Existence of Time Compaction in the Human Brain: Theoretical and Experimental Study

The challenge

Nature has provided living beings with cognitive skills for interacting properly with their environment to ensure their survival. The importance of our comprehension about cognition lays both on the knowledge it could provide us about ourselves and on the wide social application of this knowledge, especially in the field of robotics and artificial agents.

In near future robots will be an essential part of our life. In order to integrate them smoothly in our society it is desirable that their mental processes were similar to our brain mechanisms. Neurorobotics focuses on the development of artificial cognition inspired by the nervous system of animals to provide robots with mental abilities similar to those exhibited by living beings. Such an approach ensures an efficient, versatile, and robust interaction of robots with our world, naturally facing complex tasks that demand a proper combination of movement, navigation, and manipulation. Therefore the challenge is to reveal those basic brain mechanisms responsible for cognition of complex dynamic situations with which animals and humans must properly interact to ensure survival.

Figure 1. Survival is a matter of cognition. Proper understanding of a situation will ensure the optimal decisions to behave correctly and increase survival chances. Nervous system has evolved to provide animals and humans with the neural mechanisms for dealing with complex dynamic situations in a fast and efficient way.

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. In brief, there exist different neuronal populations that code distinct spatial attributes of the environment, 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 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 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.

- *How can it be solved?*

  Recently our group has proposed a novel paradigm of information processing in the brain. It is based on a generalization of the biological concept of cognitive map, named *Generalized Cognitive Map*. Figure 2 illustrates a GMC in the context of navigation. It is an abstract static representation of a perceived dynamic situation, where time is compacted by extracting the critical events (possible collisions with the pedestrian) and projecting them into the map.

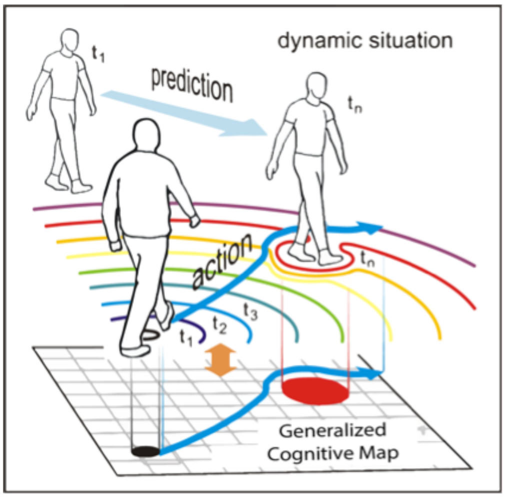

Figure 2. Concept of Generalized Cognitive Maps. The cognitive subject (dark black line) predicts the movement of a pedestrian (light black line) and simultaneously simulates its own possible actions (coloured curves denote possible agent's positions at different times). Coincidences of its possible actions with the predicted pedestrian's movements form a static effective obstacle (red area) leading to the GCM. Avoidance of this static obstacle following routes contained in the map ensures collision-free walking.

Time compaction and the GCMs constitute a natural framework for cognition, where understanding, learning and memory emerge in a unified way from a unique dynamic flux of information (Fig. 3). GCMs have been implemented in an artificial proto-cerebrum and successfully applied to robot navigation in dynamic situations.

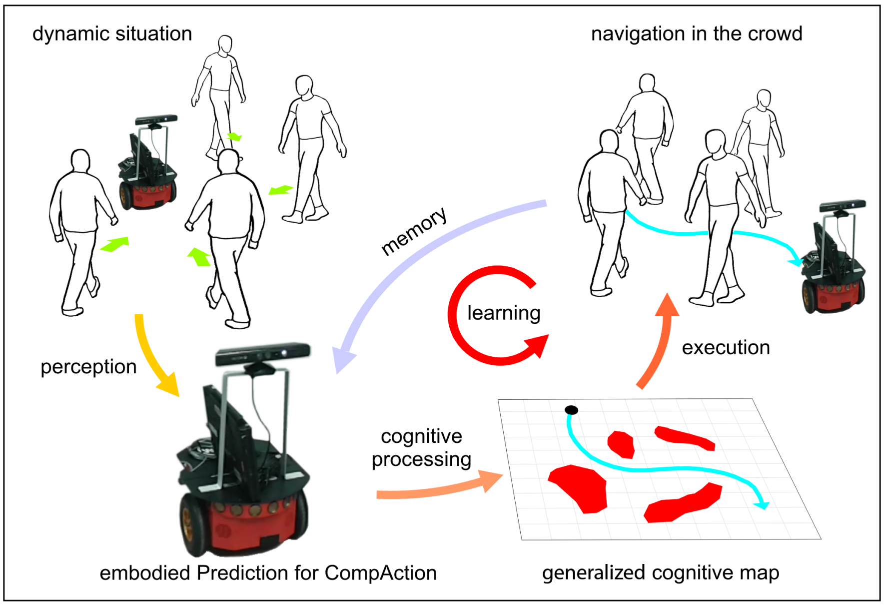

Figure 3. *Cognition based on Generalized Cognitive Maps*. According to GCM theory, a time-changing situation perceived by the cognitive agent (our neurorobot moving in a crowd) is processed as a compact cognitive map, which supports the decision-making and execution of the decision (how to navigate safely among pedestrians). This static map is now suitable to be 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 brain mechanisms involved in the interaction with complex dynamic situations, even if we consider only those restricted to navigation, are a central and still open problem in neuroscience. The objective of this introduction to research will be to *explore the existence of time compaction in the human brain* by using combined theoretical and experimental approaches to tackle the problem.

The work plan

To accomplish the objective we will propose a behavioural task to enlighten the presence of time compaction during its processing by human brain, and we will analyse the outcome from two parallel and complementary theoretical and experimental perspectives.

1. *Theoretical approach.*

   We will design and implement computationally basic neural networks that could mimic the process carried out by the brain during the task undertaking. This theoretical approach will be programmed in Matlab and computational simulations will try to provide predictions about the findings to be obtained from the experimental stage.

2. *Experimental approach*

   The task will be tested in human subjects by conducting a behavioural experiment. The group should design the experimental procedure, considering systematization, possible factors affecting results; minimize potential bias, and those other elements of the experiment design. Finally they will conduct the experiment on the ground, selecting volunteers from the other Modelling Week groups.

3. *Results analysis*

   In this final stage the students will analyse theoretical and experimental results, facing different problems as statistical significance of experimental results, their interpretation, matching with theoretical findings, etc.

4. *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.