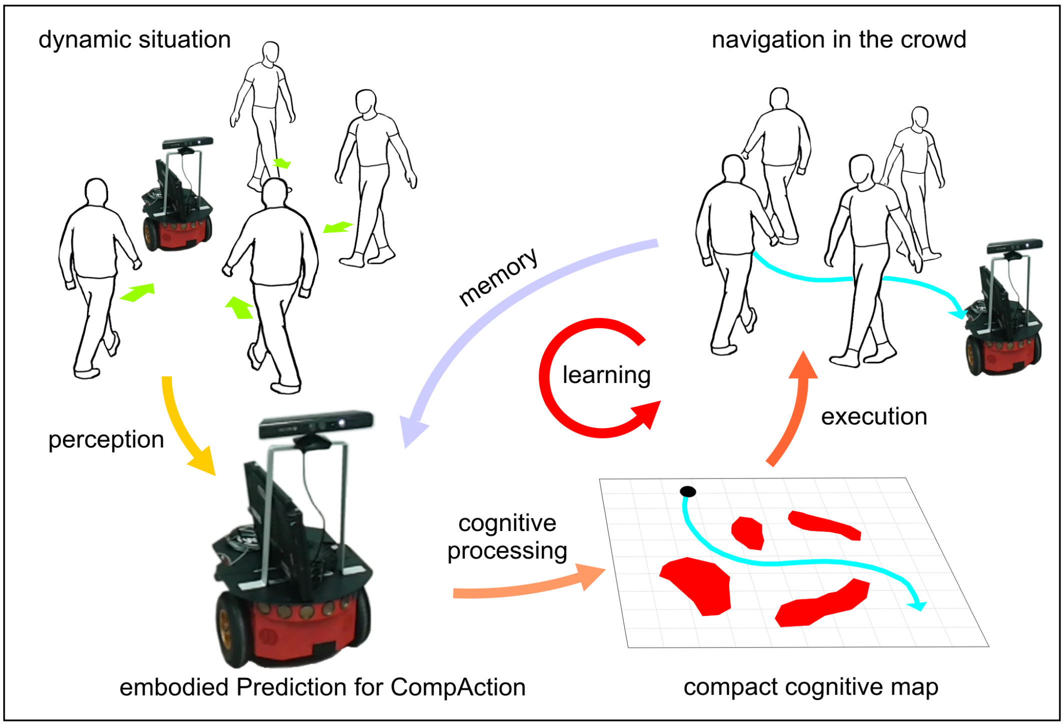

Figure 2. *Cognition based on Prediction-for-CompAction*. According to PCA a time-changing situation perceived by the cognitive agent (e.g. our neurorobot walking in a crowd) is processed as a compact cognitive map, which supports the decision-making and execution of the decision (how to navigate safely among pedestrians). The perceived dynamic situation transformed into this static map is now suitable to be, among others, stored in the memory, compared with previous experiences (also in terms of their corresponding compact cognitive maps) in a dynamic learning loop, etc., representing a unified substrate for cognition.

The objective

Cognitive interaction of robots with our world and us is far to be restricted to navigation. A central type of interaction concerns the coordinated movement of limbs for performing complex actions, in particular manipulation and locomotion, which are key abilities to ensure survival in animals and humans (run, jump, fight, etc.). The objective of this research will be to *outline the extension of the Prediction for CompAction paradigm from navigation to cognitive manipulation in dynamic situations* (as simple example, to catch a flying ball).

The research

The problem will be tackled in four steps:

- *Familiarization with the mathematical modelling of Perception for CompAction paradigm*

  The students will be introduced to the mathematical principles of PCA and its computational modelling. *Phases*: simulation of virtual exploration by using nonlinear reaction-diffusion systems and autowave propagation, modelling of virtual scenarios and virtual robot navigation in dynamic situations.

- *Modelling of cognitive manipulation based on PCA*

We will extend the PCA principles used in navigation to the movement of a virtual arm that should interact with a time-changing environment. *Phases*: deriving mathematical transformations from the ordinary space to a suitable space for representing the arm, translate the functional principles of PCA and propose plausible situations for simulating cognitive manipulation.

- *Proof of concept by simulation of some simple situations*

  We will implement in computer the achieved theoretical progresses by simulating different dynamic environments resembling real situations. *Phases*: programming and testing of results, and proper visualization.

- *Conclusions and exposition*

  The results of the research will be properly structured for a rigorous and accessible communication for a general audience. We will emphasize the clarity of the message, impact of results and conclusions.