Worldwide AI

■ *This column describes the efforts of a group of German knowledge representation and reasoning researchers to pursue a research initiative focusing on hybrid reasoning.*

Gerhard Brewka, Gerhard Lakemeyer

Hybrid Reasoning for Intelligent Systems: A Focus of KR Research in Germany

For quite a while, research in knowledge representation and reasoning (KR) had a strong focus on purely symbolic methods, for instance in subareas like description logics, logic programming and nonmonotonic reasoning, belief revision, reasoning about action, and the like. Although the motivation for studying symbolic methods is still valid, it becomes more and more apparent that numerical methods are needed to handle certain aspects — such as time, resources, uncertainty, and preferences — of realistic problems. To model realistic problems, one has to enhance symbolic reasoning methods with capabilities to exploit and process numerical information. In other words, one has to rely on hybrid methods that combine qualitative and quantitative reasoning in one way or the other.

With this in mind, a group of German KR researchers decided to start a research initiative focusing on hybrid reasoning. The primary funding agency for basic research in Germany is the German Research Foundation (DFG). One of DFG's funding instruments are Research Units (*Forschergruppen* in German), which consist of a collection of closely related projects, typically around five, that investigate different aspects of a fundamental joint research question (figure 1). Funding is granted for up to six years, with an intermediate evaluation after the first phase of three years.

The application for the Hybrid Reasoning for Intelligent Systems (Hybris) Research Unit was successful and Hybris began its work in 2012. Since then, Hybris has also passed the intermediate evaluation and so funding will be available until 2019. Seven principal investigators from six different German universities are involved in the current, second phase of the project: Franz Baader, TU Dresden; Gerhard Brewka, Leipzig University; Wolfram Burgard, University of Freiburg; Gabriele Kern-Isberner, TU Dortmund; Gerhard Lakemeyer, RWTH Aachen (coordinator); Bernhard Nebel, University of

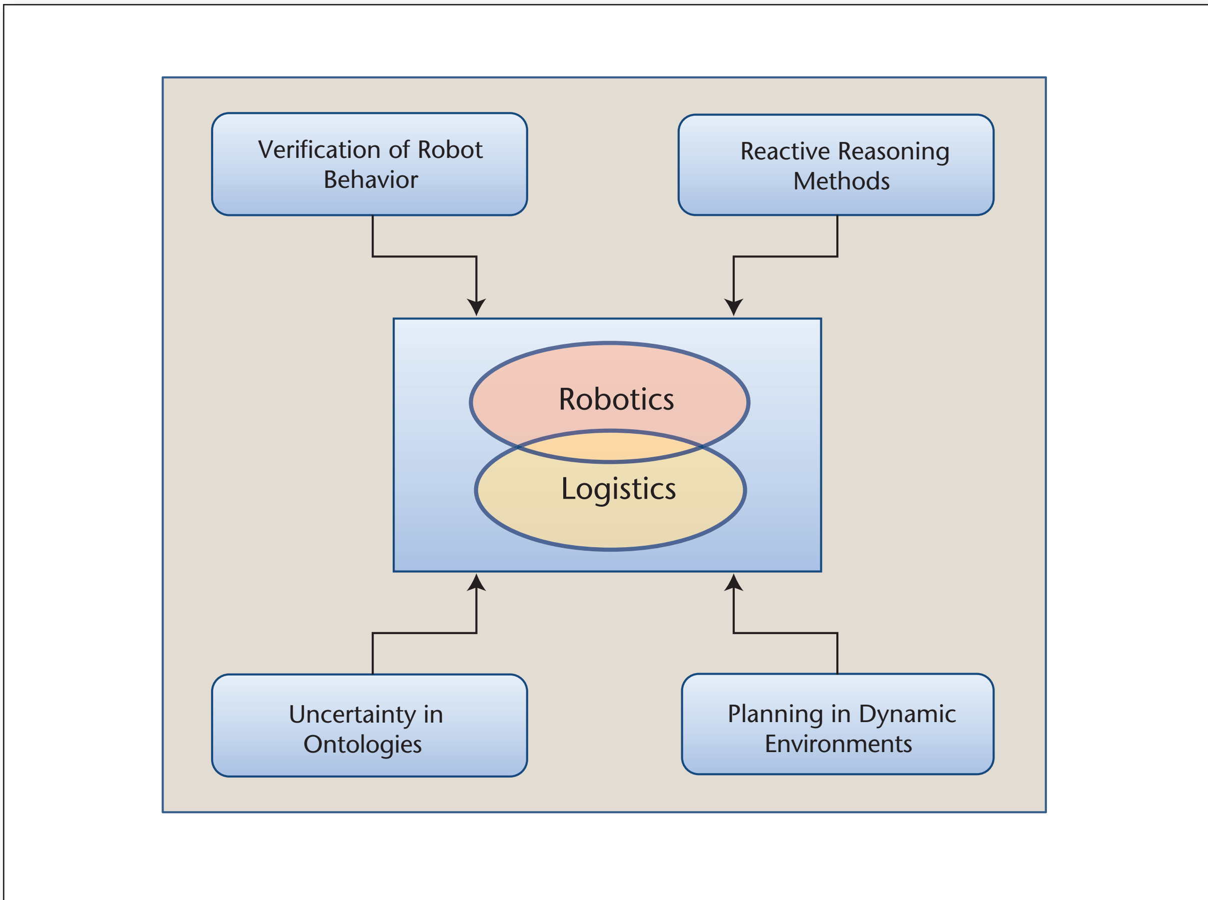

Figure 1. Hybris Overview.

Freiburg; and Torsten Schaub, University of Potsdam.

To increase the practical impact of the Research Unit, robotics, bioinformatics (phase I), and logistics (phase II) were included as application areas. In robotics, the quantitative aspects of reasoning include dealing with noisy sensors and continuous robot arm trajectories. In bioinformatics, they include learning formal ontologies from text databases and modeling protein interaction networks. The applications in logistics are developed in cooperation with Fraunhofer IML in Dortmund, one of Germany's leading research institutes in logistics.

The Research Unit currently consists of four projects, each involving researchers from at least two universities. This way, there's a diversity of competencies and background, which benefits the projects. We briefly describe each of the projects below. Fig. 1 illustrates the thematic connections among the projects.

Verification of Nonterminating Action Programs

GOLOG is a high-level language for the specification of the behavior of agents, including mobile robots. The language is based on an underlying action theory expressed in the situation calculus.

Modern variants of GOLOG allow, among other things, for programs with stochastic actions and noisy sensors. The programs are typically nonterminating, that is, they describe what the robot should do indefinitely.

In many situations, it is essential to guarantee that "nothing goes wrong." In other words, one has to ensure that the execution of the program leads to intended behavior. One way to achieve this alignment is to formally specify and then automatically verify the desired (temporal) properties. This project investigates this kind of verification of GOLOG robot programs.

Unfortunately, GOLOG verification in general is undecidable due to the formalism's high expressiveness in terms of first-order quantification and program constructs. We therefore looked at and identified a number of interesting fragments that admit decidable verification, yet retain as much of GOLOG's expressiveness as possible.

In our studies, verification was tackled from two directions: on the one hand, by means of nontrivial abstractions that allow a reduction to classical model checking; and on the other, by devising new model checking–inspired verification techniques specifically tailored for the situation calculus and GOLOG. Decidability results were obtained for a large class of of action theories, where restrictions were imposed on the (conditional) effects of actions. Moreover, the verification of GOLOG programs with sensing actions, where the agent's knowledge is formulated in an epistemic description logic, was also shown to be decidable.

We are currently advancing the applicability of such verification methods towards more realistic scenarios, with a special focus on robotics applications. In particular, we are going beyond mere decidability to study the feasibility of verification, incorporate notions of continuous change as well as probabilistic uncertainty, and consider the case where models of the dynamics of the environment exist as well.

The principal investigators are Wolfram Burgard and Gerhard Lakemeyer.

Advanced Solving Technology for Dynamic and Reactive Applications

Online applications are applications for which relevant additional information may become available at any time during the solving process. This project aims to provide hybrid reasoning methods suitable for such applications. We investigate argumentative reasoning methods and reactive multicontext systems (that is, systems that integrate different reasoners in a systematic way). A main focus, however, is on answer set programming (ASP).

Although ASP is being used more and more to tackle industrial problems, certain aspects are more naturally modeled using variables over finite domains rather than in standard ASP. Consider a planning problem that involves scheduling different machines, each of them producing goods while also consuming energy and material. Resources like runtime, power, fuel, and storage are difficult to handle with propositional approaches. Therefore, in ASP, a dedicated treatment of numeric variables and constraints — as available in constraint processing — is needed. We extended ASP with constraints over integers, while preserving its declarative nature and excellent performance.

This strategy resulted in the hybrid ASP solver clingcon, which enhances the learning techniques of an ASP solver with the inferences induced by the underlying constraint satisfaction problem in a lazy way. In other words, the relevant knowledge is made explicit only when needed. This delay is useful in reactive solving, for instance, in online planning with continuous domains and durations.

In collaboration with Fraunhofer IML, Dortmund, the ASP techniques developed in the project have been applied to logistics problems. A Cellular Transport System is a goods-to-person order picking system in which autonomous vehicles provide picking stations with article bins. We set up a multiagent system with the vehicles being modeled as ASP agents that select driving jobs from a horizon. We provide the agents with knowledge restricted to the scope of their specific tasks, which plays a critical role for their performance, especially when the planning horizon is large. The approach is tailored to work in a real-life environment, and its evaluation shows a considerable improvement of performance without any physical adjustment of the system.

Warehouse planning is a strategic task that requires a tremendous amount of expert knowledge. We developed a software tool that makes use of the strengths of ASP, especially complete declarativeness, understandability, and solving efficiency, to facilitate warehouse planners. In particular, the tool supports process planning, technology dimensioning, and selection and layout generation, as well as the assessment of alternatives. The inclusion of expert knowledge enables even inexperienced designers to create a number of feasible and valuable planning alternatives.

The principal investigators are Gerhard Brewka, Gabriele Kern-Isberner, and Torsten Schaub.

Probabilistic Description Logics Based on the Aggregating Semantics and the Principle of Maximum Entropy

Description Logics (DLs) are a well-investigated family of logic-based knowledge representation languages that are tailored towards representing terminological knowledge. Probabilistic extensions of DLs are motivated by the fact that, in many application domains, knowledge is not always certain. In such extensions, there is a need for treating knowledge about specific individuals differently from general terminological knowledge. In a nutshell, probabilistic terminological knowledge has a statistical flavor, whereas probabilistic knowledge about individuals is rather subjective. Previous work in this area has not addressed this dual need in a satisfactory way.

The main idea underlying this project is to adapt and extend the recently developed aggregating semantics for probabilistic knowledge from a restricted first-order case to DLs. This semantics seems suitable for the project goals, as it combines subjective probabilities with population-based statements on the basis of a possible-world semantics. It thus provides a common semantic framework for both subjective and statistical probabilities.

As a second main feature, we apply the principle of maximum entropy on top of aggregating semantics. This approach overcomes the pitfall of obtaining large and uninformative intervals for inferred probabilities, which is a common feature of many approaches that reason with respect to sets of probability distributions.

Whereas the semantic properties of the approach have been investigated in some detail, its algorithmic and computational properties are still challenging. To be useful in practice, the probabilistic DLs obtained by applying this approach need to be equipped with effective reasoning procedures. Thus, another main emphasis of this project is on investigating computational properties (decidability and complexity) of the probabilistic logics obtained by instantiating the approach in particular with DLs of different expressive power.

We plan to apply these methods to set up and use probabilistic ontologies for autonomous vehicles in cellular transport systems and warehouse planning in logistics.

The principal investigators are Franz Baader and Gabriele Kern-Isberner.

Planning and Action Control for Robots in Human Environments

The aim of this project is to develop approaches that help a robot operate in an autonomous and flexible manner in human-centered environments. One of our goals is to assist human users with everyday tasks in a way that aligns with their personal preferences, for example, regarding how to organize objects or prioritize tasks. We address this goal by exploring techniques from recommender system theory to enable a service robot to learn such preferences in a lifelong manner and to tailor its behavior to its environment. This approach allows us to make task (goal) recommendations to high-level planners in order to trade off user preferences with resources such as time or battery life.

This point brings us to another focus of this project, automated planning, where we address the challenge of enabling planners to efficiently react to changing goals and situations. To that end, we adopt an anytime planning approach in which we incrementally produce promising plan prefixes, start executing them, and in the meantime continue to refine the plan in the background. We also investigate heuristics that efficiently guide the search for solutions by abstracting away from geometric states and planning at the symbolic level.

In the context of so-called continual planning, symbolic and geometric reasoning are typically interleaved through semantic attachments. Here, we aim to improve planning efficiency by extending geometric reasoners to incorporate relevant symbolic information. Additionally, we are developing approaches that enable a robot to continuously update its knowledge by learning manipulation skills (for example, how to grasp a new object) from nonexpert user demonstrations, and encoding these skills both symbolically (for example, as plan operators) and in continuous terms.

Another approach to increase the efficiency of planning considers the use of macro-actions. The idea is that plans for typical household tasks such as clearing a table often share short sequences of actions. We identify such plans from a large collection of previously computed plans and turn the shared actions into macro-actions so as to speed up future planning. We have shown that this sorting can be done in a provably correct way for an expressive fragment of the Planning Domain Definition Language (PDDL).

In other work, we are endowing robots with the ability to deal with task interruptions, for example, briefly interrupting a tidying-up task to open the door for a guest. Our continual planner handles this task switching by enabling new searches in the changed situation to reuse the explored space from previous planning requests. Additionally, our high-level controller is able to store what is believed before the interruption and to restore it afterwards to facilitate resuming the stopped task. To support these and other features, we have developed a generic robot memory capable of remembering, updating, and forgetting both short- and long-term information that ranges from abstract symbolic representations to raw sensory data.

Finally, we are closely collaborating with our partners in the Advanced Solving Technology project in the domain of multiagent production logistics as modeled in the RoboCup Logistics League (RCLL). This partner project involves addressing several challenges to improve cooperation within a fleet of robots and hence optimize material flow in a dynamic factory environment. We aim to achieve this optimization using a centralized, global-scope planner based on reactive ASP.

The principal investigators are Wolfram Burgard, Gerhard Lakemeyer, and Bernhard Nebel.

Summary

We believe that the hybrid methods developed in the Hybris Research Unit substantially increase the applicability of symbolic reasoning methods to real-world applications. Some of the principal investigators of the project are currently working on a follow-up proposal that will focus on applications in logistics. We consider logistics an area where hybrid techniques are particularly promising and beneficial. For more information on the Research Unit and links to publications, visit www.hybrid-reasoning.org.

Gerhard Brewka is a professor and chair of Intelligent Systems at the University of Leipzig. He is an ECCAI fellow.

Gerhard Lakemeyer is a professor in the Department of Computer Science and head of the Knowledge-Based Systems Group at RWTH Aachen University.