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Participating nodes: TUWIEN (leader), HUT, UMAN/TUCLAUSTHAL, UCY, BATH.

WP5 Report: Model Applications and Proofs-of-Concept

Introduction

After a long period of theoretical research on non-monotonic logic programming, in the recent years several implemented systems have become available, including DLV [1, 2], Smodels [3, 4], NoMoRe [5, 6], ASSAT [7, 8], and Cmodels. These systems provide a computational backbone for the Answer Set Programming (ASP) paradigm [9, 20, 192, 194], a promising approach to declarative problem solving which uses concepts from knowledge representation [10].

The objectives of the workpackage WP5 are

- to investigate the use of Answer Set Programming (ASP) in various applications from a global perspective;
- to explore the integration of ASP techniques and tools in problem solving; and
- to provide showcases and model scenarios in applications which demonstrate the usage of the ASP paradigm.

In this report, we try to categorize and survey promising application areas giving the focus onto the research which is carried out by members of the European Working Group on Answer Set Programming (WASP).

In addition, a selection of showcase-applications is available at the web under:
http://www.kr.tuwien.ac.at/projects/WASP/showcase.html.

Planning

During the last years, logic programming and answer set programming in particular have been widely accepted as a useful tool for solving classical planning problems by means of suitable transformations [11, 12]. The key issue making ASP an appealing core language for planning problems is indeed the non-monotonic formulation of frame axioms using negation as failure.

The system DLVK, developed at TUWIEN, is a sophisticated planning-frontend to the system DLV. Leone *et al.* [13] have shown some integrated encodings for conformant planning and simple forms of conditional planning, and later extended their work with respect to planning under uncertainty, incomplete information, and action costs, adopting useful concepts of Answer Set Programming such as weak constraints [14, 15, 125].

In a joint project TUWIEN and UMAN/TUCLAUSTHAL, have proposed the use of DLVK in a planning approach supporting design and monitoring of multi-agent-systems [16, 126].

Planning problems based on Hierarchical Task Networks (HTN) are considered in [21, 127]. The use of ASP makes it possible to improve and extend HTN planning in various ways, for instance since ASP is well suited to handle incomplete information (while HTN planning is not), there are possibilities to deal with extensions of HTN planning under incomplete information.

Two new tools, KDiagnose and KMonitor provide implementations for advanced problems in knowledge-based planning. While KDiagnose finds explanations for a plan execution discrepancy, KMonitor observes plan execution in a non-deterministic environment, where one may reach some state which does not correspond to any of the expected trajectories. Both systems are based on DLV and DLVK. Related references are [128, 129]

Another system PAL (Pertinence Action Language) is implemented at UNICORUNA using Smodels as a back-end (see also [97]).

Further work within WASP-nodes related to planning includes [17, 133, 18, 19, 20, 82, 83, 84, 98, 99, 100, 101, 130, 131, 132].

Collected Links:

- DLVK-homepage: http://www.dbai.tuwien.ac.at/proj/dlv/K/
- Graphical user interface for DLVK: http://sourceforge.net/projects/dlvkgui/
- Project description for DLVK: http://www.kr.tuwien.ac.at/staff/axel/planning/
- Planning as monitoring: http://www.cs.man.ac.uk/~zhangy/project/monitor/
- PAL-homepage: http://www.dc.fi.udc.es/ai/~cabalar/pal/
- HTN-planning: http://www.in.tu-clausthal.de/~yzhang/ASP_Planning
- KDiagnose: http://www.kr.tuwien.ac.at/research/plan_diagnosis/index.html
- Kmonitor: http://www.kr.tuwien.ac.at/research/monitoring/

Preference Reasoning and Advanced Web Data Access

One of the most promising areas for applying ASP in a real-world setting is to provide advanced reasoning services in the context of the Semantic Web. Such services clearly require declarative methods dealing with default and preference information. These requirements are perfectly met by ASP [22] and its extensions for preference reasoning [23, 24, 25, 26, 110, 111, 112, 122, 134, 135], which are supported by several available implementations. We mention here the plp front-end [27, 28] which implements different preference-handling strategies developed in the literature [88] on top of the DLV -engine, the gcplp-system [29, 113], as well as the more recent system nomore< [136], which both make use of graphs following the NoMoRe approach, and the system psmodels, a modification of Smodels that can be used to compute preferred answer sets under the ordered disjunction semantics. Another approach is to consider a "quantitative" preference relation that associates a weight with each rule in a program. Applications for this extension are discussed in [140, 141]. As recently shown, preferences are also a desired feature in planning and casual reasoning [89]. Another important core equipment for the required reasoning systems could be so-called open logic programs, in which not all parts of a program are known in advance [30] and thus reflect the inherent incompleteness of the information provided by the WWW. A similar role may be played by taking different notions of equivalences [31, 32, 33, 34, 90, 119] between logic programs into account.

Furthermore, in order to apply ASP for advanced web access the possibility to deal with domain-specific languages and ontologies, as well as suitable treatment of dynamic knowledge bases are crucial. In this context there has been remarkable success within the last years [35, 36, 37, 38, 39, 40, 41, 137, 138]. From a more abstract point of view, the work at VUB [42, 43, 121, 139] extends ASP in order to integrate an expressive class of description logics which are able to play the role of an ontology language, as well as a rule language on the Semantic Web. This kind of logic programs proves to be suitable for Semantic Web reasoning by simulating an expressive subclass of the ontology language OWL DL and provides a natural framework for representing rule-based knowledge and ontologies. Some additional benefits of using ASP, compared with OWL DL, are the ability to close the domain at will and to succinctly represent knowledge that is not trivially expressible using OWL DL.

A similar technique combining description logics and ASP is drawn out at TUWIEN where so-called description logic programs are proposed and a corresponding solver called NLP-DL is available. The technical details are addressed in several papers [85, 145, 146, 147, 148, 149]. Further work relating nonmonotonic reasoning principles with the Semantic web includes [44, 45] and is also part of work packages in REWERSE, the EC Network of Excellence.

Another related project is INFOMIX initiated by the two WASP-nodes TUWIEN and UNICAL together with Universita "La Sapienza" - Roma and the polish company Rodan Systems S.A. The main goal of the INFOMIX project is to provide a set of techniques and associated tools for powerful information integration by using advanced reasoning capabilities, as for instance ASP; see [87] for a concrete application of ASP, or [117, 124 152, 153] for dedicated features for data integration in DLV. General information about this project can be found in [150, 151, 154, 155].

Further work on information integration and related tasks are [142, 143] which use the ASP-like ID-Logic as underlying semantics, [144] which employs abductive logic programming techniques, and research at WASP-nodes UNIVAQ [46], UNIME [156, 157, 158, 159, 160], and UNILEIPZIG [161]. Finally, an application of ASP for Web Service Composition [193] has won the first prize in the EEE-Web Service Composition Contest.

Collected Links:

- plp-homepage: http://www.cs.uni-potsdam.de/~torsten/plp/
- gcplp-homepage: http://www.cs.uni-potsdam.de/~konczak/system/GCplp/
- psmodels-homepage: http://www.tcs.hut.fi/Software/smodels/priority/
- INFOMIX-homepage: http://sv.mat.unical.it/infomix/
- REWERSE-homepage: http://rewerse.net/
- nomore< homepage: http://www.cs.uni-potsdam.de/wv/nomorepref
- NLP-DL prototype: http://www.kr.tuwien.ac.at/staff/roman/semweblp

Verification and Configuration

Viewing ASP as basis for a constraint programming paradigm [20] leads to the computation of optimal solutions which may be specified by weights [47, 48]. This allows for numerous further applications. For instance, in product configuration [49] ASP can be used as a declarative semantics providing formal definitions for main concepts in product configuration, including configuration models, requirements and valid configurations. A similar application field is software configuration [50]. This research has led to a prototype configurator for the complete Debian Linux system distribution [51]. For further information on ASP-applications in configuration refer to [162, 163, 164, 165, 166]. Moreover, the important area of symbolic model checking is well suited for ASP as shown in [52, 53, 54, 55], and recently in [114], where Boolean equation systems are solved via ASP.

In particular, HUT is focusing on symbolic model checking and software configuration. An overview about this research is summarized in two projects titled Constraint Programming Based on Default Rules, and respectively, Applications of Rule-Based Constraint Programming; both links include basic information about the aforecited topics, a comprehensive list of references, and links to relevant software. Furthermore, the product configuration research employing ASP techniques for implementation is also done in the product data management group of HUT, where interesting applications are emerging, e.g., the WeCoTin project on Web configuration technology with Smodels employed as a core-engine.

Other work includes an application [167] addressing the problem of VLSI-routing using ASP. Finally, we mention that also the concept of inheritance [56] can be used for configuration tasks, providing a natural representation of reasoning with exceptions. Inheritance is implemented as a frontend within DLV.

Collected Links:

- Research at HUT (Projects, Software, ...): http://www.tcs.hut.fi/Research/Logic/
- Debian configuration: http://www.tcs.hut.fi/~tssyrjan/configuration/
- WeCoTin-homepage: http://www.soberit.hut.fi/WeCoTin/
- DLV with inheritance: http://www.dbai.tuwien.ac.at/proj/dlv/inheritance/

Multi-Agent Systems

Software agents are an approach to develop large distributed systems, and are most likely to become the next programming paradigm for this rapidly growing area. Software agents which allow to access information in a heterogeneous information system as provided by sites connected by the Internet (see also above) are an interesting application area for ASP. VUB presents in [57] systems of logic programming agents to model the interactions between decision-makers while evolving to a conclusion. Such a system consists of a number of agents connected by means of unidirectional communication channels. Agents communicate with each other by passing answer sets obtained by updating the information received from connected agents with their own private information. At UNIVAQ, an ASP solver is integrated into the DALI language interpreter. DALI is a logic programming language aimed at defining agents and multi-agent systems, with advanced reactive and proactive features, see also [102, 104, 171, 172]. Finally, also UNIRC is involved in joint research within this area, see for instance [58, 168]. Further recent research includes [169, 170].

Collected Links:

- DALI-homepage: http://costantini.di.univaq.it/DALI.htm
- Knowledge-based agents for advanced information access; project-homepage: http://www.kr.tuwien.ac.at/staff/giuliana/project.html

Security and Crypto-Analysis

Formal verification of security protocols has become a key issue in computer security. For instance, in [59, 60] it is shown how security protocols can be specified and verified efficiently and effectively by embedding reasoning about actions into a logic programming language. In particular, `Smodels` is employed in order to model two significant case studies in protocol verification: the classical Needham-Schroeder public-key protocol, and the Aziz-Diffie key agreement protocol for mobile communication.

In [61], the US Data Encryption Standard (DES) is put forward as an interesting benchmark problem for nonmonotonic reasoning systems, presenting two encodings of DES as logic programs: a direct one out of the standard specifications and an optimized one extending the work of Massacci and Marraro [62]. The computational properties of the ASP-encodings are studied by using them for DES key search with the `Smodels`-system. Results indicate that the encodings applied to `Smodels` are quite competitive: they outperform state-of-the-art SAT-checkers working with an optimized encoding of DES into SAT and are comparable with a SAT-checker that is customized and tuned for the optimized SAT encoding.

The work on security and access controls has been further extended by UNITN. One line of research (see [94, 95, 96]) uses ASP as the main inference for access control on business process for web services, by defining an architecture for interactive access control which uses abduction over ASP to determine the set of credentials needed by a user to access a service. A more sophisticated reasoning service is also available for performing trust negotiation. The system has been integrated with a mainstream privilege management infrastructure (PERMIS) and uses a state of the art engine for business processes for web services (Collaxa). The usage of `DLV` and its deduction and abduction engine is entirely transparent to the user which only needs to see the declarative policy. A second line of research resulted in the ST-Tool, (Secure Tropos Tool) a CASE tool which allows the creation of formally consistent security requirements systems. It supplies a visual editor to design the system models, performs integrity analysis according to the SecureTropos agent-oriented requirements engineering methodology and uses ASP solvers to perform automatic verification on system models, in order to detect security lacks. For details, see [91, 92, 93, 188, 189, 190].

Finally we mention that the concept of open logic programs has been shown to be relevant for tasks as policy verification [17].

Collected Links:

- Propositional crypto challenges: http://www.ing.unitn.it/~massacci/CryptoSAT/
- DES-benchmarks: http://www.tcs.hut.fi/Software/smodels/tests/des.html
- General ASP-benchmarks: http://www.asparagus.cs.uni-potsdam.de/
- ST-tool: http://sesa.dit.unitn.it/

Diagnostic Systems and Inconsistency Management

Abductive Logic Programming [63, 64] is widely accepted as a promising approach for diagnostic reasoning tasks. Most research in this area is concerned with the SLDNFA-procedure [65], extending the well known prolog-resolution. In recent work [109], it is shown how to effectively use ASP to deal with abduction over unbounded domains. Another feature is to add penalization to the abduction problem [173].

For implementations within the core answer-set paradigm we refer to the diagnosis frontend integrated to the `DLV`-system, see [66]. One of the most prominent applications for diagnosis using logic programs is a project between Texas Tech University and United Space Alliance on developing a decision support system for the ground controllers of space shuttles [67].

Related to diagnostic reasoning is dealing with inconsistent data *per se*. In [68] it is shown how `DLV` can be used to repair inconsistent or incomplete census data; see also [116] in this context. Recently, a logical foundation for inconsistent answer sets has been proposed in [174].

Brewka [76] suggests to use ordered disjunctions [26, 111] as well as abduction techniques [66] for qualitative decision making within the context of ASP. Another approach is followed in [69, 122] using so-called ordered logic programs where the answer set semantics is extended to deal with inconsistent programs (containing classical negation), by finding a ''best'' answer set. It turns out that this preferred answer set semantics is useful for several applications, for instance database repairs, where minimal repairs are shown to correspond to preferred answer sets. In [70] this approach is further developed by showing that a diagnostic system, both consistency-based and abductive, can be regarded as an ordered logic theory. The preferred answer set semantics nicely fits this intuition: if the observations contradict the normal system behavior, then the semantics will provide an explanation from the fault rules. Furthermore, [71] shows that this approach can be extended to perform abductive reasoning in general, with either a preference relation on the set of abducibles or on the system description itself. The latter case appears naturally in applications such as legal reasoning where rules carry a natural precedence. Finally, recent work extends this approach to model reasoning of agents [105, 106, 120].

Collected Links:

- Frontend for OCLPs: http://www.cs.bath.ac.uk/~mdv/oct/

Game Theory and Games

In [72, 73, 74] programs are extended by a new connective representing exclusive disjunction and later by a method to express circumstance-dependent preferences. More specifically, this kind of programs allows for an elegant and intuitive tool to transform finite extensive games with perfect information such that the answer sets of the program correspond, depending on the transformation, to either the Nash equilibria or the subgame perfect equilibria of the game. For some recent developments, see [75, 107, 108]. In distinct recent work, UNIME combines ASP-planning with interactive gaming environments [123]. Furthermore, the following links provide games(-like) applications for ASP.

Collected Links:

- Sokoban (download): http://www.tcs.hut.fi/~tssyrjan/software/ssokoban.tar.gz
- Constraint Lingo: http://www.cs.uky.edu/~raphael/cl.html

Further Applications

Applications from various areas can be found in the literature, including

- auctions [77, 175],
- scheduling [78],
- policy description [79],
- workflow management [80],
- outlier detection [115, 118],
- linguistics [176, 177, 178, 179, 180],
- text analysis [181, 182, 183],
- E-learning [184], and
- bio-informatics [185].

Finally, we refer to papers concerned for engineering ASP-solution. The work in [86, 191] presents a general technique to implement guess and check programs in ASP, which is helpful in several application domains, while [186, 187] are starting points for debugging ASP-programs. Furthermore, we mention the DLV Java Wrapper [81], a library that "wraps" the DLV-system in an external application, and thus allows to embed ASP-techniques inside object-oriented source code.

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