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Explanation-based learning with analogy for impasse resolution

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ABSTRACT

This paper proposes an algorithm for the inclusion of analogy into Explanation-Based Learning (EBL). Analogy can be used when an impasse is reached to extend the deductive closure of EBL's domain theory. This enables the generation of control laws, via EBL, for hardware which is not catered for in the domain theory. This advantage addresses a problem which represents a dearth in the current literature. Integrated Modular Avionics (IMA) literature has thus far been concerned with the architectural considerations. This paper seeks to address the impact of hardware changes on the controllers within an IMA architecture. An algorithm is proposed and applied to control an aviation platform with an incomplete domain theory. Control rules are generated when no deductive explanations are possible, which still reflect the intent of the domain theory.

1. Introduction

Modularity in aviation has been gaining interest (Wilson & Preyssler, 2009) because of both the additional future-proofing inherent in having easily replaceable modules and the flexibility of role that this engenders (Committee on Materials, Structures, & Aeronautics for Advanced Uninhabited Air Vehicles, Commission on Engineering & Technical Systems, 2000). Modularity makes changing the hardware of platforms easier in order to fit specific missions, as advocated in (López, Royo, Barrado, & Pastor, 2008). Changes to a hardware platform may require changes to the control software. The impact of changes in the constituent hardware of a platform on the software control systems, which operate on said platform, forms a gap in the existing literature, as do coping strategies for this scenario.

Modular Avionics are aviation electrical systems which are integrated using a modular design paradigm. The components forming a modular aviation platform can be easily swapped (Kahn, 2001). An Integrated Modular Avionics (IMA) architecture involves the interconnection of physically separate hardware components which share computing hardware, whilst remaining logically separate (López et al., 2008).

The interest in modularity in aviation hardware, and the current gap in the literature highlights an open problem. It would be advantageous for software to adapt to control new items of hardware with a minimum of extra work. This objective can be satisfied in this work by the generation of control rules for an item of hardware which lies outside the original deductive closure of the domain theory.

The foundations of generating fuzzy rules from Explanation-Based Learning (EBL) explanation structures are in (Timperley, 2015). An assumption employed was that an appropriate, general, domain theory had been elicited. In this paper, it is assumed that the domain theory is incomplete for the intended purpose. This new assumption leads to an impasse being reached when attempting to form an explanation. As explanations are used as the basis of new fuzzy rules, no control laws will be derived.

EBL is focussed on generalisation, usually through the introduction of variables. This facet of EBL is what lends itself to modular control. In this work EBL can be further extended to support the generalisation of predicates, using analogies as supporting evidence.

The aim of this paper is to incorporate analogical learning into EBL. Analogy is proposed as a way to increase the deductive closure of the domain theory upon reaching an impasse. This allows a controller to generate rules for hardware outside of its original design, and therefore not mentioned in its domain theory. Such a situation can occur when the hardware of the controlled platform changes.

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1.1. Analogy

A previous work has augmented EBL to reach a deductive solution by combining two incomplete domain theories (Hirowatari & Arikawa, 1994). Analogy is used as the basis for linking predicates within two incomplete domain theories. The combination of domain theories leads to a deductive solution, in contrast to what is proposed in this work. Augmentation of EBL with analogical capabilities is an area which merits further work. This paper builds upon the previous work by allowing analogy to extend an existing domain theory.

Analogy can be employed to continue explanation upon reaching an impasse. It is likely that a new component will share both similarities to other components and an energy management strategy. This transfer of knowledge between situations can be achieved by derivational analogy (Carbonell, 1983). Analogy has been used to map different situations to one another, in order to apply prior knowledge to a new situation (Huhns & Acosta, 1988); thereby performing transfer learning.

This paper aims to use EBL and analogy in order to generate useful control rules for hardware which is outside the design of the controller. The objectives of this paper are to: (i) Introduce an algorithm which augments EBL with analogy to perform transfer learning; and (ii) demonstrate the the augmented EBL algorithm can generate rules which are useful but lie outside the deductive closure of the domain theory. The objectives will be demonstrated by applying the augmented EBL algorithm to control a hardware platform where no rules can be generated deductively i.e., without transfer learning. If the generated rules control the platform in a manner which reflects the intent of the domain theory then the second objective will be satisfied.

This paper is further divided into five sections. Section 2 compares the combination of EBL and analogy presented in this paper to existing methods. The advantages of combining EBL and analogy are described in Section 3, which also provides the proposed algorithm and satisfies the first objective of this paper. In order to satisfy the second objective of this paper the algorithm is applied to pitch control. The experiment described in Section 4 uses a domain theory for throttle control which cannot produce rules for pitch deductively. Analogy is used to generate rules for pitch. The result of applying these rules is given in Section 5. The paper concludes with Section 6.

2. Related Work

Transfer learning can be applied as an alternative to an impasse, such as in (Burstein, 1986). In other applications of analogical reasoning (e.g., (Carbonell, 1983; Klenk & Forbus, 2009)) a known solution to a similar problem is found and mutated to be applicable to the current problem.

Case Based Reasoning (CBR) was the method of analogical reasoning in (Carbonell, 1983) and (Klenk & Forbus, 2009). CBR uses similarities between previous solutions to various problems to solve the one at hand, the target (de Mántaras & Plaza, 1997). Closely similar solutions are modified to solve the target problem. Similarity metrics are used to guide searches for similar solutions. In this work a similarity between terms is used as the basis for analogy.

If comparing the technique proposed with that of derivational analogy (Carbonell, 1983), the analogue is a concept rather than a situation. Another difference is, the presented technique, rather than tailoring a previous solution to a new situation, generalises a previous line of reasoning within a solution, to more concepts. Applying analogy to only a single line within an example is similar to when students refer to a specific line of a previous example to justify some reasoning rather than the example as a whole (VanLehn & Jones, 2014). This technique also shares some conceptual similarities with (Ishikawa & Terano, 1996).

Both this work and that of Könic et al. (Könik et al., 2009) map between concepts in order to apply knowledge from one situation to another. There are some differences between this work and Könik et al. (2009). This technique is proposed to derive links between previously unrelated concepts. These links are embodied in a new, more abstract, concept definition. This technique has a different method of application, as an alternative to failure. Both works use a goal and explanation, as a bias, to constrain the possible analogies. This technique also maps between potentially overlapping concepts rather than like terms.

This type of analogy, from information in Falkenhainer (1987), could be stated as using similarity-based generalisation in order to perform a form of analogical reasoning. The analogical reasoning is restricted to generalising information to hold to more concepts than when derived. The algorithm forms a new concept from two existing definitions, keeping the parts specific to both and introducing variables where variation exists. In this regard the algorithm is similar to EGGS (Mooney, Bennett, & Urbana, 1986), which performs generalisation by applying the aggregation of substitutions within an explanation to the whole explanation.

In this work, an analogy is seen as evidence for predicate generalisation or swapping. The generalisation can either replace the target predicate or be taken as evidence for swapping the source for the target. Analogies could be generated using different techniques in order to generate evidence for predicate swapping. One such method which is capable of deriving analogies from natural language is Cambria, Fu, Bisio, and Poria (2015). It may be possible to use such techniques and either apply them to domain theories. However, if domain theories are lacking in data richness then the system in Cambria et al. (2015) could be applied to the expert knowledge from which the domain theory was designed.

The algorithm proposed differs from Hirowatari and Arikawa (1994) by increasing slightly the deductive closure of the program in order to apply analogical reasoning in more restricted form. This increase in deductive closure is based on the assumption that the addition of a new concept increases the number of facts that can be deduced within the system.

An application of analogical learning with EBL (Hirowatari & Arikawa, 1994) was able to construct explanations from incomplete domain theories where the combination of domains made a deductive explanation possible. This work proposes that less exact analogues can be used to derive relations between terms with different predicates. Rather than establishing a link between the same terms in different domains, the emphasis is on relating different terms within the same domain. In this paper, the algorithm proposed goes further and extends a single incomplete domain theory using internal similarities between two predicates. This is achieved by deriving an abstraction which encompasses both predicates.

3. Abstraction derivation

This paper proposes the derivation of an analogical link between two deductively separate concepts. This link is formed by the generation of a new concept, which requires commonalities between the two target concepts to be satisfied. The new concept is an abstraction of the two target concepts. Membership of this abstraction implies that concepts are analogous in the manner given by the abstract concept definition. This could be thought of as weakening the preconditions on the target concepts to form an abstraction.

An advantage of EBL can be exploited during the definition of an analogical similarity; training examples encountered can provide an inductive bias for disregarding terms that are not relevant.