Universidad Complutense de Madrid

Máster en Ingeniería Matemática

IX Modelling Week
15th-19th June 2015

Artificial cognition in neurorobotics for limb movement and manipulation

Javier Espín García
Javier León Caballero
Jorge del Val Santos

July 5, 2015

Instructor:
José Antonio Villacorta Atienza

Instituto de Matemática Interdisciplinar

Contents

1 Introduction

This work will describe how bio-inspired mathematics can be used in order to take some steps towards building an intelligent robot. The milestone that wants to be achieved is building a *cognitive* robot that can understand what surrounds it and take decisions accordingly. The developed models will cover two areas, *navigation* and *manipulation*, both on static and dynamic situations.

On the first part, navigation, there will be a robot (*agent*) that tries to reach an object (*target*), without hitting possible obstacles. Both the target and the obstacles could as well move, and the agent should take that into account.

On manipulation there will be a robotic arm, with its shoulder fixed, that wants to grab a (possibly moving) target, without colliding with (possibly moving) obstacles.

2 Cognition

Our goal would be to build a robot that can mimic human behaviour in the matter of *cognition*. So first of all we need to stablish what do we understand as cognition. Cognition is the set of mental skills that allow us to process information in order to make a decision. For example, when a ball is thrown at us, thanks to the fact that we are cognitive beings we are able to catch the ball (without needing to solve the differential equation that determines the trajectory of the ball).

2.1 Cognition in our brains

Next we are going to see how is cognition reflected on our brains. Figure 1 are the result of a series of experiments conducted on rats brains. Each of these circles represents a region on which the rat was placed, with some electrodes on its head. The colours measure how active were the neurons covered by the electrodes while the rat was on that point of the region. There are 4

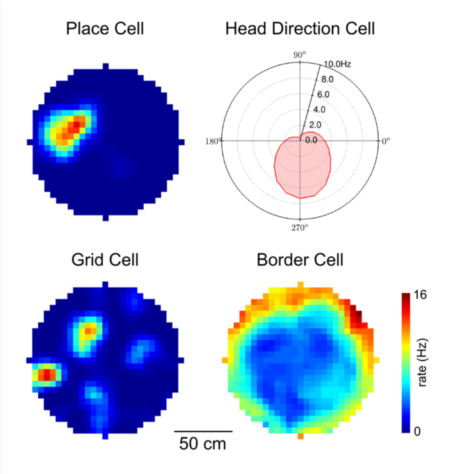

Figure 1: Stimulation of different cells on a rat's brain. The discovery of the Place and Grid cells was awarded with the Nobel Prize in Physiology or Medicine in 2014.

different kind of cells:

- Place Cell. Specific cells of its brain were active when the rat was on a certain region, providing a notion of location within a domain.
- Head Direction Cell. Other areas are active accordingly to where its head was facing.
- Grid Cell. Those cells, similarly to the Place cells, are active on a certain point of the domain, but also on some points surrounding that main point. This provides the brain with the notion of discretization of the space.
- Border Cell. These last cells were active when the rat was close to the boundary of the region.

2.2 Example

A static example is a mouse Jerry, wants to take a cheese, but there is a mousetrap in the way.

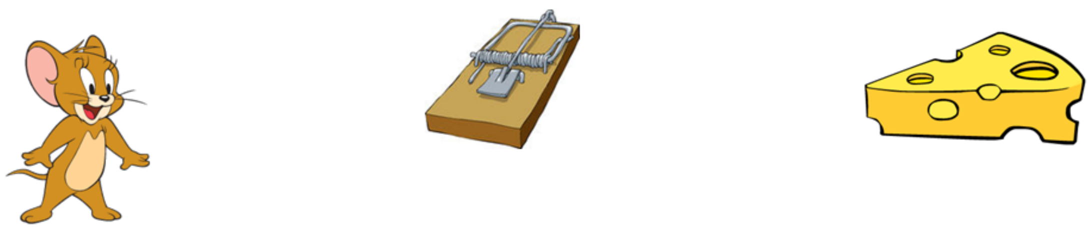

Figure 2: How would Jerry move to get the cheese? He takes into account the critical information, which is the target (cheese) and the obstacle (mousetrap). He does not need anything else.

3 Compact Cognitive Maps (CCM)

We have already said that our brain extracts the critical information of a static situation in a sort of map, but what about time? Can we extract the fundamental information of a dynamic situation? If someone throws us a ball, it is likely that we will catch it. But how can we catch the ball? We don't need all the information in time; we only extract what interests us, the critical information (in this case the initial conditions of the ball, its initial position, velocity and acceleration). We can say that in general time is redundant because even though the trajectory of the ball is a dynamic situation, if our goal is to catch the ball we don't need any other information (that arises in time) for catching it than the initial conditions.

The world is dynamic, there are a huge amount of common dynamic situation such as reading, driving, running, talking, etc, in which our brain works taking only the fundamental information. For instance, when we read a book or watch a series, we usually don't remember in which exactly chapter something specific happens. It is because our brain stores only the critical events, and it doesn't necessarily need time. It's only easy to recall the order of events when it exists a causal relation between them, but in general we only recall the critical events.

Hence if in a dynamic situation we are able to take time off the table, we will construct a *compact cognitive map* that turns a dynamic situation into a static situation, and the problem of navigation and manipulation will be solved.

3.1 Creating the Compact Cognitive Map

But what are the critical events for navigating in a dynamic situation? In the example before the critical events are deaths, romances, accidents, etc. In real life when you move anywhere the main critical event is crashing.

Retuning to the Jerry example, this time there is an obstacle in movement, Tom. To simplify Tom moves in a straight line and constant velocity[1]. Jerry realizes a mental simulation to know where he will crash with Tom, which is only the critical event (figure 3).

Having done the mental situation, the brain constructs a map called compact cognitive map. In this case the CCM is the effective obstacle, that is, all places where Jerry is going to crash with Tom (figure 4).

3.2 Learning and memory

The creation of the compact cognitive maps is linked with memory. When a new cognitive situation arises, our brain will extract the critical information out of it, and then try to retrieve the cognitive map that was previously constructed. If such a situation is completely new to us, our brain will analyze it and build the map so it can be retrieved in other occasions.

[1]Moving at a constant velocity is a perfectly reasonable assumption. In a cognitive situation, like running away from a fire, we do move at constant velocity: the maximum.

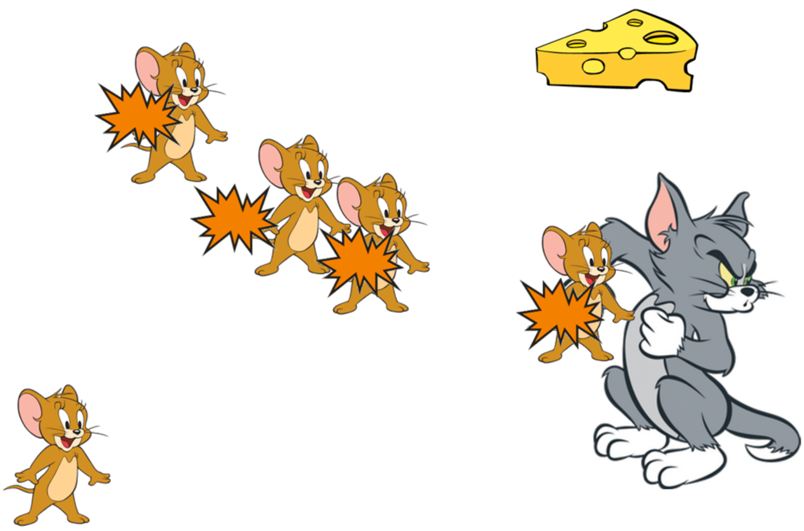

Figure 3: Mental simulation of critical events.

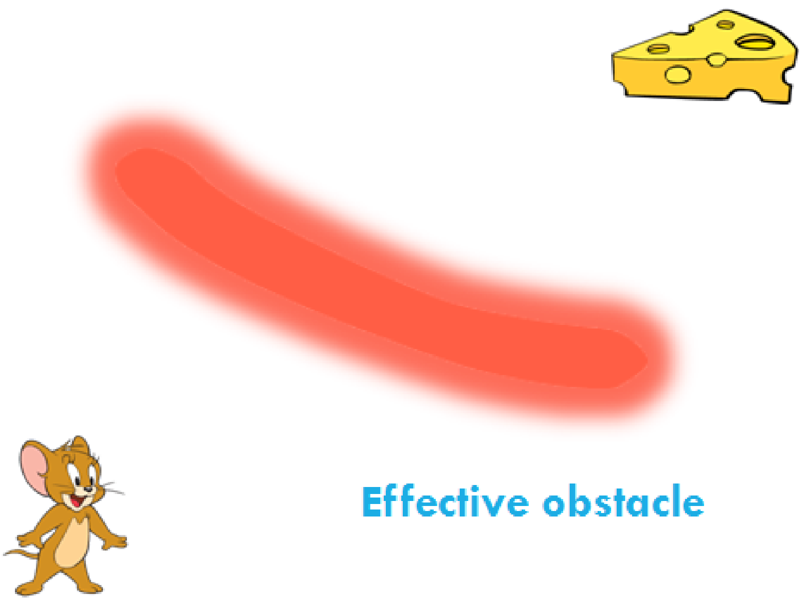

Figure 4: Compact cognitive map.

4 Mathematical model

The critical point in building the Compact Cognitive Map is the *mental simulation*. We have addressed earlier that Jerry would have to picture himself going in every possible direction simultaneously. This rapidly brings the concept of wave to our minds.

However, *usual* waves such as water or sound waves have reflections, interference, and more important, power attenuation of the wavefront. This happens naturally due to the energy conservation laws in nature, since the same energy would have to be distributed in a larger wavefront.

That means that we have to think in another type of waves that reinforce themselves as they go. Those waves would surely need non-linearity, since linear waves exhibit the characteristics that we previously discussed.

Since we need that crashing wavefronts don't continue going, the kind of waves we need are *autowaves*. One of the most famous non-linear systems that exhibit autowave behaviour is the FitzHugh-Nagumo system, that models the dynamics of neurons. Is worth to remark, that basing ourselves in neuron behaviour all this system would be completely bio-inspired.

Now we discretize space in a finite set of points (figure 5).

Here, each point would be a single neuron, governed by the coupled difference equations of FitzHugh-Nagumo:

$$\dot{r}_{ij} = q_{ij}\{H(r_{ij})(f(r_{ij} - v_{ij}) + d\Delta r_{ij} - r_{ij}p_{ij}\}$$

$$\dot{v}_{ij} = \frac{r_{ij} - 7v_{ij} - 2}{25}$$

$$f(r) = \frac{1}{7}(-r^3 + 4r^2 - 2r - 2)$$

Where Δ is the discrete laplacian and r_{ij} is the amplitude of the point. The constant d determines the coupling of the neurons and also the wave velocity (in analogy to the classical waves), which

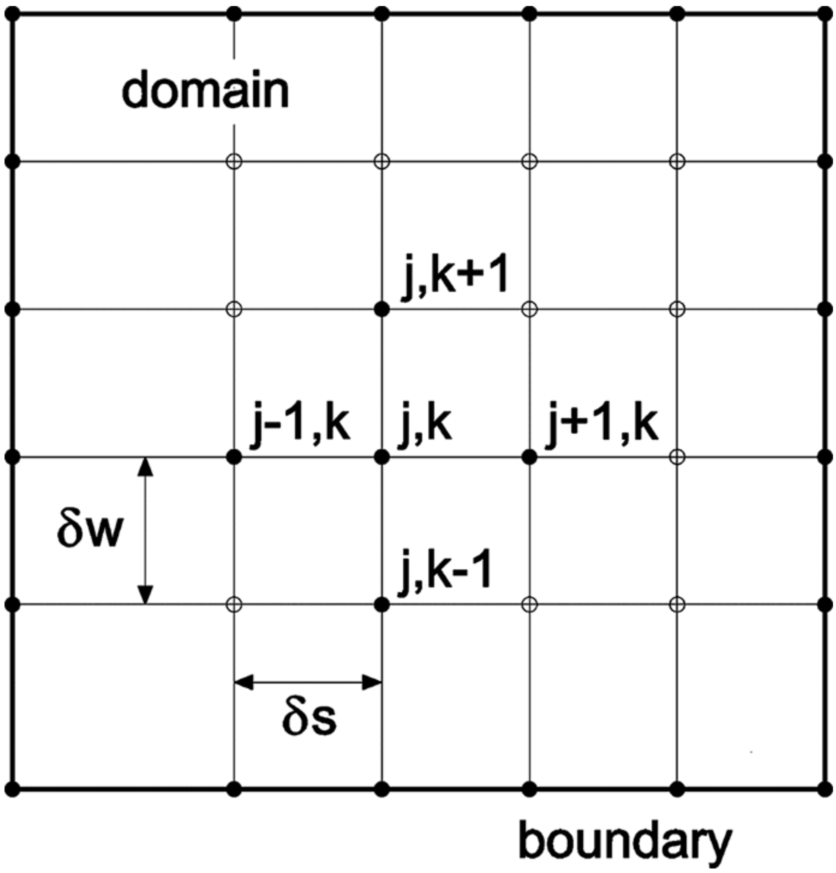

Figure 5: Discretization of space.

without loss of generality we set on 0.2. The autowaves generated by this system will travel at constant velocity.

However, we also need to model de obstacles. We will do that by considering a dynamic set:

$$\Omega(t) = \{(i,j) \mid \exists \tau \in [0,t] \text{ such that obstacle is in cell } (i,j) \text{ at } \tau \text{ and } r_{ij}(\tau) \in [0.5, 2]\}$$

This is the set of all points in which the wavefront has collided with the obstacle. By *collide* we mean that the point has a reasonable amplitude (between 0.5 and 2) and the obstacle is in the same place. For all the points in this set, we *stop* the neuron by setting:

$$q_{ij} = \begin{cases} 0 & \text{if } (i,j) \in \Omega \\ 1 & \text{if } (i,j) \notin \Omega \end{cases}$$

Looking at the equations, we see that if q_{ij} is 0, then $r_{ij} = 0$, so the amplitude stays constant. That is what models the effective obstacle, the neurons will *record* the place the obstacle hit the wavefront.

5 Manipulation

Now we turn to manipulation. We have already understood how can we navigate but the case of manipulation is not straight-forward. If we see an example:

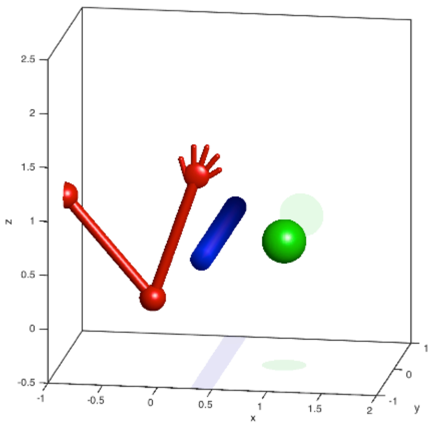

Figure 6: The red hand wants to fetch the green ball, avoiding the blue obstacle. The arm is fixed by the shoulder.

If we used navigation in this example, the blue cylinder would not be much of an obstacle, as the red hand will not have any problem to reach the ball just going in a straight line. However, we can see that if the hand does that, the forearm would collide with the obstacle. We then perceive the two main differences between navigation and manipulation:

1. The target needs to be grabed by the hand, and not by any other part of the agent.
2. The obstacle must be taken into account as a such not only for the hand but for the whole agent.

In order to solve these problems we take a look to figures 7 and 8. A formula for deducing the extended obstacle can be deduced, and what that in mind the CCM can be created.

5.1 Manipulation in a dynamic situation

Once we have dealt with the issues that arise when we want to do manipulation (solved by converting the obstacle in an extended obstacle), we want to know what can be done in a dynamic situation (for example if we need to catch a moving target or we have to avoid a moving obstacle). However we just need to do the same that we did when creating the compact cognitive map, that is, creating the effective obstacle. The only difference is that now, in each moment of time (of the wave propagation), the effective obstacle will be derived from the extended obstacle.

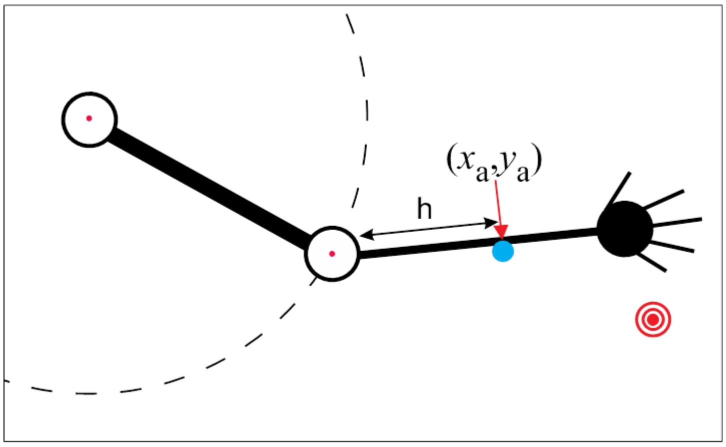

Figure 7: At this point the forearm has collided with the obstacle and therefore the hand cannot keep moving down. That is the same situation as if there was an imaginary obstacle blocking the hand that does not allow us to go any further. If now we paint all the imaginary obstacles blocking our way down, that appear when the forearm is colliding with the obstacle we will have obtained an imaginary obstacle for the hand that is named *extended obstacle*.

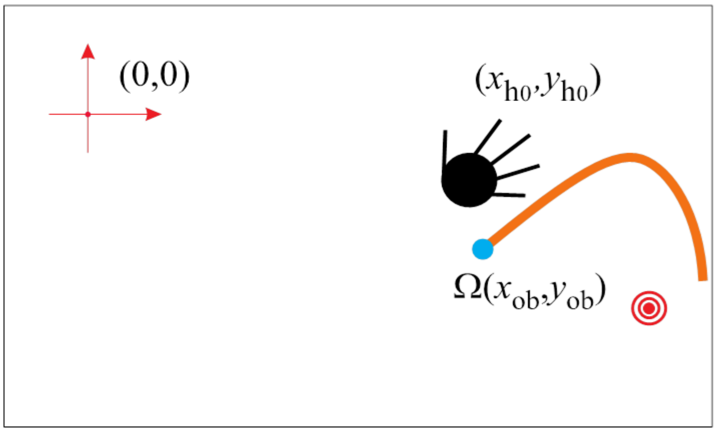

Figure 8: On orange the extended obstacle that is formed by the different posistions where the hand is whe the forearm is touching the obstacle. The hand cannot go through that extended obstacle because that would mean that the forearm is going through the blue obstacle.

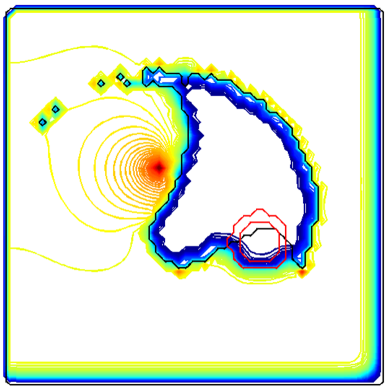

Figure 9: On red there is the target, and on black the extended obstacle. The wavefront does not go through the extended obstacle, and the solution (on figure 10) is to go under the cylinder.

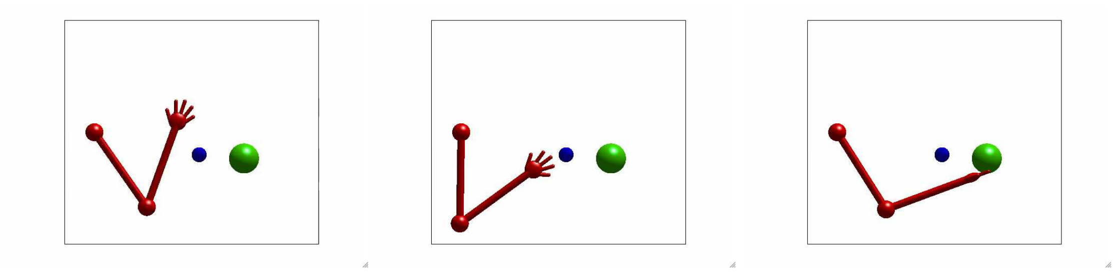

Figure 10: Some frames of one of the solutions provided by the CCM.

6 Conclusions

- Cognitive beings work only with critical information, which can be represented by Compact Cognitive Maps.
- We can exploit it to implement artificial cognition in robots.
- CCM permits to unify some fundamental types of robot behaviour (like navigation and manipulation) under a common theoretical framework.
- Compact Cognitive Maps support cognition, and their implementation could the first step in building *truly* intelligent robots.