Mi-Pal 2017 Team Description Paper

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Abstract. Our main research focus has been software architecture and verifiable descriptions of behavior for embedded and robotic systems. We apply model-driven and test-driven development to the composition of behavior enabling testing and formal model checking. Our most recent results allow run-time verification of complex adaptive robotic behaviors [1, Website 1]. In contrast with UML's state charts (which are event-driven), we achieve this with logic-labeled finite-state machines (LLFSMs), communicating extended finite-state machines where transition labels are only Boolean expressions. We have shown how to integrate planning [2, Website 12] and Prolog-based reasoning [3, Website 2] to create deliberative architectures. In contrast with publisher-subscriber middlewares, such as ROS, the predictive schedule of executing an arrangement of LLFSMs concurrently not only reduces state explosion for formal verification, but it also simplifies concurrent programming as we can communicate efficiently over shared memory [4, Website 3] without requiring explicit synchronization. LLFSMs can encapsulate the original, time-augmented state-machines of the subsumption architecture and they also completely emulate teleo-reactive systems. Importantly, since they are compiled [5, Website 8] they are extremely efficient at run-time.
We have several years of experience in the Standard Platform League for soccer with Softbank's Nao, and we participated in 2006-2007 in two editions of the RoboCup@Home. Some other areas of our research include the blending of task planning with motion planning [6, Website 5].

1 Introduction

The team is a collaborative effort between Universitat Pompeu Fabra (UPF, Barcelona, Spain), and Griffith University (Brisbane, Australia). The team is supported by

1. the *Autonomous Systems Program* of the *Institute for Intelligent and Integrated Systems* (IIIS) at Griffith, and
2. the *Grup de Recerca en Intel·ligència Artificial* of the *Departament de Tecnologies de la Informació i les Comunicacions (*DTIC*)* at UPF.

Since 2010, we have been expanding our lab at the Griffith University Nathan Campus, as a result of additional support from the University and the IIIS.

Fig. 1. Panorama of our Nathan campus facilities.

Involvement in RoboCup

Mi-Pal has a long involvement and participation in RoboCup. Prof. Estivill-Castro supervised the student team that was champion of the RoboCup Jr in Seattle in 2001, and was a team member of the NewBots (U. of Newcastle) that finished 3rd in 2001. As Mi-Pal, the team participated in the RoboCup SONY League in consecutive years (2003-2006). We were recognized for our debugging tools on the Aibo platforms as well as for our software architecture and vision systems. We also participated in RoboCup@Home twice (2006-2007). With the Nao platform, we have participated in the full competition and the technical challenges 2011-2013, in Istanbul, Mexico City, and Eindhoven, while in 2014, in Joao Pessoa, we participated in the technical challenges and drop in challenge. At those venues, the team performed competitively: in Mexico City we tied two games (0-0 and 1-1), (one goal scored brilliantly by our keeper youtu.be/F4bvClhTY4A) and we lost two matches. In 2013, we also scored one goal, but lost all matches. In 2014 in Joao Pessoa we were awarded the **second place for the drop-in challenge**, we scored very high in the *sound-challenge* and we found and kicked the ball in the *anywhere challenge* (a video summarizing those participation is youtu.be/wleig6Fa8ms). In 2014, we were awarded (by the RoboCup Federation) a sponsorship for Jonathan Ferrer-Mestres for a **short term research visit** due to his research in planning.

Description of the hardware and software

We are proud that with both platforms (the Aibo and the Nao) the software was completely developed by the Mi-Pal team, and although we review the work of other teams, we did not re-use their code. For 2012, we incorporated the Nao walk from UNSW's rUNSWift, which we we can switch on and off. We also have expertise with several simulators (Webots, Gazebo, v-rep) and the `ROS` infrastructure.

2 Focus of Research / Research Interests

The Mi-Pal research team has taken the approach of enabling robotics through knowledge-base descriptions using logics in behavior models and for task and motion planning. This constitutes model-driven engineering for robotic software and was successfully used to build all our behaviors for RoboCup (2011-2014). More recently, our research using logic-labeled finite-state machines has enabled formal methods and model checking as well as the capability to perform run-time verification [1, Website 1], a fundamental aspect to ensure proper functionality of autonomous systems acting in a physical environment that encompass adaptive and learning behaviors.

Our research program has resulted in the capability to model robot behaviors at a high level, by combining reactive mechanisms (modelled by finite state machines) with non-monotonic reasoning (represented by logics such as Plausible Logic) [7, Website 20]. Our contributions [8, Website 18] are at the intersection of software engineering and robotics [9, Website 21].

Modelling with LLFSMs [10, Website 23], where the labels for transitions can be statements in logics that demand proof [11, Website 19] has been contrasted with important behavior modelling techniques such as plain finite-state machines, Petri nets, Event-B, and Behavior Trees [12, Website 22]. Our approach produces smaller models, clarifies requirements, and we can generate implementations for diverse platforms and programming languages. E.g., the same models can generate code in Java, C++, or Swift for a Nao, Lego Mindstorms, or Arduino and embedded microcontrollers.

Prof. V. Estivill-Castro coordinated research in collaboration with academics in Early Childhood Education and experts in Education for people with disabilities. [Website 29, Website39, Website 40]. More recent collaborations are two projects with Prof. Wendy Moyle, on robot interaction with the elderly. The first project is titled “Telepresence robots: Engaging people living with Dementia” and the second is titled “Piloting an emotional response animal robot: Feasibility and impact of CuDDler on the person with Dementia”. [Website 4].

We research multi-agent systems that use non-monotonic reasoning. Directly involved in this line of research are Assoc. Prof. D. Billington, Prof. Estivill-Castro, Dr. R. Hexel, and Dr. A. Rock. The AI Group (www.ai.upf.edu) at the Department of Technology, in Universitat Pompeu Fabra, studies computational models of reasoning, action, and learning. The approach of the group is focused on efficient methods in automated planning. This work forms the base for a number of successful automated planners that have been developed by the group in collaboration with others internationally, and that has had a strong influence on the progress of the area. In particular, our joint PhD student J. Ferrer-Mestres has produced the integration of planning systems in dynamic environments [2, Website 12] and also the integration of task planning with motion planning [6, Website 5]. A video of this later success appears in www.youtube.com/watch?v=tRL8u2S9w1w.

Innovative Technology and Scientific Contribution

Our website records 42 publications directly derived from Mi-Pal’s participation in RoboCup (publications), displaying a focus in the following areas.

- High level tools and systems for describing behavior with logic-labeled finite-state machines [1, Website 1], [4, Website 3], [Website 6], [Website 7], [Website 8], [Website 13], [Website 14], and [Website 18].
- Planning and reasoning on board of robots [3, Website 2] and [6, Website 5].
- Learning and adaptivity for vision in unknown environments [Website 11].
- Protocols for robots and agents to maintain formation under unreliable communication channels [Website 10].

The other topics of the 35 publications derived from Mi-Pal's participation in RoboCup (publications) are as follows.

1.- Reasoning for behavior modelling and architecture of mobile robots [Website 6, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 28, 32].

2.- Human-robot interaction [Website 4, 29, 39, 40].

3.- Object tracking, object recognition and posture and gesture recognition: [Website 11, 33, 31, 30, 35, 37, 38, 41, 42].

4.- Localisation, formations, path planning and visibility: [Website 10, 12, 13, 27, 32, 34].

3 Re-usability for other Research Groups

Initially, Mi-Pal relevant RoboCup research included tools for analysing failures in the Aibo platform that became widely used by other teams. We also developed very fast methods for image segmentation [Website 42].

Software Released to the Community

Our download page www.mipal.net.au/downloads.php contains the following downloads.

1. `r2d2Mipal`, the only (Linux and macOS) `ROS`-compatible `C++11` driver for Lego NXT robots (github.com/mipalgu/NXTdriver.git).
2. The Mi-Pal whiteboard (`ROS`-compatible), the software engineering architecture that supports our model-driven engineering design patterns [Website 24]. This offers a cognitive architecture or a *working memory* as well as a publisher-subscriber pattern for module communication. Our whiteboard architecture is complementary to Naoqi's inter-module communication and messaging architecture in the Red-Documentation; however, our approach enables extremely fast interprocess communication and more reliability than the Nao's current ALMemory (which, when using inter-process communication, involves wrapping contents in SOAP). It is also analogous to `ROS` (`ROS:topics`, `ROS::services`), but since we avoid SOAP we are also much more efficient. We have made several comparisons of our architecture's efficiency outperforming `ROS`, the most recent for a MAV [Website 3].

3. The package clfsm (a ROS package), an engine for compiled finite-state-machines that allows concurrent execution of arrangements of logic-labeled finite-state machines as executable descriptions of behavior. State charts are arguably the most common and ubiquitous instrument for describing the behaviour of discrete systems (ATMS were the basis of the subsumption architecture of R. Brooks and are common in Behaviour-Based Control Architectures for robots). However, the variants that predominantly exist are based on an event-driven understanding of transitions which leaves the system at the mercy of event queues and complex synchronizations. Our finite-state machines whose transitions are labeled by logic formulas result in a method to derive software with a model-driven development (MDD) approach. The arrangement is scheduled in a time-triggered fashion, enabling concurrency but without the complexities of race conditions; thus, a clear and transparent semantics is obtained and model checking becomes feasible and practical. The not only has the advantage of MDD of traceability and platform-independence, but also enables validation with simulation as well as formal verification that can be used for failure-mode effects analysis.
   As opposed to smach in ROS, which is an interpreter of unstructured state charts, our tool produces compiled finite-state machines that are completely C++ compatible and also can have structural controls (e.g. resume, suspend, or restart) as well as scope for variables (per state, per machine, or global). The following videos demonstrate logic-labeled finite-state machines as compiled by clfsm.
   (a) youtu.be/gN6rIveCWNk demonstrates clfsm with a reactive architecture on the Nao, the e-puck on Webots, and expansion to a task planning architecture.
   (b) youtu.befX7ANt03Xsc compares clfsm with ROS-Bride and ROS smach on the BRIDE tutorial predator/prey example.
   (c) youtu.be/qs-jmjxOXLI demonstrates the subsumption architecture and Herbert's world using the Kuka Robot (RoboCup@Work) on Gazebo and ROS.
   (d) youtu.be/_3VylSPQoEE&t=31s demonstrates run-time verification of learning behaviors of a mobile robotic with an arm. One behavior is learning the map of the environment, the other is an adaptive controller of the arm.

Importance to the Institution/Community

At Griffith University, academics can act as supervisors of the Industry Affiliates Program for 3rd year students. Several students receive this capstone-training opportunity by carrying out their IAP in the Mi-Pal facilities. Also, the IIIS regularly awards undergraduate summer scholarships to undergraduate students so they can be introduced to research activities in ICT. Several students have been involved in the development of Mi-Pal related tools and modules in a summer scholarship. Mi-Pal is core to Griffith University's promotional activities and regularly performs presentations during Open Day. It is also core to community activities such as IBM's *EXCITE* (Exploring Interests in Technology & Engineering) amps, experience days and *STEM 6* activities. At Universitat Pompeu Fabra it is also a central to promotional activities, and also has recently been engaging in performing arts activities. A recent video of a magic-trick with the assistance of a Nao presented to a live audience can be seen at www.youtube.com/watch?v=HCFY_1cmESA and presentations for *Science Week 2015* at www.youtube.com/watch?v=yIiYT_4XnXM. Moreover, the group in Spain is directly involved in delivering robotics for children in an agreement with the US embassy.

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