Machine Learning and Adaptation of Domain Models to Support Real Time Planning in Autonomous Systems – Final Summary Report

Austin Tate and Gerhard Wickler

University of Edinburgh

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Informal Project Title: HEdLAMP – Huddersfield + Edinburgh: Learning and Adaptation of Models for Planning

Project web site: http://www.aiai.ed.ac.uk/project/hedlamp/

Introduction

The research hypothesis of this project was as follows:

Automatically learning and adapting an accurate and adequate domain model for the purposes of symbolic reasoning, in particular for the processes of automated planning, enables effective, sustained goal-directed behaviour for real time dynamic autonomous systems.

The project has two partners, the University of Edinburgh and the University of Huddersfield. The original project proposal envisaged different running times for the project at the two sites, where Edinburgh would finish work on the project approximately one year earlier than Huddersfield.

The project engaged with scientists and domain experts at Schlumberger Cambridge Research involved in the modelling and use of emergency procedures for a blow out preventer (BOP) related to oil well operations.

Dr. Gerhard Wickler was the research scientist and main investigator for the Edinburgh element of the project. He also created and maintained the main project web site.

We have developed the Knowledge Engineering Web Interface (KEWI) for capturing procedural knowledge in a shared online repository using a content management system tailored to procedural knowledge. This system is available online through the project website and has been used to represent an existing procedure related to oil well control. KEWI is ready for evaluation and use by others in the research community as well as our industrial partners.

A new hybrid hierarchical-heuristic search planner (H3) has been developed and is at an early prototype stage. KEWI and H3 are available as a tools for knowledge capture, validation and plan generation through the HEdLAMP web site.

Provision of Relevant Background Resources and Software

In the first 6 months of the project, a number of relevant background resources and open source software components were made available and briefed by both the Edinburgh and Huddersfield teams. The Edinburgh resources include the I-X technology and I-Plan artificial intelligence planner and relevant work on knowledge-rich AI plan representations and a plan ontology was input by Austin Tate, his primary contribution to the project as promised (part of deliverable D2, Tate et al., 2012). The background resources and software, including download links are described at http://www.aiai.ed.ac.uk/project/hedlamp/background

Domain Modelling with KEWI

Domain-independent planning has grown significantly in recent years mainly thanks to the International Planning Competition (IPC). Besides many advanced planning engines, PDDL, a de-facto standard language family for describing planning domains and problems, has

been developed. However, encoding domain and problem models in PDDL requires a lot of specific expertise and thus it is very challenging for a non-expert to use planning engines in applications.

The Knowledge Engineering Web Interface (KEWI) addresses this issue in an organisation where (i) non-planning experts are required to encode knowledge, (ii) the knowledge base is to be used for more than one planning and scheduling task, (iii) it is maintained by several personnel over a long period of time, and (iv) it may have a range of potentially unanticipated uses in the future. The first concern has been a major obstacle to using AI-based tools which input formal representations, in that the expertise required to encode such representations has only been possessed by planning experts. The other concerns are often not covered in the planning literature: in real applications the knowledge encoding is a valuable, general asset, and one that requires a much richer conceptual representation than, for example is accorded by planner-input languages such as PDDL.

The representation used by KEWI rests on a conceptual model that consists of three main parts:

- an ontological model for describing the concepts (types of objects) that occur in the captured domain
- a model of primitive actions that can be executed by some agent, a person and/or some automated system
- a model of hierarchical, procedural knowledge that describes high-level methods for accomplishing complex tasks

A KEWI model is internally stored in a standard database. The model is created, accessed and modified through the KEWI software, which is a module that is added to a standard Drupal 7 installation. Detailed installation instructions are available from the HEdLAMP website at: http://www.aiai.ed.ac.uk/project/hedlamp/resources/KEWI-for-Drupal7-README.html

The underlying conceptual model is described in detail in Wickler (2013) and Wickler et al. (2014). These publications contain the formal semantics of the ontological model and the model for primitive actions. The model of hierarchical, procedural knowledge is described informally as this was still in a prototype level. Essentially, the model for primitive actions follows (a sub-set of) the de-facto standard, PDDL, and its semantics. Hierarchical methods are strictly an extension of this model, adding a task to be accomplished and a partially ordered set of subtasks to a PDDL action.

This implies that a hierarchical method has effects, a feature that is not standard in the HTN literature, and which does not have an agreed semantics in the community. We have chosen to define methods as an extension of actions and thus, the semantics must be the same, that is, the state transition function for an applicable method modifies the state by deleting negative effects and adding positive effects to a given state. The result is a complete description of the state after the action or method has been completed. This type of method description can be seen as a middle ground between macros as they have been used in planning and partial specification of effects, which allows for a higher level of abstraction in methods.

More details about KEWI are given in the description of the final demonstrator below.

H3 - Hybrid Hierarchical Heuristic Planner

Some processing of procedural knowledge stored in KEWI is done by the KEWI software itself. However, the use of this knowledge to generate plans is not in the scope of KEWI. In fact, KEWI does not have access to the current world state of a system to which the procedural knowledge it contains may be applicable, nor does it have access to a goal to be achieved or a task to be accomplished. Since these are both necessary components of a planning problem that is the input to a planning engine, KEWI cannot be used to generate plans.

We have, however, developed a planner that can take the model contained in KEWI and some state and goal information (not held in the KEWI database) to generate plans. This new AI planner, called H3, aims to mix the best aspects of hierarchical task network (HTN) planning and fast heuristic search planning.

The implementation of H3 is at the stage of a working prototype that can be used to generate some plans. The code is not robust, however, and the underlying algorithm has thus far not been published. Partially, this is due to the fact that the integration with an external, heuristic-search planner is incomplete. Instead, an internal heuristic-search planner is used, but this does not have the speed of high-performance planners as used in the IPC.

Attempts to use FF as a heuristic-search planner with a complex domain and problem were not successful due to the fact that FF pre-processes the planning problem to create a propositional version of the problem. This propositional version grows exponentially in size with the given planning problem and this caused severe problems for the oil well control procedure used to evaluate KEWI. Since the technique of propositionalizing a problem first is common amongst IPC planners, an internal planner was developed and used in H3.

The basic algorithm used by H3 is described in a set of slides that has been used for non-public, academic presentations at various universities. These slides are attached in an appendix to this report.

Final Demonstrator: A Procedure for Oil Well Control

KEWI and H3 have been evaluated using two domains. The first is a complex toy domain, the Dock Worker Robot domain, which is well understood in the planning community and poses some serious challenges for search-based planning. This domain has been used for testing and in publications.

Schlumberger has supplied various documents on oil well control describing a number of procedures that drillers must follow. These procedures were clarified in a number of knowledge engineering meetings. Thus, well control, and specifically handling the procedures for dealing with a blow-out, formed the second, real-world domain modelled with KEWI.

The final result of the modelling process is contained in the KEWI database. The model contains an ontology layer of about 30 domain-specific, drilling-related concepts, about ten property types, and three generic relations. The procedural knowledge consists of 16

primitive actions and ten hierarchical methods of different complexity. The model can be browsed through the HEdLAMP website which provides many links for efficiently navigating the knowledge, thus allowing domain experts to inspect the procedures.

Most aspects of the software are used in the final demonstrator system which can be accessed through the HEdLAMP website, but only after login. This is to protect the procedures from unauthorized access. The demonstrator shows how the knowledge is displayed in the system and how the automatically generated links can be used to browse the procedures. It also shows how this knowledge can be exported and then deployed by the H3 planner to automatically generate plans of actions that may be used by human operators, or they may form the basis for a fully autonomous system.

A detailed description of the demonstrator including many screen shots and the complete exported knowledge are given in the appendices.

Summary

This report summarizes the most significant results of the HEdLAMP project achieved at the Edinburgh site and lists the publications which arose. This output consists of the Knowledge Engineering Web Interface (KEWI) that supports distributed knowledge engineering approach for multiple domain experts to collaborate on procedural knowledge for a specific domain. The tool provides sufficient support to allow domain experts who are not familiar with planning technology to contribute to the modelling online. This is partially due to the semi-formal nature of the underlying representation. However, only the formal aspects are validated by the system and used for planning by the H3 planner.

KEWI has been used to model a real-world domain taken from the area of oil well control. The result is a formal model that can be used to generate action plans that potentially form the basis for a fully automated drilling system.

Publications

Tate, A., Wickler, G., McCluskey, T.L. and Chrpa, L. (2012) Machine Learning and Adaptation of Domain Models to Support Real Time Planning in Autonomous Systems - Month 6 Report, August 2012.

http://www.aiai.ed.ac.uk/project/ix/documents/2012/2012-hedlamp-report-tate-month-6-report.pdf

Wickler, G. (2013) Using Static Graphs in Planning Domains to Understand Domain Dynamics, Proceedings of Knowledge Engineering for Planning and Scheduling 2013, June 2013.

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Wickler, G. (2014) KEWI - A Knowledge Engineering Tool for Modelling AI Planning Tasks, Proceedings of International Conference on Knowledge Engineering and Ontology Development 2014, pp. 36-47, October 2014.

http://www.aiai.ed.ac.uk/project/ix/documents/2014/2014-keod-wickler-kewi.pdf

Wickler, G., Chrpa, L. and McCluskey, T.L. (2014) Creating Planning Domain Models in KEWI, Proceedings of Knowledge Engineering for Planning and Scheduling, Volume 2014, Issue June 2014, pp. 54-60, June 2014.

http://www.aiai.ed.ac.uk/project/ix/documents/2014/2014-keps-wickler-kewi-model.pdf

Wickler, G., Chrpa, L. and McCluskey, T.L. (2015) Ontological Support for Modelling Planning Knowledge. Communications in Computer and Information Science (CCIS), Springer-Verlag, to appear.

Software Outcomes

KEWI - Knowledge Engineering Web Interface

http://www.aiai.ed.ac.uk/project/hedlamp/resources/KEWI-for-Drupal7-README.html

http://www.aiai.ed.ac.uk/project/hedlamp/resources/KEWI-for-Drupal7-2015-06-24.zip

H3 - Hybrid Hierarchical Heuristic Planner - a new AI planner by Gerhard Wickler to mix the best aspects of hierarchical task network (HTN) planning and heuristic planning.

http://www.aiai.ed.ac.uk/project/h3/