Cobots Understanding Skills Programmed by Demonstration

Isacco Zappa
isacco.zappa@polimi.it
Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria
Milan, Italy

Maximilian Diehl
diehlm@chalmers.se
Chalmers University of Technology, Department of Electrical Engineering
Gothenburg, Sweden

Karinne Ramirez-Amaro
karinne@chalmers.se
Chalmers University of Technology, Department of Electrical Engineering
Gothenburg, Sweden

Andrea Maria Zanchettin
andreamaria.zanchettin@polimi.it
Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria
Milan, Italy

ABSTRACT

Traditional robot programming requires skilled operators, contrasting with small and medium-sized enterprises' lack of robotics expertise. This abstract presents the outcomes in enriching Programming by Demonstration to encode the meaning that the operator associates with the skill being demonstrated. Therefore, the depiction of skills by the operator and the robot can be levelled, enabling a more effective teaching of actions and a better interpretability of the robot's inner reasoning process. Given the increased dexterity of dual-arm robots in complex tasks, the current efforts to enable multi-agent systems to learn skill semantics through demonstration are discussed. Finally, the abstract outlines the challenges to be addressed to provide the robots with an understanding of the constraints given by a shared workspace and the synergies required for certain skills.

KEYWORDS

Programming by Demonstration, Intuitive Robot Programming, Semantic Understanding of Skills

ACM Reference Format:
Isacco Zappa, Maximilian Diehl, Karinne Ramirez-Amaro, and Andrea Maria Zanchettin. 2018. Cobots Understanding Skills Programmed by Demonstration. In *Proceedings of Workshop@HAI 2023: The Importance of Human Factors for Trusted Human-Robot Collaborations (Workshop@HAI 2023).* ACM, New York, NY, USA, 2 pages.

1 BACKGROUND

Despite the effort made by manufacturers in the development of intuitive programming interfaces, an expert operator is still required to program a collaborative robot. The problem becomes paramount for small and medium-sized enterprises, which usually lack such expertise in robotics.

Programming by Demonstration [1] provides the operator with a more accessible programming method that does not involve coding. The underlying concept is that the robot can learn how to execute a task from a demonstration. The demonstration spans from pure observations to kinesthetic demonstrations. The latter consists of the operator physically moving the robot along the execution of the skill. A key enabling technology is cobot's hand-guiding, devised by robot manufacturers to save movement waypoints and record trajectories. However, during the demonstration, the operator provides the robot with information about how to execute an action and the meaning of the action itself. Nevertheless, the robot still depicts the demonstration as a series of movements. Capturing the meaning of a skill from a demonstration and a proper representation of this knowledge would not only provide the robot with a certain degree of autonomy but also make its reasoning interpretable.

Semantics is the study of the meaning that we give to the entities around us, their properties and relations, and how we structure this knowledge [5]. Semantics applied to robotics enable the robot to build abstractions from the raw data recorded by its sensor to represent the state of the environment as a list of first-order logic predicates. Providing the robot with the capability to build a semantic description of the scene enhances the interpretability of how the robot perceives the environment, resulting in more intuitive and meaningful interactions with the operator. An example of a state description with predicates can be seen in Figure 1.

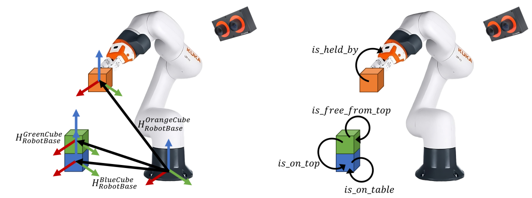

Figure 1: Example of a semantic representation of the state of the environment built from sensor data.

Recent works propose to exploit this representation to extrapolate the meaning of the demonstrated skill in terms of its preconditions and effects from basic set operations on the semantic state of the system before and after the demonstration [6]. Such knowledge is then formalized in PDDL [2]. An example can be seen in Figure 2, with the resultant encoding of the skill in PDDL shown in Listing 1.

Workshop@HAI 2023, December 04, 2023, Gothenburg, SWEDEN

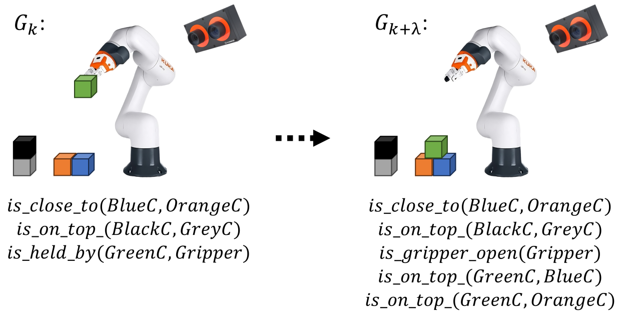

Figure 2: Semantic representation of the state of the environment before and after the demonstration.

Listing 1: PDDL encoding of the demonstrated skill.

```
(:action skill_0
  :parameters (
    ?c1 ?c2 ?c3 - cube ?g - gripper
  )
  :precondition (and
    (is_held_by ?c1 ?g) (is_close_to ?c2 ?c3)
  )
  :effect (and
    (is_gripper_open ?g) (is_on_top ?c1 ?c2)
    (is_on_top ?c1 ?c3) (not (is_held_by ?c1 ?g))
  )
)
```

Moreover, the study proposes a low-level skill encoding that is capable of untying the skill execution to the specific settings in which the demonstration took place, thus enabling the execution of the skill in a different scenario.

The operator is then provided with a method to teach by demonstration the basic modular skills he/she thinks that the robot must know for the specific job. Finally, after specifying the goal, a symbolic planner can use the PDDL skill models to compute the sequence of skills required to perform the task.

2 TEACHING SKILLS IN A MULTI-AGENT SCENARIO

A single robotic manipulator may not be appropriate for some tasks due to its workspace constraints and intrinsic limitations. Indeed, some tasks, such as screwing the cap of a bottle or lifting a tray from two handles, cannot be tackled by a single manipulator. Dual-arm robotic manipulators brought a significant innovation in the field of industrial robotics. By emulating the human structure and coordinated movements, this type of robot shows a higher level of dexterity and adaptability to a broader range of skills concerning its single-arm counterpart. Dual-arm robots have gathered the interest of a niche in the industry, where high productivity in complex tasks is required, with precision and speed [4].

Our current work focus on enabling a multi-agent system, such as dual-arm robots, to learn the semantics of skills taught by demonstration. The challenges to be tackled are manifold. The basic formulation of PDDL is not appropriate for multi-agent planning. Indeed, it is possible to define the entities in the scene to account for both

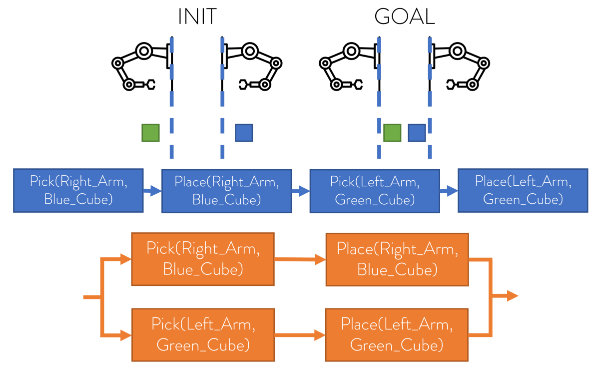

Figure 3: From top to bottom: Initial and Goal condition of the planning problem, standard PDDL plan, Multi-Agent PDDL plan.

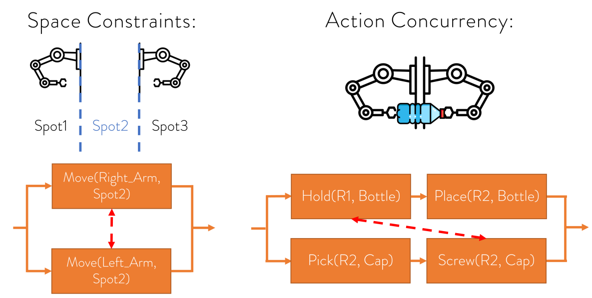

Figure 4: Unfeasible plans that may be computed from a bad description of a shared workspace and skills synergies.

the robot arms. However, the planner would not generate a plan where actions are scheduled in parallel, thus not exploiting the advantages of a dual-arm robot coordinated motion. Figure 3 visualize the problem. Moreover, the robots must be provided with an understanding of space constraints and skills synergies to avoid unfeasible plans to be computed by the planner, such as in the examples depicted in Figure 4.

The pipeline to address the issues has already been defined. The system will employ the Multi-Agent PDDL (MA-PDDL) formulation introduced in [3]. Space constraints and actions that must be scheduled in parallel, such as lifting a tray by holding the two handles, will be addressed with additional PDDL requirements in the skill descriptors.

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