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CAMPAIGN PLANNING - Research Transition Plan for Joint Maritime Planning

SRI International

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RESEARCH TRANSITION PLAN FOR JOINT MARITIME PLANNING

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13. ABSTRACT *(Maximum 200 words)*
This report presents a preliminary working plan for the transfer of the technology and applications developed by SRI under the Joint Maritime Crisis Action Planning (JMCAP) project into operational Navy systems. The systems and concepts developed within the Advanced Concept Technology Demonstration (ACTD), sponsored by the Office of Naval Research (ONR) and called Extending the Littoral Battlespace (ELB), provide the likely transfer path for the JMCAP prototype. The overall approach to technology transfer is to conduct user-centered, participatory design of end-to-end systems, supported by the integration of both commercial technologies and advanced research prototypes that have already been shown to be feasible for military planning and execution problems in projects such as JMCAP.

Presented are the operational concepts for a system using JMCAP within the context of the ELB operational concept, focusing on its capability for supporting plan in distributed, continuous planning. Background information is provided on the technologies that are relevant for transfer and the draft plan for that technology transfer.

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1 INTRODUCTION AND OVERVIEW

The Joint Maritime Crisis Action Planning (JMCAP) system is under development as a combined effort of the U.S. Navy Space and Naval Warfare Systems Center (SPAWAR, formerly NRaD*); SRI International (SRI), under Contract No. F30602-95-C-0175; and other SPAWAR-supported contractors. This report, CDRL Item A011 of the above-mentioned contract, presents a preliminary working plan for the transfer of the technology and applications developed by SRI under the JMCAP project into operational Navy systems. The systems and concepts developed within the Advanced Concept Technology Demonstration (ACTD), sponsored by the Office of Naval Research (ONR) and called Extending the Littoral Battlespace (ELB), provide the most likely transfer path for the JMCAP prototype. Our overall approach to technology transfer is to conduct user-centered, participatory design of end-to-end systems, supported by the integration of both commercial technologies and advanced research prototypes that have already been shown to be feasible for military planning and execution problems in projects such as JMCAP.

In the remainder of this report, we present the operational concept for a system using JMCAP within the context of the ELB operational concept, focusing on its capability for supporting plan deconfliction in distributed, continuous planning. We then present background information on the technologies that are relevant for transfer and finally, we present the draft plan for technology transfer.

2 OPERATIONAL REQUIREMENTS

The new operational concept for littoral warfare in ELB calls for a virtual command center, the Enhanced Combat Operations Center (ECOC), divided into tightly coupled cells. Within the ECOC, human planners in the Planning and Shaping Cell (also a virtual entity) plan operations involving force and fire employment and naval support for ground forces, while considering evaluation criteria such as maintaining force mobility and effective use of resources. In this cell, distributed tactical planning and execution occurs through the collaborative efforts of onshore, afloat, mobile, and in-transition units. In this high-tempo, near-real-time situation, collaboration among units is required, to jointly deconflict shared plans or to recognize opportunities for coordination.

The unique problems in supporting ELB-type operations arise from the move toward shorter planning timelines, and the greater authority and autonomy invested in the small teams, combined with the need for greater cooperation and coordination. In a tactical situation, time is simply not available to conduct an extensive, face-to-face plan deconfliction and negotiation session.

The Defense Advanced Research Projects Agency (DARPA) and ONR/SPAWAR are already investigating collaboration support technology for various military planning situations (e.g., for the Joint Forces Air Combat Command [JFACC] program and for the Joint Task Force [JTF] Advanced Technology Demonstration [ATD]). These programs, and others,† seek to research and/or apply

*NRaD: Naval Research and Development. Specifically, support is provided by the Advanced Decision Support Branch, Code 44207.

†SRI is conducting one such project under DARPA's Intelligent Collaboration and Visualization program on using task models to route information among collaborators.

commercial video-teleconferencing, synchronous application sharing, Multi-User Virtual Environments (MUVEs),* and other collaboration support services for strategic planning operations. In the ELB operational context of plan conflict detection and repair, lengthy collaborative sessions, where the participants argue over the allocation of resources or negotiate the assignment of weapons, are infeasible. Also, experience has shown that although conflicts can be worked out at this pre-execution stage, those that arise during execution are more difficult to address.

The ELB ACTD requires the coordination of activities during such operations as forcible entry and restraining operations (e.g., operations to prevent the spread of hostilities). Under the guidance of a unified commander (e.g., Commander in Chief, Pacific [CINCPAC]), the coordination of the Naval and Marine units is critical, as well as their coordinating with the heavier follow-on forces. Past experience has shown that managing several lesser, regional operations (e.g., a Non-Combatant Evacuation Operation [NEO]), perhaps in concert with a major regional conflict, can lead to unnoticed inconsistencies. With increasing specialization of fighting units, one asset (e.g., a civil affairs special unit) may be required in a number of conflicts. Temporal conflicts may also arise, as some operations must be completed prior to others.

The technology that we desire to transition provides useful capabilities to support the better coordination of planning activities. Ultimately, we see a plan deconfliction system as a facility for instant collaboration that is driven by, and focused on, an automated analysis of the plan that highlights conflicts and/or opportunities. To broaden the concept beyond deconfliction, we call this analysis *plan overlap detection*. Our current work is identifying categories of overlap in plans. The overlaps can be inter- or intra-echelon, and can be based on plan components that are temporal, geographic, cause-effect, resource usage, or goals.

A necessary step in handling plan overlap, besides detecting it and calling in human planners to review it, is to apply a context-sensitive plan understanding or explanation to explicate the overlap for all of the effected participants. In our latest DARPA-sponsored work on U.S. Air Force campaign planning, we developed a prototype software mechanism for traversing constraint-based plan representations to extract items for plan comparison or explanation. These specialized routines differ from the more general visualization tools required during planning, rehearsal, or after-action review, whose focus is to provide an understanding of the plan at various levels of detail. These visualization tools may employ 3-D graphics, animation, and terrain modeling to show the flow of the plan, whereas explanation in the context of overlap correction will focus on comparisons of the plans, highlighting of conflicts, and the like.

The plan overlap may be handled by creating a merged plan that contains each plan, appropriately modified to create a consistent plan, or by negotiating changes in each plan to arrive at consistency. This capability is the subject of SRI's current JMCAP research, and thus is not ready for early ELB insertion. However, an interactive replanning capability already exists within the JMCAP software; combined with the Joint Force Level Execution (JFLEX) plan monitoring software, this capability could be used as leverage to provide human-in-the-loop replanning and plan merging. Replanning also could be applied to plan repair in execution monitoring.

*These are also called Multi-User Domains (MUDs) or Multi-User Domains: Object Oriented (MOOs).

3 TECHNOLOGY BACKGROUND

We see the potential, in support of ELB, of the application of a variety of advanced technologies including generative planning, case-based planning, autonomous reasoning and monitoring agents, and plan explanation. SRI is currently conducting research on these technologies for both DARPA and SPAWAR. For DARPA* we have investigated the application of generative planning and common plan representations to support both plan feasibility estimation and plan understanding (which includes comparison, explanation, and presentation). For SPAWAR, as part of the JMCAP program, we are researching ways to distribute the planning problem; integrate generative planning with execution monitoring; perform simple conflict detection; and integrate case-based planning with generative planning to develop a hybrid of these two approaches. In transitioning such prototypes, we would apply the technical results and software from those projects to ELB problems, embed the results and software in a user-friendly shell for interaction, integrate them with legacy systems and databases, and implement more hardened methods for interoperability.

3.1 GENERATIVE PLANNING

The most mature artificial intelligence (AI) planning system currently available is the System for Interactive Planning and Execution (SIPE-2†). SIPE-2 has a number of features that make it suitable for applications in crisis response and related domains. It provides good internal plan representation capabilities, as well as mechanisms for interactive and automated planning. It can provide traditional PERT‡ chart representations of the plans it produces, or partially ordered graphs that show a plan as a set of actions ordered by links that show which action should come before another. SIPE-2 is able to record the justification for specific actions, as well as their actual effects, and to use this knowledge to build a complex dependency network that captures plan rationales.

SIPE-2 can also represent procedures and operations at multiple levels of detail: this capability is critical for conflict detection. SIPE-2 supports the generation of alternative plans, and checks for internal consistency in a plan. At the end of each planning level, SIPE-2 checks to ensure that the plan is consistent, by ensuring that no actions undo the effects of others, and determining that there are no temporal or resource conflicts among concurrent branches of the plan. For example, in the Air Campaign Planning (ACP) domain, a "destroy artillery" objective might be a prerequisite for a "degrade offense" objective, and a human planner might erroneously make these concurrent. In another example, electronic countermeasures (ECM) assets might be allocated to two separate tasks that are concurrent, and there may not be sufficient ECM assets to support both. SIPE-2 is able

*SRI has been working since 1991 on the [D]ARPA/Rome Laboratory Planning Initiative (ARPI), on the following projects: Machine Learning for Military Planning (April 1993 to June 1996); SOCAP-ACPT [SOCAP: System for Operations Crisis Action Planning; ACPT: Air Campaign Planning Tool] Technology Integration and Application (June 1995 to September 1996); Decision Support for Transportation Planning in Joint COA [COA: course of action] Development (February 1991 to October 1994); and MultiAgent Planning (August 1995 to August 1998).

†SIPE-2 is a trademark of SRI International. All product or company names mentioned in this document are the trademarks of their respective holders.

‡PERT: Program Evaluation and Review Technique.

to identify these conflicts and suggest how they can be remedied, either by choosing different resources, locations, and times, or by ordering the actions such that the conflict is avoided. Such capabilities are central to plan overlap handling.

As the situation changes, SIPE-2 checks to see that operations within the plan are still applicable and mutually consistent. If not, then SIPE-2 identifies those parts of the plans that are affected by the changes, and presents choices to the user to remedy the effects of the situation change. For instance, a lowering of capacity at a seaport might create a bottleneck in the deployment plan such that another port must be used (a minor change); if no alternative ports exist, a change in the employment plan would be required (a more significant change that involves replanning actions at a higher planning level). SIPE-2's replanning capability, derived from its execution monitoring facility, also enables the user to explore how changes in the situation, assumptions, or unexpected effects can impact the plan.

Plan deconfliction, as we currently envision it, uses a representation of constraints across complete or partial plans to identify either conflicts or opportunities and to suggest means for resolving conflicts or coordinating opportunities. Constraint types that can be easily represented via SIPE-2's representation scheme include temporal, resource, and world-state constraints (e.g., the preconditions and effects of actions).

SIPE-2 also enables us to create methods for user-guided conflict resolution, by using replanning. The human planner can help to identify critical constraints and to choose the corrections. Correcting a plan via generative planning involves replanning, from scratch, a portion of the plan. Human planners, however, often reuse plans from previous situations, a method of operation that can be addressed by the following technology, case-based planning.

3.2 CASE-BASED PLANNING

Case-based reasoning (CBR) technology can be viewed as a mechanism for capturing previous experience for later retrieval and adaptation to new situations. Cases are abstractions or generalizations of all or parts of previous plans. In contrast to rule-based or plan-generation systems, which rely on sets of if-then rules or cause-effect rules, respectively, CBR brings a whole, interconnected case into consideration. Key attributes (or combinations thereof) of a case are used as indices into a case repository; these indices are used to predict which cases are useful to the current situation. Typically, the front end of an application that uses CBR will have a graphical user interface (GUI) that allows a user to easily input new cases and does not require any detailed understanding of the underlying CBR engine. The cases can be input in a free-form manner (i.e., as text) and are automatically indexed into the case library.

We see CBR as providing a better plan authoring and editing capability than can be provided by the use of generative planning alone. Specifically, we are investigating the ability to cut and paste all or parts of previous plans into new plans. As we envision this process, the user states a planning problem (e.g., an objective to solve or a situation to deconflict) and the CBR module retrieves some solutions that are similar to the current problem and situation. The user can then cut and paste portions of the solutions into the developing plan. When this is done, simple kinds of adaptation can be done automatically. These adaptations include changing times of events, replacing units, and the like.

3.3 JMCAP: DISTRIBUTED, HYBRID GENERATIVE AND CASE-BASED PLANNING

JMCAP is an applied research effort directed toward supporting distributed, collaborative, continuous planning in a maritime campaign planning domain. The problem being addressed by this research is the semiautomated generation of crisis response options, in the presence of multiple, competing objectives and constraints, within a distributed computing environment that includes multiple agents collaboratively solving the overall planning problem. Rapid, effective planning in this environment requires the ability to support automated and interactive plan generation to the human planners; to negotiate resource, temporal, and operational constraints among the distributed planning agents; to reuse previous plans, planning doctrine, and plan templates to quickly develop integrated responses to new situations; and to replan when planning conflicts arise or a situation changes.

The key technical challenges of this project are as follows: (1) identifying a common plan representation that will allow distributed plan authoring, plan generation, and execution monitoring components to share knowledge about the evolving plan; (2) developing techniques for distributing the planning problem, managing the distributed planning and plan deconfliction process, and merging the resulting component plans; (3) developing and applying a hybrid approach to plan generation that integrates AI generative planning and case-based reasoning methods; and (4) providing support for replanning as a result of conflicts that arise during planning, or execution failures.

SRI's application and technology development for JMCAP is focused on two primary areas: technology for managing a distributed, collaborative planning and execution process, and hybrid generative/case-based planning methods. The distributed planning technology developed to date incorporates innovative techniques for representing and reasoning about constraints in a distributed planning environment; representing and propagating numerous temporal constraints; synchronizing and maintaining multiple views of a distributed plan structure (e.g., effects from one plan are posted to the other); reasoning about relevance of planning constraints; plan merging; and Common Object Request Broker Architecture (CORBA) interfaces to a plan execution monitoring system. We have encoded a portion of a NEO scenario, developed with SPAWAR for testing, and have implemented methods for two planners to pass both plan parts and constraints on their plans to each other. JMCAP then uses these to merge distinct plans and to look for areas of conflict. In hybrid planning, we are integrating AI generative planning and case-based reasoning methods. SIPE-2 provides the generative planning capability; we are building on previous work at SRI and elsewhere to develop appropriate case-based plan retrieval and adaptation methods. Our work to date has focused on developing a representation for stored plans, and on developing the basic mechanisms for plan splicing and advice extraction. Future work will incorporate advice extraction techniques, as well as more sophisticated techniques for storing, indexing, and retrieving plans, and more general methods for merging multiple plan fragments.

3.4 JFLEX

Joint Force Level Execution, SPAWAR's execution monitoring system, is already being integrated with the JMCAP planner.* JFLEX graphically displays plan objectives, tasks, and preconditions in a time line format on three separate horizontal levels of the screen. Menu commands allow the display of the connections between objectives and their supporting tasks, or between tasks and their supporting preconditions. Each temporal event (objective, task, or precondition) is displayed as three concentric boxes that represent when the event is scheduled to be executed, when it is preferable that it be executed (i.e., preferred ranges for the start and end times of the event), and when it must be executed (i.e., legal ranges for start and end times). JFLEX uses fuzzy reasoning techniques to calculate the truth value of preconditions and the start and end times given above. A variety of human operators can use the system to monitor the execution of a plan. They check on whether tasks have been completed when their scheduled completion times approach, and whether important conditions have been met when their times approach. Operators edit the new plan execution record by modifying the state of various tasks and conditions (usually by modifying the times and/or dates). The software, in turn, shows the effects of the changes on the plan by shifting scheduled times to accommodate schedule slips, or by highlighting steps in the plan whose preconditions have been violated. A client-server implementation ensures that many distributed operators can monitor plan execution simultaneously. A change made to a precondition in one location will show up on the screens of all who are monitoring that plan.

3.5 ONTOLOGY-BASED SHARED PLAN REPRESENTATIONS

The need for interoperation among disparate planning elements suggests the need for a shared plan representation based on a shared domain ontology. Such a representation will facilitate the growing need for intercommunication between planners, schedulers, executors, monitors, resource consumers, briefers, and resource providers. Such a representation must support the type of rich constraint-based processing that is required for plan overlap handling.

SRI has developed a robust and useful representation for constraint-based plans. It is used for the representation of a plan before it is executed, and the plan as it is being executed in a dynamic situation. This representation has supported the development of crisis response applications in a number of domains, such as joint force employment and deployment, oil spill emergency response, and air campaign support mission planning. It is supported by a plan generation and execution system, as well as by graphical knowledge acquisition tools.

In the recent DARPA-sponsored Integrated Feasibility Demonstration (IFD)–4, SIPE-2's plan representation and manipulation was used to support a hybrid plan representation among four different software systems: a plan authoring tool, a plan generation tool, a temporal reasoning and plan display tool, and a targeting effectiveness analysis module. (These systems are, respectively, ISX Corporation's ACPT; SRI's SIPE-2; GE CRD's* Tachyon/Plan Visualization Tool; and the Conventional Targeting Effectiveness Model [CTEM] used by the USAF XOOC office [Checkmate].) This hybrid representation, supported by code for pairwise translations among the different systems, handled a variety of forms: for example, a lattice of dependencies among objectives and tasks; target-weapon pairings; strict tree representation between objectives and tasks and their parents and children, for capturing hierarchical information; and cause-effect knowledge.

*As of December 1997, JFLEX and SIPE-2 communicate via CORBA, and SIPE-2 passes plans—actions and their hierarchical organization, their ordering constraints, and their times—to JFLEX for monitoring.

*GE CRD: General Electric Corporate Research Division.

3.6 PLAN UNDERSTANDING

In our work on plan comparison and explanation in the context of air campaign feasibility assessment, we adopted a knowledge-intensive approach. We attach domain-specific plan characteristics to the planning operators inside the plan generation system, SIPE-2. These operators are used to generate parts of the overall plan and, with these attachments, we can use the operators to characterize related portions of the plan for later use in explanation

In addition to formulating plan characteristics for explanation, we defined relationships among them. Some of these relationships are simple generalization hierarchies: e.g., economy has the following specializations: force, logistics, and fuel. Some relationships, such as class/instance, are not strictly hierarchical: e.g., economy of force is also a military principle. These characteristics are used to support useful inferencing when comparing or explaining plans, and provide a taxonomy of military plan characteristics.

In addition to this knowledge-intensive component, we explain by generating and presenting plan comparisons to the user in a graphical interface. We have also formulated simple taxonomies of comparators, such as *aggregate* for resource usage and *structural* for goal networks.

3.7 AGENT-BASED SUPPORT FOR DISTRIBUTED PLANNING

Some agent architectures, e.g., the "blackboard" approach, assume a centralized resource into which all agents can tap. This approach, however, will not work with the command style envisioned for ELB: a vulnerable, single point of failure is too risky, and autonomy of operation means that no one person "owns" the entire plan. Instead, for our approach to plan overlap handling we envision a distributed peer network of autonomous agents,* each a lightweight process, that can monitor for conflicts and respond instantly. As planning proceeds and potential conflicts arise, they can be detected by the monitoring agents. We envision that conflict resolution agents would notify the human planners that there is a problem, and then assist the planner in evaluating possible resolutions. For a suitable short-term focus, automated detection and human-guided resolution could be accomplished by having the agents use constraints derived from SIPE-2's planning operation.

Our requirement for agent operation is that the implementation support both rule-based and reactive (message-based) operation. It should rely on a language for expressing belief, obligation, and capabilities. It should have a facility for interagent communication, and have a temporal capability: (i.e., believe different things at different times). It should contain a representation for actions; beliefs; obligations (a commitment to some fact); decisions (a commitment to oneself); and capabilities (the ability to perform some action).

*Research on distributed artificial intelligence (DAI) has evolved a number of interoperation methods that have now been adopted by the agent community. For example, contract nets are used to implement a propose-bid method for agents to find service providers. In specification sharing, agents advertise their specific capabilities and requirements, and these are matched. In federated systems, facilitators are used to mediate and matchmake among agents. Approaches such as are used in CORBA provide location-transparent access through a registry mechanism.

3.8 ENHANCED COMMON OPERATIONAL PICTURE: THE ECOP TOOL

Highly visual GUIs are critical for user acceptance of new tools. A Java-based system called Enhanced Common Operational Picture (ECOP), is under development by DTAI, Incorporated, may offer some useful features for map-based displays. The ECOP software provides an advanced geographic map display that includes real-time updates of positional data from a variety of data sources, as well as overlays, zooming, and other standard map operations. This system, operational from any Java-capable browser, runs on a variety of platforms, and provides one integrated display for many data sources. ECOP also can be run to distribute a common operational picture using little network bandwidth, making it suitable for remote locations. Further requirements it would need to satisfy, in order to function as the front end to a planning system, are the input of overlay icons (e.g., units) and their position, the display of hierarchical charts or networks to show action dependencies, and chart-, table-, or text-based plan elements extracted for comparison and contrast. A first step toward integration would be to enable JMCAP to read ECOP-modified databases, thereby allowing JMCAP to plan with the most current situational data.

3.9 REACTIVE PLANNING SYSTEMS

As part of the overall JMCAP effort, SPAWAR is examining the possibility of integrating a reactive planning system into the loop between JFLEX and the JMCAP planner, in order to provide a quick response plan repair capability for limited situations. They have proposed the use of a version of the University of Michigan's Procedural Reasoning System (UM-PRS) with specialized enhancements, connected to JFLEX by means of a CORBA interface. JFLEX would then have access to a reactive planning system, to deal with rapid plan repair issues that its case-based plan repair capability cannot address. This integration would require some level of distributed interaction and information exchange between UM-PRS and SIPE-2. For example, during plan execution and plan repair, if events necessitate a repair to the plan, UM-PRS might ask for planning support from SIPE-2, which would then provide a partial repair or a contingency plan that corrects the problem with the plan.

In work at SRI, SIPE-2 has been integrated with PRS for plan execution: SIPE-2 generates a plan that is passed to PRS for execution. This previous work can serve as a useful example for other such integrations.

4 PLAN FOR TECHNOLOGY TRANSFER

Assessment. An early demonstration of the operational capabilities of JMCAP within an ELB transition environment could consist of a plan overlap detection system that supports the detection and resolution of tasks and activities among separately developed plans, and monitors executions to find cases where plan repair is needed. This system would require further development of a plan explanation subsystem that would provide sufficient context to explain to each planner involved in the overlap where the overlap occurred and why.

Further extensions and "hardening" would also be needed to enable the JMCAP software to perform plan constraint monitoring and conflict detection, and to assist in conflict resolution within an ELB scenario. We would use existing technologies for such extensions, where possible, from the areas of CBR and agent operation. Initially, our system would take plans for analysis as input, but we could move to a more reactive mode of operation where intelligent agents would perform constraint monitoring and conflict resolution to support deconfliction of plans while they are being created or executed. For example, a mine warfare planning session might involve a Naval Commander (sea-borne mines), a Marine Commander (ground mines), a Mine Planning Anchor Desk, and a Logistics Anchor Desk, interacting to generate an overall mission plan. Each of these planners would have separate but related requirements, goals, and priorities. These planners could plan independently, and rely on an automated analysis of the plan overlaps provided by the JMCAP planner.

In this approach, as the individual plans are generated, plan monitoring agents would be generated to monitor the status of plan constraints that are identified as being critical to the success of the plan. These agents would notify other planners of their requirements (e.g., an agent generated by the Marine Commander might notify the Logistics Anchor Desk that a certain number of a certain type of mine must be available in a given location by a specified time). They would also monitor the dynamically evolving situation and the partial plans under construction by other planners, and identify potential conflicts (e.g., if two plans require the same resource simultaneously, a critical event that one plan depends upon might occur too late in the supporting plan, or the intelligence estimate of enemy strength might change). Conflict resolution agents would provide the users with plan editing methods for repairing plans to resolve potential conflicts.

We believe that the following effort is a feasible proposal: the development, integration, and operational demonstration of a system designed to provide support to human planners for detecting both conflicts and opportunities in separately developed tactical plans that span multiple echelons. We will consider the operational problem of coordinating the operation of geographically dispersed units operating at the same time scale, as well as units (e.g., other services) that arrive at a later time. Our current understanding of this need is that the rapid pace of battle, combined with a more decentralized operation and more autonomy of units, will exacerbate the problem of conflicts and thereby necessitates automated support.

5 ARCHITECTURE AND INTERFACES

Our architecture for a plan overlap detection system would require, at a minimum, that the JMCAP planner be integrated with (1) a graphics-based user interface, (2) a database of situation data, (3) a low-level execution monitoring system, and (4) a set of distributed JMCAP planners applied to different knowledge domains. More capabilities could be provided by extending the technology, either by developing new software (e.g., for plan explanation) or by integrating complementary technologies (e.g., reactive planning). Our implementation architecture would be based on a PC Windows NT* client-server approach, using CORBA for integration. We will design

*Franz, Inc., producers of Allegro Common Lisp (Allegro CL) in which SIPE-2 is written, have a PC Windows NT-compatible version of Allegro CL available; we estimate that a port of SIPE-2 to this platform would take about 3 weeks.

with an open systems approach to the design of our components, to maximize reuse and interoperability. We may employ a client-server approach to providing a ubiquitous interface to the plan explanation mechanism, and use agent-to-agent protocols* that are built on standard remote procedure calls (RPCs).

The primary interfaces are from (1) SIPE-2 to a situation database, (2) SIPE-2 to a graphical user interface, and (3) SIPE-2 to an execution monitoring system. The intraplanner interface that would be required is already well developed (and uses an RPC-based protocol, not CORBA). The CORBA interface for JFLEX would serve as a starting point for item 3 above, and we have some software related to connecting class/instance knowledge bases with relational databases. Our past work on developing integrated feasibility demonstrations has included file-based connections to Motif-based user interfaces, which could serve as a starting point for item 2.

6 SUMMARY

We have described both the operational context that could serve as the path for technology insertion, and a range of technologies that would be appropriate for integration. These technologies provide different kinds of support for plan generation (including plan understanding) and execution monitoring. Narrowing the field of candidate applications for insertion to a single focused requirement, plan overlap detection, provides a good first start to a broader technology transfer.

*For example, the Knowledge Query and Manipulation Language (KQML) is being proposed as an Object Management Group (OMG) standard for agent to agent communication.

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