Towards a Plan Ontology

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Abstract

This paper describes inputs to various international standardisation efforts for process and plan interchange. Our approach takes a *top down* perspective. It seeks to add the small but *vital* overview that can sit above the detailed representations or 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 Background

It is important that information about processes and activities are sharable within and across organisations. Cooperation and coordination of the planning, monitoring and workflows of the organisations can be assisted by having a clear shared model of what comprises plans, processes and activities.

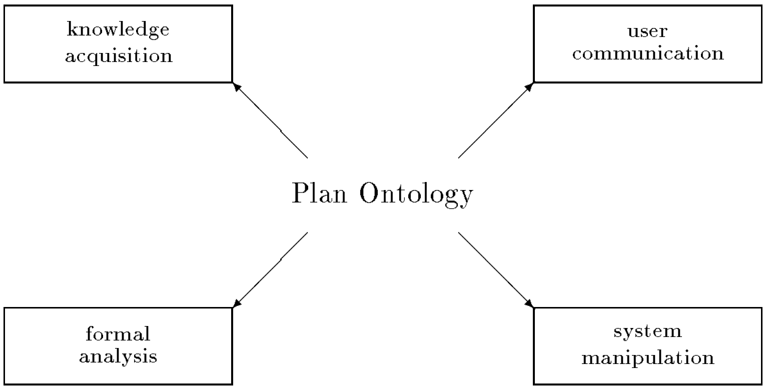
The AI planning community has used explicit domain description languages and plan definitions for more than 25 years. There is a wealth of experience of defining plan representations for both theoretical studies and practical planning. More recently, there have been a number of initiatives to standardise terminology related to processes in PIF (the Process Interchange Format [8]); workflow (the International Workflow Management Coalition [16]); and in the US military planning research community.

In 1992, under the ARPA/Rome Laboratory Planning Initiative (ARPI) [5], a number of participants created the KRSL plan language [9]. Although this has been used for some transfers of information between planning components within the ARPI [1] it has not had the widespread impact desired. Its structure is too rigid and KRSL excludes much that is already being done within planners. In 1994, a group was 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.

The current document describes a framework for a plan or activity ontology and shows the basis of inputs given to a number of standards activities that relate to plan and process interchange.

2 Purpose of the Plan Ontology

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. By having a shared model of what constitutes a plan, process or activity, organisational knowledge can be harnessed and used effectively.



For example, the Edinburgh plan/activity ontology work has provided 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) [6].
2. To rationalise the O-Plan Task Formalism (Domain Description Language) on the ARPA/Rome Laboratory Planning Initiative project [14].
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" [2].
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 ARPA/Rome Laboratory Planning Initiative KRSL [9] follow on efforts and the ARPI Plan Ontology Construction Group.
6. Input to discussions and workshops organised by ARPA into ontologies for knowledge sharing, such as the Workshop on Ontology Development and Use, November '94, La Jolla, CA.
7. Input to the Process Interchange Format (PIF) standard being worked on by a number of projects interested in exchanging process information [8]. In particular to move to a more robust basis for version 1.1 of this standard.

8. To relate to the International Workflow Management Coalition work in standardising workflow systems and process terminology via their Glossary of Workflow terms [16].

3 Ontology Structure

The following is the proposed structure of a Plan Ontology document. The structure of the ontology itself and the document that describes it are intended to increase the prospects of achieving integration of the various parts and extensions 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 then 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. This is similar to and shares the objectives of the "Partial Shared View Mechanism" adopted in the Process Interchange Format (PIF) documents [8].

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.

The detailed ontology will include:

Agent
Issue
Activity
Time
Variable
Auxiliary Constraint
Preference
Documentation and Annotation

The core activity model within this ontology draws on the <I-N-OVA> (Issues – Nodes – Orderings/Variables/Auxiliary) constraint model of plans [13] proposed recently to integrate a number of perspectives on plan and process representation.

To give detail to the various detailed sections of the plan ontology, current best practice may be derived from the ontologies in the current KRSL 2.0.2 [9], SRI's ACT language [15], O-Plan's Task Formalism [12], Toronto's TOVE [7], etc.

In a complete document describing the Plan Ontology, encodings of the ontology may also be given 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 should also be brought together in some form such as a collection of papers relating experience in using, adapting or extending the ontology.

The rest of this paper gives a complete top level description of a plan ontology within the structure proposed above. It is the basis on which inputs to the various process and plan standardisation efforts and contributions to a number of collaborative projects involving plan interchange have been made.

4 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.

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

RELATIONSHIP is an association between two or more entities[1].

5 Plan Ontology

5.1 Informal Context

A Plan is a Specialised Type of Design.

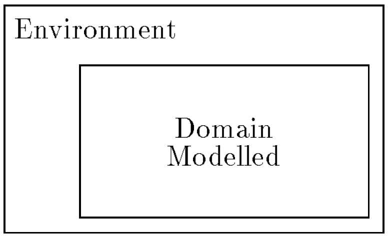
Design for some artifact is a set of constraints on the relationships between the entities involved in the artifact.

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.

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

[1]Some means to regularise the terminology used to associate functional or truth values with some relationships is advisable and included in our full proposals.



5.2 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.

5.3 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.]

6 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.

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.

7 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 [10]). These relationships can also capture the notion of commitment to plans, plan purpose relationships, etc.

AGENT to AGENT RELATIONSHIPS can express authority, delegation, contracts, organisational relationships 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.

8 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. Discussion 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 [4].

An open ended framework for issues should be provided.

9 Activity

9.1 Principal Definition of Activity

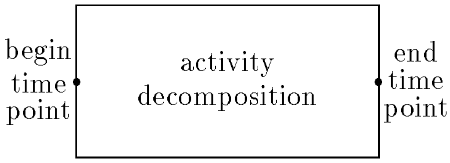
ACTIVITY is a BEHAVIOUR.

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.



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.

9.2 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").

9.3 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 is a set of ACTIVITIES.

SUB-ACTIVITY CONSTRAINTS is a set of 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.

10 Time

TIME POINT – elaboration of minimal shared ontology entity.

TIME INTERVAL is a specific TEMPORAL CONSTRAINT 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.).

Further details can be included from, e.g., the KRSL 2.0.2 ontology section 2 [9].

11 Variable

ENTITY VARIABLE – an elaboration of the minimal shared ontology entity is possible.

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.

12 Auxiliary Constraint

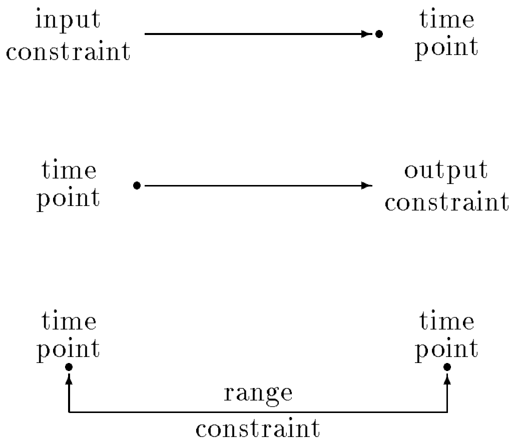
12.1 Constraints involving Time Points

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.

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.



12.2 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 <I-N-OVA> ontology [13] and as a basis for the O-Plan Task Formalism language [12]. This framework deliberately seeks to ensure overlap with activity and process representations in workflow and software engineering work.

AUTHORITY CONSTRAINTS are AGENT to AGENT RELATIONSHIPS. Possibly based on the ORDIT ontology [3]. Also see O-Plan TF Authority Statements [11].

STATE CONSTRAINTS express domain statements with respect to time. A Synonym for State Constraint might be World Condition. Possibly based upon SRI's ACT [15] and O-Plan TF condition/effect ontologies [12].

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.

RESOURCE CONSTRAINTS Possibly based on Toronto TOVE resource ontology [7]. See also KRSL [9], O-Plan TF [12]and SRI's ACT [15].

OTHER CONSTRAINTS Open ended framework (e.g., for spatial constraints and research opportunities). E.g., see O-Plan TF "other constraints" statement [12]

13 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.

14 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.

Acknowledgements

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Appendix: KRSL Plan Ontology Working Group

During 1994, the ARPA/Rome Laboratory Planning Initiative (ARPI) Plan Ontology Construction Group decided to discuss a follow on to the previous KRSL version 2.0.2 used within the ARPI. The plan ontology structure described in this paper was provided as input to these deliberations.

What is a Plan?

Following some preparatory electronic discussions, at the 12th October 1994 meeting they agreed 4 sentences to define what a plan is and how the principal entities relate to a plan. The definition was:

- A PLAN is a SPECIFICATION of BEHAVIOUR for some PURPOSE(s).
- BEHAVIOUR is something that one or more AGENTs PERFORM.
- An AGENT is an entity that PERFORMs BEHAVIOUR and/or can have PURPOSE(s).
- A PURPOSE is an EFFECT that is [INTENDED or DESIRED] by an AGENT.

KRSL-Plans Ontology for Activity

Over the following months a working group[2][3] worked on the next level of the ontology and agreed the next level of definition (draft of 2nd February 1995 with minor later lexical edits).

ACTIVITY is an important building block in the Plan Ontology. A Plan is itself a description of activity but with the additional relationship of the activity to purpose (and the agents which have the purpose).

An Activity can relate directly to an action that is performed in a discrete fashion, or may relate to the period of usage of resources. This can allow the ontological entity of activity to merge both action planning and resource scheduling perspectives.

BEHAVIOUR is the performance of one or more ACTIVITIES (a non-empty set of activities).

An ACTIVITY takes place over a TIME INTERVAL.

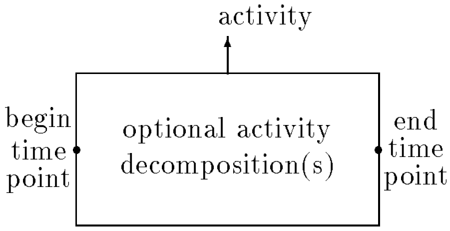
The TIME INTERVAL for an ACTIVITY is identified by its two ends, the BEGIN TIME POINT and the END TIME POINT.

An ACTIVITY may optionally have CONSTRAINTS associated with it or with its TIME INTERVAL.

An ACTIVITY may bring about certain STATES OF AFFAIRS.

[2] Austin Tate (chair), David Wilkins (SRI), Steve Smith (CMU) and Bill Swartout (USC/ISI).

[3] A more detailed level of activity model in the ontology was proposed but is not reproduced here – see `http://www.aiai.ed.ac.uk/~bat/krsl-plans.html`.



Optionally, an ACTIVITY may be decomposed into one or more SUB-ACTIVITIES to provide more detail. There can be several alternative such ACTIVITY DECOMPOSITIONS.

SUB-ACTIVITY: Sub-activities are the constituent activities designated in any ACTIVITY DECOMPOSITION.

Notes: Referring to an activity as a sub-activity refers to the role of an ACTIVITY in a relationship with another ACTIVITY such that performance of the SUB-ACTIVITY is considered to be part of the performance of the other ACTIVITY.

ACTIVITY DECOMPOSITION: The specification of how an ACTIVITY is decomposed into one or more SUB-ACTIVITIES; this may include the specification of constraints on and between the SUB-ACTIVITIES.

Notes: The constraints can be sub-activity orderings, world conditions, effects, resource requirements, organisational permissions, etc.

Notes: Activity decomposition does not necessarily imply that a different level of abstraction to that used in the main activity is used in the description of the sub-activities and the constraints on them. For example, it is possible to provide an activity decompositions which uses recursion by including the parent activity type as a sub-activity. Model Abstraction level is orthogonal to structural activity decomposition level.

PRIMITIVE ACTIVITY is an ACTIVITY with no (further) ACTIVITY DECOMPOSITION.

STATES OF AFFAIRS - broadly defined to mean things we can evaluate as holding or not in the (model of the) world. They can refer to an individual world state (such as NOW), or may refer to world histories, changes between world states, etc.

An ACTIVITY may change the STATE-OF-AFFAIRS during its performance.

CONSTRAINTS can be stated with respect to none, one or more than one time point. They express things which are required to hold. They are evaluable with respect to a specific PLAN as holding or not holding.

Such constraints may refer to world statements (conditions and effects), resource requirements and usage, authority requirements or provision, etc.