# <I-N-OVA> and <I-N-CA> - Representing Plans and other Synthesised Artifacts as a Set of Constraints

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### Abstract

This paper presents an approach to representing and manipulating plans and other synthesised artifacts in the form of a set of constraints. The <I-N-OVA>[1] (*Issues – Nodes – Orderings/Variables/Auxiliary*) constraints model is used to characterise plans and processes. The more general <I-N-CA> (*Issues – Nodes – Critical/Auxiliary*) constraints model can be used for wider applications in design, configuration and other tasks which can be characterised as the synthesis and maintenance of an artifact or product. The <I-N-OVA> and <I-N-CA> constraint models are intended to support a number of different uses:

- for automatic manipulation of plans and other synthesised artifacts and to act as an ontology to underpin such use;
- as a common basis for human communication about plans and other synthesised artifacts;
- as a target for principled and reliable acquisition of plans, models and product information;
- to support formal reasoning about plans and other synthesised artifacts.

## Motivation

As shown in figure 1, the <I-N-OVA> and <I-N-CA> constraint models are intended to support a number of different uses:

- for automatic manipulation of plans and other synthesised artifacts and to act as an ontology to underpin such use;
- as a common basis for human communication about plans and other synthesised artifacts;
- as a target for principled and reliable acquisition of plans, models and product information;
- to support formal reasoning about plans and other synthesised artifacts.

[1] <I-N-OVA> is pronounced as in "Innovate".

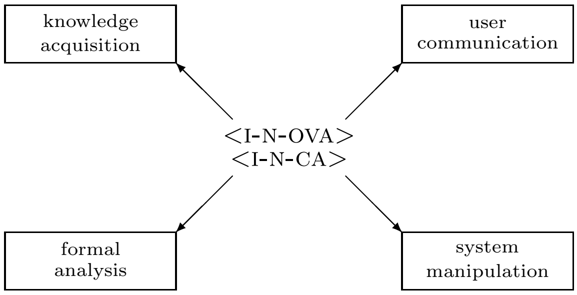


Figure 1: <I-N-OVA> and <I-N-CA> Support Various Requirements

These cover both formal and practical requirements and encompass the requirements for both human and computer-based planning and design systems.

The <I-N-OVA> (*Issues – Nodes – Orderings/Variables/Auxiliary*) Model is a means to represent plans and activity as a set of constraints. By having a clear description of the different components within a plan, the model allows for plans to be manipulated and used separately from the environments in which they are generated. The underlying thesis is that plans can be represented by a set of constraints on the behaviours possible in the domain being modelled and that plan communication can take place through the interchange of such constraint information.

<I-N-OVA>, when first designed (Tate, 1996), was intended to act as a bridge to improve dialogue between a number of communities working on formal planning theories, practical planning systems and systems engineering process management methodologies. It was intended to support new work then emerging on automatic manipulation of plans, human communication about plans, principled and reliable acquisition of plan information, and formal reasoning about plans. It has since been utilised as the basis for a number

of research efforts, practical applications and emerging international standards for plan and process representations. For some of the history and relationships between earlier work in AI on plan representations, work from the process and design communities and the standards bodies, and the part that <I-N-OVA> played in this see Tate (1998).

In Tate (1996), the <I-N-OVA> model is used to characterise the plan representation used within O-Plan (Currie and Tate, 1991; Tate et.al, 1994) and is related to the plan refinement planning method used in O-Plan. The <I-N-OVA> work is related to emerging formal analyses of plans and planning. This synergy of practical and formal approaches can stretch the formal methods to cover realistic plan representations as needed for real problem solving, and can improve the analysis that is possible for practical planning systems.

We have generalised the <I-N-OVA> approach to design and configuration tasks with I, N, CA components - where C represents the "critical constraints" in any particular domain - much as certain O and V constraints do in a planning domain. We believe the approach is valid in design and synthesis tasks more generally - we consider planning to be a limited type of design activity. <I-N-CA> is used as an underlying ontology for the I-X project[2].

The <I-N-OVA> and <I-N-CA> work is intended to utilise a synergy of practical and formal approaches which are stretching the formal methods to cover realistic representations, as needed for real problem solving, and can improve the analysis that is possible for practical planning systems.

## <I-N-OVA> - Representing Plans as a Set of Constraints on Behaviour

The <I-N-OVA> model is a means to represent and manipulate plans as a set of constraints. By having a clear description of the different components within a plan, the model allows for plans to be manipulated and used separately to the environments in which they are generated.

A plan is represented as a set of constraints which together limit the behaviour that is desired when the plan is executed. The set of constraints are of three principal types with a number of sub-types reflecting practical experience in a number of planning systems.

The node constraints (these are often of the form "include activity") in the <I-N-OVA> model set the space within which a plan may be further constrained. The I (issues) and OVA constraints restrict the plans

[2] I-X is the successor project to O-Plan - see http://www.aiai.ed.ac.uk/project/ix/.

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Plan Constraints
   I   - Issues (Implied Constraints)
   N   - Node Constraints (on Activities)
   OVA - Detailed Constraints
         O - Ordering Constraints
         V - Variable Constraints
         A - Auxiliary Constraints
             - Authority Constraints
             - Condition Constraints
             - Resource Constraints
             - Spatial Constraints
             - Miscellaneous Constraints
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Figure 2: <I-N-OVA> Constraint Model of Activity

within that space which are valid. Ordering (temporal) and variable constraints are distinguished from all other auxiliary constraints since these act as *cross-constraints*[3], usually being involved in describing the others – such as in a resource constraint which will often refer to plan objects/variables and to time points or ranges.

## Rationale for the Categories of Constraints within <I-N-OVA>

Planning is the taking of planning decisions (I) which select the activities to perform (N) which creates, modifies or uses the plan objects or products (V) at the correct time (O) within the authority, resources and other constraints specified (A). The node constraints (these are often of the form "include activity") in the <I-N-OVA> model set the space within which a plan may be further constrained. The I (issues) and OVA constraints restrict the plans within that space which are valid. The Issues (I constraints are the items on which selection of Plan Modification Operators is made in agenda based planners.

Others have recognised the special nature of the inclusion of activities into a plan compared to all the other constraints that may be described. Khambhampati and Srivastava (1996) differentiate Plan Modification operators into "progressive refinements" which can introduce new actions into the plan, and "non-progressive refinements" which just partitions the search space with existing sets of actions in the plan. They call the former genuine planning refinement operators, and think of the latter as providing the scheduling component.

[3] Temporal (or spatio-temporal) and object constraints are cross-constraints specific to the planning task. The cross-constraints in some other domain may be some other constraint type.

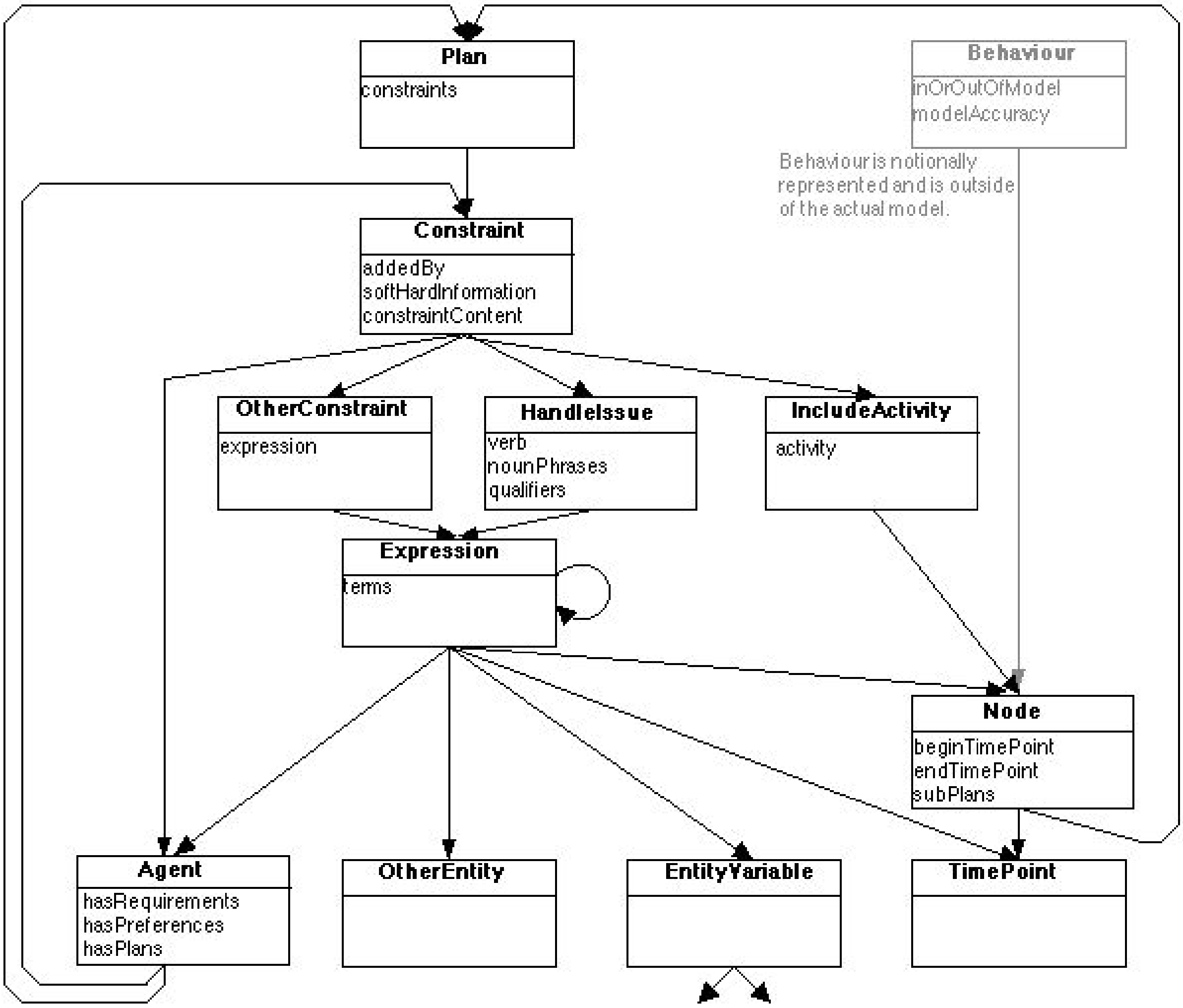


Figure 3: Top Level of <I-N-OVA> Object Model

If we consider the process of planning as a large constraint satisfaction task, we may try to model this as a Constraint Satisfaction Problem (CSP) represented by a set of variables to which we have to give a consistent assignment of values. In this case we can note that the addition of new nodes ("include activity" constraints in <I-N-OVA> ) is the only constraint which can add variables dynamically to the CSP. The Issue (I) constraints may be separated into two kinds: those which may (directly or indirectly) add nodes to the plan and those which cannot. The I constraints which can lead to the inclusion of new nodes are of a different nature in the planning process to those which cannot.

Ordering (temporal) and variable constraints are distinguished from all other auxiliary constraints since these act as cross-constraints, usually being involved in describing the others – such as in a resource constraint which will often refer to plan objects/variables and to time points or intervals.

## Mappings to an Object Model

Plans, processes, activity and other synthesised artifacts when described in the form of a set of <I-N-OVA> and <I-N-CA> constraints have a straightforward and easily extended mapping to an object-oriented model, the top level of which is shown in Unified Modelling Language (UML) notation in figure 3[4].

[4] See http://www.aiai.ed.ac.uk/~oplan/inova.html for more details and specialisations of the object model related to <I-N-OVA> and <I-N-CA>.

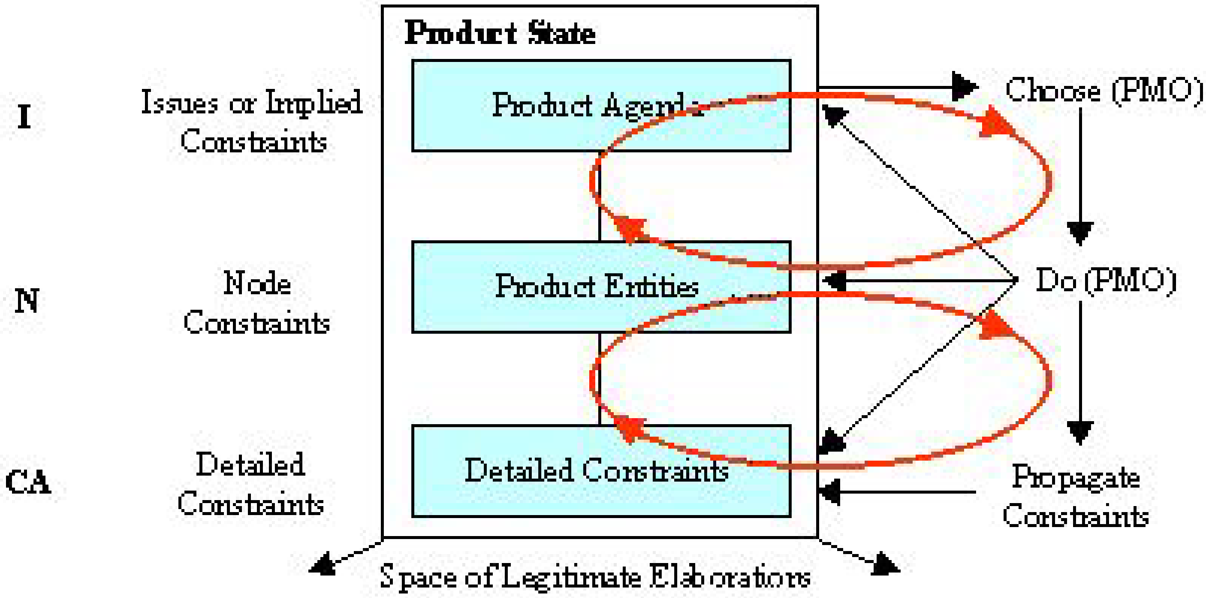


Figure 4: Two Cycles of Processing - Handle Issues, Respect Constraints. PMO=Product Modification Operator

## Sorted First Order Logic Base, and XML

<I-N-OVA> and <I-N-CA> are meant as conceptual models which can underly any of a range of languages which can describe activities, plans, processes and other synthesised artifacts. For example, O-Plan is based on <I-N-OVA> , but utilises the Task Formalism domain description language which has a simple keyword introduced syntax.

It is anticipated that any <I-N-OVA> or the more general <I-N-CA> model in whatever language or format it is expressed can be reduced to a conjunctive set of statements in first order logic with strong requirements on the type of the terms involved in each statement - i.e. a Sorted First Order Logic. See Polyak and Tate (2000) for further details, and for a use described in a planning domain modelling support system.

<I-N-OVA> and <I-N-CA> constraint sets lend themselves very well to being used in eXtendible Markup Language (XML) representations of synthesised artifacts, especially when these are still in the process of being designed or synthesised. The processes that are used to do this synthesis and the collaborations and capabilities involved can also be described in <I-N-OVA> and/or <I-N-CA> .

## Relationship to Planning Architectures

A general approach to designing AI-based planning and scheduling systems based on partial plan or partial schedule representations is to have an architecture in which a plan or schedule is critiqued to produce a list of issues or agenda entries which is then used to drive a workflow-style processing cycle of choosing a "Plan Modification Operator" and then executing it to modify the plan state. Figure 4 shows this graphically for the more general case of designing or synthesising any product - where the issue handlers are labelled "PMO" - which then stands for the more general "Product Modification Operator".

This approach is taken in systems like O-Plan, OPIS (Smith, 1994), DIPART (Pollack, 1994), TOSCA (Beck, 1994), etc. The approach fits well with the concept of treating plans as a set of constraints which can be refined as planning progresses. Some such systems can also act in a non-monotonic fashion by relaxing constraints in certain ways.

Having the implied constraints or "agenda" as a formal part of the plan provides an ability to separate the plan that is being generated or manipulated from the planning system itself and this is used as a core part of the O-Plan design.

Mixed Initiative Planning approaches, for example in O-Plan (Tate, 1994), improve the coordination of planning with user interaction by employing a clearer shared model of the plan as a set of constraints at various levels that can be jointly and explicitly discussed between and manipulated by user or system in a cooperative fashion.

## Summary

The <I-N-OVA> Constraint Model of Activity and the more general <I-N-CA> Constraint Model for Synthesised Artifacts has been described. These are designed to relate strengths from a number of different communities: the AI planning community with both its theoretical and practical system building interests; the issue-based design community, those interested in formal ontologies for processes and products; the standards community; those concerned with new opportunities in task achieving agents on the world wide web; etc.

<I-N-OVA> is intended to act as a bridge to improve dialogue between the communities working in these areas and potentially to support work on automatic manipulation of plans, human communication about plans, principled and reliable acquisition of plan information, and formal reasoning about plans. <I-N-CA> is designed as a more general underlying ontology which can be at the heart of a flexible and extensible systems integration architecture involving human and system agents. This is the aim of new work on the I-X project.

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