A Plan Ontology – a Working Document – October 31, 1994

Austin Tate
Artificial Intelligence Applications Institute
The University of Edinburgh, 80 South Bridge, Edinburgh EH1 1HN, UK
E-mail: A.Tate@ed.ac.uk Tel: (+44) 131 650 2732 Fax: (+44) 131 650 6513

Contents

Abstract

The AI planning community has used explicit domain description languages and plan definitions for more than 25 years. There is a wealth of experience of defining plan representations for both theoretical studies and practical planning.

In 1992, under the ARPA/Rome Laboratory Planning Initiative (ARPI), a number of participants created the KRSL plan language. Although this has been used for some transfers of information between planning components within the ARPI it has not had the widespread impact desired. Its structure is too rigid and KRSL excludes much that is already being done within planners. A group has been formed to approach the creation of an ontology for plans using new insights gained over the last few years in the knowledge-sharing community in the US and Europe.

KRSL and a number of project specific ontologies and domain description languages (such as SRI's ACT, O-Plan Task Formalism, Toronto's TOVE, CMU's domain description language, etc.) all provide rather detailed descriptions of elements within plans. This paper takes a different *top down* perspective. It seeks to add the small but *vital* overview that can sit above the detailed ontologies already available. It seeks to provide a framework within which alternative detailed ontologies can be created and evaluated in use.

The contribution of this paper is to propose a structure for a plan ontology which is intended to allow for the progressive definition of the various components in a way which should increase the prospect of achieving a smooth fit of the various components into the whole.

1 Purpose

The plan ontology is intended to contribute to a range of purposes including domain modelling, plan capture, plan generation, plan analysis, plan communication, behaviour modelling, etc.

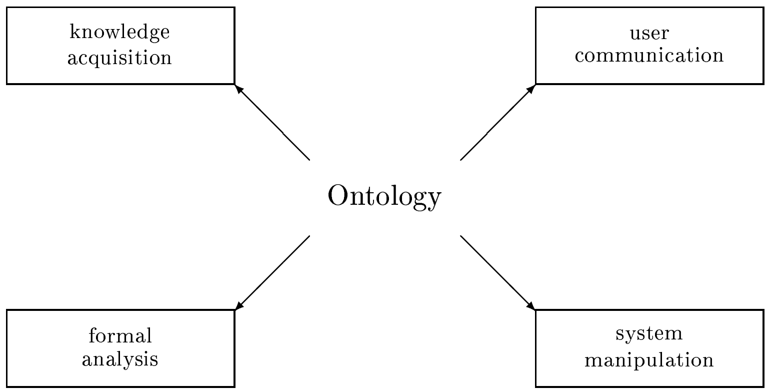

Figure 1: The Ontology Supports a Number of Requirements

The aim of this document is to provide input for the following:

1. The ontology for the Enterprise Toolkit on the UK Enterprise Project (partners AIAI, Lloyds Register, Logica, IBM(UK) and Unilever).
2. To rationalise the O-Plan Task Formalism (Domain Description Language) on the ARPA/Rome Laboratory Planning Initiative project.
3. To provide a target representation for a Plan Knowledge Capture Tool on the UK Defence Research Agency project Acquiring and Using Planning Knowledge for Search and Rescue.
4. To provide a relationship to work on Structured Analysis and Design Techniques (e.g., SADT), Issue-Based Design Methods (e.g., IBIS), Process Management Models and Methods (e.g., IDEF), Entity-Relationship Modelling, Object-Role Modelling (e.g., NIAM), Process Workflow Support, etc.
5. Input to the ARPI Plan Ontology Workshop, 12-Oct-94, Washington D.C.
6. Input to the Workshop on Ontology Development and Use, 2/4-Nov-94, La Jolla, CA.

2 Ontology Structure

The following is the proposed structure of the ontology document. The structure is intended to increase the prospects of achieving integration of the various parts into the whole.

Meta-ontology Fundamental ontological elements used to describe the ontology itself and the assumptions behind the description.

Top Level Ontology The minimal ontology used as a framework for detailed sections of the ontology. The detailed sections refine this top level definition.

Library of Shared Ontological Elements Ontological elements which are shared across the detailed sections but which are not necessary for the description of the top level ontology. These are introduced to ensure that detailed ontology sections are more easily integrated into the whole and shared aspects are standardised across the detailed ontologies.

Detailed Ontology Sections The specific section headings for the detail of the ontology reflects experience in the field. They also may reflect a division of responsibility for some aspects of the ontology. Alternative section groupings are admitted. These detailed ontology sections refine the top level ontology and are, where appropriate, encouraged to make use of components from the library of shared ontological elements.

For the plan ontology, the detailed sections may be derived from the ontologies in the current KRSL 2.0.2, SRI's ACT language, O-Plan's Task Formalism, Toronto's TOVE, etc.

A proposed list of detailed ontological sections is as follows:

Agent
Issue
Activity
Time
Variable
Auxiliary Constraint
Preference
Documentation and Annotation

Encodings of the Ontology Statements in a language which expresses the ontological entities and relationships in symbols. KIF, Conceptual Graphs, LOOM or other representations of the ontology are possible.

Experience of Using the Ontology A collection of papers relating experience in using, adapting or extending the ontology.

[. . .] surrounding text in the sections which follow indicates parts of the definition which are options for possible inclusion and need more discussion.

3 Meta-ontology

The Plan Ontology is composed of a set of ENTITIES and a set of RELATIONSHIPS between ENTITIES.

A RELATIONSHIP is itself an ENTITY that can participate in further RELATIONSHIPS.

3.1 Entities

ENTITY is a fundamental thing in the domain being modelled. An ENTITY may participate in RELATIONSHIPs with other entities.

There may be entity *types* and *instances* in a language based on the ontology.

3.2 Relationships

RELATIONSHIP is an association between two or more entities.

ROLE is the name of the way in which an ENTITY participates in a RELATIONSHIP.

RELATIONSHIP NAME is the name of a relationship in a RELATIONSHIP.

There may be relationship *types* and *sets* of relationship *instances* in a language based on the ontology.

Example

If there is a relationship A SUPPORTS B, then A plays the role of the "supporting-entity" in the relationship, B plays the role of the "supported-entity" in the relationship and the relationship name is "supports".

3.3 Functional Relationships

Some means to regularise the terminology used to associate functional or truth values with some relationships is also required. The following three definitions seek to do this in a general and minimum commitment way.

FUNCTIONAL RELATIONSHIP NAME is a RELATIONSHIP NAME within a RELATIONSHIP in which a number of ENTITIES are uniquely related to certain other ENTITIES.

ATTRIBUTE is a FUNCTIONAL RELATIONSHIP NAME within a FUNCTIONAL RELATIONSHIP in which a given ENTITY is uniquely related to another given ENTITY.

VALUE is an ENTITY. If one ENTITY is uniquely related to another ENTITY, the first ENTITY may be described as a VALUE of an ATTRIBUTE of the second ENTITY. More generally, VALUE is a ROLE of an ENTITY within a FUNCTIONAL RELATIONSHIP.

The 3 definitions given here can be used to express relationships such as fn(ent1,ent2, . . .)=true, fn(ent1,ent2, . . .)=value or even fn(ent1,ent2, . . .)=(entn,entm,. . .) where the entities on the right hand side of the "function" are uniquely related to the fully ground set of instances of the entities on the left side.

Truth valued relationships or expressions are certainly required in almost all planners. An attribute expression capability is a simple and useful form of such a functional relationship - and used by many systems. Richer functional relationship information is used in systems like O-Plan.

It is possible to use such functional relationships to give clause mode declarations to Prolog programs to reduce their search spaces – in some cases drastically. The information is also common in data bases which express unique key sequences to access other fields of a relationship that are functionally dependent on (i.e., unique wrt) the key fields. We would also gain a very direct mapping to Object/Attribute/Value models if this information is available – while not insisting that everything was put into such a modelling view.

Examples

1. If there is a relationship COLOUR(FILTER-4,BLUE) in which the functional relationship is COLOUR(FILTER-4)=BLUE, then "colour" is the attribute of a functional relationship, "filter-4" has the role of being the object of the relationship and "blue" is the value.

2. If there is a relationship DISTANCE(PORT-1,PORT-2,1200) in which the functional relationship is DISTANCE(PORT-1,PORT-2)=1200, then "distance" is the functional relationship, "port-1" and "port-2" have the roles of locations in the functional relationship and "1200" is the value (in some conventional units for that functional relationship).

3. If there is a relationship LOCATION(ROBOT-1,TP-N,POSITION(X,Y,Z)) in which the functional relationship LOCATION(ROBOT-1,TP-N)=POSITION(X,Y,Z), then "location" is the functional relationship, "robot-1" and "tp-n" have the role of being objects of the functional relationship and "position(x,y,z)" is the value of the functional relationship.

4 Plan Ontology

4.1 Informal Context

A Plan is a Specialised Type of Design.

Design for some artifact is a set of constraints on the relationships between the entities involved in the artifact.

Plan is a set of constraints on the relationships between agents, their purposes and their behaviour.

The ontology defines a domain model within which some agents may have purposes and some agents may be capable of performing behaviour. A plan is related to agent purposes and behaviour. Purposes are expressed as constraints on the plan.

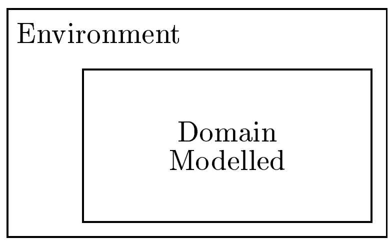

Figure 2: The Domain Modelled and its Environment

The domain modelled sits within an outer environment which may also contain agents whose behaviour is not directly specifiable.

4.2 Principal Definition of a Plan

PLAN is a SPECIFICATION of BEHAVIOUR for some PURPOSE(s).
A PLAN may or may not be EXECUTABLE.

BEHAVIOUR is something that one or more AGENTs PERFORM.

AGENT is an entity that can do one or both of the following:

- PERFORM [, or participate in the PERFORMance of,] BEHAVIOUR.
  It can be a supplier of force behind BEHAVIOUR.
- HOLD some PURPOSE(s).

EXECUTABLE means a PLAN can be PERFORMed by some AGENT(s).

PURPOSE is a CONSTRAINT which is HELD by one or more AGENT(s).

CONSTRAINT is a RELATIONSHIP. It expresses an assertion that can be evaluated with respect to a given PLAN as "something that may hold" and can be elaborated in some language.

SPECIFICATION is a set of CONSTRAINTs.

4.3 Agent to Constraint Relationships

There is a need to differentiate constraints associated with a plan which are hard (environmental and set) requirements and those soft constraints or desirable features. There is also a need to recognise the agent (or computer process) that adds specific constraints during the planning process. It is likely that this information will be needed in the core ontology rather than being left to the detailed ontologies. The following is one suggestion for this.

INTEND, DESIRE, ENFORCE, SYNTHESIZE An AGENT may INTEND, DESIRE, ENFORCE or SYNTHESIZE a CONSTRAINT.

INTENDED CONSTRAINT is a CONSTRAINT, INTENDED by some AGENT, which, when satisfied, supports the RELEVANCE of a PLAN.

DESIRED CONSTRAINT is a CONSTRAINT, DESIRED by some AGENT, which, when satisfied, [supports or increases] the EFFECTIVENESS of a PLAN.
It may be a DOMAIN OBJECTIVE CRITERION in domains for which such criteria have have defined.

AGENT HELD CONSTRAINT is an INTENDED CONSTRAINT or a DESIRED CONSTRAINT.

I.e., PURPOSE = CONSTRAINT which is HELD by an AGENT = AGENT HELD CONSTRAINT.

ENFORCED CONSTRAINT is a CONSTRAINT, ENFORCED by some AGENT, which, when satisfied, supports the EXECUTABILITY of a PLAN.

[The AGENT is often the "ENVIRONMENT" but can also be some other agent outside of the modelled agents (e.g., regulatory authorities if these are not modelled).]

SYNTHESIZED CONSTRAINT is a CONSTRAINT, SYNTHESIZED by some AGENT, which is added to a PLAN as part of the planning process.

[The AGENT is often a computer system assisting with planning.]

5 Library of Shared Ontological Elements

The library of shared ontological elements contains elements which are shared across the detailed sections but which are not necessary for the description of the top level ontology. These are introduced to ensure that detailed ontology sections are more easily integrated into the whole and minimum shared aspects are standardised across the detailed ontologies.

This library can be viewed as having two parts:

1. a minimum set of shared elements common to many of the ways in which detailed ontology sections are provided within the ontology. These are provided as a way to ease the integration of the detailed ontology sections into the whole ontology. The minimal set of shared ontological elements is likely to be quite small.

2. convenient extensions shared across two or more detailed sections. We can thus view the library as making available a range of already defined ontological elements which we can draw on to define the detailed ontological sections. Existing ontologies for relevant or commonly used elements can thus be made available.

5.1 Minimal Set of Shared Elements

Only two entities and one relationship are proposed for inclusion in the minimum set – TIME POINT, ENTITY VARIABLE and TEMPORAL CONSTRAINT.

Since the subject of the ontology is activity plans which are modelled with a temporal aspect, a single shared ontological entity related to time is provided to assist in defining detailed ontologies for time itself and for other related detailed ontological components.

TIME POINT is an ENTITY that represents a specific, instantaneous, point along a time line which is an infinite sequence of time points.

TEMPORAL CONSTRAINT is a RELATIONSHIP between a CONSTRAINT and one or more TIME POINTs.

A detailed ontology of time defines the relationships possible between time points (e.g., a TIME INTERVAL may be defined as a RELATIONSHIP between two TIME POINTs.

ENTITY VARIABLE allows reference to an entity without naming the specific entity. An ENTITY VARIABLE is a virtual entity which anticipates a deferred real entity.

It is often necessary to defer the naming of an entity within a plan or an activity – much in the same way that natural language provides pronouns. A single shared ontological entity is provided to assist in defining the detailed ontologies.

The detailed definition for ENTITY VARIABLE is given in the detailed ontology for variables.

5.2 Extended Library of Shared Elements

The shared ontological elements library will need to include:

SET [and BAGs]

NUMBER

NAME

. . .

6 Agent

Detailed ontology for Agent.

AGENT to PLAN RELATIONSHIPS are certainly important to model the notion of "having a plan" (as described by Martha Pollack in her thesis [6]). These relationships can also capture the notion of commitment to plans, plan purpose relationships, etc.

AGENT to AGENT RELATIONSHIPS can express authority, delegation, etc.

Predefined Constants

ENVIRONMENT – There is a predefined AGENT called the "environment". It can only establish ENFORCED CONSTRAINTS and cannot participate in INTENTED, DESIRED or SYNTHESIZED CONSTRAINT relationships. It may be used to describe all BEHAVIOUR which is not EXECUTABLE by specifically modelled AGENTs.

7 Issue

ISSUE is an implied or pending constraint on a plan. Issues or requirements remaining to be addressed in the plan. These can be used to hold outstanding requirements, the results of plan analysis (e.g., critics) which need attention, etc.

The ontology for issues is likely to be the subject of active research. Discussions of the granularity level of issues is also likely. One source of the types of Issues used in planning is from the ontology used on the PLANIT project [2].

An open ended framework for issues should be provided.

8 Activity

8.1 Principal Definition of Activity

ACTIVITY is a BEHAVIOUR.

ACTIVITY is PERFORMed by one or more AGENTs.

BEGIN TIME POINT, END TIME POINT An activity has a BEGIN TIME POINT and an END TIME POINT.

The CONSTRAINT BEFORE(BEGIN TIME POINT,END TIME POINT) holds.

TEMPORAL CONSTRAINTS may be stated with respect to the BEGIN TIME POINT and/or END TIME POINT of an ACTIVITY.

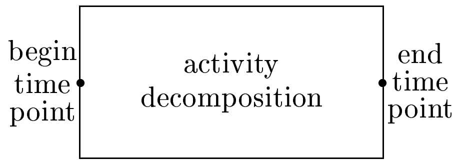

Figure 3: Activity

An activity may optionally have one or more ACTIVITY DECOMPOSITIONs. These provide encapsulation of the detailed descriptions of activities.

Abstraction level modelling may or may not be used within such an encapsulation. Abstraction is an orthogonal issue which can be addressed in a detailed ontology.

Note that an activity may be an action, a resource usage period or some external (to the model) event at this level of the ontology, as no ontological commitment to an action based representation is made at this level.

8.2 Actions and Events

ACTION is an ACTIVITY done by a known (modelled) AGENT.

EVENT is an ACTIVITY done by an unknown (or unmodelled) agent (conventionally referred to as the "environment").

8.3 Activity Decomposition

ACTIVITY DECOMPOSITION is the set of SUB-ACTIVITIES and/or SUB-ACTIVITY CONSTRAINTS.

In general there may be multiple ways in which an activity can be decomposed.

SUB-ACTIVITIES . . .

SUB-ACTIVITY CONSTRAINTS . . .

Predefined Constants

SELF – Within an activity decomposition, the activity itself can be referred to as "SELF" (if necessary).

START, FINISH may be defined to assist in the definition of activity decompositions for a top level activity which serves to specify a PLAN.

9 Time

Mostly from the KRSL 2.0.2 ontology section 2?

TIME POINT – elaboration of minimal shared ontology entity.

TIME POINT CONSTRAINT – . . .

TIME INTERVAL is a specific TIME POINT RELATIONSHIP that is usefully defined in the detailed time ontology. It is a RELATIONSHIP between two TIME POINTS.

DURATION – an absolute distance between two time points measured in some units (e.g., years, weeks, etc.).

Predefined Constants

The following are special cases of a duration:

INFINITY – arbitrarily large duration,

EPSILON – arbitrarily small duration,

ZERO – duration of zero length.

10 Variable

ENTITY VARIABLE – elaboration of minimal shared ontology entity.

ENTITY VARIABLE CONSTRAINT allows RELATIONSHIPS such as co-designation (equality) between variables, non-co-designation (in-equality) between variables, and possibly other constraints such as type membership, general restriction facilities, ranges, etc.

11 Auxiliary Constraint

11.1 Constraints involving Time Points

Three types of TEMPORAL CONSTRAINT are usefully defined – input, output and range constraints. They are not the only types of constraint which can be stated in the ontology (as any relationship between two or more entities can be a constraint). However, they are used frequently in describing other entities in the Auxiliary Constraint ontology.

INPUT CONSTRAINT is a TEMPORAL CONSTRAINT between a CONSTRAINT and a TIME POINT that may or may not be satisfied immediately before the given time point. It is evaluated with respect to that time point.

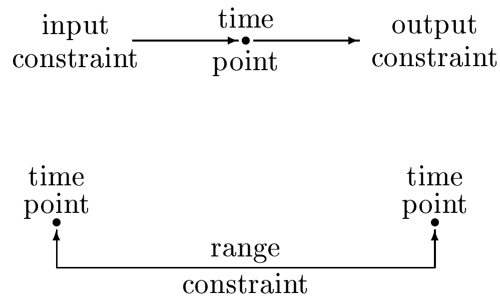

Figure 4: Input, Output and Range Constraints

OUTPUT CONSTRAINT is a TEMPORAL CONSTRAINT between a CONSTRAINT and a TIME POINT that may or may not be satisfied immediately after the given time point. It is evaluated with respect to that time point.

RANGE CONSTRAINT is a TEMPORAL CONSTRAINT between a CONSTRAINT and two TIME POINTs that may or may not be satisfied at all times between the two given time points.

11.2 Details of Auxiliary Constraints

This is likely to be the subject of active research, so a general framework and extension facilities should be provided. The following is the framework adopted in the O-Plan ontology and Task Formalism language.

AUTHORITY CONSTRAINTS are AGENT to AGENT RELATIONSHIPS.
Possibly based on the ORDIT ontology?
Also see O-Plan TF Authority Statements.

STATE CONSTRAINTS express domain statements with respect to time.
A Synonym for State Constraint might be World Condition.
Possibly based upon SRI's ACT and O-Plan TF condition/effect ontologies?

There are three purposes for state constraints:

1. context or environment constraints (filter conditions).
2. value added input/output chain.
3. setup conditions and/or side-effects.

Examples of state constraints might be:
CONDITION(ON(A,B),TRUE,TP-M)
EFFECT(ON(A,B),TRUE,TP-N)

RESOURCE CONSTRAINTS Possibly based on Toronto TOVE resource ontology?
See also KRSL, O-Plan TF and SRI's ACT.

OTHER CONSTRAINTS Open ended framework (e.g., for spatial constraints and research opportunities).
E.g., see O-Plan TF "other constraints" statement.

12 Preference

DESIRED CONSTRAINTS relate individual AGENT DESIRES for some CONSTRAINT within a plan. An ability to describe the relationship between different agent's preferences and to provide facilities to allow a pairwise comparison of two plans with respect to these preferences should be provided in a detailed ontology.

13 Documentation and Annotation

Although not part of the ontology, any supporting language in which the ontology can be expressed is required to provide documentation and annotation facilities.

An ability to name and give a version number or revision date to an ontology section, or to an ontological element in a library of such elements is to be provided.

An ability to note which other ontology sections or library elements are used as a basis for any given section is to be provided.

14 Notes and Discussion Points

14.1 Alternative Terms

This is a list of alternative terms and partially equivalent usages for some of the terms in the ontology.

ENVIRONMENT = NATURE?

Activities that take place (automatically) outside of the modelled environment or constraints enforced from outside of the modelled environment are attributed to the ENVIRONMENT AGENT for regularity of modelling within the ontology. In some cases, such constraints could be viewed as laws of nature or natural events.

CONSTRAINT = STATEMENT, PROPOSITION, CONDITION OR EFFECT?

ENFORCED CONSTRAINT = PHYSICAL CONSTRAINT, SUFFICIENCY CONSTRAINT or EXECUTABILITY CONSTRAINT.

An ENFORCED CONSTRAINT (enforced by the ENVIRONMENT or perhaps by some other non-modelled AGENT) may be called a LAW?

INTENDED CONSTRAINT = REQUIRED CONSTRAINT, NECESSARY CONSTRAINT or HARD CONSTRAINT.

DESIRED CONSTRAINT = PREFERENCE or SOFT CONSTRAINT.

SYNTHESIZED CONSTRAINT = DERIVED CONSTRAINT?

PURPOSEs and PREFERENCEs = GOAL(s)?

ATTRIBUTE = PROPERTY.

14.2 Other Issues

OCCURRENCES, EVENTS, EXECUTIONS and ACTIONS – David Traum and James Allen of Rochester use OCCURRENCE for what we call an ACTIVITY entity here. They split OCCURRENCES into EVENTS (as used here) and EXECUTIONS (caused by intentional activity). EXECUTIONS are like ACTIONS here. They model the relationship between PLANs and AGENTs with relationship names such as ADOPT and COMMIT.

ENFORCED CONSTRAINTS (which are unavoidable or inviolate) need discussion. They are introduced to separate required goals and objectives to be satisfied from the physical and other constraints external to the modelled domain and which cannot be violated in any plan or behaviour considered as executable in that domain.

SYNTHESIZED CONSTRAINTS (which are added during the problem solving process) need discussion. The may be implied by or derived from the ENFORCED, INTENDED or DESIRED CONSTRAINTS expressed by AGENTS. Or they might be "arbitrary" constraints added to narrow down the plan space implied by the plan constraint set for some purpose (e.g., during search for a feasible solution).

Acknowledgements

The present state of this ontology of plans has benefited from detailed comment and input from Mike Uschold and members of the Enterprise and the Defence Research Agency Search and Rescue project teams.

The details have been refined in discussion with members of the KRSL planning ontology development group formed under the ARPA/Rome Laboratory Planning Initiative (ARPI) and the ARPA Ontology Development and Use Group.

References

[1] Howard Beck, Ken Currie and Austin Tate, A Domain Description Language for Job-Shop Scheduling, AIAI-TR-137 October 1993. Artificial Intelligence Applications Institute, University of Edinburgh.

[2] Mark Drummond and Austin Tate, PLANIT Interactive Planners' Assistant – Rationale and Future Directions. Reprints of working papers to the Alvey Programme PLANIT Community Club distributed in 1986-7. Available as AIAI-TR-108, AIAI, University of Edinburgh.

[3] Mark S. Fox, John F. Chionglo, and Fadi G. Fadel, A Common-Sense Model of the Enterprise, Proceedings of the Second IERC. Department of Industrial Engineering, University of Toronto.

[4] Michael Gruninger and Mark S. Fox, An Activity Ontology for Enterprise Modelling. Department of Industrial Engineering, University of Toronto.

[5] Nancy Lehrer (ed.), ARPI KRSL Reference Manual 2.0.2, February, 1993. ISX Corporation.

[6] Martha Pollack, Inferring Domain Plans in Question Answering, Ph.D. Thesis, Department of Computer and Information Science, University of Pennsylvania, May 1986.

[7] Austin Tate, O-Plan Task Formalism Manual, Version 2.2, July 5, 1994. Artificial Intelligence Applications Institute, University of Edinburgh.

[8] Austin Tate, Characterising Plans as a Set of Constraints – the <I-N-OVA> Model – a Framework for Comparative Analysis, to appear in Special Issue on "Evaluation of Plans, Planners, and Planning Agents", ACM SIGART Bulletin Vol. 6 No. 1, January 1995.

[9] David E. Wilkins and Karen L. Myers, A Common Knowledge Representation for Plan Generation and Reactive Execution, SRI International Artificial Intelligence Center. This paper has been accepted to the Journal of Logic and Computation, and should appear in late 1994 or 1995.