Automated Generation of Plans through the Use of Context-Based Reasoning

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Abstract

Automated planning within the scope of middle level echelon decision making processes is beginning to receive increased research attention in an attempt to reduce the size of the support staff needed to conduct large scale command and staff training exercises. In order to better understand the issues involved, the requirements for this domain will be outlined and current planner technologies will be evaluated with respect to these requirements. The artificial intelligence technique of Context-Based Reasoning will also be discussed as it applies to this domain.

Introduction

This paper addresses the area of automated planning for middle echelon military command post simulations. The efforts described in this paper are targeted for application at the Battalion and Brigade levels. Current technologies being used for this purpose will be identified and evaluated, and new techniques potentially beneficial to this application will be discussed.

Simulations that automate a large variety of tasks and allow a human to be efficiently trained in operational procedures alleviate the need for large numbers of dedicated, expensive support staff to conduct training exercises. However, current techniques for automating those tasks are typically limited to simulations of reactive behaviors at echelons below the battalion level. In the area of middle echelon military command and staff training, a large team of role players is currently required to conduct training exercises. Obviously improvements in this type of simulation procedure are highly desirable.

In order to determine the current limitations in these simulation methods, research has been done in the area of general planning systems and processes as well as planning systems that currently exist for military applications. Systems that concentrate on middle level echelon planning are of special interest. Focus has been placed on the technology currently being used to meet the requirements connected with this topic - the different types of Artificial Intelligence methods, their strengths and weaknesses.

Current planner implementations allow for lower echelon planning with relative success. However, higher echelon planning brings with it a different set of unique parameters and design issues. Several authors have tried to identify the requirements that must be met in developing such a planner. (Harmon, Yang and Tseng 1994; Wilkins et al. 1995; Pryor and Collins, 1996; Smyth and Keane 1993; Devanney and Ram 1997; Salisbury and Tallis 1993; Turner 1995; Bienkowski, DesJardins and Desimone 1994; Karr et al. 1995)

Planner Classifications

There are several general classifications of planners that we will address in this paper. A few definitions will facilitate the understanding of the various technologies currently used in automated planning systems.

Goal Dependency: Linear Planners are based on the premise that sub-goals are not dependent upon each other, and therefore, can be attained in any random order (Devanney and Ram 1997). Non-Linear Planners on the other hand, believe the opposite: the order in which sub-goals are achieved is very important to reaching the main goal state. They use a least commitment approach and delay the ordering of sub-goals for as long as possible (Devanney and Ram 1997).

Level of Abstraction: Abstraction is the process of taking real-world domain knowledge and filtering it into a format and quantity that is manageable for a planner to handle and use. Non-hierarchical planners use only one level of abstraction (Wilkins and Desimone 1994). All goals, whether they contribute towards achieving the main goal or not, are treated equally. Planning in this manner can be inefficient, resulting in wasted resources, unrealistic plans, and an inability to reach the main goal (Smyth and Keane 1993). Hierarchical planners generate plans at multiple layers of abstraction goal (Smyth and Keanne 1993; Wilkins et al. 1995). Initial skeletal plans evolve (as more information is gathered) into a detailed set of plans that satisfy the main goal. This approach helps to identify the factors most important to achieving the main goal early in the planning process (Smyth and Keanne 1993; Kambhampati 1997).

Current State of the Art in Planner Technology

The requirements outlined above are issues representing real-world domain planning. These issues must be addressed when developing or evaluating a planner. How do current planner technologies and implementations handle these requirements?

First generation or Classical Planners (Wilkins 1988) were developed with certain assumptions: all knowledge necessary for making planning decisions was available. Furthermore, the stability of domain information was a given, the consequences of actions were deterministic, and planning activities terminated once an initial plan was generated (Pryor and Collins 1996; Smyth and Keane 1993; Kambhampati 1997).

A fundamental problem with these planners is their inability to generate a valid plan when given incomplete situational knowledge with which to work. Any initial plans generated would most likely fail at the first unexpected action that occurs, based on new situation information (Pryor and Collins 1996; Turner 1995; Salisbury and Tallis 1993).

The next generation of planners includes the state of the art in planning technologies. A small representative sampling is discussed in the following paragraphs.

SIPE-2 is a domain-independent, hierarchical, nonlinear AI planning system used for the generation of real-world Courses of Action in a variety of domains including Military Planning (Wilkins and Desimone 1994; Bienkowski DesJardins and Desimone 1994). SIPE-2 uses a depth-first search method with backtracking to traverse a problem space and generate plans. Abstract plans are initially developed and, as new information is gathered, are expanded into fully detailed plans (Wilkins 1988). Replanning based on new information is also supported (Wilkins et al. 1995). SIPE-2 cannot relax constraints however, and cannot reason about goals that have only been partially achieved, and about their ramifications with respect to the overall plan (Wilkins and Desimone 1994; Bienkowski, DesJardins and Desimone 1994). In addition, depending upon the way domain knowledge is structured for a planner, a particular search type (depth-first, breadth-first, etc.) may not be appropriate and therefore could result in less than optimal planning results (Kautz and Selman 1996).

The ModSAF Mission Planner is also used for Military Planning. According to Karr et al. (1995), it uses a finite state machine implementation that can handle plan generation at the Company echelon level. Skeletal Plans are input by the user and represent the higher level orders to be transformed into a plan. A World Database is used by the planner to store the battlefield knowledge it acquires during plan generation. The current implementation is limited in the ability to only generate one route per start and end locations. This is not conducive to the generation of multiple COA's. There are no (constraint) techniques currently implemented to prevent the generation of invalid plans. As a result, time and computational resources may be wasted in compensating for this. (Karr et al 1995)

The EAGLE-AP is an automated adversarial planner that performs military planning and replanning at the Brigade command level. It plans hierarchically and uses a backtracking search method to generate plans (Salisbury and Tallis 1993). The problem space is made up of partial plans. This space is traversed to develop a set of Battalion actions that will achieve the goal state plans (Salisbury and Tallis 1993). Replanning is also supported. In a search space based planner, the search time can be directly proportional to the size of the problem space and the amount of backtracking that is required to produce a usable plan.

The CCTT SAF Behaviors prototype uses a rule-based approach to generate tactical plans at the Platoon level (Bimson et al. 1994). In small domains, rules are a concise and structured method of knowledge representation. However, rule-based systems tend to be costly and expensive to maintain and expand for complex domains. Domain complexity is directly proportional to rule complexity and size. When expanding a rule-based system, there can be a high degree of difficulty associated with maintaining the integrity of the rule hierarchy. It can also be very time consuming to traverse the rule base of a complex domain.

In the next section we discuss another new technology for complex domain planning.

Context-Based Reasoning

In a real world environment, a troop's survival is directly related to an awareness of the situation at hand; in other words, the context. Consequently, by having a good understanding of the current situation, one can better know what to expect from it. (Turner 1993; Gonzalez and Ahlers 1995)

Military tactics define the attributes of a situation and then describe the recommended behavior for handling the situation. A context style implementation fits well into this format. (Gonzalez and Ahlers 1995; Weaver and Mullen 1994)

A context can be defined as the representation of a situation at a particular period in time. (Gonzalez and Ahlers 1995) It captures the important attributes of the situation, providing a definition that can be used to identify possible future actions. Contexts can be ordered in a hierarchical manner (Gonzalez and Ahlers 1995; Turner 1995), where the top of the hierarchy is composed of very general knowledge contexts. As the tree is traversed down to the bottom of the hierarchy structure, the contexts are progressively more detailed in their knowledge content. Lower level contexts inherit information from upper level contexts. This helps to limit redundant knowledge (Turner 1995) and reduce contradictory information. Knowledge is simply and efficiently represented without the loss of germane information. This is a very important consideration when attempting to simulate a complex domain.

A context may include a large amount of implicit information that can be used to make valid assumptions (Turner 1993) as to what a military unit can reasonably encounter based on the situation the context represents. There are only a limited number of actions or goals appropriate within a context and also a limited number of occurrences (Gonzalez and Ahlers 1995).

A context contains information about other contexts. These contexts represent the valid contexts to which the current context is able to transition based upon the new situation (Gonzalez and Ahlers 1995). A context transition occurs when the goal defined in the active context is achieved or when new information is received that changes the current situation to the extent that the active context is no longer valid.

This knowledge representation facilitates the ability to focus (Turner 1993) on the important attributes of the situation in order to achieve the major or minor goal at hand. Only goals applicable to the active context are considered. And within a context, goals are ordered according to their relative importance with respect to the situation that the context represents. (Turner 1993)

The use of contexts has the further benefit of being prepared to handle any new information that becomes available. (Turner 1993) An initial plan is devised to achieve the mission goal. This plan was generated based upon all the available information at the time. For example, initial reports described enemy forces consisting of platoons of soldiers at certain terrain coordinates. Execution of the initial plan begins. As a company of soldiers reaches a strategic location, it discovers enemy forces where none had been identified. At this point the active context would transition to a context that could handle the new threat. A threat for which the initial plan had no instructions for dealing with because it had no knowledge of the threat. Once the new situation is taken care of, if the situation and constraints allow, the original plan can be resumed.

Opportunities that arise during plan execution (Smyth and Keane 1993) can also be handled in the same manner. Deviation from the initial plan can occur with a simple transition in context and one can take advantage of an opportunity that may arise (Turner 1995).

Contexts are capable of handling situations that are created as a result of actions from the initial plan as well as actions from the environment that are not triggered by the plan (Smyth and Keanne 1993; Wilkins et al. 1995). No matter the source, a context is available to meet a new threat. This is a result of the context hierarchy structure that goes from very general contexts with little content, to highly specific contexts with narrow, but detailed content. A very detailed context may not be available to deal with a new threat, but some form of general context might be. That may be enough to address the threat in most cases. (Turner 1993; 1995)

When transitioning to a new context, there may be several different contexts available to which transition can take place. This is due to the fact that there may be different actions available that all have the potential of achieving the mission goal. In this situation, the constraints that exist would be used to make the most appropriate choice. If avoidance of loss of life is of much greater priority than mission success, then a context would be chosen that would not violate the loss of life constraint.

Planned Approach

Given the difficulties described above, a novel technique is required to facilitate the automated synthesis of plans by mid-echelon military tacticians, such as may be found in a Battalion Tactical Operations Center (TOC).

Planning can be classified as the process of assigning limited resources to tasks where they can be most effectively utilized. By evaluating the available resources against a tree structure of potential contexts representing mission goals and their underlying tasks and sub-tasks, the most viable scenario is identified.

In a rich domain such as that of military tactics, the search space for a planning engine can be vast. Pruning this problem space is of prime importance to obtaining a workable plan.

Furthermore, military operations consist of opportunities as much as they do about limitations. Certainly, some weapons systems, as well as organizations of forces, have constraints as to their abilities. But, to a decision-maker, the status of the enemy, combined with the forces at his command, can also represent opportunities to be taken advantage of in the plan. In order to compensate for the difficulties described above, we propose to use the following approach to plan generation:

We believe that the problem space pruning inherent in Context-based Reasoning (CxBR) can be used to advantage in a planning tool. CxBR appears to be very well suited for use not only in initial plan generation, but also throughout plan execution and replanning as required by a changing military scenario. Nevertheless, for purposes of initial proof of concept, Context-based Reasoning (CxBR) will only be used to generate an initial plan.

A plan consists of making decisions that will define the course of action to be taken by the executor of that plan. These decisions, in turn, are simply the assignment of values to attributes that are relevant to mission at hand (military or otherwise). Knowing which attributes to assign values to, however, can be the greatest difficulty in plan generation as the problem space can be very large. Contexts, by their nature, can prune this search space by defining what decisions need to be made based on the mission and other goals. A plan can be defined in terms of what contexts will be instantiated, and the sequence of their instantiations. Each of these planned contexts, in turn, contain certain implications which require further decisions to be made. These will be represented through additional attributes that need to be assigned a value. Such values can be either final values, or other contexts that make more, increasingly fine-grained, implications. This recursive selection of contexts and values for attributes continues until all attributes have final values assigned to them. This will represent the plan. Replanning can be done by modifying the contexts at any level in reaction to changing conditions.

The first step in the process will be to develop a set of offensive mission contexts for the battalion echelon (movement to contact, hasty attack, deliberate attack, exploitation, pursuit) and the tasks and sub-task contexts associated with each mission. These contexts will be laid out in a hierarchical and non-redundant tree structure. Contexts are used to organize tasks by mission, subtasks by task, and so on down the tree structure to the lowest level tasks or terminal nodes identified as the leafs within the tree. Only offensive missions are being considered at the moment in order to help narrow the initial domain of the prototype and to concentrate efforts on the new technological approach. Even though the battalion echelon is the current focus, the approach does not prohibit the addition of mission contexts for any other military echelon.

Each context will consist of a representative set of variables that have been organized under a METT-T (Mission, Enemy, Terrain and Weather, Troops, and Time available) (Fink and Veloso 1995) configuration. METT-T is the process by which the military analyzes a battle situation in preparation for a military operation. Even though it is understood that many opinions exist as to the greater significance or weight factor of one or more components of METT-T over other components, for the purposes of this prototype each component of METT-T will be weighted equally.

Each context deals with variables specific to the subject matter of that context thereby imparting a logical modularity and minimizing redundant functionality. Variables within a context can have different weight factors. If an input violates a particular facet of the context, such as using a wide formation (context) in a narrow zone (input), then it is inconsequential that all other facets of the context are consistent with the input scenario. The context cannot be incorporated into the current plan.

Based upon the input scenario, variables whose values are derived from the specified inputs can be generated by a context. These implied variables are a benefit of the CxBR technology and allow the input of a scenario to hopefully not be an involved and complex process for the user despite the rich domain.

The next step in the process will be to evaluate the above contexts. A small, concise set of rules connected with each context performs this evaluation as follows: A context is represented by a set of variables. The rules within the context set the values for these variables based on the user inputs and the scenario information that represents the context. The value for a variable within a context may actually be a lower level context. The process thereby uses recursive contexts to set values and to identify valid contexts for the evolving plan.

The context rules are organized consistent with the rest of the prototype to minimize redundancy and are kept simple and focused in order to allow for manageable maintenance and ease in future scope expansion.

Those contexts deemed compatible with the current scenario will be identified and used in the generation of an appropriate plan. To do this, the current scenario information, in the form of a brigade OPORD, must be input into the process. We expect that the process will ultimately be able to, both, input and output the military five paragraph OPORD format. However, initial focus will be placed on the output of a battalion OPORD. The inputs will be organized in a brigade near-OPORD format. The process will categorize these inputs under METT-T to maintain consistency and then feed them into the mission context tree structure in order to produce a valid plan.

Once all inputs have been evaluated against the existing contexts, if possible, a plan, developed from traversing the context hierarchy and identifying valid contexts, is formatted into a battalion OPORD and presented to the user.

Conclusion

This paper has outlined the requirements that drive automated planning at the mid-echelon military decision-making process. It has discussed technologies and representative systems currently used to generate plans for domains including that of military tactics. It has also provided a brief description of the attributes of context-based reasoning. An outline of a proposed implementation of context- and constraint-based reasoning in the domain of military planning has been described. Future work will include the implementation of a prototype system utilizing these artificial intelligence techniques for automated planning for mid-echelon in the military decision-making process.

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