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Knowledge Systems for Coalition Operations

Improving Coalition Planning by Making Plans Alive

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The Collaborative Planning Model (CPM) supports human planners in managing planning information and facilitating automated reasoning. It aims to make plans "alive" by digitizing planning concepts to facilitate their dynamic use, modification, dissemination, and reuse.

Planning for military operations is a multifaceted, knowledge-intensive, and collaborative endeavor. It's conducted before and during an operation by specialist military personnel who typically work in distributed service-based (for example, navy, air force, or army) and function-based (such as maneuver, intelligence, fires, engineering, and logistics) teams. These teams often work asynchronously, in different locations, at multiple echelons (such as battalions versus brigades), and with different perspectives.[1] During the planning process, the general officers develop a campaign plan that includes the mission, the commander's intent, and a concept of operations. The staff officers and staff use this high-level guidance to develop possible courses of action, including detailed tasks and schedules. Function-based teams, such as intelligence and maneuver, continually share information, including partial plans.

Each team's output is a plan, which is typically a printed copy containing an abridged output of the planning process;[1] a commander then merges all teams' plans and uses them to direct subordinates for action. Planning is a specific example of a problem-solving activity undertaken across multiple (human) collaborative agents. To collaborate, these humans must form a shared understanding of various aspects of the plan, mutual goals, other agents' contexts, and the rationale for others' decisions and assumptions. Failure to reach this shared understanding can have serious implications in the execution of the resulting plan and the operation's success.

Over the years, military planning has received considerable attention from researchers aiming to provide automated planning-support tools. For example, the ARPA/Rome Laboratory Planning Initiative (from 1989 to 1998) demonstrated advanced concepts for planning and scheduling to support military crisis action planning.[2] This effort produced some notable successes, including the Dynamic Analysis and Replanning Tool (DART) system, which the US military used for movement planning during the first Gulf War.[3] Unfortunately, such specific examples haven't led to more generic successes in planning-support tool provision. Currently, there's a dearth of integrated planning-support tools, and the planning activity remains primarily manual, supported by standard office automation tools used mostly to generate written orders.

Automated planning-support tools have not achieved widespread adoption for a number of reasons. First, human planners might not be interested in giving up the decision-making part of the planning process to automated systems—they only want tools that help them do some of the more tedious and repetitive tasks or determine the plan's viability.[4] Second, approaches that attempt to introduce high levels of automation can result in reduced situation awareness, complacency, and skill degradation.[5] Third, the time and manpower needed to enter all the information into the computer for a single tool to use erodes the tool's overall usefulness—if it doesn't save time and effort, why use it?[6] Furthermore, human planners might hesitate to adopt an automated planning tool that requires them to enter too many details or prompts them to provide information in steps that are out of sync with their planning process and workflow.[7] A fourth issue is the difficulty in converting human concepts into a language that computers understand. In one case study, the human planners understood what they wanted to do militarily, but didn't know how to express their ideas to enable automation.[8] Automated intelligent agents might not be able to interpret the human planner's intentions[9] and could lack the ability to plan and reason under uncertainty when engaged in collaborative problem solving with human planners.[7]

These findings suggest an alternative approach to military planning support: developing a plan representation language that both supports human understanding and provides a mechanism for synthetic agents to reason with the information. Representational formalisms that capture and communicate plan-relevant information should be usable (that is, easy for humans to understand and manipulate), expressive (represent the different types of plan-relevant information), and machine processable.

Collaborative Planning Model

The *collaborative planning model* (CPM) was originally designed to support human planners in managing planning information and facilitating automated reasoning. Our goal with the CPM was to make plans "alive" by digitizing planning concepts to facilitate their dynamic use, modification, dissemination, and reuse. Rather than teams sharing only paper copies of the final, static, abridged outputs of their planning process, they add to a collective "joint plan" that includes all of the information that each planning team has generated during the process. This is held digitally so different planning teams can selectively visualize and amend the plan as necessary. The CPM differs from other planning models in that it also seeks to represent the problem-solving process itself and the rationale for constructing the plan's entities and relationships. This additional information about the user's intent facilitates shared understanding of the plan and team collaboration, and lets planners analyze dependencies, constraints, and the follow-on effects of plan modifications. The CPM doesn't capture the human insights and intangibles that a general officer considers when developing a campaign plan or conveying a commander's intent, but it does include mechanisms for inputting assumptions, constraints, and rationale.

In evaluating the CPM, we determined that in addition to making plans "alive," the framework provided an effective mechanism for sharing information between tools.[10–12] The generation of timely and quality plans by collaborative planners within a coalition environment requires help from a network of planning-support tools. No single tool will be adopted by every function, at every level, in every service; rather, each team will use tools tailored to its individual needs. The only requirement is that the tools use a common representation of the planning concepts. This common representation can be the basis of the tool, or, if an existing tool has its own semantics, then the tool can achieve interoperability by creating a mapping between ontologies.

Representational Framework

The CPM is a conceptual model developed to support military planning by distinctly representing concepts such as goals, plans, constraints, logical rules, and human rationale associated with decisions made while creating the plan.[13] It shares many concepts from other planning models focused on the military domain,[14,15] and models similar entities such as tasks and goals. The design of the CPM is based on military planning doctrine and influenced by evaluation results from its use in collaborative planning.[9] However, the CPM also represents the problem-solving process itself and the rationale for constructing the entities and relationships in the plan. This additional information is central to a shared understanding of each planner's intent as well as to enabling planners to analyze dependencies, constraints, and follow-on effects of plan modifications.

The CPM is a Web Ontology Language (OWL) ontology based on constraint-based planning[14] and teamwork[16] concepts. It differs from existing representations in that it focuses on distributed and collaborative problem solving. The starting points for CPM representation[11] include the <I-N-OVA>

(Issues Nodes-Orderings/Variables/Auxiliary) focus on constraints[14] and PLANET's (for a PLAN semantic NET) clear differentiation of goals and plans.[15] The CPM defines concepts in terms of entities, attributes, and relations; it also includes a set of logical rules that define the logical constraints that occur between the ontology's elements (for instance, rules describing how timing constraints can flow between tasks related in time). Such rules help to define the ontology concepts' meaning, enable deductions about the plan's aspects (to assist in plan validation, for example), and contribute to the rationale.

The CPM's use of logical rules takes a different approach to that of OWL. First, all inferences are explicitly defined by logical rules—rather than implicitly within the OWL reasoning system—which facilitates greater understanding of the conceptual model. Second, the logical rules can't easily be defined within OWL; thus, they're primarily represented in Controlled English (CE), with a mapping to OWL, as we describe later.

We define the CPM as a set of conceptual layers (see Table 1), each of which is a separate OWL file that imports and is based on the higher layers. The CPM achieves layering by subclassing. For example, a military unit (*military planning* layer) is a subclass of an agent (*basic logic and rationale* layer). By basing the CPM on a series of conceptual layers from the most generic to the most specific, we can easily add new concepts without distorting the overall structure. To the degree that this contributes to understanding a concept, the CPM strikes a balance between abstracting out unnecessary details and not losing connection to the real world. As they descend, the layers correspond to more practical details, ranging from abstract problem solving, down through semi-abstract problems such as resource allocation and scheduling, to practical military planning. We based many of the layers on layers in other models, such as Shared Planning and Activity Representation (SPAR)[17] and <I-N-OVA>,[14] because they make sense to planners (for example resources or actions).

Table 1. Conceptual layers of the Collaborative Planning Model.

Conceptual layer	Description	Example concepts
Basic logic and rationale	Provides a logical foundation; contains logical and metalogical concepts and basic mathematical concepts such as sets and containers	`Agent`, `Assumption`, `ConceptualSpace`, `Container`, `Entailment`, `Inconsistency`, `PossibleWorld`, `Proposition`, `Quantity`, `ReasoningStep`, `Set`, `Triple`, `WorldState`
General	Contains logical entities that pertain to human reasoning (such as constraint-based reasoning), the use of context, and the use of controlled natural languages for communication	`ConceptualThing`, `Constraint`, `Synchronisation`, `Context`
Temporal	Represents temporal information, timing relations between entities, and Allen's temporal logic	`Precede`, `TemporalConstraint`, `TemporalEntity`, `TimeInterval`, `TimeLine`, `TimePoint`
Space	Represents spatial information and spatial relations between entities; in lower layers, this can be combined with temporal layer concepts to provide a "spatio-temporal" entity	`Area`, `Elevation`, `Line`, `Point`, `SpatialConstraint`, `SpatialCoordinateSystem`, `SpatialEntity`, `SpatialIntersection`, `SpatialLocation`, `SpatialUnion`
Resources	Represents resources used in resource allocation; defines different types of allocation, their collection into resource pools, and their availability	`Resource`, `ResourceAllocated`, `ResourceCapability`, `ResourceConstraint`, `ResourceQuantity`, `ResourceSet`
Actions	Specifies actions that change the world, with spatial and temporal characteristics; requires using resources; preconditions and the effects	`Activity`, `Effect`, `Precondition`

	of actions are also represented	
Collaborative problem solving	Provides a generic representation of problem solving and collaboration in which problems are set by agents for other agents and the relation between the problem and the solution is maintained; influences model dynamics in team situations	`Choice Point`, `Collaboration`, `Commitment`, `Communication`, `ConstraintViolated`, `Decision`, `GoalSpecification`, `Influence`, `Issue`, `JointPersistentGoal`, `MutualGoal`, `Problem`, `Solution`, `Trust`
Planning	Represents planning as a more specific form of problem solving; problems are specified as planning problems, the solutions are plans, contexts specify key constraints and world states, actions must be executed, and resources must be available	`Allocation`, `Evaluation`, `InitialState`, `Plan`, `PlanTask`, `PlanTaskTemplate`, `PlanningProblem`, `PlanningProblemContext`, `ResourceCommitment`, `ResourceReq`, `TaskCommitment`
Military planning	Provides a specific representation of planning as performed by the military and documented in military planning manuals	`Terrain`, `Brigade`, `Division`, `Field Artillery`, `Rotary Wing`, `Mission`, `Intent`, `SEIZE`, `FIND`, `Intent Area`, `Decision Point`, `ResourcePool`

Reasoning with the CPM

We define rationale informally as the "reason" a human constructs a plan component; for example, a specific task has been planned because it preconditions another task, or because it achieves a certain effect. Furthermore, the system might also automatically construct plan components, or might deduce their attributes (such as a timing constraint on a task), and might thereby generate rationale. Other aspects of plan analysis can have rationale, such as the observation of an inconsistency because of conflicting timing requirements, the absence of a task's key component, or the potential failure of a task to achieve a goal.

Rationale plays an important role in many planning aspects: military staff's presentation of plans to colleagues, the explanation of a plan's components to subordinates, or operational order analysis. Knowing a planner's rationale facilitates shared understanding by exposing the sequence of reasoning steps, assumptions, and decisions leading to conclusions; exposing reasoning flaws due to hidden assumptions; and helping planners formulate solutions.[18] During evaluations with the CPM, military planners strongly experienced "aha" moments when presented with the rationale behind the need for a plan component.[9] Structured rationale (see Table 2) contains machine-processable formal substructures. The CPM captures unstructured rationale as a string of text. An assumption is a statement that's presumed to be true unless evidence exists to the contrary.

Table 2. Examples of rationale.

Type	**Example propositions**
Rationale (structured; with premises and conclusions in Controlled English)	The task `Build Bridge` has 18 as the earliest start time *because* the task `Build Bridge` is achieved after the task `Clear Road A`, and the task `Clear Road A` has 18 as the earliest completion time.
Rationale (unstructured; with premises and conclusions as text strings)	"The troops must be protected when crossing the bridge" *because* "the enemy is on the other side of the bridge."
Assumptions	It is assumed by the commander CO40 that the task `Build Bridge` has 30 as the earliest completion time.

We can define rationale more formally as the result of applying reasoning steps to generate inferences from premises or assumptions, where a premise is a known (or inferred) statement, and an assumption is a statement presumed true by an agent (human or automated). We can derive these reasoning steps from logical inference or from a more intuitive human inference not necessarily grounded in formal logic.

Additionally, human planners might provide assumptions or rationale based on information not known to an automated planning tool. The sequence of reasoning steps defines a network of rationale, leading from premises or assumptions to inferred conclusions. Such a network captures dependencies between plan inputs (requirements, constraints, higher-level decisions, assumptions, and context) and plan solutions (tasks and resource allocations). In collaborative planning, planners can share and build on rationale networks to construct a valid collaborative plan.

Given the information contained in the network of reasoning steps, we can demonstrate how conclusions depend on a combination of premises. Figure 1 illustrates how the task `fire_support` has a specific "latest start time."

Figure 1. Rationale graph showing the reasoning steps leading to a task's time constraint. Each circle defines a single rule application. The grey circles depict unstructured rationale added directly by human intervention; unfilled circles represent machine-generated structured rationale. The square-edged boxes are propositions, either reference facts derived from known facts or facts derived from rule applications. The dashed-line box is an assumption.

Human Interface to the CPM

Although it's a useful machine-understandable representation, raw OWL isn't a human-friendly representation.[13] To address this, we took two approaches. First, we developed a text-based, human-readable, CE representation, and mapped it to and from OWL. Second, researchers independently developed three tools for creating, editing, visualizing, and exchanging plans in the CPM. Two of these tools were developed explicitly for the CPM, while the third was developed with its own semantics and then extended to enable it to exchange plans in the CPM. These tools provide graphical representations of a plan's spatial and nonspatial aspects, including displaying the plan on a map; displaying relationships between entities; editing the plan, including objectives, tasks, resource requests, and assignments; importing and exporting plans in the CPM; and displaying and capturing rationale.

Controlled English. CE is a controlled natural language designed to be readable and writeable by an English speaker while representing information in a structured and unambiguous machine-processable form. CE is given a semantics (meaning) by a mapping from the CE syntax to a logical form such as Common Logic.[19] CE is extended for military planning to let it speak about assumptions, information sources, and uncertainty. It can be generated automatically from graphical plan visualization tools and turned into OWL, and vice versa. Some examples of propositions (which if true are "facts") include

- The division "3 UK DIV" has command of the brigade "12 (MECH) BDE."
- There is a task named `destroy_enemy` that realizes the goal "Enemy destroyed by 11."
- The task `destroy_enemy` is achieved after the task `cross_bridge` and has 8 as earliest start time.
- It is false that the hostile unit IAB has the bridge BR1 as location.

CE has effectively facilitated communication between Honeywell and IBM tools.[12] Our experience in using CE suggests significant benefits:

- It facilitates communication via a single language that's both human- and machine-understandable.
- It facilitates development and understanding of logical conceptual models containing both structured and logical relationships.
- It facilitates viewing, constructing, and understanding rationale, and thus encourages novel, hybrid reasoning methods.

Visualizing the CPM. Figure 2 shows three current tools that visualize the CPM. The IBM Visualizer (Figure 1a) inputs rationale and dependencies in the CPM or CE, calculates certain logical implications of the current plan, overlays the plan display with key assumptions, and calculates the effects of changing assumptions. The Boeing G-PAL tool (Figure 1b) lets users create and visualize plans via dynamic graphical representation and focuses on the appropriate level of abstraction that individual planners prefer. The G-PAL ontology is different from the CPM, but the G-PAL system can import and export plans to and from the CPM based on a semantic mapping between the CPM and the G-PAL ontology. The Honeywell PlanEditor (Figure 1c) can create, visualize, modify, and export CPM-based plans.

Figure 2. Visualizing the Collaborative Planning Model. Three current tools visualize the CPM: (a) the IBM Visualizer, (b) Boeing G-PAL, and (c) the Honeywell PlanEditor.

The IBM Visualizer stores plans (created or imported) in a logical CPM-based representation. A rule-based processor can infer new information, such as inconsistencies between the timing of different tasks. Plans can be imported and exported between the tool and other systems via OWL or CE. The tool determines rationale for information contained in the plan, from user input, assumptions and decisions made, the internal rule processor, or the reasoning that external reasoners employ. The user can visualize rationale (as in Figure 1) derived by logical reasoning from certain assumptions, and can withdraw assumptions and revisualize the resulting plans.

The Boeing G-PAL tool assists military planners with an easy and graphical means of plan creation, understanding, and composition.[20] The explicit semantics captured in the CPM let tool designers address user information overload problems. G-PAL leverages a context-aware information retrieval mechanism[21] to identify what's important for particular users in particular situations. It focuses on abstracting the information content into a semantic model that describes the plan's information resources. The goal is a plan representation that facilitates better communication between human planners and a representation scheme that supports the machine processing of data. The notation G-PAL uses is based on the NATO 2525B symbology.

The Honeywell Plan Editor explores the CPM's representation capabilities. It integrates Jastor (http://jastor.sourceforge.net), OpenJump (http://openjump.org), and IsaViz (www.w3.org/2001/11/IsaViz/) to provide a Java-based tool for displaying and editing the CPM. These tools and the custom software linking them provide a graphical representation of the CPM's spatial and nonspatial aspects and can import and export CPM plans.

Collaborative Planning

To gain significant benefits from distributed planning, each planning team must be able to communicate and maintain a shared understanding of the commander's intent, objectives, resources, and constraints, as well as decisions made and justifications for the planning options chosen or alternatives rejected. Losing this shared understanding results in decisions that are inconsistent with the team's overall goals and constraints.[10] This is particularly true in coalition planning, where work is distributed across different organizations, from different military traditions, and with different resources. Decision-support tools, planning representations, and asynchronous communication networks can mediate the planning process.

In addition to DART, several planning-support tools support elements of the hierarchal, cross-functional planning process. For example, FOX-GA provides an intelligent decision-support tool for assisting US Army planners and military intelligence in rapidly generating and assessing large numbers of battlefield courses of action (COAs).[22] The Joint Assistant for Deployment and Execution (JADE) implements case-based and generative planning methods to allow planners to handle large-scale, complex plans by enabling rapid retrieval and reuse of previous plan elements.[23] The Anticipatory Planning Support System (APSS) prototype provides an automated mechanism for assisting planners in producing plans and evaluating scenarios, and lets planners anticipate events rather than react to them in dynamic and uncertain battlefield environments.[24] The Collaborative Operational Planning System (COPlanS) is a workflow-based system that lets planners create and select a common COA in an integrated, flexible suite of planning, multicriteria decision-aid, and analysis tools.[25] The Tool for Planning, Force Activation, and Simulation (TOPFAS) is an integrated set of collaborative planning and decision tools to support NATO's comprehensive approach to crisis resolution.[26]

These planning-support tools have successfully addressed important aspects of campaign or mission planning. However, no single tool can address all the required functionality at every level, in every service;

rather, each team will use tools tailored to its individual needs. The proposed concept to make plans alive would create a common representation that provides the glue between planning-support tools; each tool can receive and exchange digital dynamic plans for use, modification, dissemination, and reuse to create a living planning-support capability.

Evaluation

We conducted three evaluations over two and a half years using the CPM to facilitate collaborative planning between multiple military planners in different configurations. Each planner used a different planning tool, but everyone shared CPM plans.

The first evaluation successfully demonstrated that the IBM Visualizer and Honeywell PlanEditor could visualize, create, share, and merge separate plans to facilitate collaborative planning across two levels of military hierarchy.[10] The second evaluation showed that the IBM Visualizer and Boeing G-PAL, each with its own underlying planning model and planning ontology, could let planners share plans (by creating a mapping between the CPM and G-PAL ontologies).[11] The final evaluation showed that the CPM could be used as an interoperability mechanism to develop a plan across multiple levels of the military hierarchy.[12] Specifically, the commanding officer developed a main plan at the brigade level, and then other planners created battalion "subplans" and merged them back into the main plan. In addition, the scenario required planning from two different militaries (each located in their home countries) within a distributed, network-enabled coalition environment. The second and third evaluations explored some differences between the US and UK planning processes by immersing the participants in a planning problem, which was an excellent motivator to resolve perceived differences. Unsurprisingly, the US and UK planners used some of the words (and hence associated concepts) differently. We must consider this when further developing the CPM and the tools that use it.

Over the course of these three evaluations, we compared

- two similar but separate tools, both designed for the CPM;
- two disparate and separate tools, where a mapping between two representations was necessary to enable interoperability;
- multiple levels of military planning (brigade and battalion);
- different planning disciplines (maneuver planning and fire support);
- CPM and CE representations;
- two different militaries; and
- colocated and distributed planning.

In each case, planners successfully built coherent, feasible plans, as judged by the commanding officer responsible for constructing the main plan. Work is under way to demonstrate the CPM's ability to support interoperability between TOPFAS and other national planning and decision-support tools.[27]

Collaborative planning in a multinational coalition environment is a challenging and unsolved problem. Planning-support tools are essential to the timely output of plans. However, before such tools can be effectively deployed, three key issues must be addressed: restricting automated support to the more tedious and repetitive tasks, managing knowledge that supports the planner's workflow, and encoding the human planner's rationale into the tool. The CPM planning representational framework has made significant progress in addressing these issues.

First, the CPM supports the human planning process, but doesn't replace it. It allows synthetic agents to automate some mundane tasks, and can improve plan quality by automating tasks humans often don't have time to do (that is, constraint checking).

Second, the CPM is the underlying representation across functions, hierarchical levels, and services. Rather than replace the tools they're using, it lets teams share their results (and the rationale for planning segments) across tools/teams, supporting shared understanding and team collaboration up and down the chain.

Third, the CPM and related CE are human readable and writeable. Human planners manipulate entities using the military planner's language, not a highly structured computer programming language.

We've also found the CPM to be effective in enabling different tools to share planning concepts. This is key to improving coalition planning, because different nations would typically use their own planning-support tools to generate their plans, which normally would be passed to their allies in paper documents. With a CPM interface, all of the planning concepts (including assumptions, constraints, and rationale) can be shared. The current work with the TOPFAS tool demonstrates this capability.

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