

# CODA: Coordinating Human Planners

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**Abstract.** Effective coordination of distributed human planners requires timely communication of relevant information to ensure the overall coherence of activities and the compatibility of assumptions. The CODA system provides targeted information dissemination among distributed human planners as a way of improving coordination. Within CODA, each planner declares interest in different types of plan changes that could impact his or her local plan development. As individuals develop plans using a plan authoring tool, their activities are monitored; changes that match declared interests trigger automatic notification of appropriate planners. In this way, distributed planners can receive focused, real-time updates of plan changes that are relevant to their local planning efforts.

## 1 Introduction

The scope and complexity of large-scale planning tasks often necessitates cooperation among multiple planners with differing areas of expertise, each of whom contributes portions of the overall plan. These planners may be distributed both geographically and temporally, thus further complicating coordination.

As a concrete illustration, consider special operations forces (SOF) mission planning for the military (the motivating domain for our work). SOF planning involves numerous people working on separate but interconnected facets (e.g., strategy, logistics, medical, intel) of an overall plan. The SOF planning process is time constrained, concurrent, and iterative. Individual planners construct subplans based on their expectations for the operating environment and requirements. As the overall plan develops, expectations evolve and modifications must be made. Currently, such changes are communicated informally by word of mouth, or transmitted in batch mode at regularly scheduled coordination sessions. This approach can lead to omissions and delays that reduce the effectiveness of the planning process and the quality of the resulting plans.

The SOF planning domain lies well beyond the range of current automated planning technologies. Moreover, fully automated approaches are unlikely ever to succeed because (a) planning for this domain involves a huge strategic component that is extremely difficult to model, and (b) successive planning tasks (e.g., disaster relief, counter-terrorism) tend to be unique, making it difficult to formulate reusable background knowledge with adequate coverage.

Techniques from the AI planning community can still contribute to complex domains of this type. In particular, *plan authoring* tools can improve the plan

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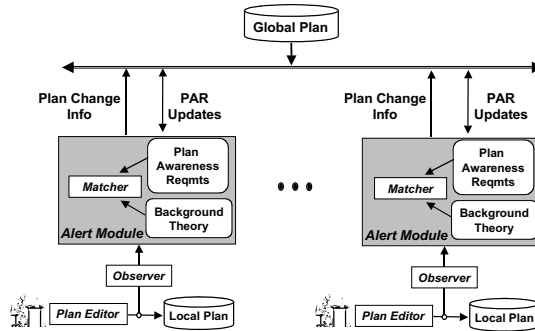


Fig. 1. CODA Architecture

development process [2, 3]. Plan authoring tools provide a structured set of plan editing operations that support users in developing large-scale plans, yielding principled representations of plans with well-defined semantics. Their main role is to augment rather than replace human planning skills, but they may provide limited automated capabilities. Planning aids can be defined that reason over the plan structures produced by these tools, including capabilities for supporting multiplanner coordination.

The CODA system (*Coordination of Distributed Activities*) provides automated support for focused information sharing during collaborative plan development by a team of humans using plan authoring tools [5]. CODA is designed for applications where distributed human planners are assigned responsibility for developing subportions of a global plan. These subplans are expected to have a moderate degree of coupling due to the need to reflect coherent strategy, to coordinate actions, and to share limited resources. Within CODA, each planner declares the kinds of plan changes that are of interest to him or her; we call these declarations *plan awareness requirements* (or *PARs*). As users develop plans with a plan authoring tool, their activities are monitored. Changes that match detected PARs are forwarded automatically to the person who declared interest in them. In this way, distributed planners can receive focused, real-time updates of plan changes that are relevant to their local planning efforts.

## 2 CODA Architecture

Figure 1 presents the architecture of CODA. Within the context of a global plan, individuals work independently to produce local plans for their assigned tasks. Plans are developed using a structured *plan editor*, which supports a broad range of plan manipulation capabilities. User interactions with the plan editor are tracked by an *observer* module, which maintains a history of all editing operations. As events are logged, a semantically grounded representation of the local plan is built.

The *matcher* provides the main inferential capability within CODA, being responsible for linking observed plan changes to declared PARs. The matching

process may involve reasoning with a *background theory*, whose role is to bridge the gap between low-level plan edits and the high-level languages used to define PARs. When matches are detected, notification is sent to the local planner who registered the matched PAR.

CODA could be linked to a variety of manual and automated planning tools. Currently, it is connected to the SOFTools Temporal Planner – a plan authoring tool that supports graphical editing of SOF mission plans [2]. CODA’s event monitoring for the Temporal Planner covers most of the available editing operations, including creation, modification and deletion of objects, modification of object attributes, temporal shifting of activities, and resource assignment.

CODA supports two modes for controlling PAR matching. In *real-time* mode, PARs are checked after every plan edit, thus providing immediate notification to planners of relevant changes. Real-time notification is suitable for the endstages of planning or execution, when plans are mostly stable and changes could be significant. For earlier stages of plan development, when changes would be frequent and wide ranging, CODA provides a *batch* mode of matching. Users can invoke batch mode to summarize PAR matches for a sequence of plan modifications relative to a designated checkpoint plan.

### 3 Plan Awareness Requirements

The PAR representation language builds on a general-purpose query language for the CODA plan ontology. It consists of a typed first-order language that builds in a model of frame representation systems as well as equality, term constructors for lists and intensionally defined sets, and quantification with respect to an enumerable type. CODA supports two types of PAR: *plan-state* and *transition*.

Plan-state PARs describe conditions of a plan and are modeled in terms of a formula in the plan query language. For example: *There is an arrival to staging base Gold scheduled for after 8 PM*. Matching of a plan-state PAR occurs when a modification results in a plan that satisfies the associated plan query.

Plan transition PARs describe changes between two plan states. We distinguish several categories, based on the nature of the underlying plan changes:

- *Instance Creation PARs* are used to declare interest in the addition of an object to a plan that satisfies stated conditions. For example: *Addition of decision points related to weather calls*.
- *Instance Deletion PARs* are used to declare interest in the removal of an object from a plan that satisfies stated conditions. For example: *Elimination of a landing zone south of the embassy*.
- *Instance Modification PARs* are used to declare interest in the modification of an object that satisfies stated conditions. For example: *Changes to movements by the 4th-platoon*.
- *Attribute Modification PARs* specialize Instance Modification PARs to changes to a specific attribute of a plan object, possibly satisfying stated change conditions. For example: *Delays of > 1 hour in time to secure the Church*.
- *Aggregate Modification PARs* can be used to declare interest in changes to an intensionally defined collection of objects. The change may be to membership

in the collection, or to some *aggregation value* defined over the collection. As an example: *Decrease of  $> 2$  in the number of fire-support aircraft.*

CODA includes an interactive *PAR authoring tool* that helps users define the plan changes in which they are interested. This tool builds on the Adaptive Forms technology [1], a grammar-based framework that supports the specification of structured data through a form-filling interface that adapts in response to user inputs. With this tool, users create PARs by filling in forms using an English-like syntax; as users incrementally specify PARs, remaining options adjust in accord with constraints of the underlying grammar. An internal compiler transforms the completed forms into the formal PAR structures required by CODA's matcher.

When designing user input tools, the competing requirements of expressivity and ease of use must be balanced. To address this issue, CODA's PAR authoring tool provides two sets of forms. First, a set of *general forms* provides the full expressive power of the PAR language. While powerful, these forms require more effort to complete; in addition, people unaccustomed to formal languages require training to use them effectively. Second, the tool includes specializations of the general forms that capture commonly used *idioms* within the SOF planning domain. The specialized forms build in values that users would have to specify in the general case, thus simplifying the specification process.

## 4 Conclusions

CODA provides a practical solution to the problem of coordinating distributed human planners. By having human planners explicitly declare those aspects of the overall planning process that interest them, CODA can provide timely and focused distribution of information that will expedite and improve the quality of coordinated problem solving. The use of a rich, AI-based representation for plans and planning operations provides the key to this technology.

The AI Planning community has developed several systems that share information to coordinate multiple automated planners, using techniques such as constraint propagation [4] and relevance reasoning [6] that analyze the causal structure of local plans. These approaches do not transfer to settings where humans author plans because complete causal structures, while a by-product of automated planning methods, will not be available.

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