Real-time navigation of bioinspired cognitive robots in static and dynamic environments

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 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 to provide robots with mental abilities similar to those exhibited by living beings. This challenge will ensure that robots can interact with our world (Fig. 1) in an efficient, versatile, and robust way, naturally facing complex tasks that demand a proper combination of movement, navigation, and manipulation.

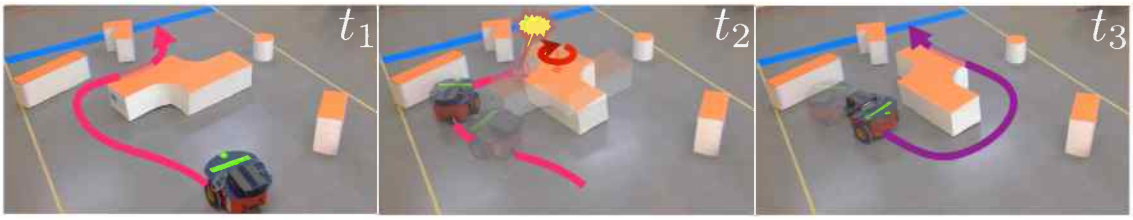

Figure 1: The problem of navigation is situated within one of the basis cognitive levels. The image shows three consecutive snapshots of an artificial agent (robot Pioneer 3DX) capable of interacting with a drastically changing environment. It achieves to cross a corridor avoiding collisions with obstacles, even when the z-shape obstacle is unexpectedly rotated, blocking its initial path.

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, based on a generalization of the biological concept of cognitive map. Prediction for CompAction (PCA) paradigm is illustrated in Figure 2 and transforms a perceived dynamic situation into a static abstract representation, where the time is compacted by extracting the critical events (possible collisions with the pedestrian) and projecting them into the map.

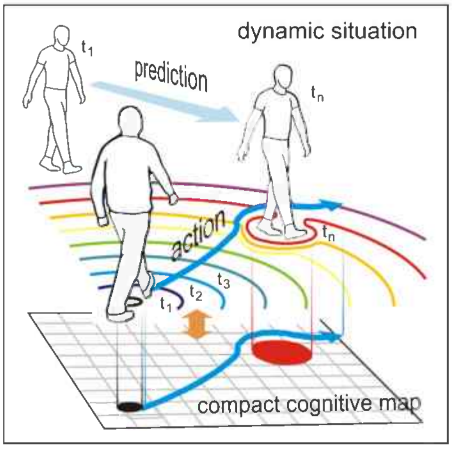

Figure 2. *Prediction-for-CompAction paradigm for cognition*. The cognitive subject (dark black line) predicts the movement of a pedestrian (light black line) and simultaneously simulates its own possible actions (coloured curves denote possible agent's positions at different times). Coincidences of 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.

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

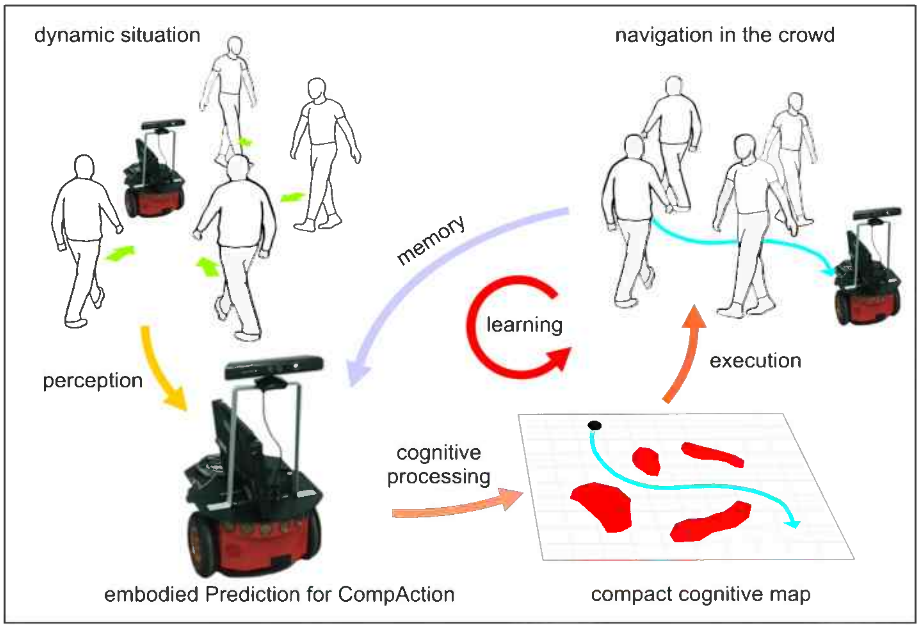

Figure 3. *Cognition based on Prediction-for-CompAction*. According to PCA a time-changing situation perceived by the cognitive agent (our neurorobot walking in a crowd) is processed as a compact cognitive map, which supports the decision-making and execution of the decision (how to navigate safely among pedestrians). 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 interaction of robots with our world and us is far to be restricted to navigation, however accurate and versatile robot displacement in real environments is a central and still open problem in robotics. The objective of this introduction to research will be to *study robot navigation by progressing from basic cognitive algorithms (local cognition) to the Prediction for CompAction paradigm (global cognition) in lab static and dynamic situations*. In order to do that the facilities of the Cognitive Systems and Neurorobotic Group (School of Mathematics, Universidad Complutense de Madrid) will be used, including the robot Pioneer (see Figure 3), which will be programmed by the students to test cognitive navigation under the proposed approaches.

The research

The research process will be tackled in three steps according to the robot 'necessities' required to navigate: perception of sensory information, cognitive processing of such information for making decision, and transformation of these decisions into motor commands to get navigation.

1. *Familiarization with artificial visual perception in controlled scenarios*

   The students will be introduced to the basic techniques of artificial visual processing and its applications to image characterization (Figs. 4, 5A,B). The main problems of basic image segmentation will be exposed and students will analyse them, proposing and discussing possible solutions.

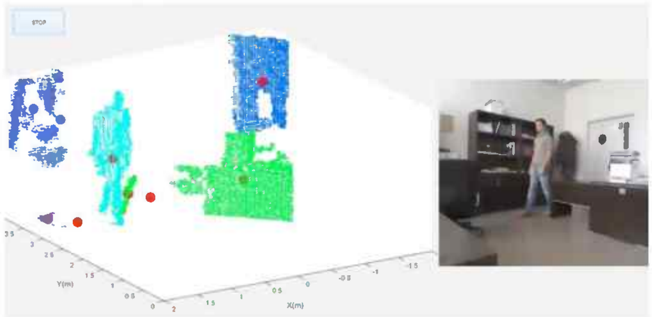

Figure 4: Artificial visual percepcion by means of Kinect-based visual system: 3D-segmentation of the environment.

2. *Development of local and global bioinspired algorithms for real-time cognitive navigation*

   We will study the PCA principles used in robot navigation, where bioinspired cognition lays and how different approaches can be proposed according to the locality required in different scenarios. Then we will move to their computational implementation for real-time processing by using Cellular Automata. These processes will support the robot decision making to choose its navigation trajectory in real static and dynamic lab scenarios, visually processed by techniques discussed in 1 (Fig. 5).

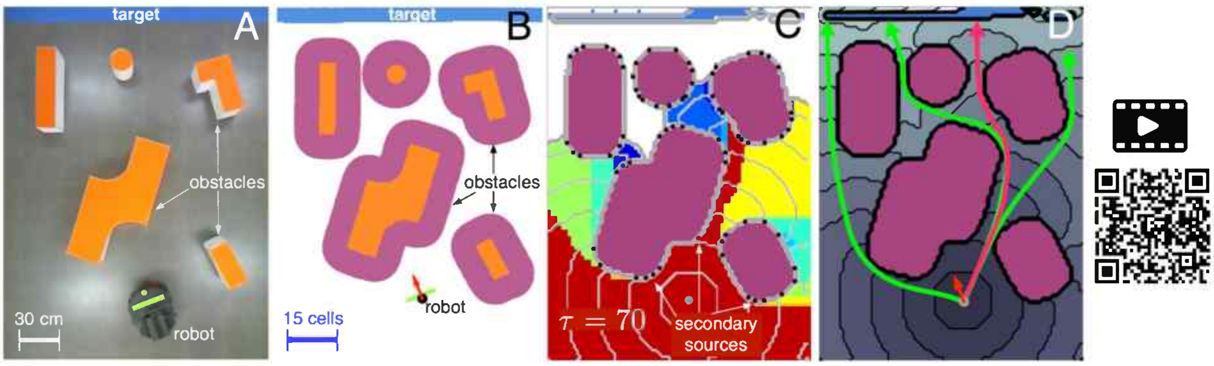

Figure 5. Real example of cognitive navigation in a static lab scenario. A) Experimental setup (top view). B) Abstract visual perception and its mapping on the CA lattice. C) A snapshot of the process of building a cognitive map in the CA model. D) Cognitive map of the situation built by the CA and feasible trajectories.

3. *Navigation through motor commands based on cognitive decisions*

   In this final stage we will translate the abstract decisions made by the robot (i.e. the trajectory to be followed) into real movements. The students will learn how robot physical limitations should be taken into account to get accurate navigation in real situations.

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.