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COLLABORATIVE ASSISTANT FOR RAPID KNOWLEDGE FORMATION AND REASONING

George Mason University

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13. ABSTRACT *(Maximum 200 Words)*
This research has developed a collaborative assistant for rapid knowledge formation and reasoning, called Disciple-RKF. Disciple-RKF enables a team of subject matter experts who do not have prior knowledge engineering experience to build an integrated knowledge base, with limited assistance from a knowledge engineer. Each subject matter expert teaches a personal Disciple-RKF agent while collaborating with it in solving specific problems. During this process, each Disciple-RKF agent learns from its expert and builds its knowledge base. All these knowledge bases are then merged into an integrated knowledge base for Disciple-RKF. Disciple-RKF has being successfully applied to develop knowledge-based agents for military center of gravity analysis which have been used in several courses at the US Army War College. Experimental results with Disciple-RKF demonstrate that the developed approach facilitates the acquisition of knowledge directly from subject matter experts and improves the knowledge base development process. The emphasis of this research was on acquiring expert's problem solving knowledge that is not normally represented in written documents. This task is complementary to that of acquiring knowledge that has already been expressed in textbooks or other documents.

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Artificial Intelligence, Knowledge Acquisition, Multistrategy Learning, Subject Matter Expert, Knowledge Engineering, Instructable Agent, Knowledge Base, Center Of Gravity Analysis

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1. Introduction

The general objective of this research project was to develop and to experimentally validate a collaborative assistant for rapid knowledge formation and reasoning. This assistant will enable a team of Subject Matter Experts (SME) who do not have prior knowledge engineering experience to rapidly construct, update and extend an integrated knowledge base for a complex application. The emphasis of this research was on acquiring expert's problem solving knowledge that is not normally represented in written documents. This task is complementary to that of acquiring knowledge that has already been expressed in textbooks or other documents. This research has benefited from the basic research done under the AFOSR's Software and Systems project titled "Mixed-Initiative Knowledge Base Development" (2000-2003) and from collaboration with the US Army War College. It resulted in the development, experimental use, and transition of a complex knowledge engineering environment, called Disciple-Rapid Knowledge Formation (RKF), and its application to the military Center of Gravity (COG) analysis domain, as described in the following, and in the papers from section 10.1.

Figure 1: General Approach to Rapid Knowledge Formation by Subject Matter Experts

Figure 1 introduces the general approach investigated. In this approach, each subject matter expert teaches a personal Disciple-RKF agent, while collaborating with it in solving specific problems. During this process, the Disciple-RKF agent learns from the expert, building, extending and improving its knowledge base. The resulting knowledge bases of all these Disciple-RKF agents are then integrated by a knowledge engineer. The Disciple-RKF agent with the integrated knowledge base can then be used in three ways. It can be used by a non-expert as a problem solver. It can be used by an expert as a problem solving assistant. Finally, it can be used by a student as a tutoring system.

2. Synergistic Collaboration and Transition to the Army War College

This project involved a multi-objective collaboration between both the Learning Agents Center of George Mason University and the Center for Strategic Leadership along with the Department of Military Strategy, Planning, and Operations of the US Army War College (Tecuci et al., 2002a). The US Army War College provided the challenge problem (strategic center of gravity analysis), extensive subject matter expertise (faculty and high-ranking officers from all the military services), and experimentation support for both the developed technology and the resulting knowledge bases and agents.

A distinguishing feature of this collaboration is the synergistic integration of artificial intelligence research, with military strategy research, and the practical use of agents in education, as indicated in Figure 2.

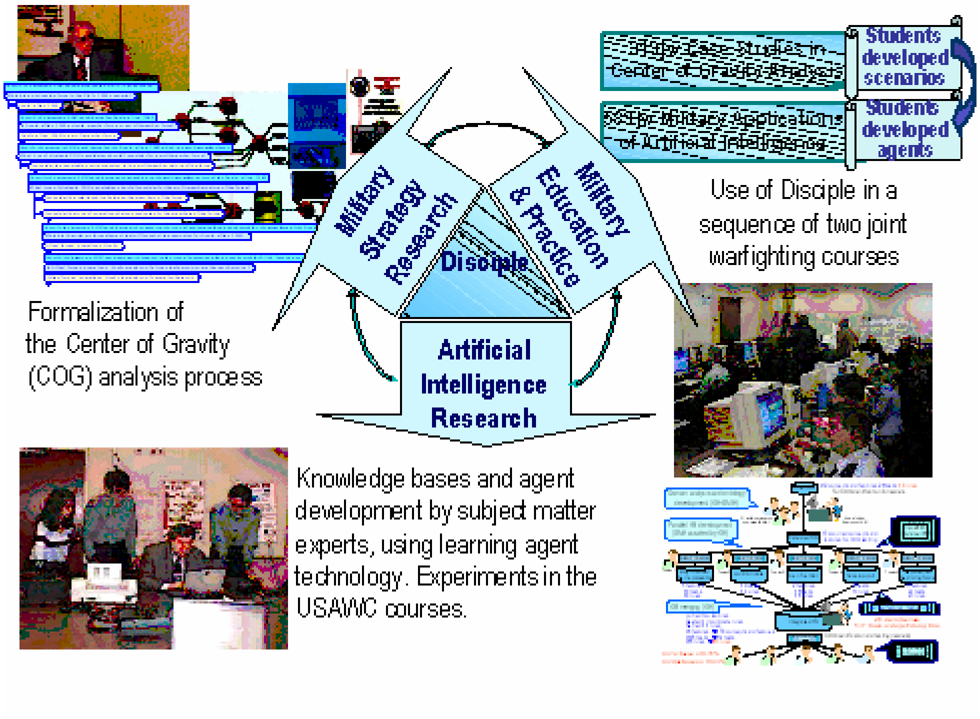

Figure 2: Synergistic integration of artificial intelligence research military stratergy research, and military education.

The artificial intelligence research objective was the development of knowledge bases and agents by subject matter experts using learning agent technology. The military strategy research objective was the development of a systematic approach to center of gravity determination. The educational objective was the enhancement of the educational process of senior military officers and strategic leaders through the use of intelligent agent technology. This integration accelerated the development of the artificial intelligence technology and of intelligent agents for center of gravity analysis. It also facilitated the transition of this work to the US Army War College, where Disciple agents have been used since 2001 in a sequence of two joint warfighting courses, “319jw Case Studies in Center of Gravity Analysis,” and “589jw Military Applications of Artificial Intelligence.”

3. The Center of Gravity Analysis Challenge Problem

Military center of gravity analysis was used as a challenge problem to test the knowledge acquisition, learning, and problem solving methods of Disciple-RKF. The concept of center of gravity, introduced by Karl von Clausewitz (Clausewitz, K.V. 1832. *On War,* translated and edited by M. Howard and P. Paret. Princeton, NJ: Princeton University Press, 1976), is fundamental to military strategy, denoting the primary source of moral or physical strength, power, or resistance of a force (Strange, J. 1996. Centers of Gravity & Critical Vulnerabilities: Building on the Clausewitzian Foundation So That We Can All Speak the Same Language.

Quantico, Virginia, USA, Marine Corps University). The most important objective of a force (state, alliance, coalition, or group), in any type of conflict, is to protect its own center of gravity while attacking the center of gravity of its enemy. Therefore, in the education of strategic leaders at all U.S. senior military service colleges, there is great emphasis on center of gravity analysis. This analysis requires a wide range of background knowledge not only from the military domain, but also from the political, psychosocial, economic, geographic, demographic, historic, international, and other domains. In addition, the situation, the adversaries involved, their goals, and their capabilities can vary in important ways from one scenario to another. Center of gravity analysis is a very good example of knowledge-intensive, expert problem-solving that a Disciple agent should be able to learn.

Our approach to center of gravity analysis, based on the work of Strange (1996) and Giles and Galvin (Giles, P.K., and Galvin, T.P. 1996. *Center of Gravity: Determination, Analysis and Application*. CSL, U.S. Army War College, PA: Carlisle Barracks), and developed with experts from the US Army War College, consists of two main phases, *identification* and *testing*, as shown in Figure 3. During the identification phase, center of gravity candidates from different elements of power of a force (such as government, military, people, economy) are identified. For instance, a strong leader is a center of gravity candidate with respect to the government of a force. Then, during the testing phase, each candidate is analyzed to determine whether it has all the critical capabilities that are necessary to be the center of gravity. For example, a leader needs

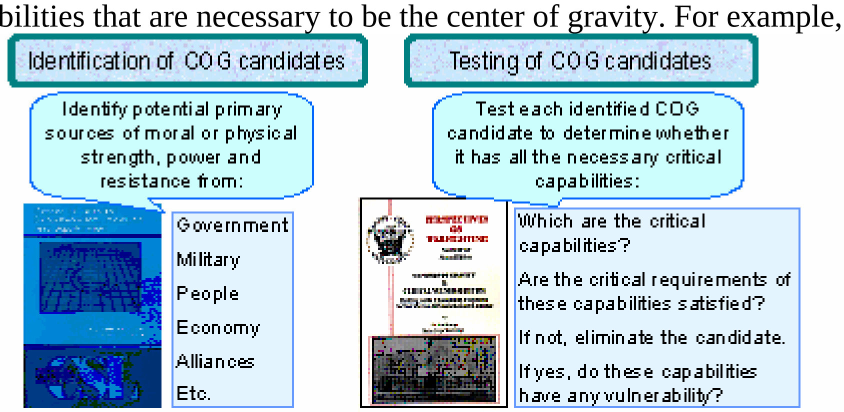

Figure 3: The identification and testing approach to center of gravity analysis.

to be protected, stay informed, communicate (with the government, the military, and the people), be influential (with the government, the military, and the people), be a driving force, have support (from the government, the military, and the people), and be irreplaceable. For each capability, one needs to determine the existence of the essential conditions, resources and means that are required by that capability to be fully operative, and which of these, if any, represent critical vulnerabilities.

4. The Architecture of the Disciple-RKF Agents

The architecture of Disciple-RKF includes the components from Figure 4 (Boicu et al., 2004). The core of the system is the learning agent shell, which has the following domain-independent components:

- A problem solving component based on the task reduction paradigm of problem solving, including the following modules:
  - Modeling assistant that helps the user to express his/her contributions to the problem solving process;
  - Interactive problem solving agent;
  - Autonomous problem solving agent.
- A knowledge acquisition and learning component for acquiring and refining the knowledge of the agent and allowing a wide range of operations (including ontology import, user definition of knowledge base elements, ontology learning, and rule learning). This component includes the following modules:
  - Ontology development modules:
    - Tree-based browsers for objects and features;
    - Graph-based browsers for objects and features (association browser, hierarchical browser);
    - Viewers and Editors for objects and features;
    - Ontology import module;
    - Knowledge base merging module.
  - Instances elicitation modules:
    - Scenario elicitation module;
    - Scripts editor.
  - Learning and refining modules:
    - Task formalization and learning module;
    - Explanation generation module;
    - Rule learning module;
    - Rule refinement with positive examples;
    - Rule refinement with negative examples;
    - Rule analysis module;
    - Rule regeneration module;
    - Exceptions-based knowledge base refinement;
    - Feature learning module.
- A knowledge base manager which controls the access to and the updates of the knowledge base. Each module of Disciple-RKF can access the knowledge base only through the functions of the knowledge base manager.
- A windows-based, domain-independent, graphical user interface.

The three components in the right hand side of Figure 4 are the typical domain dependent components of a Disciple-RKF agent that was customized for a specific application, such as center of gravity analysis. The Disciple-RKF/COG agent (also referred as Disciple-COG) includes the following components:

- A customized problem solving component that extends the basic task-reduction component in order to satisfy the specific problem solving requirements of the application domain.

- Customized graphical user interfaces which are built for the specific Disciple agent to allow the experts and the end users to communicate with the agent as close as possible to the way they communicate in their domains.
- The knowledge base of the Disciple agent that contains knowledge specific to the center of gravity analysis domain.

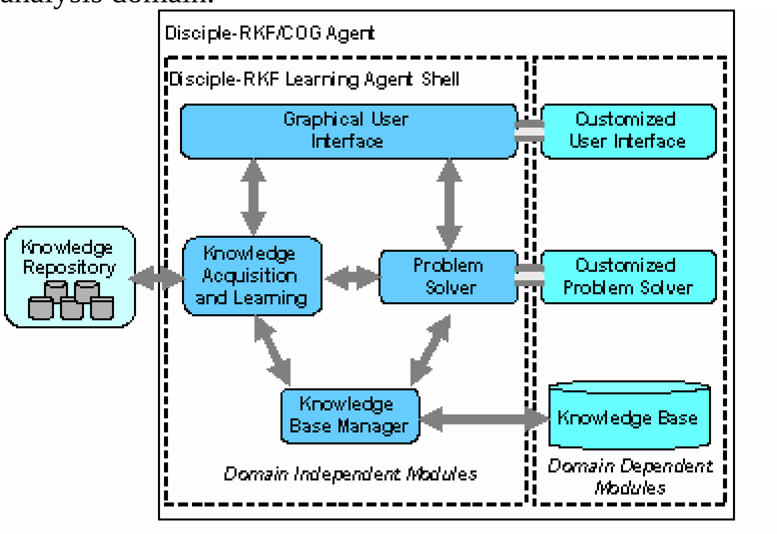

Figure 4: The Architecture of the Disciple-RKF Agents

5. Knowledge Base Development Methodology

The Disciple approach covers all the phases of agent development and use (Boicu et al., 2001c; Tecuci et al., 2002a, 2002b). First, a knowledge engineer works with a subject matter expert to develop an ontology for the application domain. They use the ontology import module (to extract relevant ontology elements from existing knowledge repositories) as well as the various ontology editors and browsers of Disciple-RKF. Figure 5 shows the interfaces of three of Disciple's ontology browsers: at top is the association browser (which displays an object and its relationships with other objects), at bottom left is the tree browser (which displays the hierarchical relationships between the objects in a tree structure), and at bottom right is the hierarchical browser (which displays the hierarchical relationships between the objects in a graph structure).

The result of this knowledge base development phase is an object ontology which is complete enough to be used as a generalization hierarchy for learning, allowing the expert to train the Disciple agent on how to solve problems, with limited assistance from a knowledge engineer. The expert formulates a specific problem solving task and shows the agent the corresponding problem solving steps, helping the agent to understand them. Each problem solving step indicated by the expert consists of a task to be reduced, a question related to that task, the answer to the question, and one or several subtasks or solutions that reduce the task. The top part of Figure 6 shows a fragment of a reasoning tree (generated by the interactive problem solver) consisting of a sequence of task reduction steps. The bottom part shows the interface of the Modeling Assistant that helps the expert express how to reduce the task from the bottom of the reasoning tree. This assistant may suggest the question to be asked, the answer to the question,

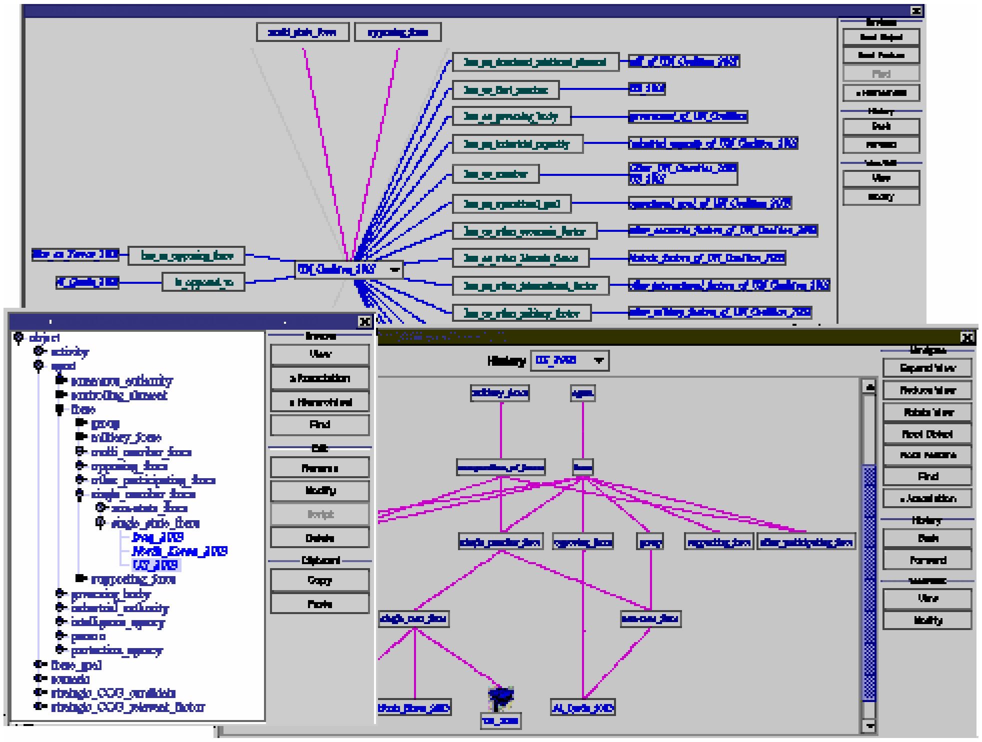

Figure 5: Three ontology browsers of Disciple-RKF.

and the knowledge base elements the expert may be referring to, since the expert's input is in natural language.

Each problem solving step indicated by the expert is an example from which the agent learns a general problem solving rule. First, the expert and Disciple collaborate in formalizing the tasks from the expert's examples and Disciple learns general task patterns. Next the expert helps Disciple find an explanation of why the task reduction step is correct and Disciple learns a general task reduction rule. The top part of Figure 7 shows the interface of the task formalization module, with the tasks in natural language in the middle and their formalizations in the right. The bottom part of Figure 7 shows the explanation generation and selection interface. The task reduction rule learned from the example specified in the modeling assistant (see bottom of Figure 6) is shown in the rule viewer from Figure 8.

As Disciple learns new rules from the expert, the interaction between the expert and Disciple evolves from a teacher-student interaction toward an interaction where both collaborate in solving a problem. During this mixed-initiative problem solving phase, Disciple learns not only from the contributions of the expert, but also from its own successful or unsuccessful problem solving attempts, which leads to the refinement of the learned rules. At the same time, Disciple extends the object ontology with new objects and features.

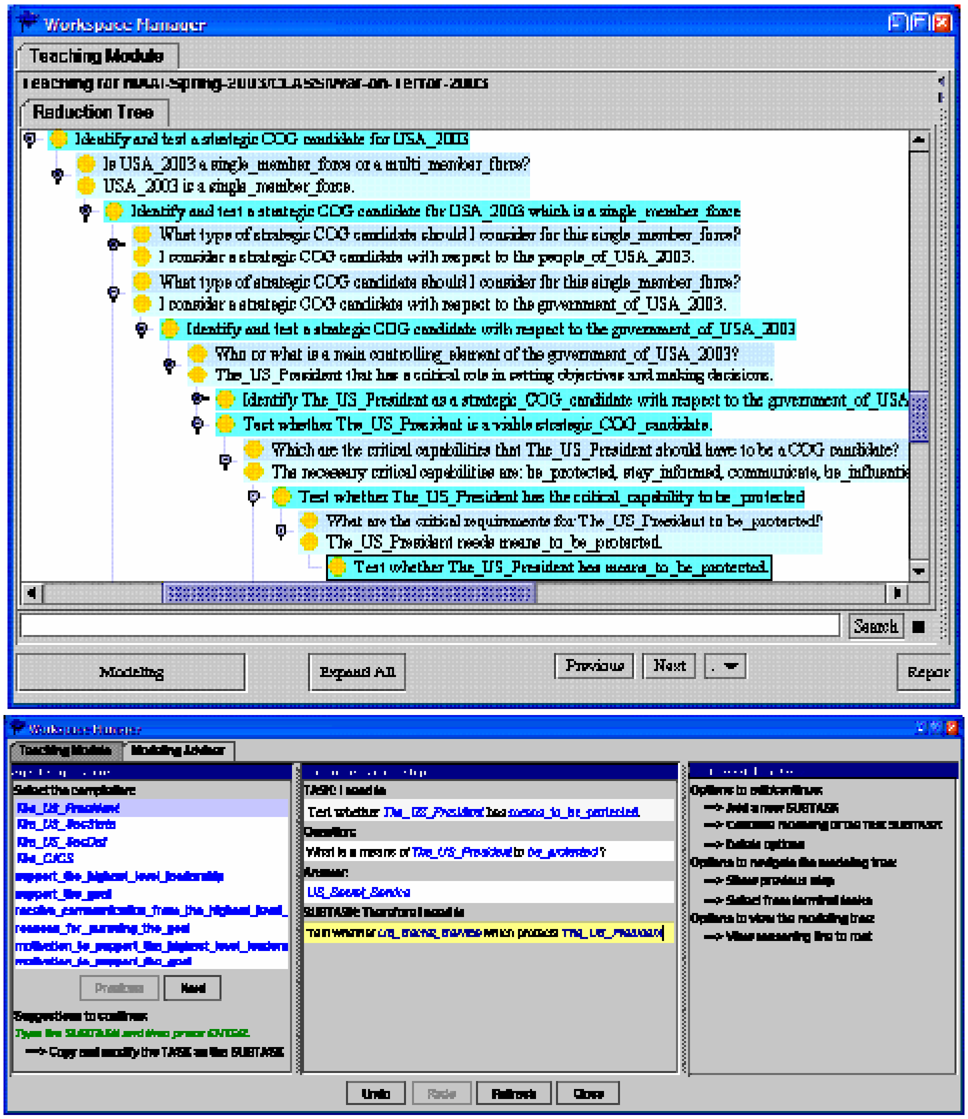

Figure 6: The reasoning tree and the modeling assistant interfaces.

Copies of Disciple agents may also be trained in parallel by different experts. In this case, the individual knowledge bases have to be merged into an integrated knowledge base, as discussed in section 8.

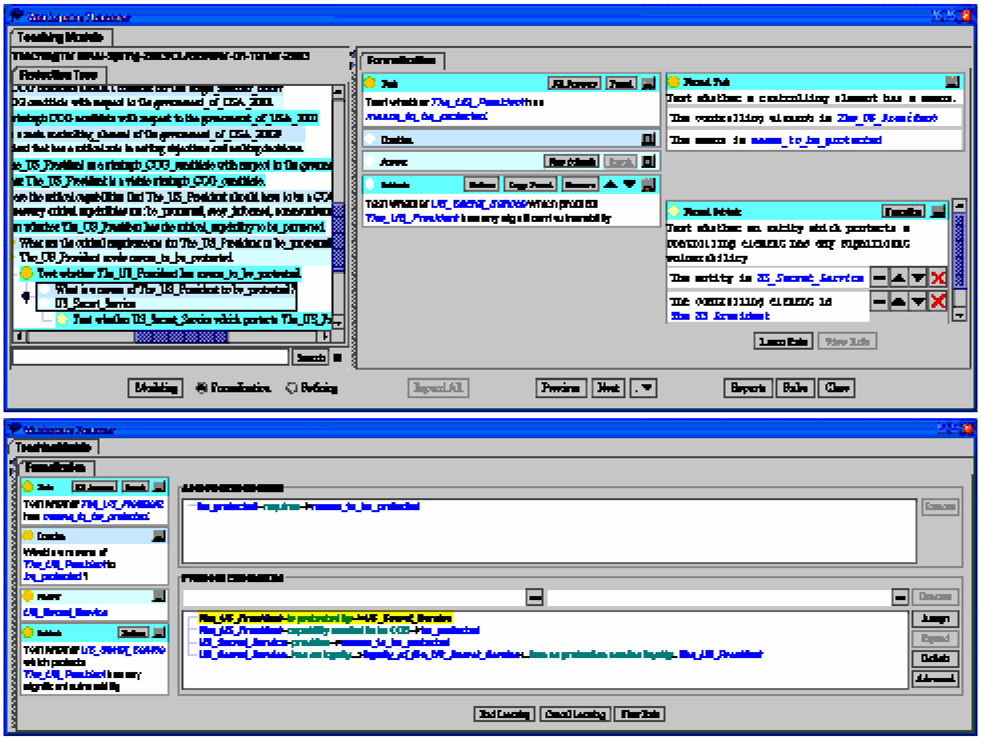

Figure 7: Task formation and example explanation.

6. Use of Disciple-COG in the "Case Studies of Center of Gravity Analysis" Courses: Scenario Elicitation Experiments

Successive versions of the customized Disciple-RKF/COG agent were used in the "Case Studies in Center of Gravity Analysis" course at the Army War College since 2001, becoming part of its regular syllabus. Figure 9 shows how the agent was used. First Disciple was taught how to analyze a scenario, based on the expertise of the course's instructor. The students then used Disciple as an intelligent assistant that helps them to develop a center of gravity analysis of a war scenario. Each session of this course was an experiment in scenario elicitation from subject matter experts. These experiments demonstrated that the Disciple approach can be used to develop agents that have been found to be useful for a complex military domain (Tecuci et al., 2004c).

7. Use of Disciple-RKF/COG in the "Military Applications of Artificial Intelligence" Courses: Agent Teaching Experiments

Figure 10 shows the use of Disciple in the "589jw Military Applications of Artificial Intelligence" at the US Army War College. In this course, the students teach personal Disciple agents their own expertise in center of gravity analysis and then evaluate both the developed agents and the development process. In the 2001 experiment, the students used historic scenarios with state actors (such as Okinawa 1943) to teach personal Disciple agents how to identify center of gravity candidates. In the 2002 experiment, the students used historic scenarios and a hypothetical scenario with state actors to teach personal Disciple agents how to identify center of gravity candidates and to eliminate those candidates that do not pass certain tests. In the 2003 experiment, the students used historic, current and hypothetical scenarios, with both state and non-state actors, to teach personal Disciple agents how to test center of gravity candidates based on the concepts of critical capabilities, critical requirements and critical vulnerabilities. A total of 38 US and international officers from all the military branches and the national reserve have attended these courses. At the end of these three experiments, 10 of them strongly agreed, 20 agreed, 7 were neutral and only one disagreed with the statement *"I think that a subject matter expert can use Disciple to build an agent, with limited assistance from a knowledge engineer."* This result shows that significant progress has been made in developing the technology that will allow subject matter experts to build their own intelligent assistants (Tecuci et al., 2004a).

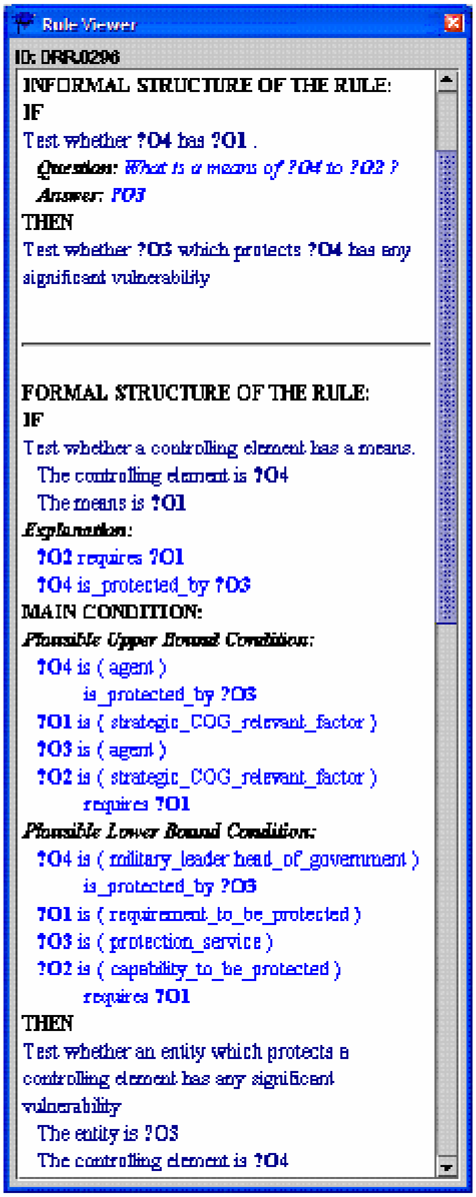

Figure 8: Learned Rule

8. Experiment of Parallel Knowledge Base Development by Subject Matter Experts

The Spring 2003 session of the "Military Applications of Artificial Intelligence" course included an experiment in parallel knowledge base development by subject matter experts, which is illustrated in Figure 11 (Tecuci et al., 2004b). Before starting the experiment, the Disciple-RKF agent was trained to identify leaders as center of gravity candidates. The knowledge base of this agent contained the definitions of 432 concepts and features, 29 tasks and 18 task reduction rules. However, the agent had no knowledge of how to test the identified candidates. Then

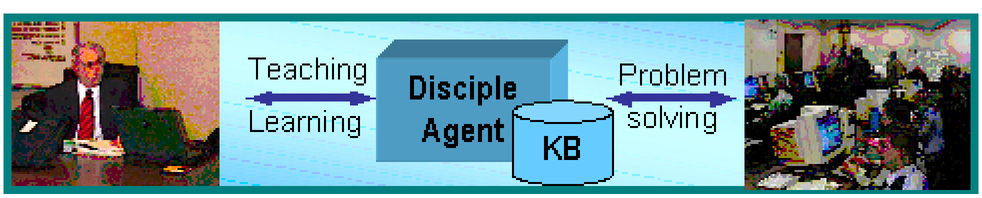

Figure 9: Training and using the Disciple agent (the COG course).

a domain analysis and ontology development was performed, by involving all the subject matter experts. This considered the example of testing whether Saddam Hussein, in the Iraq 2003 scenario, has all the required critical capabilities to be the center of gravity for Iraq. Based on this domain analysis, the ontology of Disciple-RKF was extended with the definition of 37 new concepts and features identified with the help of the subject matter experts.

The 13 subject matter experts were grouped into five teams (of 2 or 3 experts each), and each team was given a copy of the extended Disciple-RKF agent. After that, each team trained its agent to test whether a leader has one or two critical capabilities, as indicated in Figure 1. For instance, Team 1 trained its agent how to test whether a leader has the critical capabilities of staying informed and being irreplaceable. The training was done based on three scenarios (Iraq 2003, Arab-Israeli 1973, and War on Terror 2003), the experts teaching Disciple-RKF how to test each strategic leader from these scenarios. As a result of the training performed by the experts, the knowledge base of each Disciple-RKF agent was extended with new features, tasks, and rules, as indicated in Figure 11. For instance, the knowledge base of the agent trained by Team 1 was extended with 5 features, 10 tasks and 10 rules. The average training time per team was 5 hours and 28 minutes, and the average rule learning rate per team was 3.53 rules/hour. This included the time spent in all the agent training activities (i.e., scenario specification, modeling expert's reasoning, task formalization, rule learning, problem solving, and rule refinement).

After the training of the 5 Disciple-RKF agents, their knowledge bases were merged by a knowledge engineer, who used the knowledge base merging tool of Disciple-RKF. The knowledge engineer also performed a general testing of the integrated knowledge base, in which the acquired 10 new features, 102 new tasks, and 99 new rules were included. During this process two semantically equivalent features were unified, 4 rules were deleted, and 12 other rules were refined by the knowledge engineer. The other 8 features and 83 rules acquired from the experts were not changed. Most of the modifications were done to remove rule redundancies, or to specialize overly general rules.

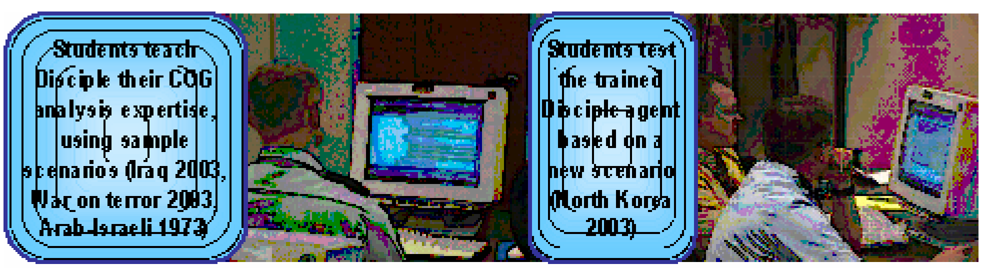

Figure 10: Teaching and testing a personal Disciple agent (the MAAI courage).

Next, each expert team tested the integrated agent on a new scenario (North Korea 2003), and was asked to judge the correctness of each reasoning step performed by the agent, but only for the capabilities for which that SME team performed the training of the agent. The result was 98.15% correctness.

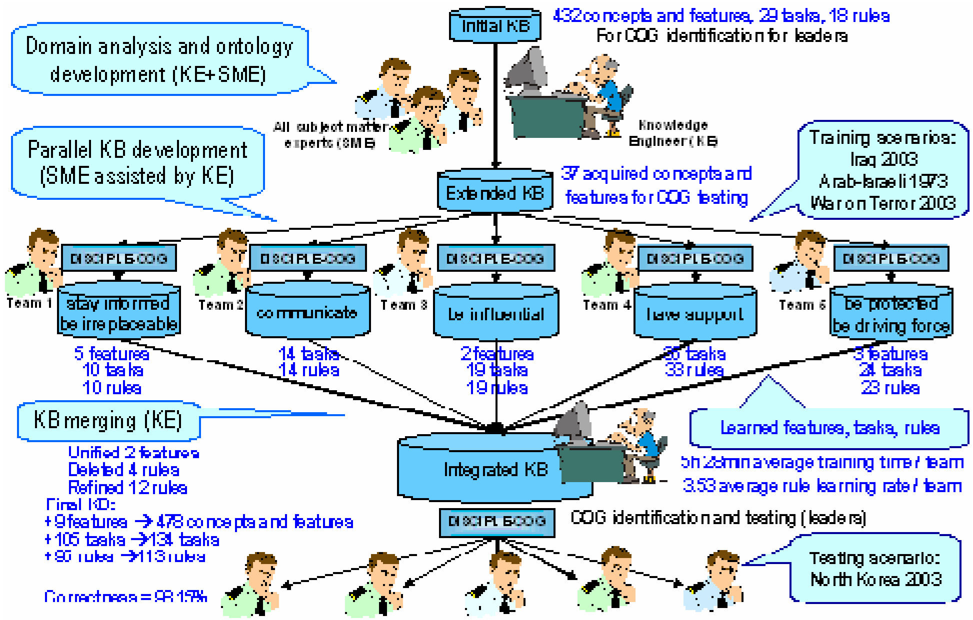

Figure 11: Experiment of rapid knowledge base development by subject matter experts.

9. Conclusions and Future Research Directions

The experiment described in section 8 and illustrated in Figure 11 is the first of this kind ever performed, showing Disciple's capability for rapid and parallel development of knowledge bases by subject matter experts, with limited assistance from knowledge engineers, and for the integration of the developed knowledge bases into a functioning agent. However, while significant progress has been made in developing a capability of rapid knowledge formation by subject matter experts, much work remains to be done to improve the developed methods. For instance, while the subject matter expert has an increased role and independence in the agent development process, the knowledge engineer still has a critical role to play. The knowledge engineer has to assure the development of a fairly complete and correct object ontology. The knowledge engineer also has to develop a generic modeling of the expert's problem solving process based on the task reduction paradigm. Even guided by this generic modeling, and using natural language, the subject matter expert has difficulties in expressing his reasoning process. Therefore more work is needed to develop methods for helping the expert in this task, along the path opened by the Modeling Advisor. The performed experimentations have also revealed that the mixed-initiative reasoning methods of Disciple-RKF could be significantly empowered by developing the natural language processing capabilities of the system.

The development of Disciple-RKF has emphasized initial knowledge acquisition from a subject matter expert, which results in an initial knowledge base. Further work is required to develop knowledge acquisition and learning methods for knowledge base extension and refinement, as well as the integration, validation, and maintenance of the knowledge acquired from different subject matter experts. In particular, the Disciple approach can naturally be extended with methods and tools for:

- Knowledge acquisition for knowledge base refinement (including rule refinement and ontology learning) using mixed-initiative and multistrategy techniques that will exploit the complementarity between human and automated reasoning, and between several learning strategies (such as learning from examples, from explanations, by analogy, by abduction, or by abstraction).
- Acquisition of meta-rules that will capture an expert's rational for choosing among different ways of performing a problem solving task.
- Knowledge bases integration, validation, and maintenance (which will address problems such as ontology merging, inconsistencies within a knowledge piece, redundancies and inconsistencies among knowledge pieces acquired from different experts, refinement and reorganization of the object ontology for increased performance, restructuring and refinement of the acquired problem solving rules, etc.).

10. Appendix

10.1 Publications describing the results of this project

Barbulescu M., Balan G., Boicu M., Tecuci G., "Rapid Development of Large Knowledge Bases," in *Proceedings of the 2003 IEEE International Conference on Systems, Man & Cybernetics,* October 5–8, Washington D.C., 2003.

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Boicu C., Tecuci G., Boicu M., Marcu D., “Improving the Representation Space through Exception-Based Learning,” in *Proceedings of the 16th International FLAIRS Conference* (FLAIRS-2003), Special Track on Machine Learning, May 2003, Key West, Florida. AAAI Press, Menlo Park, CA, 2003a.

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