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(editors):

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Dagstuhl-Seminar-Report; 77
25.10.-29.10.93 (9343)

ISSN 0940-1121

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Deductive Approaches to Plan Generation and Plan Recognition

October 25th–29th, 1993

Planning is a branch of Artificial Intelligence that has received increasing attention. The seminar is devoted to a special aspect, namely to deductive planning and plan recognition. The main topics to be discussed include questions around logic-based representations of plannning domains, the use of logic in plan recognition and the generation and recognition of complex plans. General discussions will focus on the prospects and limitations of deductive approaches in the field, logic-based solutions to the classical AI planning problems, and real applications.

October 25th, 1993

Susanne Biundo Richard Waldinger

Abstracts

Terminological Plan Recognition

Diane Litman, AT&T Bell Laboratories, USA

Description logics are widely used in AI to construct concept taxonomies based on subsumption inferences. However, current description logics are unable to handle complex compositions of concepts, for example constraint networks where each node is described by an associated concept. Plans can be thought of as constraint networks, collections of actions and states related by a rich variety of temporal and other constraints. We have developed the T-REX system, which integrates description logics with constraint network reasoning, to classify plans into an abstraction taxonomy. T-REX also introduces a new terminological view of plan recognition, which dynamically partitions the plan library by modalities (necessary, optional + impossible) while actions are observed. Plan recognition is performed by computing subsumption + compatibily relations from the taxonomy.

Plan Recognition in a Modal Temporal Logic

Gabriele Paul, DFKI Saarbrücken, Germany

It is natural to regard plan recognition as an abductive task: Given some description T of the world and a set of observations (e.g., actions performed by an agent), try to find a plan P that—when added to T—allows to explain the observations. In a logical framework this explanation relation is based on the notion of entailment.
The classical approach to logic-based abduction with predicate logic is to generate one ore more suitable elements contained in a predefined set of so-called abducibles and to perform appropriate instantiations in order to obtain ground formulas as explanations.
As, however, the (plan) hypotheses which are available to the plan recognizer in this approach are formulated in the very expressive modal temporal logic LLP (Logic Language for Planing), things become more complicated. Here, intuitively valid hypotheses do not satisfy the correctness criterion of classical abduction. This problem is caused by the fact that the hypotheses themselves contain a certain temporal extension. So, a weaker notion of explanations is introduced and characterized semantically. The basic idea of this new form of so called temporal abduction is to refine the abstract hypotheses by stepwise incorporating the observations into their temporal and logical structure. This implies that the hypotheses can only be ground up to the current point in time.
The validity of this approach is demonstrated by a prototypical implementation in the framework of an intelligent help system.

Planning, Plan Recognition and Situation Semantics

Wayne Wobcke, University of Sydney, Australia

The frame, ramification and qualification problems are three well known epistemological problems facing any agent reasoning about action. Many approaches to addressing these problems suppose certain semantic principles, e.g. the frame problem is addressed by a principle of minimal change, stating that as little as necessary changes in the world as the result of performing an action. However, an agent does not reason directly with such a principle: agents are supposed to use an epistemic principle of minimal chage, stating that as little as necessary changes in an agent's description of the world as the result of performing an action. We claim that much current research does not bridge the gap between the agent's epistemic principles and the theorist's intended semantics principles, and that part of the problem is the conception of agents as functions over complete world states. We propose an alternative conception of actions as primitive semantic objects occurring in the situations of situation semantics. We also argue that constraints as captured in a hierarchy of types of situations can form the basis of an agent's reasoning about action, and that the necessary constraints can be represented using a standard hierarchy of planning schemas. We present a conditional logic of constraints and show how both planning and plan recognition can be characterized as inference in the logic. We claim that our approach to formalizing action models the practice of existing planning systems more closely than alternative approaches.

Probabilistic Methods in Plan Recognition

Mathias Bauer, DFKI Saarbrücken, Germany

Plan recognition systems usually can only infer a disjunction of possible plans each of which is equally plausible. If, however, the system is forced to come up with a decision for <u>one</u> alternative—e.g., to produce a certain type of cooperative behaviour like supporting the user of a complex system—there must be a criterion to judge the 'quality' of these hypotheses. Certainly, a formalism like probability theory might serve as the basis to define such a selection criterion.
In this talk, however, it is argued that Dempster-Shafer Theory has many advantages over classical probability theory, the most important being the fact that also ignorance about the agent's preferences can be represented explicitly and taken into account during the computations.
On this basis a rule-based approach to plan recognition is proposed which can utilize various forms of statistical information describing the agent's typical behaviour. The resulting numerical values are shown to possess a proper semantics in terms of probability theory and thus form a sound foundation to define a variety of criteria with which hypotheses can be assessed. The availability of such criteria enables the system to produce a kind of anytime behaviour in the sense that the "best" hypothesis can be selected whenever this is required.

Reactive Plan Recognition

Annika Waern, Swedish Institute of Computer Science, Sweden

Plan and goal recognition must typically be performed reactively, that is, they must be performed in limited time, and the solutions are subject to changes as new information is obtained. In previous work, I have addressed the problem of limited time, by defining a search strategy for weighted abduction that entails anytime behaviour.

However, this approach poses problems when adaptivity is sought. Typically, the abductive approach will add assumptions that may or may not be useful in subsequent modifications of the inferred plan. More seriously, explanation is minimised on the set of assumptions made, rather than on the number of explanations ruled out.

My proposed solution is to use observations as conditions on proofs for desired actions. Intuitively, this means that we will seek an explanation for an observed action, only if this explanation is important for the selection of a response action.

This requires a deduction system which allows one to reason "backwards" from conditions to equate a condition with a disjunction over its possible explanations. A candidate system is Partial Inductive Definitions, which contains a deduction rule Definitional Reflexion that does precisely this. Using PID also achieves that assumptions typically rule out possible explanations of observations, allowing for more adequate minimisation criteria.

Several details remain unsolved. Most serious is the task of defining an adequate consistency requirement on assumptions. Secondly, this approach constitutes a general "alternative abduction principle" with a wide variety of applications. In order to be applied to plan inference, a working theory of actions and plans must be selected. Finally, the definition of the limited time search strategy must be extended to include definitional reflexion, in order to achieve reactivity.

Action and Events in Interval Temporal Logic

George Ferguson, University of Rochester, USA
(Joint work with James Allen)

We present a representation of events and action based on interval temporal logic that is significantly more expressive and more natural than most previous AI approaches. The representation is motivated by work in natural language semantics and discourse, temporal logic, and AI planning and plan recognition. The formal basis of the representation is presented in detail, from the axiomatization of time periods to the relationship between action and events and their effects. The power of the representation is illustrated by applying it to the axiomatization and solution of several standard problems from the AI literature on action and change (as gathered by Sandewall). An approach to the frame problem based on explanation closure is shown to be both powerful and natural when combined with our representational framework. We also discuss features of the logic that are beyond the scope of many traditional representations, and describe our approach to difficult problems such as external events and simultaneous actions.

Deductive Planning in a Temporal Logic Framework

Susanne Biundo, DFKI Saarbrücken, Germany

The project PHI aims at the implementation of a logic-based system which supplies intelligent help systems by plan generation and plan recognition facilities. LLP, the Logical Language for Planning, is the underlying logical framework. Plan generation and recognition components are implemented as special purpose inference procedures on its basis. Following the paradigm that plans are programs, LLP combines features of programming and temporal logics. It provides various control structures for plans as well as several plan features. This is appropriate for the context of intelligent help systems since the plans to be generated must be formulated in terms of the command language of the application system. In LLP basic actions are axiomatized like assignment statements in programming logics. This requires only one axiom schema in order to express the immediate effects of an action as well as the facts which remain unchanged; with that, LLP provides an efficient treatment of the frame problem. Plans are special type LLP formulae. They are generated by proof of formal plan specifications using a sequent calculus for LLP. The deductive planner is implemented following a tactical theorem proving approach, thereby performing deductive planning in a strictly goal-directed way.

Will Deduction work in dynamic domains?

Jim Hendler, University of Maryland, USA

Many real-world domains for planning systems have dynamic or uncertain properties. To demonstrate this we show how difficult block-stacking is by a real robot. Uncertainty comes from sensor noise, effector error and unexpected events. We show that solving such problems requires a logic-programming approach that can handle numeric calculation, uncertainty, and modularity. A Logic Programming system that takes some steps in this direction is shown.

State-Event Logic

Gerd Große, TH Darmstadt, Germany

Recently, a number of attempts have been undertaken to extend the state-based approach by introducing operations on events for modeling the simultaneous occurrence of events or causality between events. Such operations always look a bit cumbersome, because events are usually seen as state transitions.
We propose a novel logic that extends the previous approaches in the following directions: first, events enjoy the same attention as states. In the same way as states can be viewed as models of the formulae describing the facts that hold in them we think of events as models of the formulae describing the subevents. Second, instead of postulating just one set of states as primitive objects we use two sets, a set of states and a set of events. In terms of modal logic, the universe then becomes a set of pairs in which one component is a state and the other is one of the events following the state. The connection between two subsequent pairs is expressed by an accessibility relation. This extension permits an elegant treatment of causality and simultaneity, which in turn are the corner stones of our theory of events.

Properties vs. Resources—Evaluating formalisms for planning

Wolfgang Bibel, Technische Hochschule Darmstadt, Germany

There is a plethora of formalisms and methods for planning in the literature (and in this seminar). We argue for efforts towards a clarification of the strengths and weaknesses of these approaches according to suitable criteria. In pursuit of this research program the situational calculus along with Reiter's solution to the frame problem is compared with resource-sensitive formalisms such as the linear connection method, its encoded form ELP^2 and linear logic. It is demonstrated by way of a generic example that the lengths of proofs in the situational calculus are at least quadratically longer than in the resource-sensitive formalisms for members of the class represented by this example. It is conjectured that this class contains in fact all problems. Other virtues of the resource-oriented approaches are discussed (solving the frame problem without frame axioms, accounting for specificity, soundness and completeness w.r.t. Gelfond & Lifschitz' general formalism A, and so forth).

Deductive Planning and the Frame Problem

Camilla Schwind, GIA-CNRS, Faculté des Sciences de Luminy, France

Most logic based approaches to action systems represent an action by a pair of formulae (precondition, postcondition). An action can then possibly occur in a world whenever the precondition holds, and the action yields a new world where the result holds. But when an action occurs, many facts, which are not involved in the action do not change, and other facts, which are indirectly involved, do change. The frame problem can be seen as the problem of how deriving that a fact which is independent of the action does not change as the action occurs. In order to formalize this correctly, we need a formalization of the independency relation. In philosophical logic, there exist some approaches to this problem which could probably be applied. The ramification problem can be seen as the problem of how deriving that a fact which has been caused by a fact that disappears (or which is caused by a fact which appears) also disappears (appears). A formal account for this problem would need a theory of causality. Lacking such a theory generally accepted, we propose to explicitely defining causality between facts.

Planning vs. non-monotonic logics for action and change

Erik Sandewall, Linköping University, Sweden

Knowledge-based planning has usually considered planning in simple worlds with inertia (all changes caused by actions) but without a range of difficulties such as observations at time > 0, actions with extended duration, concurrent actions, causal chains, qualification, ramification, surprises, etc. However, practical appplications often require these harder cases to be considered.

In the research on methods (logics) for reasoning about action and change, non-monotonic logics are commonly used for addressing several (not all) of the above mentioned difficulties. I reviewed recent work where some of the proposed logics have been analyzed w.r.t. upper and lower bounds on the range of correct (= semantically sound and complete) applicability. I argued that (1) the range of a proposed nonmonotonic logic should be assessed before one implements and uses a theorem prover for it; (2) some of the constraints that have been identified in the course of the assessments are of relevance also for planning. For example some methods work correctly only provided the schedule part of the scenario is executable as a plan; (3) some of the distinctions that are needed for the assessments are relevant also for planning. For example, do we require semantic completeness of the nonmonotonic logic whenever planning is performed, or is soundness enough?

Tractable Planning Problems: A Challenge for Deductive Planning

Christer Bäckström, Linköping University, Sweden

We have previously presented a number of planning problems which are computationally tractable, i.e. solvable in polynamial time. These problems are proposed as a challenge for deductive planning in the following way. If the idea of deductive planning is to have one single general planner (a theorem prover) which is supposed to handle all planning problems in the given (logic) formalism, then it should be possible to tune this planner (by adding axioms, for instance) such that it solves one or several of the known tractable planning problems in polynomial time. Ideally, the planner should also recognize such problems automatically.

Reuse of Plans in Deductive Planning Systems

Jana Köhler, DFKI Saarbrücken, Germany

The reuse of plans is widely considered to be a valuable tool for the improvement of efficiency in planning systems. While current approaches extend STRIPS-like planners or are settled within the field of case-based planning, no approaches are known that integrate plan reuse into deductive planning.
I present a unified and logic-based formalization of deductive plan reuse. The basis of the approach is a four-phase model that structures the reuse process. For the formalization of plan reuse those phases are grouped together that perform similar tasks.
Plan modification is based on a theorem proving attempt, where it is shown that a current planning problem P is a logical instance of a previously solved planning problem P'. If the proof is successful, an instance of the plan solving P' will also solve the current planning problem P. If the proof fails, modification information is extracted from the failed proof.
The formalization of the plan library and of the retrieval and update operations working on it, is based on an approximation of the theorem proving attempt performed during plan modification. With that, plan libraries are dynamically built up by learning abstract classes of typical planning problems.
The unified deductive formalization of plan reuse possesses several advantages:

- It is independent from a particular planning formalism and application domain.
- It allows to semantically compare planning problem in contrast to syntactic matches.
- It guarantees that modified plans are provably correct.

Deductive Planning and Analysis of Interplanetary Scientific Missions

Richard Waldinger, SRI International, Menlo Park, California, USA (Joint work with Mark Stickel, SRI, and Michael Lowry, Thomas Pressburger, and Ian Underwood, NASA Ames/Recom Technologies)

Automated deduction techniques are being used in a system called AMPHION to derive, from graphical specifications, software composed of primitives drawn from a subroutine library. The system has been applied to compose software for the planning and analysis of interplanetary missions.

The library is a collection of procedures written in FORTRAN-77 at JPL to perform computations in solar-system kinematics. A theory has been developed that describes the procedures in a portion of that library, as well as some basic properties of solar-system astronomy, in the form of logical axioms. Specifications are expressed in a graphical notation that is congenial to space scientists. The specification is translated into a logical theorem, which is proved constructively in the astronomical theory by an automatic theorem prover SNARK. An applicative program is extracted from the proof and then converted into FORTRAN-77. By the method of construction, the program is guaranteed to meet its specification and requires no further verification.

The system was tested on a set of fifteen sample problems devoleped at NASA in consultation with researchers at JPL and Stanford. The problems involved typical computations involving the sun, planets, moons, and spacecraft. Programs for all fifteen sample problems were constructed entirely automatically, in less than two minutes each; a programmer unfamiliar with the library might have required two or three weeks to construct any of those programs. The system has since been tested successfully with potential NASA users, and arrangements are being made to have the system used from JPL via E-mail, on an experimental basis.

On Constructive Correctness of Deductive Programming Systems

Heinrich Herre, Universität Leipzig, Germany

I present a framework for discussing questions of constructivity and completeness in the field of deductive program synthesis. One of the main problems in this area is to find sufficiently constructive proofs of Π_2-sentences. This does not mean that the proof has to be carried out in a constructive logic. It is desirable to treat proofs in a non-constructive theory and to give a computational meaning to existential quantifiers only. A calculus $\mathcal{S} = (L_{KB}, L_Q, \vdash_C)$ is a system determined by a set L_{KB} of knowledge bases, a language L_Q to formalizing specifications, and a derivability relation $\vdash_C$. Roughly speaking, a calculus $\mathcal{S}$ is constructive for Π_2-sentences if for every sentence $\psi := \forall\bar{x}\exists y\varphi(\bar{x}, y) \in L_Q$ and knowledge base $S \in L_{KB}$ satisfying $S \vdash_C \psi$ a program $\pi(\bar{x})$ can be constructed such that $S \models_H \forall\bar{x}\varphi(\bar{x}, \pi(\bar{x}))$ ($\models_H$

means Herbrand-consequence). It turned out that there are (at least) three versions of constructivity which are called constructive correctness, program correctness and strongly c-correctness. Elementary properties of these notions are studied. Another topic of investigation is the notion of completeness in the sense of constructivity. One can distinguish six versions of constructive completeness (c-completeness), and it is shown that the most important kinds of c-completeness cannot be axiomatized by suitable calculi. This approach to constructivity is new, and thus there remain a number of open problems.

Formal Systems for Plan Synthesis

Edwin Pednault, AT&T Bell Laboratories, USA

A formal system is presented for constructing plans given descriptions of the goals to be achieved, the actions one is allowed to perform, and the initial conditions that exist at the time the plan is executed. The language of the formal system has three parts. The first is a description of a directed acyclic graph in which the vertices correspond to actions and the edges correspond to a partial ordering of the actions. The second part of the language is a set of ordered pairs, where each pair consists of a vertex in the graph and a goal to be achieved immediately before the action corresponding to the vertex is executed. The third part of the language is a set of ordered triples, where each triple consists of a goal whose truth value is to be preserved during the execution of the plan, and two vertices that define the interval in the plan execution during which the truth value of the goal is to be preserved. The inference rules of the formal system are nondeterministic in that they map partially specified plans described in the language to a set of refined plans that correspond to a set of alternative ways of modifying the input plan so as to achieve one of the outstanding goals yet to be achieved in the input plan. When applying an inference rule, one of the alternative plan refinements must be nondeterministically selected before applying further inference rules. The inference rules therefore define a search space over the possible ways of refining a plan to achieve a goal. The mathematical basis for the inference rules is provided by several general theorems of the state transition model of actions. The notion of a secondary precondition is introduced to account for actions with context-dependent effects. A secondary precondition is a condition that must be true at the time an action is performed in order for that action to have a desired effect. Secondary preconditions are defined in terms of, and can be constructed automatically from, regression operators for each action. A language called ADL (for Action Description Language) is presented that in turn allows regression operators to be constructed automatically from descriptions of the effects of context-dependent actions. ADL embodies several constraints that allow the frame problem to be easily solved. It is shown how this solution to the frame problem can be transferred to the situation calculus, resulting in a syntactically restricted form of the situation calculus. This restricted form has been further constrained by Ray Reiter, and a comparison of these two restricted forms is presented.

Recursive Plans

Werner Stephan, DFKI Saarbrücken, Germany

One of the greatest challenges in deductive planning is the generation of recursive plans. We propose an approach that is based on so-called "dynamic" axioms and state-constraints and a general, problem independent form of induction. The logical framework that is used combines STRIPS-like ideas with techniques taken from Program Logics, in particular Dynamic Logic. Basic actions as well as composite plans are defined by PASCAL-like procedures that use add- and delete operations instead of assignments. In order to reason about recursive plans finite and non-circular relational structures are characterized by termination assertions. The induction principle is based on bounds in the number of recursive calls. It is problem independent in the sense that it does not take into account the relational structures that make up the states or situations of a particular planning scenario. As an example we present a solution to the problem of clearing a block in the well known blocks world scenario. By showing the most important proof-steps of the inductive proof we also demonstrate the use of a tactical theorem prover, in particular the Karlsruhe Interactive Verifier (KIV), in deductive plan generation. We claim that the paradigm of tactical theorem proving allows the efficient implementation of correct planning procedures.

Plans and linear logic

Marcel Masseron, Université Paris-Nord LIPN (URA 1507 du CNRS), France

Let us call "disjunctive formal action" a proof in the $\otimes, \oplus$ fragment of Girard's linear logic with proper axioms sequents of the form $A_1, \ldots, A_m \vdash B_1 \oplus \ldots \oplus B_r$ (A_i are atoms, $B_k = B_{k,1} \otimes \ldots \otimes B_{k,n_k}$ are conjuctions of atoms). It is known that a disjunctive formal action represents faithfully an action in a nondeterministic system (inner nondeterminism).
The aim of this work is to represent a disjunctive formal action by a plan, that is a graph of the following type: A node takes pattern by a proper axiom ($\{iA_1, \ldots, iA_m\}$ = entry block, $xB_{k,1}, \ldots, xB_{k,n_k}$ = exit block for every k). An orientation is defined by means of formal algebraic expressions built in a systems $(V, +, x)$: an entry block is labelled by an expression (several entry blocks may have the same label) and an exit block is labelled by an element of V which is unique (proper to the block): $\prec$ is then the transitive closure of 1) $E \prec X$ when X is the exit block of the node of entry E, and 2) when the expression of the entry block E contains the label of the exit X. Atomical links $xB \rightarrow iA$ are then possible when $B = A$ and $xB \in X$, $iA \in E$ satisfy $X \prec E$.
An oriented graph of this type is not necessarily the representation of a disjunctive formal action: the correctness condition is expressed by means of rewriting calculus $(\langle\pi\rangle + \langle\pi'\rangle \rightarrow \langle\pi + \pi'\rangle$, $\langle\pi\rangle\langle\pi'\rangle \rightarrow \langle\pi\pi'\rangle$, $(S + S')T \rightarrow ST + S'T$, and proper

rules defined by nodes). When the application of these rules are correct (w.r.t. the management of atomic entries and exits) a graph corresponds to a disjunctive formal action iff there exists an expression Σ, and a calculus of $\langle\Sigma\rangle$ which "visits" every node exactly once. The main tool is a specialization of the coherent semantics to the concerned fragment of L.L.

Plan Generation with Linear Connection Proofs

Bertram Fronhöfer, TU München, Germany

At the beginning the concept of Linear Connection Proofs was presented by means of a plan generation example. Next the relationship of this approach to STRIPS was discussed. Afterwards a set-based semantics for Linear Connection Proofs was given via an embedding into modal logic. Finally, matrix characterisations of contraction-free logic and of linear logic were presented.

Plan Generation by Linear Deduction

Josef Schneeberger, FORWISS Erlangen, Germany
(Joint work with Steffen Hölldobler and Gerd Große, TH Darmstadt)

Recently, three approaches to deductive planning were developed, which solve the technical frame problem without the need to state frame axioms explicitly. Since these approaches use general deductive principles, they promise to provide full deductive power in order to solve the ramification problem in addition. The three approaches are based on the Linear Connection Method, an equational Horn logic, and Linear Logic. At a first glance these approaches seem to be very different. In the Linear Connection Method a syntactical condition—each literal is connected at most once—is imposed on proofs. In the equational logic approach situations and plans are represented as terms and SLDE-resolution is applied as an inference rule. The Linear Logic approach is a Gentzen style proof system without weakening and contraction rules. On second glance, however, and as a consequence of our result which has been rigourously proved, it turns out that the three approaches are equivalent. They are based on the very same idea that facts about a situation are taken as resources which can be consumed and produced.

RAP – Reasoning about Plans: A New DFKI Project

Wolfgang Wahlster, DFKI Saarbrücken, Germany

The goal of the RAP project is the design of a generic module for reasoning about plans. The reasoning services provided by RAP include the generation, modification, recognition, optimization, validation, and verification of plans.

Any reasoning about plans presupposes a consistent domain model. RAP will provide a domain modeling tool that supports a user in setting up consistent domain axiomatizations in LLP, the Logical Language for Planning developed in the PHI project. We discussed the problems that arise when we want to deal with concurrent actions in plans. In particular, in RAP mechanisms for temporal projection, the symbolic execution, and the merging of concurrent plans will be integrated. Goal structuring techniques are applied to plan specifications for the generation of concurrent plans. The temporal relations between individual goals are incorporated into this ordering process.

One of the reasons for the efficiency of the PHI system is the fact that the proofs performed by the sequent calculus prover for LLP are guided by tactics. We highlighted some approaches to extend the tactic language of a tactical theorem prover so that it will be able to cope with concurrency.

Planning as Tactical Reasoning (or: reasoning about failure and success)

Paolo Traverso, IRST, Italy

We are interested in a semantics and a proof theory for reasoning about the behaviours of a planning agent, e.g. for reasoning about plan generation and execution, failure at execution/planning time, goals/facts acquisition. Most of the work on deductive planning investigates on how "good plans" can be generated by deduction. But we know that there are actually cases where there is no way to "build an a-priori good plan". Plan generation is only one of the possible behaviours of a planning agent. In most real world situations, different kinds of behaviours are indeed required to achieve a goal (plan execution - monitoring - failure handling etc.). The theory of planning that we have in mind aims at providing the foundations to planners able to reason about all these behaviours.

We are at the beginning of this research. We focus on a very important issue: failure. In most of the real world applications no action, even if apparently simple, is guaranteed to succeed. No reasoning can be sound if it does not take into account failure. We discuss how failure and failure handling can be represented explicitly in a theory of planning, how it is possible to reason about failure. We see this as an important preliminary step towards the long term goal of this research.

Power and Thrift: Controlling the Trade-offs in Deductive Planning

Stephen Cranefield, Massey University, New Zealand

There are many advantages of using a deductive approach to planning, especially the extra expressive power available. However, deductive planners are intrinsically less efficient than specialised custom-built planners and their general nature makes them more susceptible to problems of intractability. The key problem in deductive planning is to find ways of gaining the benefits without losing too much in the trade-off between expressive power and computational complexity. It is necessary to combine the descriptive and analytical *power* of logical representations with the *thrift* (in terms of computational resources) that can be achieved by 'hard-wired' planners. Also, as the problem of domain-independent planning is intractable, deductive planners must include some facility for users to communicate their specialised knowledge of the problem domain to the planner.
This talk describes an extensible specialised logic for planning that addresses these issues, and discusses the techniques used to implement it efficiently.

An adaptive deductive planning system

Dietmar Dengler, DFKI Saarbrücken, Germany

If a planning system is used in the context of intelligent help systems then multi-faceted specific requirements have to be fulfilled by its plans generated. Various plan consumers have to be considered in the context mentioned, e.g. a plan recognizer needs plans as hypotheses for the observation of a user of the application system, an advice-giving component would like to have an optimized plan according to a user's suboptimal plan which was recognized to be able to give the user an active support, the user himself needs plans which are adapted on his current knowledge level, and an automatic plan execution facility needs plans without any user-specific overhead. Now, the consequence for a deductive planning system based on theorem proving to be utilized in the scenario mentioned above is that it must be possible to generate a lot of plan variants w.r.t. the same formal plan specification according to dynamically changing requirements. A way this can be done is to use a tactical theorem proving approach and extend it by the concept of configuration tactics. Thereby, it is possible to configure dynamically concrete tactics from an abstract planning tactic w.r.t. an abstract description of planning-specific choice points. Choice points are concerned with, e.g., how subgoals has to be ordered, which control structure has to be used, or in which way a subgoal has to be realized. The expression of specific needs of the different plan consumers is supported by the ability to have a individually structured domain knowledge base.

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