UNCERTAINTY MANAGEMENT: KEEPING BATTLESPACE VISUALIZATION HONEST

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"Shared situation awareness, coupled with the ability to conduct continuous operations, will allow information age armies to observe, decide and act faster, more correctly and more precisely than their enemies."[1]

ABSTRACT

The digital battlefield of the future will remain a highly dynamic, uncertain environment. The greater dispersion of forces and the faster tempo of future operations will increase the need for better tools to assist Commanders and Staffs with managing the spatial and temporal uncertainties of battlefield events. Creation of such an information support system will require explicit support for characterizing uncertainties as well as propagation of uncertainties for both dependent and independent events. Lockheed Martin and the University of Maryland have initiated an effort to implement algorithms as software components capable of maintaining belief support for different categories of uncertainty. These components take the form of a network of intelligent agents to maintain and communicate a common perception of the battlespace to multiple echelons of a joint task force. We have an on-going efforts to develop a prototype for ground operations planning, the Route PLanning Uncertainty Manager (RPLUM) tool kit. We are applying uncertainty management to terrain analysis and route planning since this activity supports the Commander's scheme of maneuver from the highest command level down to the level of each combat vehicle in every subordinate command

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1. INTRODUCTION

The digital battlefield of the future will remain a highly dynamic, uncertain environment. The faster tempo of future operations will increase the importance of being able to reason about the time sensitivity of observed and predicted events. The greater dispersion of forces will increase the need to reason about the spatial uncertainties of the battlespace. Also, there is a need to better understand when battlespace events are inter-dependent and to be able to exploit those dependencies to reduce uncertainty. While data visualization technology has made significant gains in 2D and 3D graphics, optical models, and display technology, there has been relatively little work on associating uncertainty measures with visualization. Given the spatial and temporal uncertainty associated with battlespace visualization, uncertainty management must be an integral component of future systems designed to aid commanders and staffs in developing, disseminating, and executing a commander's concept of the operation.

The nature of the intelligence gathering process — as well as the technical characteristics of sensors, exploitation models, and communications — can introduce uncertainty and seriously erode "shared situation awareness." Information warfare capabilities envisioned for the Army of the 21st century will not eliminate the need to make decisions under uncertainty. Indeed, the fact that more information will be provided more rapidly means that data visualization should include uncertainties associated with the "shared situation awareness."

Such an information support system will require explicit support for characterizing data that exhibits both temporal and spatial uncertainties as well as propagation of uncertainties for both dependent and independent events.

1. *War* in the information age, General Gordon R. Sullivan and Colonel James M. Dibik, June 1994.

Provision of such capabilities in the data storage and retrieval processes will exploit the client-server technology being implemented in the Defense Information Infrastructure — Common Operating Environment (DII-COE). Unfortunately, current belief support technologies for deductive databases and mediator frameworks ***do not*** support development of automated reasoning tools that *visualize temporal and spatial uncertainties of both dependent and independent events*. This paper describes recent work initiated to address these issues. Figure 1 summarizes use of deductive data-bases and battlespace perception agents to aid information-age armies to "… observe, decide and act faster, more correctly and more precisely than their enemies."

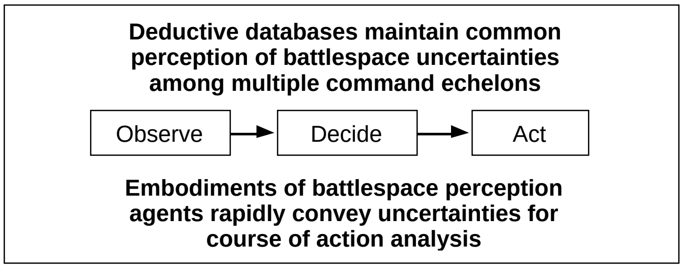


Figure 1. Decisions Under Uncertainty

2. SYSTEM OVERVIEW

Lockheed Martin and the University of Maryland have recently initiated an effort to implement algorithms as software components capable of ***maintaining belief support for different categories of uncertainty*** and an effort to demonstrate the ability of these components to enable *a network of intelligent agents* to maintain and communicate a *common percection of the battlespace* to multiple echelons of a joint task force. Significant extensions to current technologies are (1) creation and use of spatial-temporal-probabilistic tuples, (2) support for diverse probabilistic dependencies, and (3) visualizations of battlefield uncertainties.

2.1 PROBLEM

Uncertainty management is the "long pole" in the future command post tent because making decisions under uncertainty is the most important and most difficult responsibility of the commander. Better and faster understanding of uncertainty will enable better and faster decisions. For instance, DARPA's Dynamic DataBase (DDB) program recognizes that the digital battlefield of the future will be replete with uncertainty:

- Data Uncertainty: The DDB Sensor History will contain uncertainty measures
- Model Uncertainty: The DDB Dynamic Situation Modeling (DSM) models will characterize changes in battlespace uncertainty over time and distance

Characterizing uncertainty in raw sensor data and incorporating uncertainty measures in data fusion models will improve the Intelligence Preparation of the Battlefield (IPB). But there is still a wide gap in technology that would enable commanders and staffs to visualize and reason about the uncertainty of battlespace events.

Thus, uncertainty is not just a data attribute, it is a dimension of the battlespace at every echelon of command. While future data collection and exploitation systems will detect battlespace changes and provide both the current state of the battle as well as dynamic system models to predict future states, the ***gap in technology*** for future command posts is the ability to rapidly and reliably use that data for Course of Action (COA) analysis. Our Route Planning Information Server (Figure 2) will provide rapid and reliable uncertainty management support through generalized Spatial-Temporal Probabilistic (STP) queries of command post databases and other components.

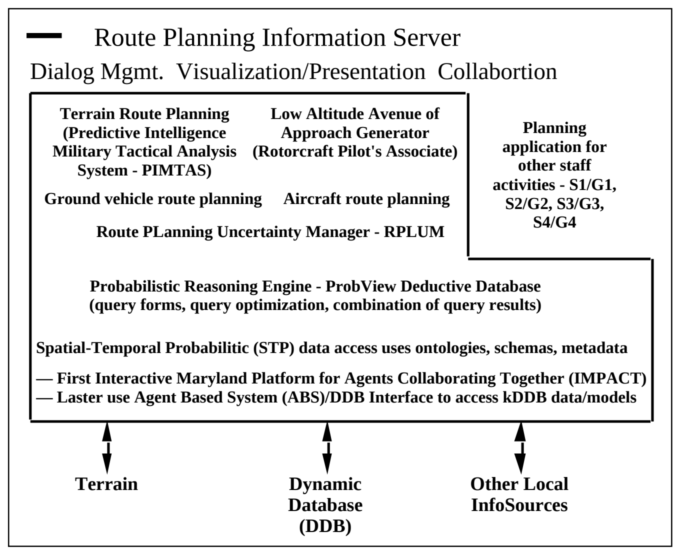


Figure 2. Route Planning Information Server

2.2 APPROACH

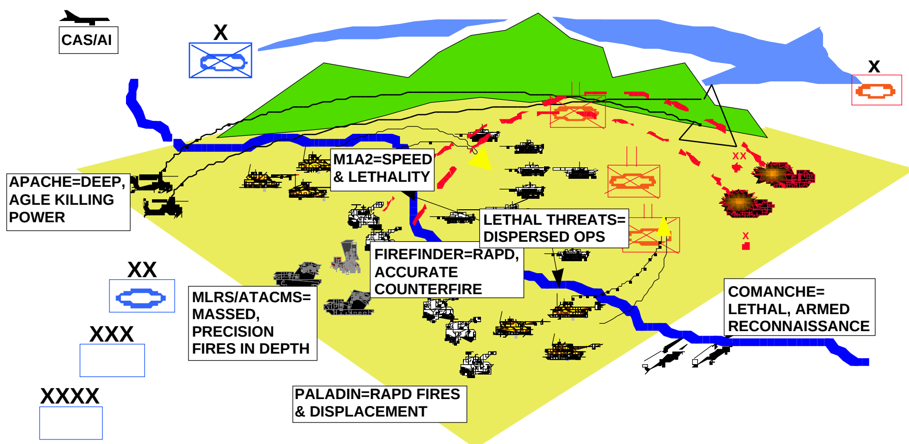
We are developing a prototype for ground operations planning, the Route PLanning Uncertainty Manager (RPLUM) tool kit. A guiding principle for the design of RPLUM is to be able to extend RPLUM to air operations planning by building a tool kit for Low Altitude Avenue of Approach analysis for air breathing vehicles (RPLUM*). Our design goal is to base extensions on virtual interfaces which can also be extended to manage uncertainty for command post course of action analysis in other mission planning areas (e.g. S1/G1, S2/G2, S3/G3, S4/G4).

We are focusing on applying uncertainty management for the terrain analysis and route planning process since this activity supports determination of the commander's scheme of maneuver for each echelon of command. The Commander's scheme of maneuver is the common thread from the highest command level down to the level of each combat vehicle in every subordinate command. Moreover, the scheme of maneuver is the means for synchronization of operations since it sets the context within which course of action analysis for other staff activities is conducted at each echelon, and it is the mechanism for maneuvering higher and lower echelon units in unison (Figure 3). Our solution for route planning scales from the level of moving individual combat vehicles (air and ground) in unison to the level of moving multiple Corps in unison.

2.3 SPATIAL-TEMPORAL PROBABILISTIC REASONING

Our existing deductive database system, ProbView, provides a probabilistic relational data model using a single unified framework for extending relational algebra to admit spatial, temporal and probabilistic queries [2]. Existing deductive database technology ***does not*** support generalized spatial-temporal probabilistic (STP) queries of databases [4,2]. The Route Planning Information Server will provide uncertainty management support to visualization and query optimization. It will also help to increase the speed of path planning by providing commanders and staffs a ***means*** *(an STP query) for assessing the relative* ***risks*** *of decisions* as well as a ***metric*** *(a probability measure) by which the* ***quality*** *of decisions can be determined*.

A hasty attack across a water obstacle requires reasoning about temporal and spatial uncertainties



The plan is nothing, planning is everthing*

- Commander's **Intent** is understood through the planning process
- **Scheme of Maneuver** provides the basis for unit route planning
- **Corps** battle is over several days and several hundreds of kilometers
- **Division** battle is faster than Corps battle and over smaller distances
- **Brigade** battle is about a day over tens of kilometers
- **Combat vehicles** comply with the Scheme of Maneuver as they execute engagement operations
- **Terrain Analysis** is performed in context of ***Scheme of Maneuver***
- **Route planning** by echelon is done using ***different time and space scales***
- Commander's **exercise initiative** (replan) in the context of higher commander's **Intent** and **Scheme of Maneuver**
- **Synchronization** of maneuver within and between echelons is currently a manual process

****Dwight David Eisenhower***

Figure 3. Synchronization of Maneuver.

3. LEVERAGING EXISTING TECHNOLOGY

The results described above are ambitious but possible because they are based on extending existing technologies, including: the ProbView deductive database technology; intelligent agent frameworks from IMPACT and the Agent Based Systems (ABS) program; and automatic route generation technology (PIMTAS) [1]. These complimentary technologies provide automated reasoning tools that will enable multiple echelons of commanders and staffs to visualize a shared perception of battlespace uncertainties for the purpose of route planning. Significant extensions to current technologies will be required for (1) the creation and use of Spatial-Temporal-Probabilistic tuples, (2) support for probabilistic dependencies among hypothesized entities and events, (3) route planning dialog uncertainty identification and support for route planning dialog context management, (4) route uncertainty visualization data to support 1D, 2D, and 3D displays, and (5) distributed uncertainty management for collaborative route planning.

4. UNCERTAINTY MANAGEMENT FOR ROUTE PLANNING

The operation notionally depicted in Figure 3 indicates a Brigade-size mechanized force conducting a hasty attack across a water obstacle. Brigade forces must first concentrate from dispersed locations in the vicinity of the water crossings and then disperse once the water obstacle is cleared. Planning and conduct of operations across water obstacles is one of the more difficult combat operations and one in which dominant battlespace information and dominant battlespace knowledge can have a significant impact. Uncertainties concerning trafficability of terrain along routes of march between way points and in the vicinity of the crossing points (Figure 4) can play a critical role in analysis of alternative courses of action. We will extend the Predictive Intelligence Military Tactical Analysis System (PIMTAS) route planning software to accommodate results of reasoning about multiple categories of uncertainty. Our extensions to PIMTAS will also support reasoning about the *difference in spatial scales* between joint force echelons.

The simplest set of variables for reasoning about spatial-temporal-probabilistic issues will yield a 5D tuple (3 of space, one of time and one of probability surface). One way to view such a surface would be to reduce the spatial dimensions to any two plus probability shown as height on the 2D surface. A video presentation will yield the time dimension. The 2D representation of space would most typically be a planimetric view but could be a vertical slice

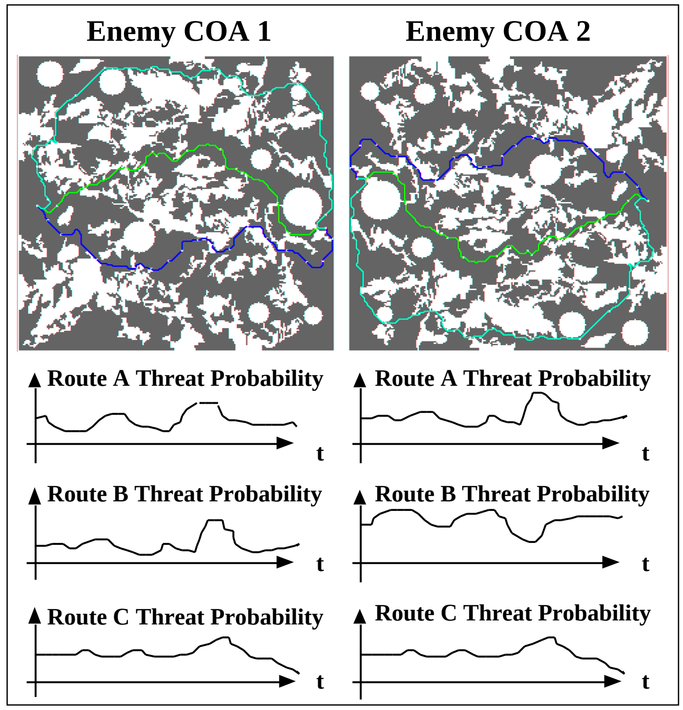


Figure 4. Automatic Planning and Replanning of Alternative Routes.

of the terrain at an arbitrary rotation from the north-south plane. As an example (Figure 4), the planimetic display could show how a planned route would change as a function of time as new information is received about threats and as friendly forces take action against threats. Figure 4 indicates that querying DDB concerning battlespace data and models with enemy COA 1 results in routes A, B and C all having a peak in threat at the same time in the future. If all three routes were being used for logistics movements, this prediction would provide commanders and staffs the ability to plan actions to take timely actions to reduce or eliminate the peak in the threat. However, if the enemy takes COA 2, an economy of force decision might be made to avoid the threat conditions along routes A and C and to increase traffic along route B during the period of increased threat along routes A and C.

5. CONCLUSION

We have discussed the need for creating deductive database technology to support course of action analysis for future command and control systems and described the RPLUM toolkit as a means of providing this capability for terrain analysis. Space limitations have prevented a more detailed overview of how RPLUM can be created through extensions to PIMTAS, ProbView and IMPACT systems.

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