

IMPERIAL COLLEGE LONDON

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# Data Efficient Deep Reinforcement Learning using Inductive Logic Programming

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# Chapter 1

## Introduction

There has been successful applications of deep reinforcement learning (DRL) a number of domains, such as games and robotics. DRL is considered to be a step towards artificial general intelligence. However there are still a number of issues to overcome in this method. As pointed by XXX, there are 3 major problems. First, it requires a large amount of data for training the model, which requires a long time of learning process. Second, it is considered to be a black-box, meaning the decision making process is unknown to human and therefore not explainable. Third there is no thoughts process to the decision making, which, as XX points out, is a fundamental to the artificial general intelligence. To overcome these problems, there are 3 main streams of research on this field. First main research is focused on applying Bayesian statistics XXX, the second main research is XXX. Recently, the XXX attempted to incorporate symbolic representations into the system to achieve more data-efficient learning, which shows a promising results of this approach. The paper was the application of symbolic representations into a very simple game to demonstrate this proof of concept would actually work.

By contrast, there is active research in symbolic machine learning, which focuses on logic-based learning rather than statistical machine learning. For example, XX shows the agent can learn XXX from a noisy examples, with only a very few training examples.

In this paper, I explore incorporation of symbolic machine learning into XXX to achieve data-efficient learning using Inductive Learning of Answer Set Programs (ILASP), which is the state-of-art symbolic learning method that can be applied to incomplete and more complex environment.

This research is based on XX, but in this paper I explore symbolic representations process and include more learning aspect.

Problem setting ?

# Chapter 2

## Background

### 2.1 Data Efficient Learning

Two most studied approach for using previous learning exprience is meta-learning and transfer learning

Artificial General Intelligence

Definision of AGI

The history of data-efficient learning What other people have done in this.

The advance of statistical machine learning methods, especially deeep reinforcement learning

AlphaGo, and AlphaGo Zero

Also business success.

Study of symbolic machine learning roots from

Baysian Optimisation

RNN approach

Symbolic Deep reinforcement learning

Some implementation: German paper

### 2.2 ASP in Reinforcement Learning

# Chapter 3

## Background

### 3.1 Inductive Logic Programming

Inductive Logic Programming (ILP) is a subfield of research area aimed at the intersection of machine learning and logic programming (MUGGLETON 1991). The purpose of ILP is to derive a hypothesis  $H$  that is a solution of a learning task, which covers all positive examples and any of negative examples.

Herbrand Model

Least Herbrand Model

Definite Logic Program is a set of definite rule where

a definite rule is of the form  $h \leftarrow a_1, \dots, a_n$ , where  $h, a_1, \dots, a_n$  are all atoms.

whereas

Normal Logic Program is a set of normal rule where

a normal rule is of the form  $h \leftarrow a_1, \dots, a_n, \text{not} b_1, \dots, \text{not} b_n$  where  $h$  is the head of the rule, and  $a_1, \dots, a_n, b_1, \dots, b_n$  are atoms.

#### 3.1.1 Stable Model Semantics

Stable Model of a normal logic program

#### 3.1.2 Answer Set Programming

Literals

Negation as a failure

constraints is of the form  $\leftarrow a_1, \dots, a_n, \text{not} b_1, \dots, \text{not} b_n$

Constraints are to filtering any irrelevant answer sets.

Syntax Examples

There are two types of constraints: soft and hard constraints. Soft constraint is XXX

Hard constraint is XXX

optimisation statement is of the form.

Which is useful to order the answer sets in terms of preference.

Syntax examples.

Aggregate

choice rules

An ASP program  $P$  is normal logic program with addition of choice rules, constraints and optimisation statement.

Answer set of  $P$  is

### Cautious Induction

Cautious induction is based on the cautious semantics of answer set programs.

Sakama 2008

no concept of negative examples.

### Brave Induction

Brave Induction is

Brave induction cannot learn constraints

Sakama 2009

### 3.1.3 Learning from Answer Sets (LAS)

Learning from Answer Sets was developed in XX to overcome limitations of cautious induction and brave induction.

Partial Interpretations of the form

### 3.1.4 Inductive Learning of Answer Set Programs (ILASP)

ILASP is an algorithm that is capable of solving LAS tasks

It is based on two fundamental concepts: positive solutions and violating solutions.

A hypothesis  $H$  is a positive solution if and only if 1.  $H \subseteq S_M$

2.  $\forall e^+ \in E^+ \exists A \in AS(B \cup H) \text{ subject to } A \text{ extend } e^+$

A hypothesis  $H$  is a violating solution if and only if 1.  $H \subseteq S_M$

2.  $\forall e^+ \in E^+ \exists A \in AS(B \cup H) \text{ subject to } A \text{ extend } e^+$

3.  $\exists e^- \in E^- \exists A \in AS(B \cup H) \text{ subject to } A \text{ extend } e^-$

$ILP_{LAS}$  is positive solutions that are not violating solutions.

ILASP task containing a context-dependent example

TODO Explain how symbolic learning works

TODO What would you learn in my context? Relationship of the objects? Objects, types, locations and interactions.

## 3.2 Reinforcement Learning

An RL agent may include either Policy, Value function or Model, where

### **3.3 Symbolic Reinforcement Learning**

Explain the paper

### **3.4 GVGAI Framework**



# Chapter 4

## Project Overview

### 4.1 Motivation

Why symbolic reinforcement learning is good attempt

Reason 1: Comprehensive by humans -> Explainable rather than black-box Reason 2:

Similar to the human, it uses reasoning

Use of previous experience (background knowledge)

Not much explored yet.

However there is a room for exploration on this field.

TODO Explain how reinforcement learning works

Reason 3: Recent advance of ILASP is promising

Because of the recent advancement of logic-based learning and deep reinforcement learning, combination of both approach would be a next exploration toward artificial general intelligence.

### 4.2 Objectives

combining the two novel approaches to overcome the problems of the QND

### 4.3 Project outline

The project outline

Implement baseline performance (DQN)

Pipeline Implement the CNN side that is able to extract features of the game and convert into ASP syntax.

Apply ILASP to the ASP, which involves development of the pipeline of ILASP in Python

Finally use Q-learning that allow

which measurement would you use? (grid world, something else? GVGAL games)

Summarise different types of knowledge representations (Objects ?? relationship?)

Common sense

Implement based on Towards Deep Symbolic Reinforcement Learning

## 4.4 Contribution

## 4.5 Legal and Ethical Issues

???

## 4.6 References