Michael Fisher
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Preface

Logics provide a formal basis, and key descriptive notation, for the study and development of applications and systems in Artificial Intelligence (AI). With the depth and maturity of formalisms, methodologies, and systems today, such logics are increasingly important. The European Conference on Logics in Artificial Intelligence (or Journées Européennes sur la Logique en Intelligence Artificielle — JELIA) began back in 1988, as a workshop, in response to the need for a European forum for the discussion of emerging work in this field. Since then, JELIA has been organised biennially, with English as official language, and with proceedings published in Springer's Lecture Notes in Artificial Intelligence. Previous meetings took place in Roscoff, France (1988), Amsterdam, Netherlands (1990), Berlin, Germany (1992), York, UK (1994), Évora, Portugal (1996), Dagstuhl, Germany (1998), Málaga, Spain (2000), Cosenza, Italy (2002), and Lisbon, Portugal (2004).

The increasing interest in this forum, its international level with growing participation from researchers outside Europe, and the overall technical quality, has turned JELIA into a major forum for the discussion of logic-based approaches to AI. JELIA 2006 constituted the Tenth International Conference on Logics in Artificial Intelligence, and was held in Liverpool (UK) in September 2006. As with previous JELIA conferences, the aim of JELIA 2006 was to bring together active researchers interested in all aspects concerning the use of logics in AI to discuss current research, results, problems and applications of both a theoretical and practical nature.

We received a total of 96 submissions, comprising 77 regular papers and 19 tool descriptions. These submissions represented a wide range of topics throughout Artificial Intelligence and, as well as originating in Europe, we were pleased to receive submissions from a variety of other countries across the world, including Australia, Brazil, China, Sri Lanka, South Korea and USA. We would like to take this opportunity to thank all those who submitted papers and whose contributions have helped make such a strong final programme.

The regular paper submissions were usually evaluated by at least three members of the Programme Committee (see below) and in many cases further discussion on the merits of particular papers was entered into. Tool description papers were each evaluated by two members of the Programme Committee. We would like to thank all the members of the Programme Committee and the additional referees (see below) for the professional way in which they carried out their reviewing and selection duties.

The review process was extremely selective and many good papers could not be accepted for the final program. As a result of the reviewing process 34 regular papers (44% of submissions) were selected for full presentation at JELIA 2006. In addition, 12 tool descriptions (62% of submissions) were selected for presentation and demonstration. The papers appearing in these proceedings cover a range of topics within the scope of the conference, such as logic programming, description logics, non-monotonic reasoning, agent theories, automated reasoning, and machine learning. Together with the programme of technical papers, we are pleased to acknowledge a strong series of invited talks by leading members of the Logic in AI community: Sašo Džeroski (Jozef Stefan Institute, Slovenia); Ilkka Niemelä (Helsinki University of Technology, Finland); and Andrei Voronkov (University of Manchester, UK). We are confident that you will find the contents of this volume stimulating and enlightening, and that it will provide an invaluable reference to many current research issues in Logics in AI.

Finally, we are indebted to the members of the JELIA Steering Committee (see below) for selecting Liverpool for the tenth JELIA event, to sponsorship from EPSRC, AgentcitiesUK and the University of Liverpool, and to Catherine Atherton and Dave Shield for their invaluable assistance in hosting this conference.

July 2006

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Table of Contents

I Invited Talks

II Technical Papers

III Tool Descriptions

From Inductive Logic Programming to Relational Data Mining

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Abstract. Situated at the intersection of machine learning and logic programming, inductive logic programming (ILP) has been concerned with finding patterns expressed as logic programs. While ILP initially focussed on automated program synthesis from examples, it has recently expanded its scope to cover a whole range of data analysis tasks (classification, regression, clustering, association analysis). ILP algorithms can this be used to find patterns in relational data, i.e., for relational data mining (RDM). This paper briefly introduces the basic concepts of ILP and RDM and discusses some recent research trends in these areas.

1 Introduction

Logic programming as a subset of first-order logic is mostly concerned with deductive inference. Inductive logic programming (ILP) [24], on the other hand, is concerned with inductive inference. It generalizes from individual instances/observations in the presence of background knowledge, finding regularities / hypotheses about yet unseen instances.

In its early days, ILP focussed on automated program synthesis from examples, formulated as a binary classification task. In recent years, however, the scope of ILP has broadened to cover a variety of data mining tasks, such as classification, regression, clustering, association analysis. Data mining is concerned with finding patterns in data, the most common types of patterns encountered being classification rules, classification and regression trees, and association rules.

ILP approaches can be used to find patterns in relational data, i.e., for relational data mining (RDM) [12]. The types of patterns encountered in data mining now have relational counterparts, such as relational classification rules, relational regression trees, relational association rules. The major classes of data mining algorithms (such as decision tree induction, distance-based clustering and prediction, etc.) have also been upgraded to relational data mining algorithms.

In this paper we first briefly introduce the task of inductive logic programming. We assume the reader is familiar with basic logic programming notation. We start with logical settings for concept learning and continue with discussing the task of relational rule induction. We next discuss the relational extensions of two major types of patterns considered in data mining: classification and regression

M. Fisher et al. (Eds.): JELIA 2006, LNAI 4160, pp. 1–14, 2006.

trees and association rules. We only discuss the patterns, not the algorithms for finding such patterns from data. We conclude with a discussion of recent trends in ILP and RDM.

2 Inductive Logic Programming: Settings and Approaches

Logic programming as a subset of first-order logic is mostly concerned with deductive inference. Inductive logic programming, on the other hand, is concerned with inductive inference. It generalizes from individual instances/observations in the presence of background knowledge, finding regularities/hypotheses about yet unseen instances.

In this section, we discuss the different ILP settings as well as the different relational learning tasks, starting with the induction of logic programs (sets of relational rules). We also discuss the two major approaches to solving relational learning tasks, namely transforming relational problems to propositional form and upgrading propositional algorithms to a relational setting.

2.1 Logical Settings for Concept Learning

One of the most basic and most often considered tasks in machine learning is the task of inductive concept learning. Given $\mathcal{U}$, a universal set of objects (observations), a *concept* $\mathcal{C}$ is a subset of objects in $\mathcal{U}$, $\mathcal{C} \subseteq \mathcal{U}$. For example, if $\mathcal{U}$ is the set of all patients in a given hospital $\mathcal{C}$ could be the set of all patients diagnosed with Hepatitis A. The task of *inductive concept learning* is defined as follows: Given instances and non-instances of concept $\mathcal{C}$, find a hypothesis (classifier) H able to tell whether $x \in \mathcal{C}$, for each $x \in \mathcal{U}$.

Table 1. The task of inductive concept learning

Given:

- a language of examples L_E
- a language of concept descriptions L_H
- a **covers** relation between L_H and L_E, defining when an example e is *covered* by a hypothesis$H$: $covers(H, e)$
- sets of positive P and negative N examples described in L_E

Find hypothesis H from L_H, such that

- **completeness:** H covers all positive examples $p \in P$
- **consistency:** H does not cover any negative example $n \in N$

To define the task of inductive concept learning more precisely, we need to specify $\mathcal{U}$ the space of instances (examples), as well as the space of hypotheses considered. This is done through specifying the languages of examples (L_E) and concept descriptions (L_H). In addition, a coverage relation $covers(H, e)$ has to be specified, which tells us when an example e is considered to belong to the concept represented by hypothesis H. Examples that belong to the target concept are termed positive, those that do not are termed negative. Given positive and negative examples, we want hypotheses that are complete (cover all positive examples) and consistent (do not cover negative examples).

Looking at concept learning in a logical framework, De Raedt [9] considers three settings for concept learning. The key aspect that varies in these settings is the notion of coverage, but the languages L_E and L_H vary as well. We characterize these for each of the three settings below.

- In *learning from entailment*, the coverage relation is defined as $covers(H, e)$ iff $H \models e$. The hypothesis logically entails the exampe. Here H is a clausal theory and e is a clause.
- In *learning from interpretations*, we have $covers(H, e)$ iff e is model of H. The example has to be a model of the hypothesis. H is a clausal theory and e is a Herbrand interpretation.
- In *learning from satisfiability*, $covers(H, e)$ iff $H \wedge e \not\models \perp$. The example and the hypothesis taken together have to be satisfiable. Here both H and e are clausal theories.

The setting of learning from entailment, introduced by Muggleton [24], is the one that has received the most attention in the field of ILP. The alternative ILP setting of learning from interpretations was proposed by De Raedt and Džeroski [10]: this setting is a natural generalization of propositional learning. Many learning algorithms for propositional learning have been upgraded to the learning from interpretations ILP setting. Finally, the setting of learning from satisfiability was introduced by Wrobel and Džeroski [36], but has rarely been used in practice due to computational complexity problems.

De Raedt [9] also discusses the relationships among the three settings for concept learning. Learning from finite interpretations reduces to learning from entailment. Learning from entailment reduces to learning from satisfiability. Learning from interpretations is thus the easiest and learning from satisfiability the hardest of the three settings.

As introduced above, the logical settings for concept learning do not take into account background knowledge, one of the essential ingredients of ILP. However, the definitions of the settings are easily extended to take it into account. Given background knowledge B, which in its most general form can be a clausal theory, the definition of coverage should be modified by replacing H with $B \wedge H$ for all three settings.

2.2 The ILP Task of Relational Rule Induction

The most commonly addressed task in ILP is the task of learning logical definitions of relations [30], where tuples that belong or do not belong to the target relation are given as examples. From training examples ILP then induces a logic program (predicate definition) corresponding to a view that defines the target relation in terms of other relations that are given as background knowledge.