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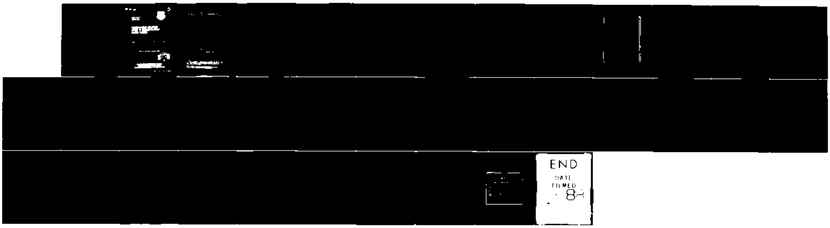

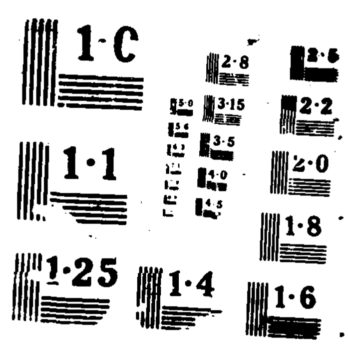
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KNOWLEDGE-BASED REPLANNING APPLIED TO COORDINATED-SERVICE MISSION PLANNING

Sharon M. Walter; Kevin M. Benner, 1Lt, USAF and Craig S. Anken

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The original objectives of the work described here were to critically analyze the Artificial Intelligence-based technology contributing to the tactical mission planning capability of its interface. The interface is comprised, in part, of a dictionary-driven parser called APE-II. The parser and a script interpreter work to develop a Conceptual Dependency representation of the meaning of user input to KRS.

The objectives of the effort were extended to include coordination with a research group from the Naval Ocean Systems Command (NOSC) Laboratory. Initiated as Project Juniper under the Joint Directorate of Laboratories (JDL) Command, Control, and Communications technology program, the extended objective would be to demonstrate the feasibility of using distributed expert system decision aids to support the planning of coordinated Air Force and Navy air strike missions.

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Knowledge-Based Replanning
Applied to Coordinated-Service Mission Planning

Table of Contents

I. Introduction: KRS, APE-II, and Project Juniper

In late December of 1984 researchers at RADC's Artificial Intelligence (AI) Laboratory were involved in the critical analysis of an AI-based tactical mission planning system and its integrated interface. Laboratory engineers from the Naval Ocean Systems Center (NOSC) of San Diego, California proposed a coordinated research effort to investigate and test joint mission planning capabilities of current RADC and NOSC prototype systems. Both laboratories had separately been sponsoring research to originate technology to support development of air strike planning aids. These aids were, of course, targetted at assisting their respective branches of the armed services. However, since the operational Air Force and Navy may need to support each other in air strike missions, the abilities of planning systems for each service must be mutually supportive. RADC and NOSC laboratory personnel first met formally, and discussed technical objectives of the joint effort, in February of 1985 at RADC.

Initiated as Project Juniper under the Joint Directorate of Laboratories (JDL) Command, Control, and Communication technology program, the specific objective of the coordinated effort was to "demonstrate the feasibility of using distributed expert system decision aids to support the planning of joint Air Force and Navy strike missions."

RADC's mission planner is called KRS (Knowledge-Based System). NOSC's carrier-based planner is called ASPA (Air Strike Planning Advisor). KRS and ASPA, described only briefly in this paper, are the interim results of research efforts and are not field-ready developments.

KRS and the Integrated Interface

KRS is a generic knowledge-based expert system developed to demonstrate expert system technology applied to Air Force tactical mission planning. It is written in LISP and runs on the Symbolics 3670 Lisp Machine.

KRS can be used to plan missions interactively with a user, as a data base and a plan verifier, or can be used to automatically generate Air Tasking Orders (ATOs) with minimal human input. The interactive and autoplanning modes of use can be freely mixed. As a data base, KRS has information about resource availability and allocation, target defense status, and some bits of information about weather conditions. Facts about different aircraft, ordnance, and target types can also be accessed. In its plan verification role, KRS checks to make sure a mission plan is logically consistent (e.g. the aircraft specified for use are available at the base specified) and does not violate current airwar doctrine.

A KRS screen display is shown on page 5. The full-screen display is partially covered by a smaller area (a "window") labeled 'OCA1003'. The larger, full-screen display is the toplevel KRS window. It keeps a list of all of the missions planned so far (or, all of the missions planned that are currently of interest to the user), and has an area for typed, user input. The smaller, mission window has a number of slots that must be given values in order to fully describe an Offensive Counter Air (OCA) mission. Mission windows each have their own area in which to accept typed, user input.

Users communicate with KRS via a multi-media interface that utilizes natural language, windows, a "mouse" pointing device, and color graphics. The natural language subsystem is comprised of a dictionary driven parser, APE-II (A Parsing Experiment), and a script interpreter. The parser and interpreter work to develop a Conceptual Dependency conceptualization of the meaning of user input to KRS. For example, the sentence "There are F-4C's at Hahn" becomes:

```
(*EXISTS* OBJECT (F-4C NUMBER (*PLURAL*))
          LOC (AT PLACE (HAHN)))
```

Here, the CD primitive '*EXISTS*' implies the existence of an object. The roles 'OBJECT' and 'LOC' have role fillers that describe the object that exists and its location, respectively.

KRS and its interface were developed by the MITRE Corporation in Bedford, Massachusetts through funding from Rome Air Development Center. Both are described in much more detail in [Dawson, et al; 1987].

ASPA

NOSC's expert system, called ASPA (Air Strike Planning Advisor), supports a carrier-based strike at a land target. The computing environment of ASPA is the Xerox 1108 Dandelion Lisp Machine. The first air strike subtask developed under the ASPA project was weapons loading, or weaponeering, for the A-6 attack aircraft. After the target, strike schedule, and ordnance have been specified, expert rules generate and test possible external loads. Constraints that limit total aircraft weight, balance the weight, minimize drag, and specify allowable physical mounting configurations, must be adherred to.

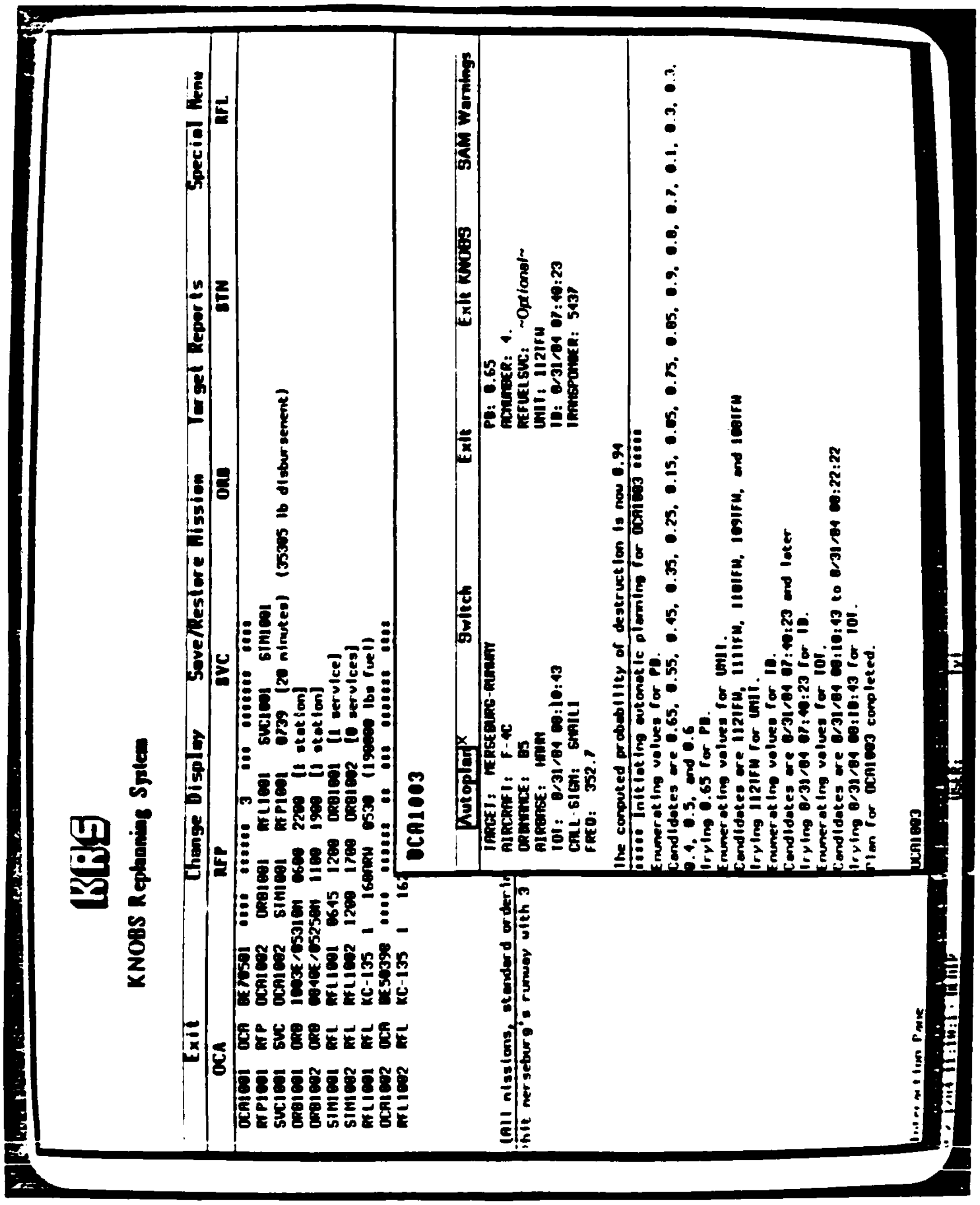

KNOBS Replanning System
Exit
Change Display
Save/Restore Mission
Target Reports
Special Menu
OCA
RFP
SVC
ORB
STN
RFL
OCA1003
Autoplan
Switch
Exit
Exit KNOBS
SAM Warnings
TARGET: MERSEBURG-RUNWAY
AIRCRAFT: F-4C
ORDNANCE: B5
AIRBASE: HAHN
TOT: 8/31/84 08:10:43
CALL-SIGN: GNALLI
FREQ: 352.7
PD: 0.65
ACNUMBER: 4.
REFUELSVC: ~Optional~
UNIT: 112TFW
TO: 8/31/84 07:40:23
TRANSPONDER: 5437
The computed probability of destruction is now 0.94
Initiating automatic planning for OCA1003
Enumerating values for PD.
Trying 0.65 for PD.
Enumerating values for UNIT.
Enumerating values for TO.
Enumerating values for TOT.
Plan for OCA1003 completed.

Figure 1

II. Scenario of Operational Air Force/Navy Coordination

The major obstacle to early progress in this effort was defining a reasonable scenario depicting coordinated operations between operational Air Force and Navy forces. Initial suggestions for the coordination of forces were shot down one-by-one as being unrealistic. One possibility, for example, was to have aircraft from one service refuel aircraft from the other in order to allow the successful completion of a strike mission. There are a multitude of problems with that idea: First, it is almost impossible, physically, for a plane from one service to refuel a plane from the other. The Air Force KC-10 is the only tanker equipped with the two types of refueling nodes for refueling both Air Force and Navy aircraft. The Air Force KC-135 can be reconfigured to refuel a Navy plane but must be taken out of service for maintenance to do so. Also, Air Force refueling missions are not planned or ordered by Tactical Air Command (TAC), the operational component which KRS is designed to assist. Refueling services are entirely under the aegis of Strategic Air Command (SAC). Although it was not felt to be necessary to go strictly "by the book", there was, of course, a strong desire to remain within the realm of believability.

In discussions with operational Air Force personnel, the distinction between 'joint' and 'coordinated' multiple-service missions was stressed. 'Joint' mission planning implies that some of the assets of one of the services are given to another service and are under their direct control. Joint mission planning is rare since neither service wants to give up control of any of its assets. In 'coordinated' missions, each force receives their orders about where and when to be through their usual chain of command. The supported force plans the operation and makes the specific request for support from the planning organization of the other service. Sensitivity to this distinction in terms increases as one goes down the hierarchical chain of command in either branch of the service.

A prevailing difficulty of coordinated air strikes is the fact that missions are planned at two different command levels within the Navy and the Air Force. In the Air Force, plans are made at the numbered Air Force level and disseminated in the ATO. Mission planning in the Navy is done at a lower command level, onboard the carrier. In addition to the probable difficulties caused by the requirement for communication and coordination between Air Force and Navy officers of different rank, are the difficulties associated with communication with a carrier due to EMCON (emissions control) status.

EMCON is important to the Navy because, unlike a strike against an airbase, an air strike against a carrier jeopardizes the entire base of operations. In the interest of carrier self-preservation, great care must be taken in the use of radio communications. But radio-silence inhibits mission synchronization and is prohibitive of mission coordination. Additionally, carrier self-preservation requires keeping sufficient forces in reserve for carrier defense. These measures for self-preservation are often misunderstood and perceived as a lack of cooperation by members of other services.

Apparently, the one consistent area of cooperation between the operational Air Force and Navy pertains to the use of the AWACS (Airborne Warning and Control System). Its communication resources allow it to give assistance to both Air Force and Navy aircraft. For this reason, coordination involving use of the Air Force AWACS resource was considered as the basis for a scenario. (As will be seen in the next section, AWACS services were not used in the final demonstration.)

Current lack of coordination between the operational services did not diminish the value of the objective of Project Juniper, that is, to demonstrate distributed expert systems in support of coordinated Air Force/Navy air strike planning.

Operational service people invariably beleive in the necessity of inter-service operations but find them improbable under current political and practical (ie. communications, carrier self-preservation requirements, etc.) conditions. Research laboratories can play an important role in making such coordination, in the practical aspect, feasible.

Two excellent activities for obtaining operational information were the Bold Eagle 86 Exercise held in late October of FY-86 and the Battle Staff Course taught at the USAF Air Ground Operations School (AGOS), Hurlburt Field, Florida.

Lt Kevin Benner and Ms. Sharon Walter were observers for three days of the Command Post Exercise (CPX) portion of Bold Eagle. The CPX consisted of the planning and tasking portions of the operational tactical environment. Participants in the Bold Eagle CPX, and in the Live Fly, or Flight Exercise (FTX), of the following week included Air Force, Army, Navy and Marine units. As CPX observers, Lt Benner and Ms. Walter were free to observe and interact with staff officers within the Tactical Air Control Center (TACC) on a non-interference basis.

It is interesting to note that two computerized systems, CAFMS (Computer Assisted Force Management) and JAMPS (JINTACCS Automated Message Processing System) were in use during the exercise. CAFMS is basically a database management system.

The very carefully, hand-prepared, hand-checked and double-checked ATO is typed on CAFMS into templates which are not unlike KRS mission templates. The system complains when resources have been overexpended. After the ATO has been entered, it can be sent via JAMPS, in full or in part, to all appropriate offices. (One of the complaints that the Navy has about working with the Air Force is that ATOs are sent in their entirety to all involved parties. Navy carriers receive the entire ATO. Communications are slow. The ATO transmission holds other communication up for long periods of time, increasing the opportunity for enemy detection and carrier location tracing.) JAMPS sends messages to specified receivers in the JINTACCS (Joint Interoperability of Tactical Command and Control System) format (intended to be the all-service standard).

Critiques of the CPX, filled out by exercise participants, demonstrated the willingness of operational personnel to accept computerization of their operational environment. One such critique recommended "CAFMS terminals at each duty desk." This suggestion seems inappropriate in view of the type of task assistance provided by CAFMS, but may be an indication of the kind of acceptance that TEMPLAR will experience. TEMPLAR (Tactical Expert Mission Planner) is a research project that is extending and fortifying the technology developed in KRS. It is intended to bring computerized, intelligent mission planning capabilities closer to field deployment. TEMPLAR is scheduled to be tested at the USAF Blue Flag Exercise in September 1987.

The three-week long Battle Staff Course is taught on a regular basis at AGOS. It provides information on the tactical battle management functions within the Tactical Air Control System (TACS) with emphasis on the real-time employment of joint Air Force/Army air and land resources. Battle Staff faculty stress that the structure of the tactical environment as it is taught is generic, with each existing such environment demonstrating wide-ranging variation from their model. While a few course participants complained that course content was often inaccurate or outdated, most felt that an adequate model was presented.

The Air Force and Army have a very detailed and effective system of cooperation, especially as demonstrated by J-SEAD (plans for Joint Suppression of Enemy Air Defense). The minimal participation of Navy and Marine personnel as either students or briefers, and comments by the lone Marine speaker, demonstrate the strained relations existing between the operational Air Force and the Navy/Marines. The basic cause for the emotionalism was characterized as a case of differing interpretations of Air Force and Navy/Marine responsibilities in the tactical environment. The Marine speaker described the _functional_ (Air Force) separation of responsibility and the _service_ (Navy/Marine) understanding of the separation of power. Functional responsibilities are divided into air, ground, and naval functions. Each services' air assets, according to Air Force doctrine, are the responsibility of the Air Component Commander (usually, but not necessarily, an Air Force person), similarly with ground and naval assets. According to Navy/Marine interpretation of Joint Chiefs of Staff (JCS) Publications, each service maintains full responsibility and control of their respective assets (see the pictoral demonstration in Figure 2 of the differing interpretations).

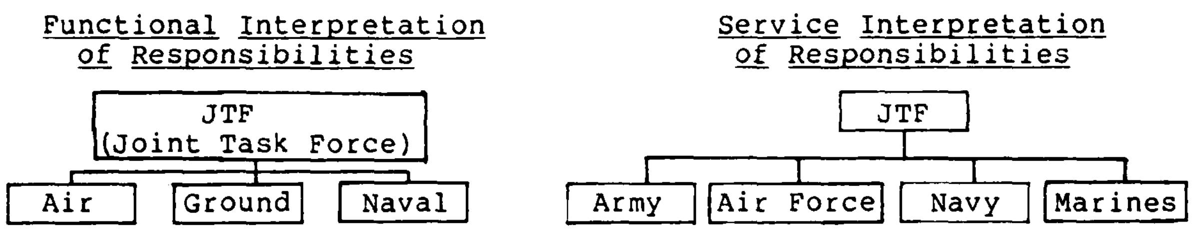


Figure 2

Attendance at the AGOS Battle Staff course provided valuable information on the operational environment, including the field-related jargon and copious acronyms, for which RADC produces computerized assistance. While much of the course had no specific relevance to Air Force/Navy relations, sessions provided valuable information on the operational Air Force environment.

III. Effort Activities and Results

In early December of 1985, an interim project presentation to the Project Juniper sponsors, the Decision Aids subpanel of the JDL, demonstrated the successful redefinition of the KRS domain setting, and a scenario demonstrating the "feasibility" of coordinated Air Force/Navy mission planning. At that time KRS and ASPA did not technically communicate directly with one another since a means of communication between the two types of hardware (Xerox and Symbolics Lisp Machines) and software had not yet been completed. Eventually, the exchange of information between ASPA and KRS took place across an ethernet connection using the TCP/IP communication protocol (Figure 3, on the next page).

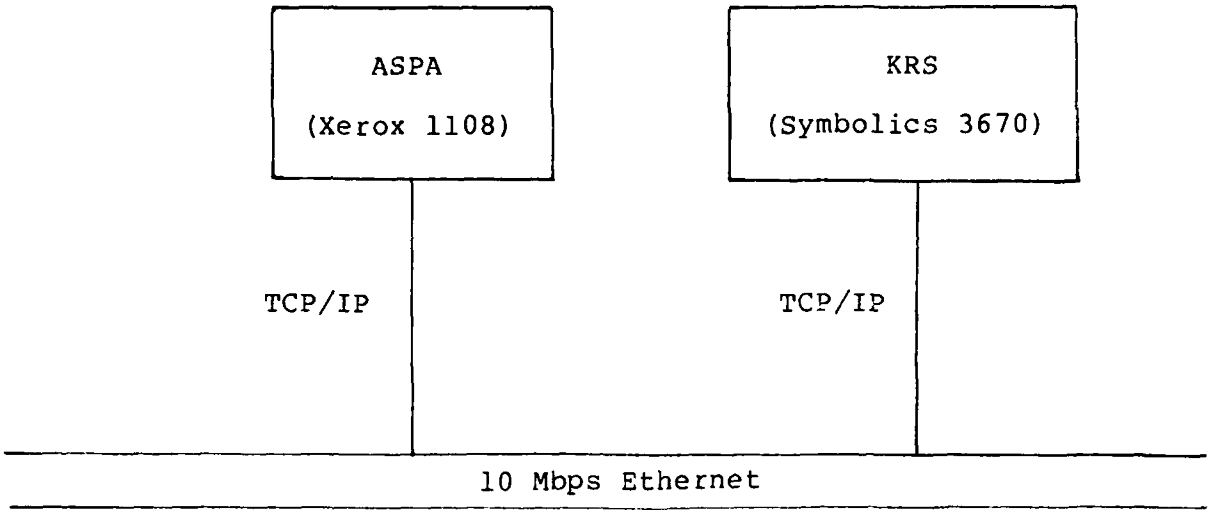


Figure 3

The scenario finally settled on is based in Southeast Asia. According to the scenario, Clark Air Force Base and Subic Bay have been closed. Air Force resources at Guam and two Navy task forces with the USS Enterprise and the USS Carl Vinson are to be employed. The tasking directive to the TACC requests strikes on four targets. KRS is used to successfully plan the assignment of Air Force resources at Guam to the targets but then determines that refueling services are available to support only three of the sorties. Via KRS (to ASPA), strike support is requested from the Navy. Navy planners, through ASPA, respond affirmatively and identify available aircraft and the launch platform, window, and location. KRS is then used to replan the four strike missions using both Air Force and Navy assets, and sends a message to ASPA identifying the exact target to strike, the desired damage level, and the time-over-target (TOT). On the Navy side, ASPA is used to complete the Navy portion of the plan and returns the results to KRS. With final Air Force and Navy plan coordination completed, KRS incorporates the ASPA plan into their Air Tasking Order.

For the most part, transforming the domain of scenario operation from the Fulda Gap region of western Europe to the Southeast Asian scenario consisted only of changing the database information. The relative ease of transportation demonstrated what was considered to be an appropriate independence in the KRS software structure, of the knowledge base from the control structures. Other, more significant and telling software alterations were made later. For instance, the ability to quantify resources at airbases was added. Previous to this, an unlimited number of aircraft could be detailed from any airbase. The system knew of no bounds on its resources. Alterations to the system allowed it to keep track of its resources and provide notification when they were used up. (The contractor developing KRS, MITRE, also had this feature fixed in the next released version.)

One nagging roadblock in the realistic portrayal of coordinated mission planning had been the fact that different planning tasks exist at different command levels in each of the services. The level of planning demonstrated by KRS is shore-based in the Naval command structure. The planning task level for which ASPA was developed is at carrier level, lower in the hierarchical command structure. ASPA should be receiving information of the type produced by KRS from its superior command level before proceeding with its task of planning the details of specific missions. The decision, then, was to develop a version of KRS with a database of Naval assets (carriers and Navy aircraft, instead of airbases and Air Force aircraft), and Navy-specific rules and slot constraints (ex. carriers launch aircraft only within the limits of narrow, time-constrained "launch windows"). Additional changes included relabeling screen display items to give them more of a Navy flavor, and providing the system with the notion of moving airbases (ie. carriers). Thus, in the final demonstration of coordinating systems, respective Naval and Air Force KRSs interact directly, and ASPA receives its planning directives and data from the Navy-KRS. The structure of the communication among systems is shown in Figure 4.

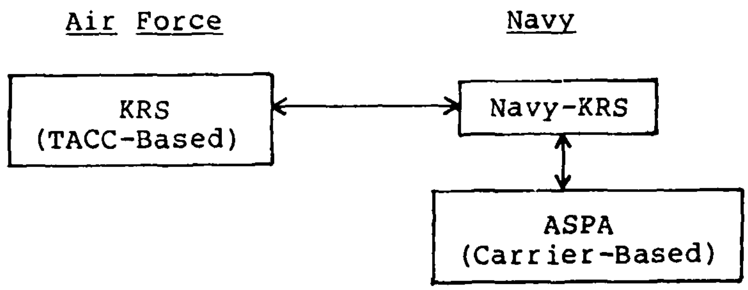


Figure 4

A common window for interaction, the "Juniper window", was developed to display the passage of messages between KRS and Navy-KRS.

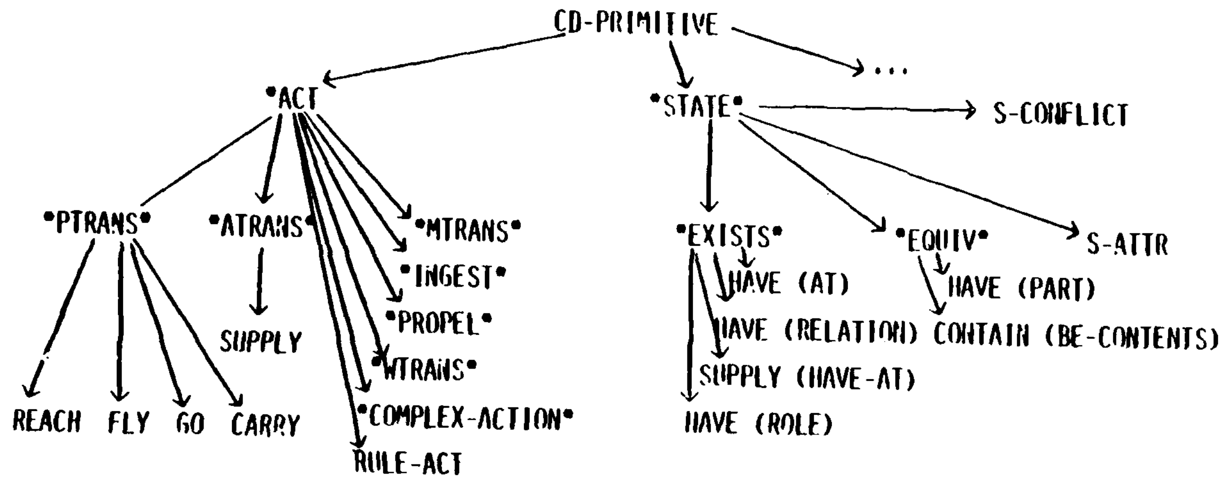
To assist in the development of the Navy-KRS, a Frame Editor, called FED, was developed. FED, based on the Frame Representation Language (FRL) ([Roberts and Goldstein; 1977]), guides a user in making changes to the planning domain. The RADC Technical Memorandum, "Database Editor for a Frame Based System" ([Anken; 1986]), describes the system. A copy of the program was delivered to NOSC Project Juniper researchers to allow continued refining of Navy-KRS.

APE-II: Domain Transfer and Analysis

Porting of APE-II to the Navy domain was, fortunately, largely a matter of word replacement in the dictionary. Navy domain words were attached to the word definitions already in the system. Structuring of new word definitions was not necessary. Neither was it necessary to extend the form of questions that were allowed, since similar forms of questions are asked of a Navy mission planner and an Air Force mission planner (eg. "What aircraft are at the airbase?"; "What aircraft are on the carrier?"). Defining Navy domain words exactly like similar words in the Air Force domain, or defining them as synonyms (using the facility which provides this capability), allowed development of a front-end for the Navy planning systems with pretty much the same breadth of understanding as the original KRS. It is fortuitous that the domains were similar enough to allow this course of action because semantics-based understanding systems are known to be much more difficult to extend or port than syntax-based systems. Some of the difficulty is evident from an analysis of the KRS interface.

Input interpretation is dictionary-driven by APE-II. As each word is processed, its dictionary definition is copied onto a list representing concepts that are currently in focus. The definition of a word is largely determined by its location in a hierarchy of concepts similar to the frame hierarchy of the KRS knowledge base. While items in the frame hierarchy are mainly physical objects or names for groups of similar physical objects (ie. "Hahn", "airbase", "location", etc.), items in the hierarchy of dictionary terms are mostly conceptual. For example, 'reach', 'fly', 'go', or 'carry' are examples of the *PTRANS* concept. (Classically in CD theory, a PTRANS refers to a physical transfer of something.) As another example, 'country' is conceptually a kind of *LOC* (ie. location). Figure 5 shows part of the hierarchy of concepts. The topmost concepts of the hierarchy (the 'primitive' concepts) are: *LOCSPEC*, *ACT*, *STATE*, *ARTICLE*, *CONREL*, *GROUP*, *?*, *PLURAL*, *ATTRIBUTE*, *RELPRO*, *OBJECT*, *GOAL*, *PLAN*, and *MODE-ATTR*. (Note that these are similar but not the same set of primitives that are used by Roger Schank to describe Conceptual Dependency Theory as he defined it. Schank's set of eleven primitives were used to clarify the theory and not necessarily intended to be the standard set for all applications.) The point to be made here is that it can be quite difficult to know where to install new words in the hierarchy without having all the information about the concept meanings that the developers intended.

Figure 5


CD-PRIMITIVE
...
•ACT•
•STATE•
S-CONFLICT
•PTRANS•
•ATRANS•
•MTRANS•
•INGEST•
•PROPEL•
•WTRANS•
•COMPLEX-ACTION•
RULE-ACT
SUPPLY
REACH
FLY
GO
CARRY
•EXISTS•
•EQUIV•
S-ATTR
HAVE (AT)
HAVE (RELATION)
SUPPLY (HAVE-AT)
HAVE (ROLE)
HAVE (PART)
CONTAIN (BE-CONTENTS)

Eventually, the concepts associated with the input, and word sense expectations, are resolved into a representation of the input. There may be more than one word sense for a word and each word sense has a set of expectations that help the process towards a final resolution. To illustrate, the lone word sense for the word "the" is:

```
(SENSE  (*DEF*)
        EXPECTATIONS
        ((IF (MODIFIES (OR *PP*
                           *EVENT*
                           *RELATION*
                           SCRIPT
                           *BPRED*
                           *TPRED*))
          THEN ((SLOTS (* REF))))
```

Thus, the sense of the word "the" represented by '*DEF' is the appropriate sense to use if it modifies a concept that is derived, in the concept hierarchy, from one of *PP*, *EVENT*, *RELATION*, SCRIPT, *BPRED*, or *TPRED*. Since "airbase" is derived from *PP* (ie. "airbase" is a 'picture-producer'), the simple phrase "the airbase" becomes:

```
(AIRBASE REF (*DEF*))
```

Responses to questions are made by comparing the conceptual representation of the question to each member of a set of question-answer pairs. Each question-answer pair consists of a pattern to match against, and an associated action to execute. Patterns are made general enough to match against a set of similar inputs. A simple example would be the pattern that matches against the representation for both, "How many F-4C's are at Hahn" and "How many F-111E's are at Bitburg." Question-action pairs are ordered so that the best match for an input will be found before less well-matched, but conceivably appropriate, pairs. Note that, again, a very good understanding of the historical development of the interface is necessary to extend it.

IV. Summary

Work on Project Juniper at RADC ended in September 1986. The KRS planning system and its natural language interface had been ported to the new domain of Southeast Asia. Hardware incompatibilities (NOSC's Xerox 1106; RADC's Symbolics 3670) and software incompatibilities (Interlisp; Zetalisp) were successfully overcome.

ASPA and KRS planning level differences were surmounted by the port of KRS to still another domain, Navy mission planning, and using this Navy-KRS to act as the Navy, land-based planner one level above ASPA-level planning. Modifications to Navy-KRS were then made to allow the airbase (carrier) locations to be dynamic. The "Juniper window" displays the messages passed between KRS and Navy-KRS.

The process of porting KRS and its interface to two new domains greatly added to the involved researchers' understanding of the planning and natural language software. A paper describing the system was presented at the AGARD Avionics Panel Symposium in 1986 ([Benner and Hilton; 1986]). [Anken; 1986] describes software that was designed and constructed to assist in porting the planner.

The Project Juniper goal of demonstrating Air Force and Navy mission planning systems, operating to plan missions cooperatively, has been successful. Mission planning coordination was demonstrated on a technical, computing level. The authenticity of operational Air Force/Navy mission coordination remains, of course, beyond our control and in question.

The KRS and Navy-KRS systems have been delivered to NOSC where work continues on fine tuning and extending system coordination capabilities.

V. Commentary

Mutual Naval Laboratory and Air Force Laboratory benefits were derived from coordinated research between participants in this project and NOSC researchers working on Project Juniper. The coordination provided us with assistance in defining the new KRS planning domain of Southeast Asia and the extended goal of redefining the system to suit a Navy domain. Beyond the technical success achieved, the basis of a relationship for future work with NOSC has been developed.

Individual researcher understanding of the operational environment for which RADC is tasked with developing technology was improved in the process of collecting domain data for this effort. The AGOS Battle Staff Course was an excellent source of general information and contacts (i.e., the other students) for future reference. The AGOS faculty should be considered a friendly, knowledgeable, and available resource for future work. The RADC Intelligence Office (IN) provided enthusiastic assistance in researching documentation, as did the RADC Technical Library. Still, additional resources of operational information require development.

One final word regarding the difficulty of porting or extending a semantics-based Natural Language interface: Much of the difficulty is based on the requirement for total understanding of the historical development of a system. This difficulty is often considered to be a sufficient reason to dismiss inclusion of semantic interpretation in an interface. However, the gain in system understanding of Natural Language to be made in the future is estimated to be considerable. Here then, is a possible application for RADC's Knowledge-Based Software Assistant (KBSA) [Green, et al; 1983]. The KBSA is a "knowledge-based, life-cycle paradigm for the development, evolution, and maintenance of large software projects." The KBSA is being developed to provide a corporate memory of the software development. It will act throughout the software life cycle as a knowledgeable software assistant. Development of semantic interpreters using the KBSA software development paradigm should provide software extensibility and portability.

ACRONYMS

AGOS Air Ground Operations School

ATO Air Tasking Order

APE-II A Parsing Experiment

ASPA Air Strike Planning Advisor

AWACS Airborne Warning and Control System

CAFMS Computer Assisted Force Management

CPX Command Post Exercise

EMCON Emissions Control

FED Frame Editor

FRL Frame Representation Language

FTX Flight Exercise

JAMPS JINTACCS Automated Message Processing System

JCS Joint Chiefs of Staff

JINTACCS Joint Interoperability of Tactical Command and Control System

JDL Joint Directorate of Laboratories

J-SEAD Joint Suppression of Enemy Air Defense

JTF Joint Task Force

KBSA Knowledge-Based Software Assistant

KRS Knowledge-Based Replanning System

NOSC Naval Oceans Systems Command

OCA Offensive Counter Air

POL Petroleum, Oil, Lubricant

RADC Rome Air Development Center

SAC Strategic Air Command

TAC Tactical Air Command

TACC Tactical Air Control Center

TACS Tactical Air Control System

TEMPLAR Tactical Expert Mission Planner

TOT Time-Over-Target

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