Inductive Logic Programming and Embodied Agents:
Possibilities and Limitations

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ABSTRACT

Open-ended learning is regarded as the ultimate milestone, especially in intelligent robotics. Preferably it should be unsupervised and it is by its nature inductive. In this article we want to give an overview of attempts to use Inductive Logic Programming (ILP) as a machine learning technique in the context of embodied autonomous agents. Relatively few such attempts exist altogether and the main goal in reviewing several of them was to find a thorough understanding of the difficulties that the application of ILP has in general and especially in this area. The second goal was to review any possible directions for overcoming these obstacles standing on the way of more widespread use of ILP in this context of embodied autonomous agents. Whilst the most serious problems, the mismatch between ILP and the large datasets encountered with embodied autonomous agents seem difficult to overcome we also found interesting research actively pursuing to alleviate these problems.

*Keywords: dimensionality; embodied autonomous agents; inductive logic programming (ILP); open
learning; scallability; uncertainty*

INTRODUCTION

Open ended learning, particularly in intelligent (sometimes also called cognitive) robotics, is regarded as the ultimate milestone in the development of the discipline. Ideally, an autonomous robot enabled with its sensors and actuators, after spending some time in an unknown environment, would come up with some knowledge about that environment. That knowledge would then be used to gain more knowledge (in a sort of a bootstrapping process)

and/or enhance performance in specific tasks. Preferably the open-ended learning should be unsupervised and by its nature it is inductive. Based on the sensory motor traces the robot should come up with learned constructs that would help it interpret the incoming sensory flux in a more abstract manner. In other words, the learned constructs would help the robot develop higher level perception which would group and integrate the low level sensory input into coherent perceived scenes and possibly temporal narratives.

Open-ended learning is also referred to as *task-independent* or *task non-specific*. Different mechanisms are then needed in order to guide the behavior of the robot and quite often researchers talk about *internal motivation systems*. In this context *artificial curiosity* is understood to be the mechanism that would drive these robots to do *something* rather than *nothing* (for an overview of different implementations of artificial curiosity as well as more general *internal value systems* please see (Stojanov and Kulakov, 2006). Sometimes artificial curiosity is explicitly referred to as *goal-generation mechanism*.

Given the properties of Inductive Logic Programming (capability to learn new concepts given positive and negative instance of the concept and some amount of background knowledge) its choice for artificial agent capable of open-ended learning may seem natural. Another advantage of ILP is that its output is easily understandable and easily modifiable by the human user. Background knowledge would be provided by the innate knowledge of the agent, and the agent itself would sample its environment for positive and negative examples.

This article is organized in the following way: In section one, we give a brief introduction of ILP, we mention some theoretical limitations which we deem relevant to understand the range of applicability of ILP in robotics, and finally we enumerate the areas where it has been applied with considerable success.

The second section is devoted to the review of six papers reporting on research efforts to apply ILP in the context of robotics. We analyze

individually what the goals of these projects were and evaluate what the lessons are that can be learned from these efforts; what are the encouraging results, and on the other hand, what are the difficulties that were encountered with ILP.

In section three we summarize how some of the problems that have emerged while applying ILP in robotics have been addressed.

Finally, in the last section we take a look at several approaches that we judge promising when pursuing an increase in ILP performance to cope with the requirements of intelligent robotics.

ILP: A Brief Introduction

Inductive Logic Programming (ILP) is the intersection of inductive learning and logic programming (LP) (Lavrac & Dzeroski, 1994), a field of interest and great promises in the early 90's. From inductive learning, ILP inherits the goal of inducing hypothesis from observations and by using LP's representational mechanism it overcomes the representational limitations of propositional logic and the difficulties in using substantial background knowledge.

On the other hand, ILP extends the computational logic by investigating induction as opposed to the traditional usage of deduction as the basic mode of inference (e.g. *exploitation* of a PROLOG program). While computational logic describes deductive inference from logic formulae provided by the user, ILP describes the inference of logic programs (which can be thought of as describing *concepts*) from samples (positive and negative instances of the concepts being learnt) and some background knowledge.

The main distinction between ILP and the related areas of inductive inference such as **grammar induction** (Biermann & Feldman, 1972), **finite state automata induction** (Moore, 1956), **Turing Machine induction** (Biermann & Krishnaswamy, 1976) and **LISP induction** (Summers, 1975) is the emphasis on universal representation, which should have provided it a much wider application. The output of ILP is

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