Preface

In the bio-inspired robotics field, robots can be used to reproduce animal behavior in order to study their interaction with the environment. Robots help to improve the understanding of animal behavior and, on the other side, animal behavior and neurobiological inspection help to create efficient and robust robotic systems. The study of animal brains is interesting from an Engineering perspective since it can allow to introduce new control systems that can endow robots with orienting capabilities in complex environments, new decision making strategies, and dangerous missions solving capabilities, to achieve an ever increasing autonomy level. Robotic implementation of biological systems could also lead to the introduction of new models for basic sciences, in particular when investigating the emergent properties of models. Several attempts are present in the literature related to algorithms or bio-inspired networks able to mimic the functionalities of parts of the brain. A lot of work has been done in several animal species belonging to mammals, mollusks, and insects. Looking into the insect world different research groups around the world are trying to design models that are able to reproduce interesting behaviors shown by insects: cooperation mechanisms in ants, navigation strategies in bees, looming reflex in locusts, homing mechanisms in crickets, central pattern generator and obstacle climbing in cockroaches, reflex-based locomotion control in the stick insect, just to cite some examples. It is evident that the effort is focused on specific peculiarities associated with the different insect species that can be also useful for robotic applications. Nevertheless, a more challenging task consists in trying to model the main functionalities of an insect brain by analyzing the dynamics from a higher level and trying to identify the mechanisms involved in the sensing-perception-action loop.

In the recent years, biological experiments unraveled details of the *Drosophila* brain, with particular emphasis to Mushroom Bodies (MBs) and Central Complex (CX), and a number of functional blocks, explaining the main functionalities of such centers were designed. The proposed work is focused on the development of an insect brain computational model mainly focused on the *Drosophila melanogaster*, the fruit fly. The insect brain architecture, structured in functional blocks, has been developed in a complete software/hardware framework in order to evaluate the capabilities of this bio-inspired control system on both simulated and experimental robotic platforms. In order to develop a useful and suitable architecture, the proposed framework is flexible and robust and presents a structure able to decouple simulations from control algorithms. The functional separation helps to isolate the application itself from graphic interfaces and the underlying hardware. The main aim is to develop an extensible and general-purpose architecture. The insect brain model has been evaluated in scenarios directly linked to the neurobiological experiments to make a direct comparison. Moreover, the available data on wild-type flies and mutant brain-defective flies allow to identify the main role of each neural assembly in performing specific tasks like visual orientation, olfactory learning, adaptive termination of behaviors, and others. Finally, the main guidelines used for the definition of evaluation criteria and the creation of benchmarking scenarios where the system performance can be evaluated, are also investigated.

The developed software/hardware framework, named RealSim for Cognitive Systems (RS4CS), transparently uses, as a final actor, either a robot (wheeled, legged or hybrid) simulated in a detailed dynamical simulator (included within the simulation environment), or experimental robotic platforms in a real environment. From the hardware point of view, mainly two robotic structures were used to test the architecture performance, one classical dual-drive wheeled robot, the Rover, and one hybrid robot, named Tribot: this is composed of two whegs-based modules and a front module with two legs that can be also used to manipulate objects.

Among the proposed strategies for the design and assessment of robotic experiments, a biologically driven and a robot-oriented approach have been considered. This choice was adopted both for the direct links to the neurobiological results and for the possibility to further extend the robot capabilities by scaling-up the insect brain blocks controlling the robot behavior. The considered scenarios include situations of increasing complexity to show the acquisition of cognitive capabilities (starting from the basic behaviors but going beyond these skills) like multisensory integration, contradictory cues resolution, efficient information storage and retrieval. These capabilities can be tested starting from classical exploration and foraging tasks, going up to tasks involving motivation based on reward functions. The neural structures responsible for these behaviors have been enriched with new substructures inspired by very recent discoveries in the insect counterparts. This gave the opportunity to design and simulate new networks that, via processes that can be described through reaction-diffusion dynamics, are able to lead to the emergence of complex behaviors like attention and expectation. These can be considered the basis of a cognitive behavior, i.e., the capability of planning ahead. The experiments can be tailored to the sensory-motor loop available in each robotic structure. The scenarios were scaled to the model capabilities, using the robots as test beds. Learning in this case is fundamental and should be performed autonomously in an unsupervised way, but cognitive skills could also be acquired by introducing a teacher (a signal or another agent) in the arena, in a supervised or semi-supervised way, as this happens in cooperation tasks.

The activities performed in the directions outlined above, were carried out by scientists from four institutions: the Institute of Neurobiology of the University of Mainz (Germany), the Instituto Pluridisciplinar, Universidad Complutense de Madrid (Spain), the Company Innovaciones Microelectronicas s.l., ANAFOCUS, from Seville (Spain). The Consortium was Coordinated by the Dipartimento di Ingegneria Elettrica Elettronica e Informatica of the University of Catania (Italy).

The book is organized into five parts. *Part I Models of the Insect Brain: From Neurobiology to Computational Intelligence* reports the biological background on *Drosophila melanogaster* with particular attention to the two main centers, the mushroom bodies and the central complex used for the implementation of the insect brain computational models.

Part II Complex Dynamics for Internal Representation and Locomotion Control introduces the locomotion control principles used to integrate body and brain. Mathematical bases of the Central Pattern Generator used for the gait generation in a six-legged robot are illustrated looking at the complex dynamics emerging from a network of nonlinear units. Similarly, the Reaction-diffusion principles in nonlinear lattices are used to develop a compact internal representation of a dynamically changing environment to plan the best behavior to reach a target while avoiding moving obstacles.

Part III Software/Hardware Cognitive Architectures develops upon the basis presented in the previous part. In particular a software/hardware framework conceived to integrate the insect brain computational model in a simulated/real robotic platform is illustrated. The different robots used for the experiments are also depicted analyzing their peculiarities in terms of basic behaviors. Moreover, the problems related to the vision system are herewith addressed proposing robust solutions for object identification and feature extraction. A whole chapter is also dedicated to the design and implementation on FPGA of the compact internal representation model discussed in the previous part.

The last part of the book *Part IV Scenarios and Experiments* is related to the identification of the relevant scenarios used in the experiments to test the capabilities of the insect brain-inspired architecture taking as comparison the biological case. A number of experimental results are finally reported, whose related multimedia material can be found in the SPARK II web page: www.spark2.diees.unict.it

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Paolo Arena
Luca Patanè

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