Self-organization in embodied reconfigurable architectures.

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***Abstract*—This paper describes a bio-inspired architectural approach to design highly adaptive and reconfigurable systems in the context of mobile robotics. The purpose is to design the hardware architecture of an intelligent controller for a robot that exhibits several behaviors such as landscape learning, obstacle avoidance, path planning, sensorimotor control. The Embodied Computing approach presented is employed in this context to integrate the reconfiguration management as a part of the behavior of the global system. We propose a hardware implementation of the approach based on artificial neural networks.**

I. INTRODUCTION

The aim of this work is to design an intelligent embedded controller that will be able to self-organize its elements in order to adapt its architecture to the robot behavior and to its environment. This paper explores the way of biologically-inspired systems in order to face the complexity of the design of a such systems[1]. We argue that reconfigurable (or adaptive) computing has to be thought as a part of a global system, composed of sensors, actuators, a source of energy and a controlling unit that implements each processing step of what can appear as the behavior of that artificial entity.

Inspired from psychological models of human visual attention[2], the controller will lead the robot to focus only on the most outstanding information. It will be able to adapt the allocation of its different processing elements (PEs) according to the saliency of the information from its external and internal environment.

In section II we present the reconfigurable architecture of the controller. This section also provides an analysis of the self-organizing properties of this system and its behavior in the context of robotic applications. Then section III presents the functional results obtained in simulation. We conclude the paper and discuss the future works in section IV.

II. DATA-DRIVEN SELF-ORGANIZED ARCHITECTURE

As introduced in a previous paper[3], the proposed architecture adapts itself to its environment in a data driven way.

This can be done thanks to its layered organization (illustrated in Fig. 1). The first layer is responsible for acquiring the data from the input sensors. Then it leads the primitive signals to the preprocessing layer. This second one processes the information using data parallelism to compute saliency between the different maps and prepares the needed information to the third one. The adaptation layer then implements a Kohonen neural network that learns the data structure (p.119 [4]) and leads the replication mechanism of the fourth layer. This last one is the high-level computing layer that consists in an array of processing elements. There, the PEs can self-replicate their configuration (functionality) in each others influenced by the dynamics of the previous layer. Then different tasks will compete for the PEs and will colonize different areas.

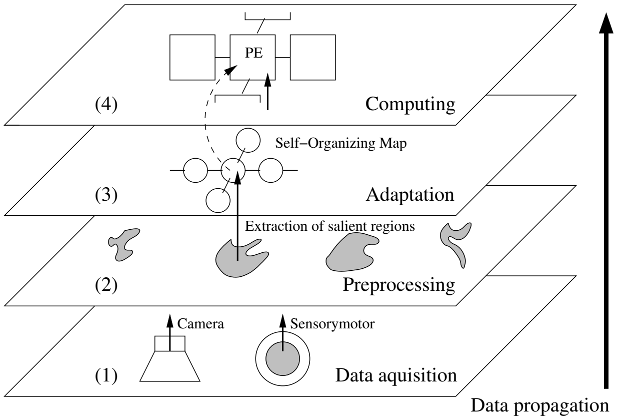

Fig. 1. The layered view of the system architecture.

As the SOM learns the data structure and converges to an organization that fits the needs of the application, different areas emerge from it. Each of them are specialized in relation to the different inputs of the system. An illustration of the result of this process is depicted in Fig. 3, the areas represent the sets of winning neurons after having presented several inputs.

In our robotic context, we are designing a sensorimotor application (more described in [5]). The robot entries are images provided by a camera and proprioceptive information that let the robot know about the position and force given to its own actuators. With the particular preprocessing layer of this application, the SOM converge in three main areas. The first and the second are allocated to compute the static and the dynamic saliency map. The result of these maps is to extract the interest points in the image in relation with the shapes and motions in the visual scene. The third one is used as a sensorimotor map. It will merge the information from the first two areas and from the actuators of the robot in order to learn and to adapt its behavior relatively to its actions and its environment.

III. EXPERIMENTS AND RESULTS

Here we describe the results given by simulation and the dimensioning results of the first hardware implementation.

A. Behavior of the system

The simulator, implemented in C++, exposes a modular design. It is composed of three modules containing an implementation of the first three layers (Fig. 1).

Each layer uses synchronous connections and provides the resulting information frame by frame to connected layers. The reconfiguration process is simulated by a labeling of the cell.

For this first experiment, we use the amount of information in each feature map as an entry for the adaptation layer.

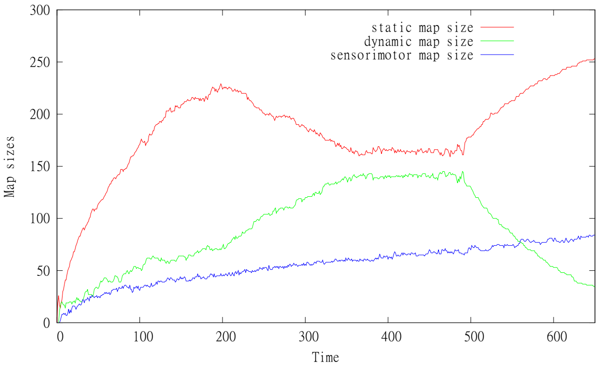

Fig. 2. Evolution of cells colonization by tasks over the time

As we can see in Fig. 2, the maps compete for the resources (PEs) available into the controller according to their inputs. The three stages of the robot mission are clearly visible. From the first to the 200th frame, the robot remains static and a few objects are moving in front of it. From frames 200 to 490, the robot is moving. The motion estimation map takes the space of the static map. This ensures enough computing power to the motion processing tasks. Finally the robot remains stationary, moreover, there is no motion in front of it. Therefore the stationary map is gaining space from the dynamic one.

The profiling of the application behavior resulting from simulation is very promising for the next stages of design.

B. Architecture dimensioning

From the first VHDL implementation results, we can assume that the consumption for a 10x10 map remains easily compatible with the FPGA capacity. For instance, the implementation of the Kohonen neuron model described in Fig. 3 consumes 803 LUTS over the 1507720 available on a VIRTEX 6 LX240 and for the fives states of the cell. But the idea would be in the long term to integrate the preprocessing layer in a real artificial retina that could deal with high-resolution sensors. The Embodied Computing approach exactly allows to totally dissociate the size of the preprocessing map and the size of the high-level processing map.

The behavior of the system obtained in simulation has now to be verified when deployed into the FPGA device.

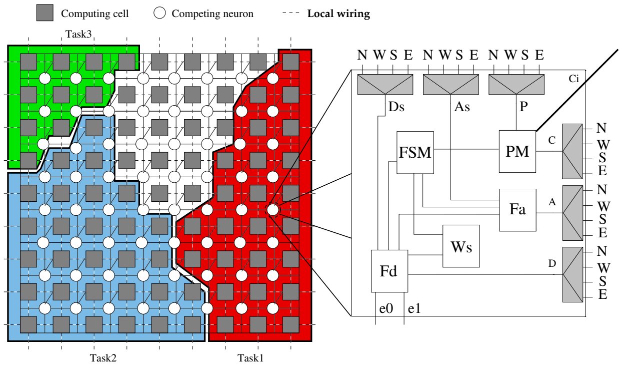

Fig. 3. The Kohonnen neuron is implemented thanks to different VHDL modules. Fd is dedicated to handle the distances computing. Fa handles the activation function. Ws is used to store and compute the synaptic weights. Finally PM is responsible of the replication and configuration of the current program of the cell.

IV. CONCLUSION AND PERSPECTIVES

We presented in this paper a survey of our design approach for self-adaptive reconfigurable architectures. Inspired from the Embodied Computing theory [6], the adaptive process is the result of a relationship between the sensors, the actuators and the computing substrata that implements the behavior (the application) of the target system. The method is experimented in the context of mobile robotics where the vision is the main source of perception of the external environment. We demonstrate that the set of resources can be managed in a totally distributed manner following a data driven process tightly coupled to the amount and the nature of the input system sensors.

We are now working on some interesting problems related to the programmability of this architecture. But the access from a reconfiguring PE to the data of the underlying layers is still an open problem since the organization of the computation areas does not respect the input data topology. The Embodied Computing theory has then to be generalized. Finally, with regard to this special use case, the hardware self-configuring architecture has to be refined and optimized to envisage the final deployment onto the robot.

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