Multi-agent Planning via Mutually Constraining the Space of Behaviour

Position Paper

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Abstract

Work is described which seeks to support multi-agent mixed initiative interaction between a "task assignment" or "command" agent and a planning agent[1]. Each agent maintains an agenda of outstanding tasks it is engaged in and uses a common representation of tasks, plans, processes and activities based on the notion that these are all "constraints on behaviour". Interaction between the agents uses explicit task and option management information. This framework can form a basis for mixed initiative user/system agents working together to mutually constrain task descriptions and plans and to coordinate the task-oriented generation, refinement and enactment of those plans.

Introduction

Under the O-Plan Project (Currie and Tate, 1991; Tate, Drabble and Kirby, 1994) at the University of Edinburgh, which is part of the DARPA/Rome Laboratory Planning Initiative (Tate, 1996a), we are exploring mixed initiative planning methods and their application to realistic problems in logistics, air campaign planning and crisis action response (Tate, Drabble and Dalton, 1996). In preparatory work, O-Plan has been demonstrated operating in a range of mixed initiative modes on a Non-Combatant Evacuation Operation (NEO) problem (Tate, 1994; Drabble, Tate and Dalton, 1995). A number of "user roles" were identified to help clarify some of the types of interaction involved and to assist in the provision of suitable support to the various roles (Tate, 1994)

New work started in 1995 is exploring the links between key user roles in the planning process and automated planning support aids – see figure 1. Research is exploring a planning workflow control model using:

- the <I-N-OVA> constraint model of activity as the basis for communication;
- explicit management between agents of the tasks and options being considered;
- agent agendas and agenda issue handlers.

[1]This paper is based on material presented at the AAAI-97 Spring Symposium on Mixed Initiative Interaction, March 1997, Stanford University.

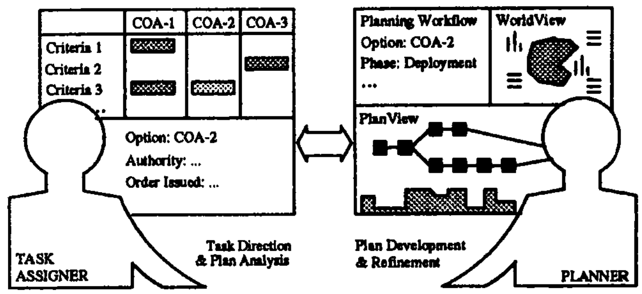

Figure 1: Communication between Task Assigner and Planner

Representing Plans as a Set of Constraints on Behaviour

The <I-N-OVA>[2] (*Issues – Nodes – Orderings / Variables / Auxiliary*) 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.

In Tate (1996), the <I-N-OVA> model is used to characterise the plan representation used within O-Plan 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 production planning systems.

<I-N-OVA> is intended to act as a bridge to improve dialogue between a number of communities working on formal planning theories, practical planning systems

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

and systems engineering process management methodologies. It is intended to support new work on automatic manipulation of plans, human communication about plans, principled and reliable acquisition of plan information, and formal reasoning about plans.

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.

```
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
```

Figure 2: <I-N-OVA> Constraint Model of Activity

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. 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.

Task and Option Management

O-Plan Architecture

Task and option management facilities are provided by the *Controller* in O-Plan. The O-Plan Controller takes its tasks from an agenda which indicates the outstanding processing required and handles these with its *Knowledge Sources.* The components of a single O-Plan agent are shown in figure 3.

O-Plan has explicit facilities for managing a number of different options which it is considering. O-Plan has an agent level agenda, and agendas which relate to each option it is considering (in fact these are part of the plan representation for these options - the I part of <I-N-OVA>). Many of these options are internal to

[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.

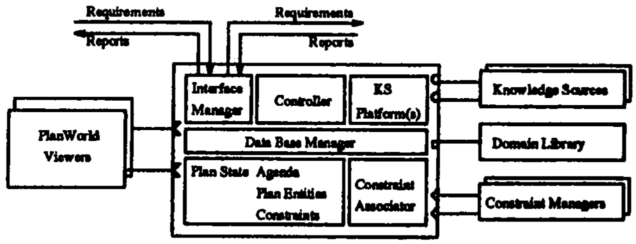

Figure 3: O-Plan Agent Architecture

the planning agent, and are generated during search for a solution. Others are important for the interaction between the planner and a user acting as a task assigner.

Abstract Model of Planning Workflow – Plan Modification Operators

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" (PMO) to handle one or more agenda issues and then executing the PMO to modify the plan state. Figure 4 shows this graphically.

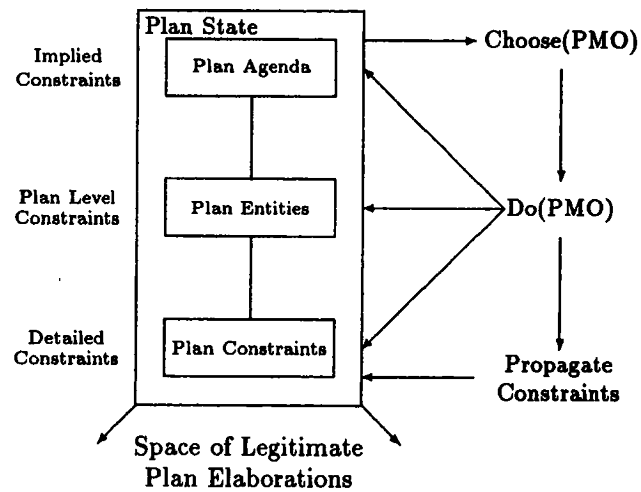

Figure 4: Planning Workflow - Using PMOs to Handle Agenda Issues

This approach is taken in O-Plan. 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 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.

Generic Systems Integration Architecture

The O-Plan agent architecture has been generalised into the generic systems integration architecture shown in figure 5. This general structure has been adopted on a number of AIAI projects (Fraser and Tate, 1995).

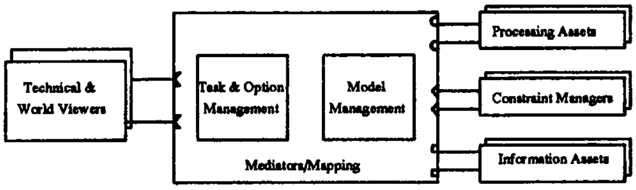

Figure 5: Generic Systems Integration Architecture

The various components "plug" into "sockets" within the architectural framework. The sockets are specialised to ease the integration of particular types of component.

The components are as follows:

Viewers – User interface, visualisation and presentation viewers for the model - sometimes differentiated into *technical* model views (charts, structure diagrams, etc.) and *world* model views (simulations, animations, etc.)

Task and Option Management – The capability to support user tasks via appropriate use of the processing and information assets and to assist the user in managing options being used within the model.

Model Management – coordination of the capabilities/assets to represent, store, retrieve, merge, translate, compare, correct, analyse, synthesise and modify models.

Mediators – Intermediaries or converters between the features of the model and the interfaces of active components of the architecture (such as viewers, processing assets, constraint managers and information assets).

Processing Assets – Functional components (model analysis, synthesis or modification).

Constraint Managers – Components which assist in the maintenance of the consistency of the model.

Information Assets – Information storage and retrieval components.

Communicating Plan Information Between the Task Assignment and Planning Agents

The <I-N-OVA> constraint model of activity allows planning process state as well as the current state of the plan generated to be communicated between agents involved in the planning process. This is done via the Issues part of <I-N-OVA> - which can be used to amend the task and option specific agenda which a planning agent is using for its problem solving. Ways to authorise agents to take initiative in the problem solving process are being explored. This can be done by communicating the types of agenda entry or issue which the planning agent may handle and giving limitations on which types of constraint that may be manipulated and the extent to which they may be manipulated while problem solving.

This involves improving the workflow controller at the heart of the O-Plan planner agent. This will allow dialogue between users and automated planners as the problem solving takes place. Methods to allow for coordination of task and option management between users and the automated planner are being added to O-Plan.

Authority to Plan

At the moment the Task Assignment agent tells the O-Plan planner when it can create a plan for a nominated task. This is done through a simple menu interface today. As described in Tate (1993) it is intended that O-Plan will support authority management in a more comprehensive and principled way in future. This section describes the way in which this is being done. O-Plan will support:

- the notion of separate ***plan options*** which are individually specified task requirements, plan environments and plan elaborations. The Task Assignment agent can create as many as required. The plan options may contain the same task[4] with different search options or may contain a different task and environmental assumptions. It is possible to have only one plan option as the minimum[5]. ***Sub-options*** may be established between the task assignment and planner agents to give some structure to the ways in which the space of such options and sub-options is explored between the two agents.
- the notion of plan ***phases***. These are individually provided actions or events stated explicitly in the top level task description given by the Task Assignment agent. Greater precision of authority management is possible by specifying more explicit phases at the task level. It is possible to have only one "phase" in the task as the minimum[6].
- the notion of plan *levels*. Greater precision of authority management is possible by specifying more explicit levels in the domain Task Formalism (TF).

[4]Multiple conjunctive tasks in one scenario is also possible.

[5]Plan options may be established and explicitly switched between by the Task Assignment agent.

[6]In fact any sub-component of any task schema or other schema included by task expansion in a plan can be referred to as a "phase" within the O-Plan planner agent. This can be done by referring to its node number.

It is possible to have only one "level" in the domain as the minimum.

- for each "phase", planning will only be done down to an authorised "level" at which point planning will suspend leaving appropriate agenda entries until deeper planning authorisation is given.
- execution will be separately authorised for each "phase".

Domain related names that are meaningful to the user may be associated with these options, sub-options, phases and levels through the Task Assignment agent.

Changes of authority are possible via Task Assignment agent communication to the Planner agent. This may be in the context of a current plan option and task provided previously or it is possible to give defaults which apply to all future processing by the planner agent.

Mutually Constraining Plans for Mixed Initiative Planning and Control

Our approach to Mixed Initiative Planning in O-Plan proposes to 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 the user or system in a cooperative fashion.

The model of Mixed Initiative Planning that can be supported by the approach is *the mutual constraining of behaviour* by refining a set of alternative partial plans. Users and systems can work in harmony though employing a common view of their roles as being to constrain the space of admitted behaviour. Further detail is given in Tate (1994).

Workflow ordering and priorities can be applied to impose specific styles of authority to plan within the system. One extreme of user driven plan expansion followed by system "filling-in" of details, or the opposite extreme of fully automatic system driven planning (with perhaps occasional appeals to an user to take predefined decisions) are possible. In more practical use, we envisage a mixed initiative form of interaction in which users and systems proceed by mutually constraining the plan using their own areas of strength.

Coordination of problem solving must take place between users and the automated components of a planning system. In joint research with the University of Rochester (whose work is described in Allen, Ferguson and Schubert, 1996) we are exploring ways in which the O-Plan controller can be given specific limitations on what plan modifications it can perform, and the specific plan options or sub-options it is working on can be coordinated with those being explored by a user supported by a suitable interface.

Summary

Five concepts are being used as the basis for exploring multi-agent and mixed-initiative planning involving users and systems:

1. a rich plan representation using a common constraint model of activity (<I-N-OVA>).
2. mixed initiative model of "mutually constraining the space of behaviour".
3. explicit task and option management – via a tasking interace which can share options and sub-options between agents.
4. abstract model of the planning agent having handlers for issues, functional capabilities and constraint managers.
5. management of the authority to plan (to handle issues) which may be given in advance or may be stated with the task specification and which may take into account options, phases and levels.

Together these provide for a *shared* model of what each agent can and is authorised to do and what those agents can act upon.

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