A Planning Agent on the World Wide Web

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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. The facilities have been provided as a planning support agent serving task assignment and planning users over the world wide web.

1 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 framework and shared models using:

[1]Parts of this paper are based on a description of the O-Plan multi-agent system given at the AAAI-97 Workshop on "Constraints and Agents", Providence, RI, USA on 27th July 1997.

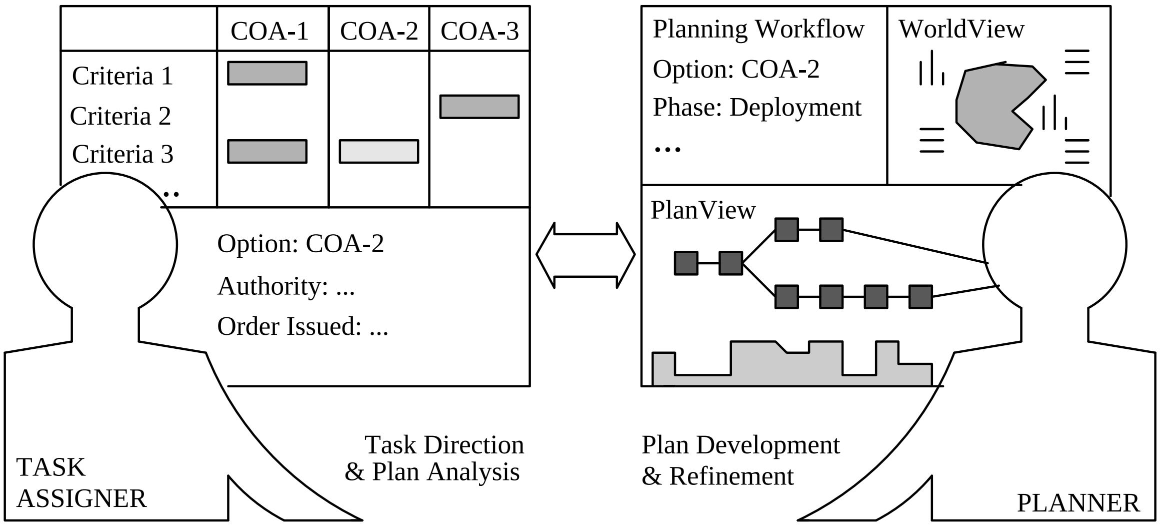


Figure 1: Communication between Task Assigner and Planner

- 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.

A demonstration environment has been created which uses the World Wide Web to allow users access from any web browser to an O-Plan planning agent[2].

2 Generic Systems Integration Architecture

The O-Plan agent architecture to be described in the next section is a specific variant of a generalised systems integration architecture shown in figure 2. This general structure has been adopted on a number of AIAI projects (Fraser and Tate, 1995). The architecture is an example of a *Model/Viewer/Controller* arrangement.

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.)

[2]The demonstration is available through URL `http://www.aiai.ed.ac.uk/~oplan/` by following the link to the "Live Demonstrations" page entry for "Pacifica COA Matrix".

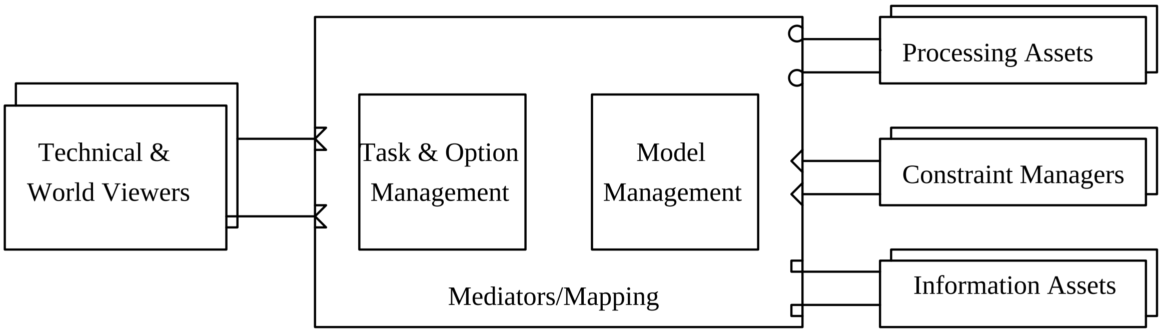


Figure 2: Generic Systems Integration Architecture

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. This is sometimes referred to as the *Controller*.

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.

3 O-Plan – the Open Planning Architecture

This section describes the O-Plan architecture and the structure of individual O-Plan agents. The components of a single O-Plan agent are shown in figure 3.

3.1 Task and Option Management

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*.

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 the planning agent, and are generated during search for

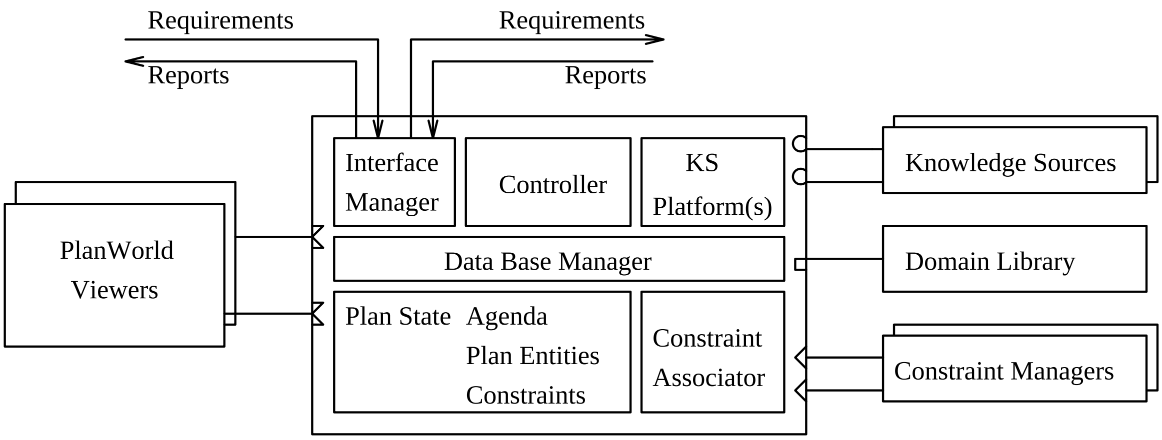


Figure 3: O-Plan Agent Architecture

a solution. Others are important for the interaction between the planner and a user acting as a task assigner.

3.2 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.

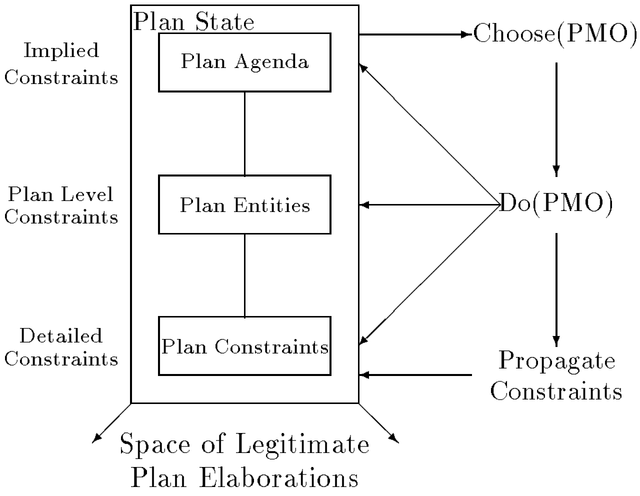


Figure 4: Planning Workflow - Using PMOs to Handle Agenda Issues

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.

3.3 Representing Plans as a Set of Constraints on Behaviour

The <I-N-OVA>[3] (*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 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 5: <I-N-OVA> Constraint Model of Activity

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

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*[4], 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.

3.4 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.

3.5 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 mechanism 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. *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. The authorities may use domain related names that are meaningful to the user and may be refer to the options, sub-options, phases and levels of tasks and plans known to O-Plan.

4 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 con-

[4]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.

straints 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.

5 A Planning Agent on the WWW

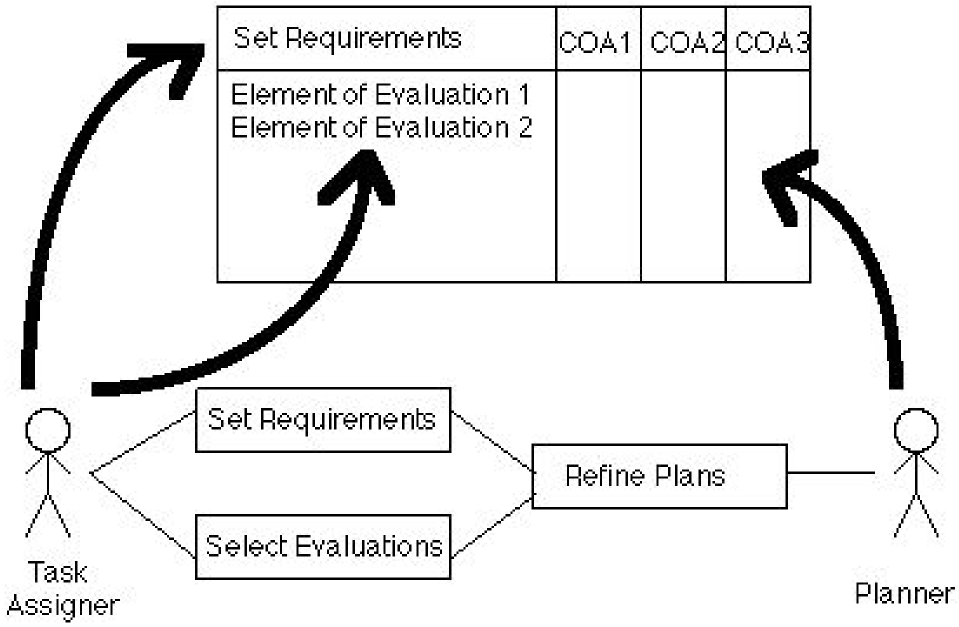


Figure 6: Roles of the Task Assigner and Planner Users

The overall concept for our demonstrations of O-Plan acting in a mixed initiative multi-agent environment is to have humans and systems working together in given roles to notionally populate a Course of Action (COA) versus Elements of Evaluation comparison matrix. This would be used to create a briefing about the alternative courses of action being proposed to meet some set of requirements together with appropriate and differentiating evaluations or advice about the options being proposed.

Figure 6 shows two human agents working together. The Task Assigner sets the requirements for a particular Course of Action (i.e., what top level tasks must be performed) and selects appropriate evaluation criteria (elements of evaluation) for the resulting plans. The Planner agent acts to refine the resulting plans by adding further constraints and splitting plans to explore two or more possible options for the same COA requirements.

The columns of the comparison matrix are alternative options being explored as a potential solution to a (possibly underspecified) problem and the rows are evaluations of the solution being considered and allow for "drilling down" into more detail of the evaluation information. The requirements, assumptions and constraints are all refined concurrently using the elements of evaluation. See the web display of the matrix in figure 7.

We have created a simple web-based demonstration which shows most aspects of the abstract framework described here[5]. The user is initially given a blank COA comparison matrix which is populated by the user and O-Plan during the course of a session (as in figure 7). The user acts in the role of the Task Assigner agent, setting the tasking level requirements for a Course of Action (see figure 8) and selecting elements of evaluation to include in the matrix.

The COA matrix is an abstract underlying notion and may not appear in an actual user interface for a completed system. However, it is useful in this demonstration to show our ideas about what is being created and refined as mixed initiative problem solving takes place.

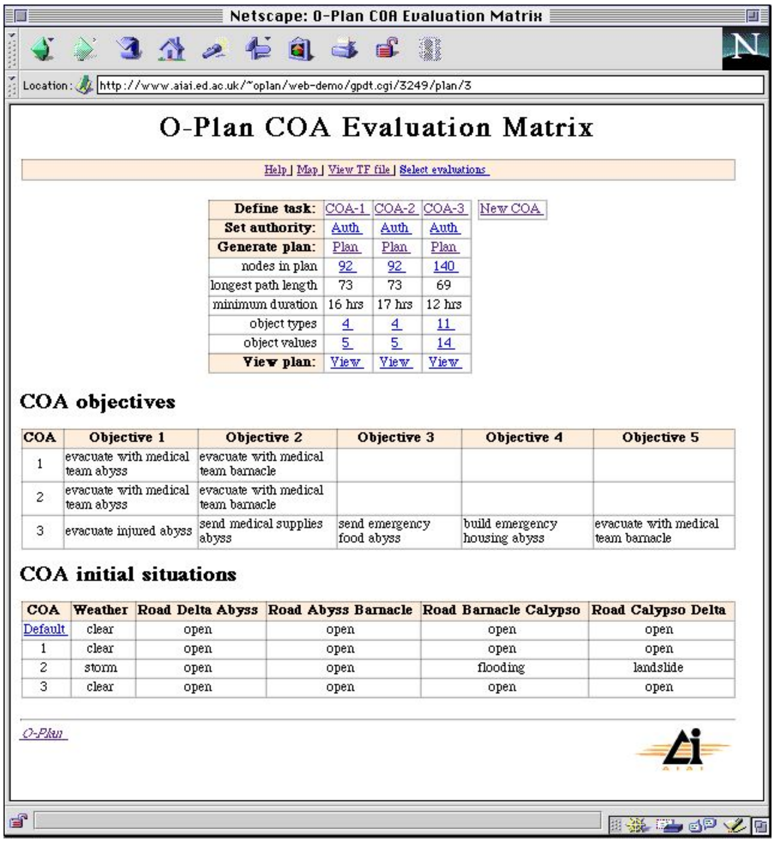
The two users involved will be collaborating via some suitable collaboration medium. This could be direct interaction if they are in the same room, but more likely will involve video teleconferencing, telephone or net-phone calls, shared displays such as text or whiteboard windows on their computers, or linked web browsers such as are provided in recent web browsers incorporating collaboration facilities. Figure 9 shows the arrangement.

The plan server itself is running on a host computer connected to the world wide web, and is accessed through Common Gateway Interface (CGI) scripts in its current version. Other means of serving commands from the web are available including specialised http servers.

6 Summary

Five concepts are being used as the basis for exploring multi-agent and mixed-initiative planning involving users and systems: Together these provide for a *shared* model of what each agent can and is authorised to do and what those agents can act upon.

[5]The demonstration is available through URL `http://www.aiai.ed.ac.uk/~oplan/` by following the link to the "Live Demonstrations" page entry for "Pacifica COA Matrix".


Netscape: O-Plan COA Evaluation Matrix

Location: http://www.aiai.ed.ac.uk/~oplan/web-demo/gpdt.cgi/3249/plan/3

O-Plan COA Evaluation Matrix

Help | Map | View TF file | Select evaluations

Define task:	COA-1	COA-2	COA-3	New COA
Set authority:	Auth	Auth	Auth	
Generate plan:	Plan	Plan	Plan	
nodes in plan	92	92	140	
longest path length	73	73	69	
minimum duration	16 hrs	17 hrs	12 hrs	
object types	4	4	11	
object values	5	5	14	
View plan:	View	View	View	

COA objectives

COA	Objective 1	Objective 2	Objective 3	Objective 4	Objective 5
1	evacuate with medical team abyss	evacuate with medical team barnacle			
2	evacuate with medical team abyss	evacuate with medical team barnacle			
3	evacuate injured abyss	send medical supplies abyss	send emergency food abyss	build emergency housing abyss	evacuate with medical team barnacle

COA initial situations

COA	Weather	Road Delta Abyss	Road Abyss Barnacle	Road Barnacle Calypso	Road Calypso Delta
Default	clear	open	open	open	open
1	clear	open	open	open	open
2	storm	open	open	flooding	landslide
3	clear	open	open	open	open

O-Plan

Figure 7: O-Plan running on the web and maintaining a matrix which compares alternative Courses of Action against a set of evaluation criteria

1. *Shared Plan Model* – a rich plan representation using a common constraint model of activity (<I-N-OVA>).
2. *Shared Task Model* – Mixed initiative model of "mutually constraining the space of behaviour".
3. *Shared Space of Options* – explicit option management.
4. *Shared Model of Agent Processing* – handlers for issues, functional capabilities and constraint managers.
5. *Shared Understanding of Authority* – management of the authority to plan (to handle issues) and which may take into account options, phases and levels.

Using these shared views of the roles and function of various users and systems involved in a command, planning and control environment, we have demonstrated a planning agent being used to support mixed initiative task specification and plan refinement over the world wide web.

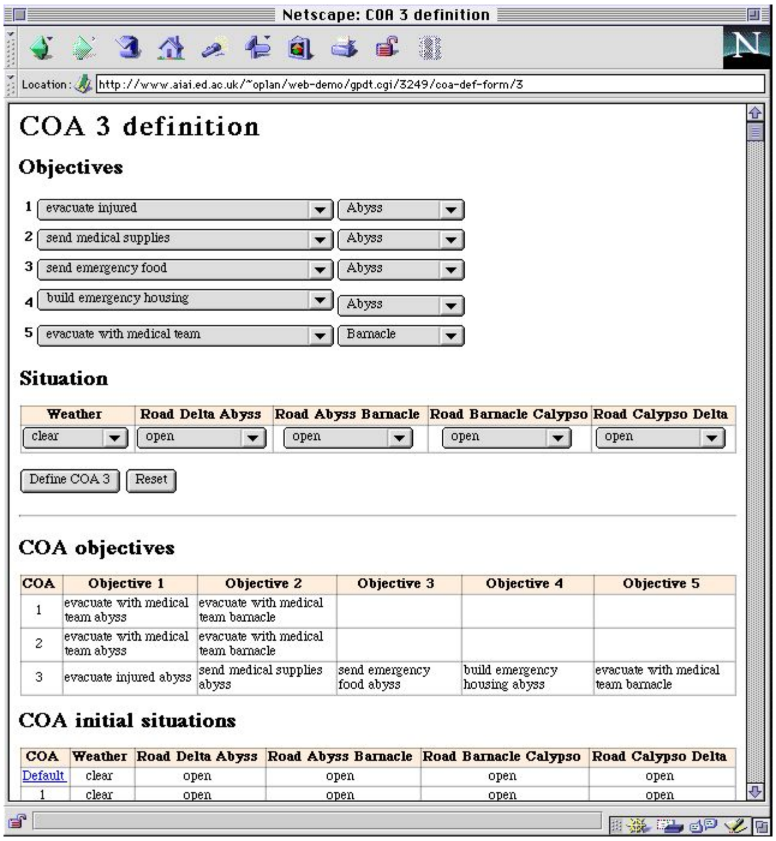


Figure 8: Using forms to set the objectives to O-Plan running on the web

Acknowledgements

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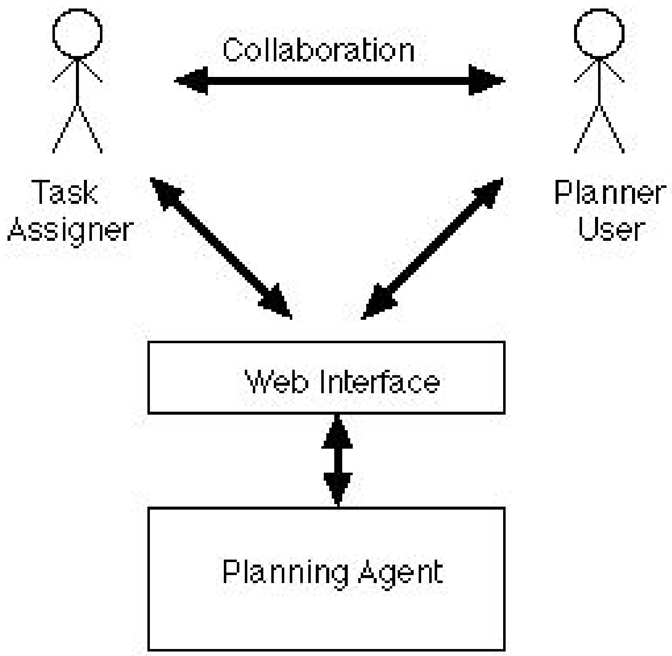

Figure 9: User Collaboration and Shared Use of the Plan Server

Press.

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