iCubSim at the mirror

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We introduce a simple example of artificial system which aims to mimic processes behind cognition. In particular we explore the mirror self-recognition – ability limited to very few species. We assume that evolution of species is reflected in the structure of the underlying control mechanism and design its modules concerning their incremental development. On this example, we demonstrate modular architecture suitable for such task. It is based on decentralization and massive parallelism and enables incremental building of control system which is running in real-time and easily combines modules operating at different pace.

1 Introduction

The mirror self-recognition is limited to humans, apes and very few other species such as elephants, dolphins, orcas and magpies (see www.animalcognition.org). These species do not feel threatened looking at the mirror since they understand that there is no enemy in their vicinity. They follow their own image in the mirror, play with the image in the mirror and associate it with themselves. On the other hand species such as cat usually attack the image as it would be another and potentially hostile individual. The ability of the mirror self-recognition is also dependent on age. Children under 18 months old tend to look for other child behind the mirror while older children recognize themselves what can be proved by so called Dot Mirror Test [3]. (Fig.1)

Fig. 1. The mirror self-recognition is limited to a few species and depends on age

When we aim to implement the ability to a robot, common features of these species give us inspiration on how to structure underlying processes. There are mechanisms such as body model, mirror neurons, social interaction, imitation and others. Merging these mechanisms into a self-recognition robot sheds light on which of them are relevant and which are not. The key idea follows Justin W. Hart & Brian Scassellati from Yale University (developers of the robot Nico which is able to perform various tasks following the image seen in a mirror) supposing that such a robot should recognize itself in the mirror due to perfect correlation between the body movement and the image seen [4]. Unlike them and just like Junichi Takeno who developed a simple robot which has passed the Dot Mirror Test [10], we work with a simplified body model of the robot.

For the simulation purposes we use iCubSim simulator developed by RoboCub EU FP7 project [9], being the best choice for us since we need a humanoid robot which image can be processed to the same body model as an image of a similarly interacting human. iCubSim provides us the ability to control individual joints of the model via yarp/rpc protocol. However we replace image which iCubSim sees in his virtual world by an image from the real world in front of the monitor which displays the iCubSim scene. (Fig. 2)

Fig. 2. iCubSim equipped with a camera

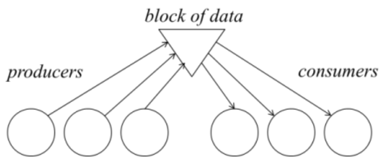

Fig. 3. Combining of slow and fast processes producing and consuming the same data

The control system of the simulated robot is built using Agent-Space architecture [6] – a software tool for building real-time control systems of robots or their virtual models which modularity is based on decentralization and massive parallelism, directly following Brooks' subsumption architecture [1] and Minsky's society model of mind [7] while enabling us to wire various module outputs to various module inputs (many:many). These modules are running in parallel, having a very various data processing speed. Such combining of either really slow or really fast processes is possible due to data produced by one module being written onto a blackboard (called *space*) and processed later, when the module-consumer is ready to process them (Fig. 3). The written data remain on the blackboard until they are rewritten by the same or another module, or their time validity expires. Such data exchange is similar to LINDA tuple-space or Java Space [11] however it is adjusted to the need of hierarchical control and its incremental development, e.g. module has to define sufficient priority for the written data, otherwise they would not be able to rewrite their previous value already written on the blackboard.

2 Design of underlying processes

What mechanisms could underlay the mirror self-recognition? Since we aim to look for correlation between the movement of the robot's own body and the body seen, the following conditions are to be met:

- The robot needs a model of its own body
- The robot needs a model of the body seen expressed in the same terms as the model of its body mentioned above
- We need to ensure that both robot's body and the body seen moves.

For the sake of simplicity we reduce the body model to a single number – the angle of the head inclination from side to side, which can be easily detected on the robot's own body (via proprioception) and on the body seen (via image processing) as well.

2.1 Mechanism 1: Proprioception

The iCubSim robot both transmits intended positions into joints of the robot and monitors actual joint positions (which can be different). Since it has a perfect model of its body, it is easy to get the angle of head inclination needed (Fig 4).

Fig. 4. Proprioception mechanism provides simplified body model (pink color indicates head gradient to the right, red color to the left – from robot's point of view)

2.2 Mechanism 2: Mirroring

The notion of the next mechanism is to get the same model from the image captured by the camera. Several species are proven to obtain analogical ability (mirror neurons [8]). How such ability has emerged and evolved, is not the subject of our exploration while it is limited to the implementation of this ability. Even though we have not been able to implement the same image processing algorithm for both human and robot image, thus we have implemented two methods running in parallel. For the iCubSim image processing (we rotate the picture of iCubSim in front of the camera) we employ the SURF method. SURF provides projection of given template to the image seen from which we can easily calculate inclination of the template. For the processing of human image (interacting person is moving his head in front of the camera) we use combination of Haar face detector and CamShift: the Haar detector detects face in the upright position and sets up template for CamShift to follow. The projection of the template to seen image calculated by CamShift provides us the required head inclination. The two methods create a mutual output corresponding to the simplified model of the body seen. All algorithms employed are available in OpenCV library (www.opencv.org) (Fig. 5).

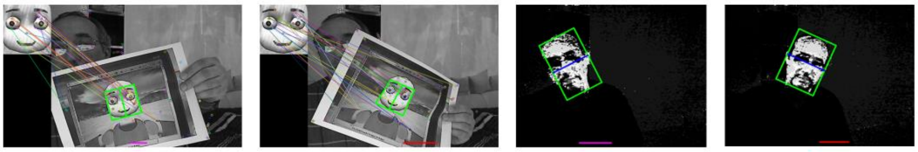

Fig. 5. Image processing provides a simplified model of the body seen (both for robot and human)

2.3 Mechanism 3: Imitation

The correlation of these two comparable models can only be evaluated by their changes through time therefore both robot and human have to be put in motion. One of the mechanisms, which can provide it, is imitation. Due to the utilized mirroring, a passive imitation can be implemented by direct putting values of the body model seen into the robot's body model. As a result, iCubSim imitates side to side movement of one's head when moving in front of the camera. Optionally we also implement the active part of imitation, which can be called the invitation to imitation and obtains a higher priority than the passive imitation and occasionally generates side to side movement of the robot's head when the body seen does not move. The invitation can be very simple (occasional random movement). However further analysis revealed that even slight inaccuracies in the model evaluation are sufficient to induce the imitation process (Fig. 6).

2.4 Mechanism 4: Society modelling

Imitation process provides us the data about correlation between the body owned and the body seen. When an individual lives within a society, it is important for him to categorize the data and associate them with the image seen (e.g. with the face of the interacting person). When such individual meets the mirror, it possibly creates a new category and finds out that the corresponding correlation is unusually high. In fact, it is so high that the image seen can not only be associated with the body model seen, but also with its own body, meaning that it sees itself.

Instead of modelling the society, for our purposes, it is enough to record the data produced by the two models since the aim of the study is to differentiate the data created when robot encounters human and when robot sees its own image in the mirror. It would be almost impossible for us to implement this mechanism completely because our body model is too simple to represent individual members of a society.

Fig. 6. Imitation process

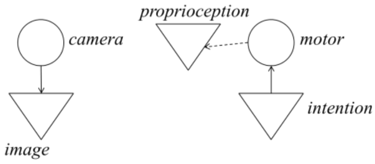

Fig. 7. Implementation phase 1. (proprioception)

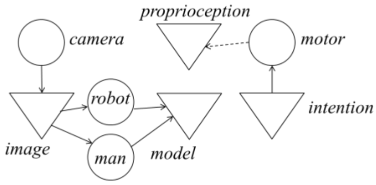

Fig. 8. Implementation phase 2. (mirroring)

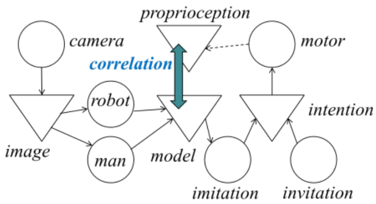

Fig. 9. Implementation phase 3. (imitation)

3 Implementation of the robot control system

The control system of iCubSim designed in the previous chapter is being implemented incrementally, combining individual modules utilizing the above mentioned Agent-Space architecture. In the first phase, the *Motor* module is implemented to communicate with iCubSim simulator via yarp/rpc protocol. This module regularly checks the position of iCub's head joint and updates the corresponding *proprioception* value on the blackboard. It also regularly checks the *intention* value on the blackboard and tries to update the position of the same joint in the iCubSim simulator. Thus when the value of *intention* is changed, the iCubSim's head position and the *proprioception* value are changed accordingly in a short amount of time. Another module regularly updates the value *image* with the current image taken by the camera (Fig. 7)

In the phase 2, the *model* value is added, being produced by two modules containing two methods of image processing – one working with the image of robot and the other with the image of human. Due to the architecture used, it is possible for both methods to produce a result in the same time – and modules reading this value have no idea by which method the read value was calculated. (Fig. 8)

In the phase 3, the *imitation* module is implemented which copies the *model* value to the *intention* value. As a result the *motor* module takes the value and sets it to the robot joint. In this way, the robot imitates the human in front of the camera. Optionally the *invitation* module can be added which occasionally generates a random model and writes it to the *intention* value thus the *motor* module processes it as it would have been written by the *imitation* module (Fig. 9).

Since situation that there is nobody in front of the camera can occur, both *model* and *intention* values are written with limited time validity. When their validity expires, the *imitation* module turns sleeping and the *motor* module turns robot's head to the upright position.

The value written by the *invitation* module not only has limited time validity but also lower priority than the value written by the *imitation* module. Thus invitation has no effect when the process of imitation has already started.

Finally the module which records *proprioception* and *model* values (which represent models of robot's own body and body seen) is added. The data recorded are dedicated to be analyzed off-line.

4 Results

When iCubSim's image is reflected into the external camera by a mirror, robot invites himself to imitation and - due to the time delay created during image processing and joint movement – it stays in an interaction with itself for certain amount of time. (Fig. 10)

Fig. 10. Robot iCubSim follows its own image in the mirror

During the period when robot sees himself in the mirror, something unusual can be seen in the recorded data. On the other hand the correlation coefficient does not tell us too much although its values converge to -1 as expected (Fig. 11). Moreover our data might be affected by differences in the recognition process for the robot and for human.[1]

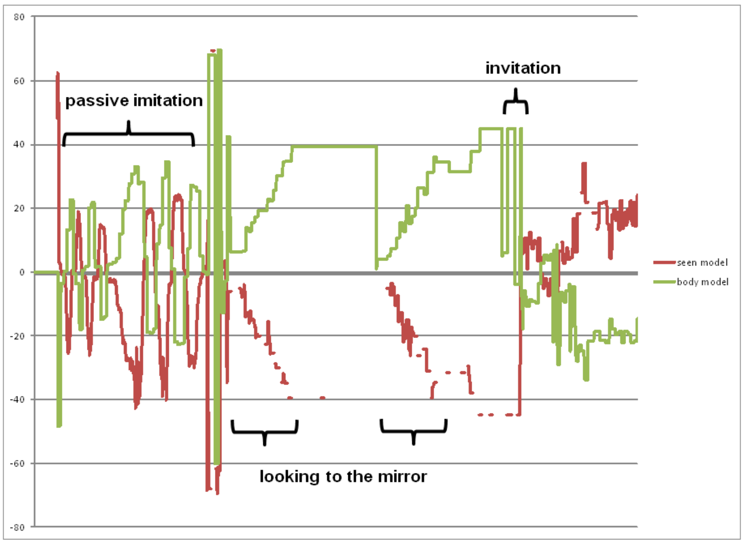

Fig. 11. The recorded data

5 Conclusion

We have implemented a control system of simulated robot with ability to recognize itself in a mirror, following inspiration from the realm of nature. We have been working with a rather simplified body model, but we discovered possible structure of simpler processes which could underlay the ability.

We have also demonstrated the use of architecture suitable for building of such systems, i.e. modular systems running in real time, combining either really slow or really fast processes and developed incrementally.

It is clear to us that we have only explored a little part of cognitive abilities. Most importantly we have to underline that we have only demonstrated self-recognition ("It is me"), not self-awareness ("I am").

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[1] The video from this experiment is available at: www.agentspace.org/mirror/iCubSimAtTheMirror.mp4
Source codes are available at www.agentspace.org/mirror/iCubSimAtTheMirror.zip

6 References

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