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Clausewitz Meets Learning Agent Technology

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> **"I did not gain a full understanding of many [Clausewitzian] concepts until I had to teach the subject [center of gravity], having read it [Clausewitz, *On War*] several times."**
>
> COL Huba Wass de Czege[1]
> A contributor to
> U. S. Army, FM 100-5 Operations (May 1986)

In the beginning

Since Michael Howard and Peter Paret published their English translation of Carl Von Clausewitz's *On War* in 1976[2], military professionals have been interpreting and finding modern day meaning in the words of the 19th Century military theoretician. Vice Admiral Stansfield Turner restructured the curriculum of the United States Naval War College, introducing among many other innovations the study of Clausewitzian theory. The United States Air War College made similar changes in 1978, as did the United States Army War College (USAWC) in 1981.[3] Of the numerous ideas and concepts put forth by Clausewitz, his concept of center of gravity (COG) has evoked a significant amount of contention, debate, and writing over the last twenty years. In 1992, a student of the U.S. Army's School of Advanced Military Studies summed up its enigmatic nature when he observed, "the concept of center of gravity seems to mean something to everyone, but not the same thing to anyone."[4] Few writings offered a unified methodology that a novice might follow and apply to gain the wisdom and understanding of the concept that a subject matter expert (SME) has. In 1993, COL (Ret.) William Mendel and COL Lamar Tooke published a paper that provided a means of assessing the validity of an identified COG.[5] But by what logical method does one identify potential strategic COG candidates so that one can apply their test of validity? In October 1993, the Center for Strategic Leadership of USAWC undertook an effort to elicit the knowledge and wisdom of a number of COG experts, and to develop a methodology for identifying COG candidates and testing their validity. This research evolved into a 1995 Master's Thesis by MAJ Timothy J. Keppler[6] and a 1996 monograph (hereafter referred to as COG Monograph) published by MAJ Phillip K. Giles and CPT Thomas P. Galvin[7].

MAJ Keppler's thesis specifically explored the question, "Using knowledge engineering techniques, is it possible to distill discernible thought patterns from selected strategists and professional literature to create a useful methodology for applying the center of gravity concept?"[8] It was an attempt to use systems and knowledge engineering techniques to model strategic level thought. The posed research question was answered affirmatively and a logical methodology was produced to help student and real world planners consistently apply the COG concept at the strategic and operational levels of war. MAJ Keppler's contemporaries back at USAWC built on his work and produced the COG Monograph that is used as a guide each time the elective course, Case Studies in Center of Gravity Determination (hereafter referred to as the COG course) is taught at USAWC.[9]

But, alas, the focus in the professional literature still continued to be on issues of interpretation, confusion, existence, controversy, and utility of the concept, rather than on improving and expanding the USAWC methodology or developing alternative methodologies. In 1996, Dr. Joe Strange, Marine Corps War College, noted that *On War* is open to a kaleidoscope of individual interpretations when not studied in a professional manner.[10] He suggested that a common language be used. He also recognized the fact that even when groups of people agreed on a common conceptual definition, when the concept was applied to a specific situation they often identify remarkably different enemy characteristics as the COG.[11] In 1997, Lieutenant Commander Jeffrey Harley, USN, wrote that the proliferation of information technology has led to the impression that information is itself a COG, which in turn has confused both the role of information and the COG concept.[12] COL Mark Caucian, USMC, wrote in 1998 that centers of gravity (COGs) just do not exist.[13] In 1999, MAJ Seow Hiang Lee, Republic of Singapore Air Force, produced an insightful paper detailing the controversy that still surrounds the COG concept and suggested four propositions to deal with the confusion as well as three principles on how to use the COG concept.[14] Most recently, Dr. Milan Vego, Naval War College, cited Keppler's research and the COG Monograph produced by Giles and Galvin but did not seek to improve or expand the logical methodology therein.[15] By August 2000, Commander Jeff Huber, USN, had written, "The center-of-gravity theory won't wash if it takes a Zen master decades of rumination from atop the highest peak in Tibet to apply it."[16]

Knowledge engineering and learning agents

Knowledge engineering, a critical activity in the development of intelligent agents, is a subfield of artificial intelligence (AI), a branch of Computer Science. It is concerned with applying knowledge to solve problems that ordinarily require human expertise. Knowledge engineers, the people who do knowledge engineering, perform three major functions: (1) Identify problem domains, (2) Perform knowledge acquisition to understand how the subject matter experts solve problems and to elicit their problem solving knowledge, and (3) Construct intelligent agents that incorporate the problem solving knowledge acquired from the experts.

Knowledge engineers seek to identify domains that give an organization a significant payoff either in cost savings or in providing an advantage over a competitor, if the organization can apply automated knowledge to the problems encountered. Appropriate problem domains for knowledge engineering are domains where humans solve problems that are unstructured, have a large number of variables some of which have unknown values due to incomplete information, have multiple or conflicting goals, and make use of highly specialized knowledge. The COG concept is certainly an appropriate domain for knowledge engineering.

A necessary condition for successful knowledge acquisition is access to experts who solve the problem well, and also know how to communicate or demonstrate that expertise. Keppler realized that the USAWC had military professionals who were recognized by their peers as being able to apply the COG concept effectively and consistently.[17] His method of knowledge acquisition was to interview these SMEs, observe practical exercises, and elicit knowledge from the professional literature of the time. This is the traditional knowledge acquisition approach that requires significant interaction between trained knowledge engineers and the SMEs.

Successful knowledge acquisition contributes to the development of an intelligent agent. An intelligent agent is a computer program that perceives its environment, reasons to interpret perceptions, draws inferences, solves problems, determines actions, and acts upon its environment to realize a set of goals for which it was designed.[18] By 1995, the USAWC had distilled the knowledge acquired into a methodology for COG determination. While their ultimate goal was to build an intelligent agent based on this knowledge and resulting methodology, as an interim solution they developed a decision support system that guides a user through this COG determination process and related considerations. This software was used to facilitate the COG course until the end of the 1998 academic year.

One of the primary impediments to learning agent construction at the USAWC was the time, effort, and expertise needed to formalize the knowledge acquired and develop an agent. In the traditional knowledge acquisition approach this "knowledge engineering" involves the transferring and transforming of the expert's knowledge into a form usable by an intelligent agent. A skilled knowledge engineer ordinarily performs this highly technical process, and it is time consuming, error prone, and inefficient. An alternative approach now available to the USAWC is the use of a computer-based learning agent, which is able to acquire and maintain the SME's knowledge with only limited assistance from a knowledge engineer.[19] The Learning Agents Laboratory (LALAB) at George Mason University (GMU) developed this new approach calling it Disciple. Disciple is an apprenticeship, multi-strategy learning approach for developing intelligent agents where an SME teaches a Disciple agent how to perform domain-specific tasks in a way that resembles the manner in which the SME would teach an apprentice, by giving examples and explanations as well as by supervising and correcting behavior.[20] Disciple agents are software programs that run on common laptop or desktop computers. The Disciple approach has been successful in a number of different applications, including assessment tasks, planning tasks, design tasks, and critiquing tasks. A recent successful military application involves critiquing courses of action for tactical military plans.[21] This agent technology, combined with the continued professional interest in strategic and operational COG determination, presented an excellent opportunity to advance the knowledge acquisition work of Keppler, Giles, and Galvin to develop an intelligent agent. Therefore, the USAWC and GMU are developing Disciple-COG, an intelligent agent for COG determination that can be taught directly by SMEs, with limited assistance from knowledge engineers. This work is a collaborative effort between the Department of Military Strategy Planning and Operations (USAWC), the Center for Strategic Leadership (USAWC), and LALAB (GMU).

Developing the theory

Clausewitz was a theoretician who attempted in his series of books, essays, and notes to lay out a system of thought regarding war. His writings, though not completely satisfactory to himself at the time of his death, present a theoretical model based on reason and logic against which judgments can be made about the real phenomenon.[22] Like the initial models presented by theoreticians in other disciplines (mathematics for example), good models deserve further development so that they can become better models. The Calculus of Liebnitz and Newton is not that which is being taught today to our engineering students at the United States Military Academy. The present Calculus model has been refined with logic and reason over many years, and today our engineering students are using graphing calculators and computer algebra systems to demonstrate and calculate solutions to problems that Liebnitz and Newton would not have dreamed of attempting. So too, we are called upon as military professionals and knowledge engineers to continue developing Clausewitz's COG theory, refining it with logic and reason and incorporating the latest technology to analyze more difficult scenarios than those of Clausewitz's day.

In a classic work, Lenat and Fiegenbaum stated their Empirical Inquiry Hypothesis, which claims that the best action AI researchers can take to further the development of the field is to take their ideas, incorporate them into programs, run the programs, and see where they fail.[23] This is where AI researchers will learn the most. The same can be said for military theoreticians. We need to take our theory (e.g., Clausewitz's COG), incorporate it into Disciple-COG, teach Disciple-COG to determine and analyze strategic and operational COGs, and see what Disciple-COG does not do well. By doing this, we will gain greater insight into the theory as well as refine a methodology for its understanding and application by our students. Ultimately, Disciple-COG will become an intelligent partner in our application of the theory to present day scenarios.

In continuing to develop the COG theory, we are making use of the various historical case studies prepared by the USAWC faculty and their students. In this journal, Dr. Steven Metz and LTC Frederick Downey cautioned in 1998, "While individual historical studies are useful for a strategic planner, their value is eroded by the absence of any general guidelines or conclusions collated from a number of cases."[24] We agree fully, and our approach abstracts such general guidelines from the cases studied. Disciple-COG will learn from examples, explanations, analogy, and its own experimentation based on a wealth of individual historical case studies provided by experts and students. Disciple-COG will synthesize these cases to learn principles that are generally applicable, without having been explicitly told them. When required to do so by a student or SME, Disciple-COG will explain in detail the reasoning it used to draw its conclusions. This reasoning may be based on one specific historical scenario that serves as an analogy for the present problem, or it may be based on fragments of knowledge from many different historical scenarios that, when recalled and reconfigured under the present problem, give a plausible solution. If Disciple-COG cannot use its historical knowledge in some way to solve a given problem, it will seek further guidance and training from a COG SME, further improving its own knowledge and expertise.

Transforming any theory into something understood by an intelligent agent cannot be accomplished overnight. As a start, we can draw upon the work of Keppler, Giles, and Galvin as well as a number of the SMEs cited in their works. In addition, however, this process needs technical expertise that is not always readily available.

The USAWC is an ideal environment for continued access to current thought on COG. In fall 2000, Mr. Murray Burke, Defense Advanced Research Projects Agency (DARPA) Program Manager for the Rapid Knowledge Formation program,[25] directed LALAB to partner with the USAWC to develop Disciple-COG to advance the state of the art in conducting knowledge acquisition from domain experts. DARPA, the Air Force Office of Scientific Research (AFOSR), and the Air Force Research Laboratory (AFRL) of the Air Force Materiel Command (AFMC) are funding the LALAB's research. In the first year of this effort LALAB and USAWC have had considerable success in acquiring domain knowledge and have begun agent development based on this knowledge. Below we describe how Disciple was successfully integrated into a course in COG determination to elicit knowledge based on historical cases.

Developing the agent

The main phases of agent development are: (1) Customization of the agent shell, (2) Development of the agent's object ontology, (3) Modeling of the problem solving process, (4) Teaching the agent, and (5) Verification and validation of the agent. In this first year of Disciple-COG development, the focus has been on Strategic COG identification and touched on all phases of agent development. In general, customization of the Disciple shell for a particular application consists of the development of new modules or, at least, the extension and adaptation of the existing modules, to satisfy the requirements of the current application. The object ontology consists of a specification of the objects and type of objects from the application domain, together with their properties and relationships. For the COG domain, the development of the object ontology was based on the previous works of Keppler, Giles, and Galvin, and on the detailed analysis of two case studies provided by the USAWC professor who taught the COG course in January 2001. These two case studies were the Sicily and Okinawa campaigns of World War II (WW II). The developed ontology is documented in over 100 pages of diagrams. Figure 1 presents a small fragment of this ontology with selected instances from the Sicily scenario.

The object ontology represents everything that the agent "knows" about the subject at hand. Figure 1 contains abstract concepts, depicted in black, as well as specific instances of those concepts, depicted in blue. For example, as defined in Disciple-COG, industrial capacity is an abstract concept, and the specific industrial capacity of the United States in 1943 is an instance of that concept. In addition to these definitions of abstract concepts and specific instances of those concepts, the ontology represents other important relationships between concepts. Arrows illustrate the presence of a relationship, and green labels specify their name. Many abstract concepts are taken from the COG Monograph, and will not vary from scenario to scenario. The specific instances in a knowledge base, however, are features that describe a particular scenario. When developing the initial ontology for Disciple-COG based on Sicily and Okinawa, knowledge engineers studied the historic cases and added the instances and the relationships needed to describe them to the agent.

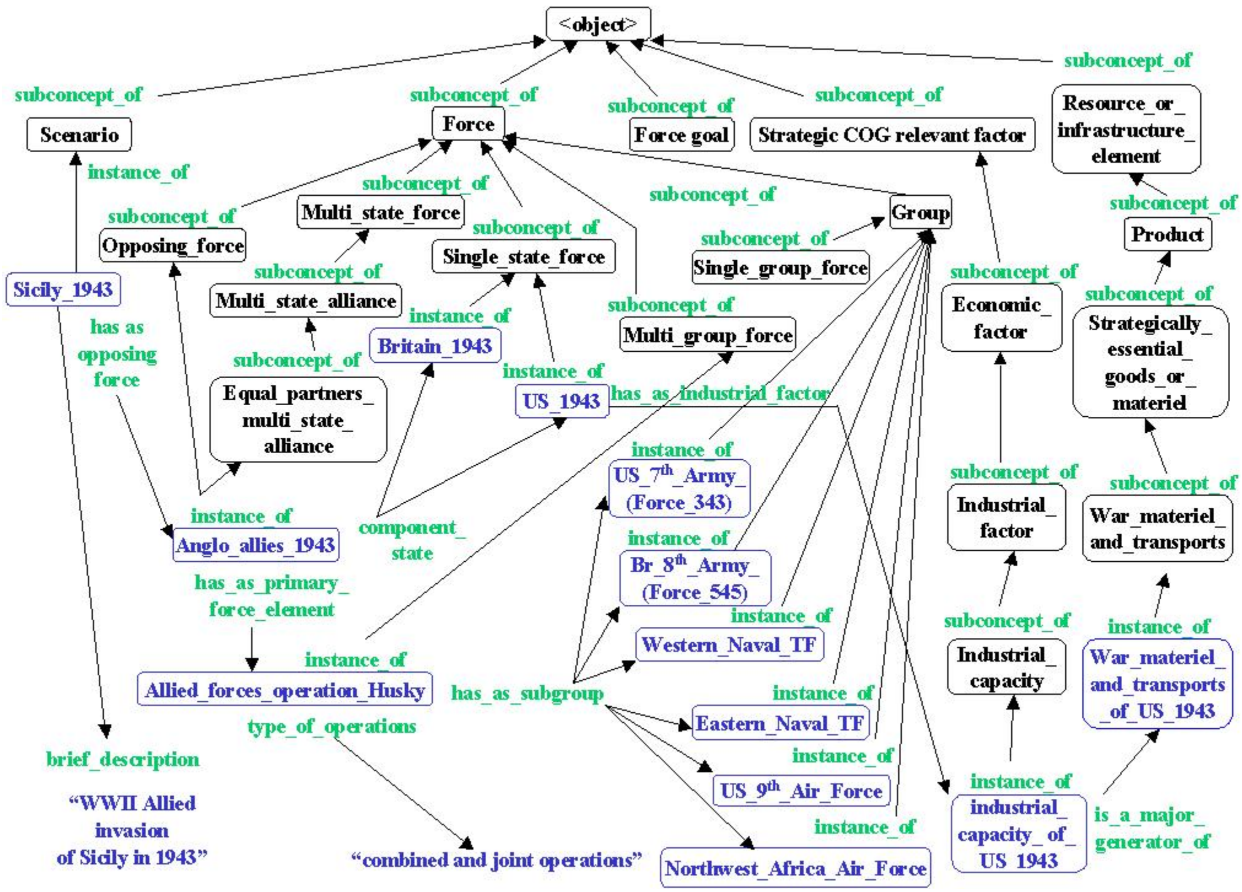

Figure 1. A fragment of the object ontology developed for Disciple-COG.

Figure 1 illustrates only a portion of the complete ontology resulting from this initial knowledge engineering effort. For example, the only instance of an opposing force shown in Figure 1 is the Anglo_allies_1943; however, the European_Axis_1943 force is also present as an opposing force in the complete ontology, and it in turn has component states (i.e., Italy_1943 and Germany_1943) as well as primary force element (i.e., Axis_forces_Sicily). Similarly, while one strategic COG relevant factor (Economic factor) is depicted, additional factors found in the COG Monograph (e.g., Psychosocial factors, Political factors, Historical factors, etc.) are found in the complete ontology.

Although the knowledge engineers prepared the Sicily and Okinawa scenarios to give LALAB researchers some typical concepts, relationships, and instances with which to customize the Disciple agent shell to Disciple-COG, it was USAWC students in spring 2001 who validated the usability of the initial ontology and expanded upon it. This was accomplished during the elective COG course. The students used the Scenario Elicitation Tool, a new customized Disciple-COG component, to describe their scenarios by answering multiple-choice questions derived from the agent's ontology and elaborating on those answers with descriptions in unrestricted English. The Scenario Elicitation Tool directly supported knowledge base development by eliciting key instances and relationships from students and linking them to the initial ontology. The USAWC students thus developed scenarios about the following historical case studies: Malaya 1941-42, Leyte 1944, Inchon 1950, Vietnam 1968-75, Falklands 1982, Grenada 1983, Panama 1989, and Somalia 1992-94.

Figure 2 shows the Scenario Elicitation Tool, displaying selected entries from the Falklands scenario. The left hand side of the display shows the table of contents created for each opposing force entered as well as the identified strategic and operational COG candidates. Only the Argentina-1982 table of contents is clearly visible in Figure 2 but the vertical slide bar can be used in Disciple-COG to reveal the table of contents for Britain-1982. Using the Scenario Elicitation Tool, the student highlights a topic in the table of contents (Falklands is highlighted in Figure 2) and enters information for that topic to the right of the table of contents. The right portion of Figure 2 shows that a student entered the scenario name, a subject summary, a brief description, and the opposing forces involved. By entering very specific information for Argentina-1982 under *Composition of forces* the student caused *Cooperation_between_members_of_Argentinean_Armed_Forces* (only partially visible in Figure 2, the horizontal slide bar can be used in Disciple-COG to see the entire text) to appear under the folder *Strategic COG candidates.* Likewise, information entered under *Control and governing elements* and supported by facts stated in *Historical factors, Military factors,* and *Political factors* produced strategic COG candidates *General_Leopoldo_Galtieri* and *Military_Junta.* The *Argentinean_Unions* became a strategic COG candidate due to information entered under *Civilization* and supported by facts in *Economic factors.* In the table of contents for Figure 2, some *Operational COG candidates* are visible. Since the Scenario Elicitation Tool also organizes and formats the report that the students were required to produce for the COG course, this component had to be made available even though it is not the focus of the research for this first year.

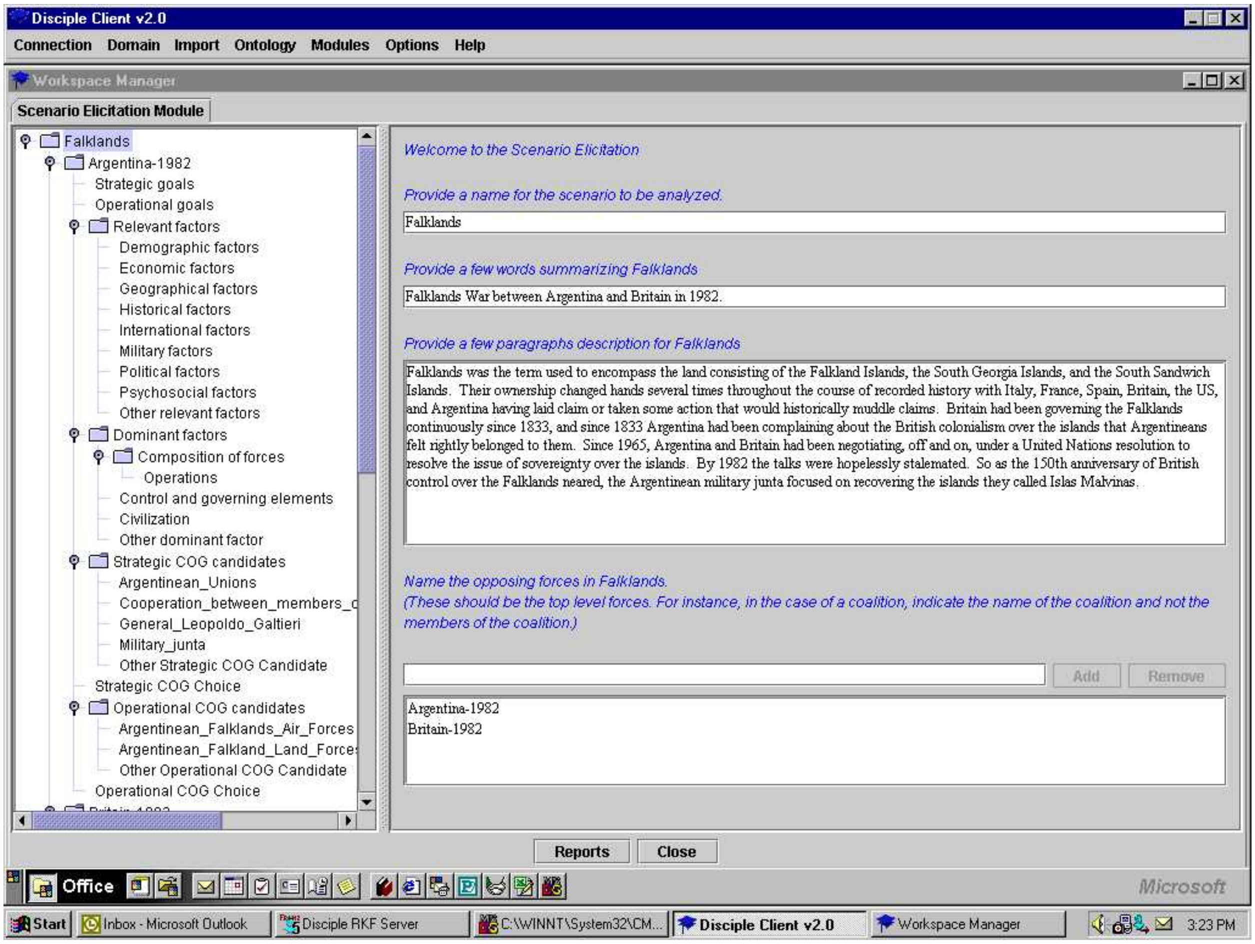

Figure 2. Scenario Elicitation Tool of Disciple-COG with information concerning the Falklands scenario.

Part of the debate over the COG concept is whether it can be applied successfully to operations other than war. To support further study in this area, USAWC students created Disciple-COG scenarios for the U.S. operations in Panama in 1989 and Somalia during the 1990s. Because of the clans involved in the Somalia 1992-94 scenario, the initial ontology was expanded beyond the WW II concepts found in the Sicily and Okinawa scenarios. Additional concepts such as *Chief_and_tribal_council* and *Democratic_council_or_board* were needed to develop the possible types of a governing body for a clan or a tribe. Similarly, the Panama 1989 scenario caused ontology expansion to include concepts such as *drug_cartel* and *crime_family*. It is expected that ontology expansion will continue with each new scenario visited by future USAWC students in the COG course.

The Scenario Elicitation Tool develops the ontology and captures instances and relationships, but it does not enable autonomous reasoning by Disciple-COG. For this we need to model the problem solving process, the next step in agent development. Another Disciple component, the Domain Modeling Tool, supports this modeling.

It is based upon a task reduction methodology that allows the user to state a task, ask a question about the task, and provide one or more answers. The fundamental concept at work in the Domain Modeling Tool is that a complex problem can be successively reduced to simpler sub-problems until the sub-problems are simple enough to be solved immediately. The solutions to the sub-problems can then be successively combined to produce the solution to the initial problem. This general concept has been given many names including problem or task decomposition, factorization, and task reduction. The term task reduction will be used as the convention of choice throughout the remainder of this paper. Figure 3 shows the Domain Modeling Tool as a student has begun doing task reduction in the Falklands scenario. The first task reduction step (shown only on the left portion of Figure 3) includes the task "Identify the strategic COG candidates for the Falklands scenario," the question "Who is an opposing force for the Falklands scenario?" and the answer "Argentina-1982." The answer suggested to the student another subtask (the current task) and further task reduction visible on the right portion of Figure 3. The follow-on question from the current task produced four answers taken from the COG Monograph that the student must further analyze.

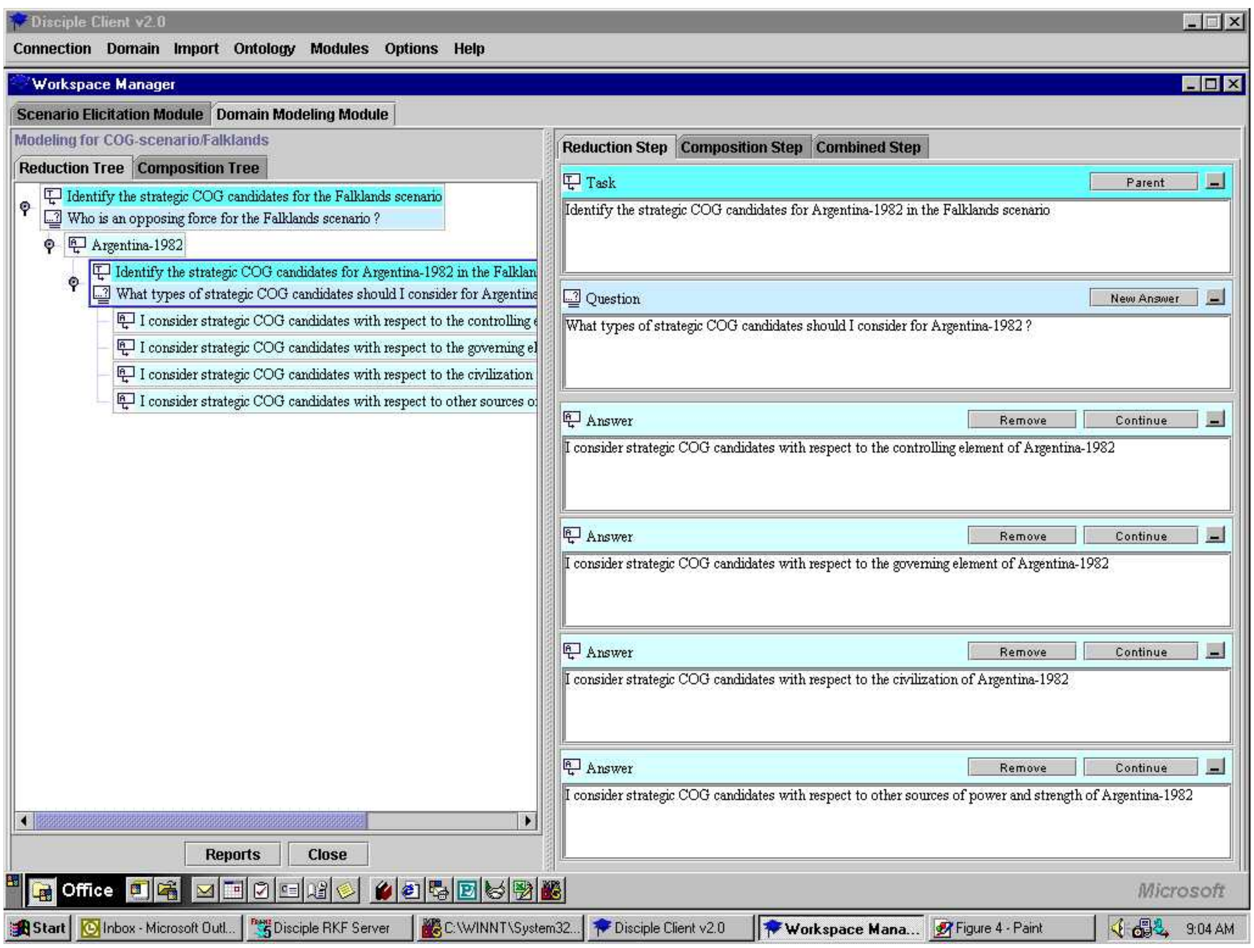

Figure 3. Employing a task reduction methodology using the Domain Modeling Tool.

During task reduction, a task is successively reduced to simpler and simpler tasks. Each subsequent reduction step is based on the consideration of some relevant factors, expressed as a question. Each answer to a question guides the user to reduce the current task to a simpler one. Eventually each task reduction sequence terminates with a result. Figure 4 shows a completed pattern of reasoning that identifies a strategic COG candidate. The right portion of Figure 4 illustrates a task reduction sequence, and the left portion shows where this trend of thought exists in the overall problem solving scheme being developed.

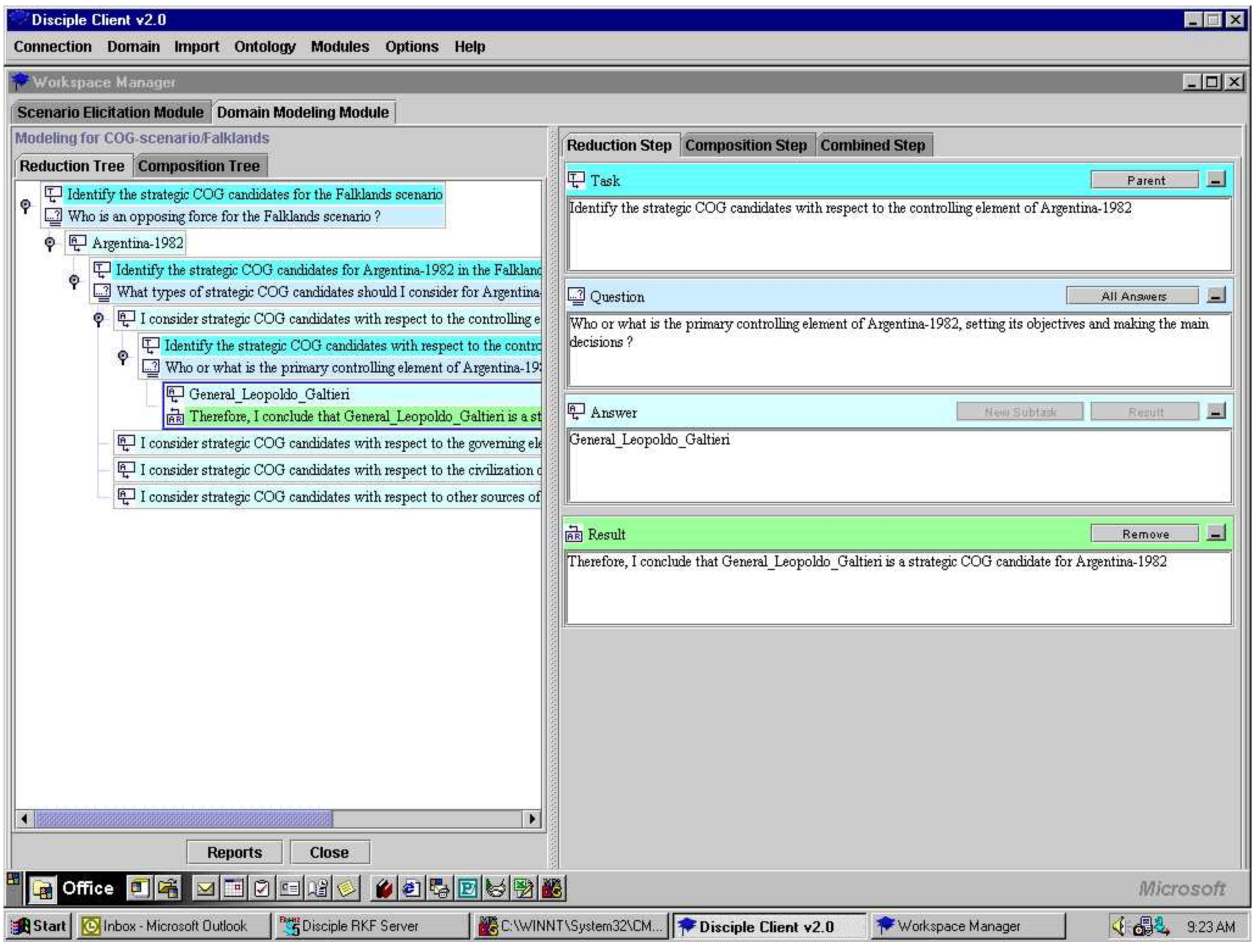

Figure 4. A task reduction thread that ends with a result.

Modeling the problem solving process of strategic COG identification was the most difficult and time-consuming aspect of the work that students did in the COG course. These students (not SMEs in COG determination) were asked to select and complete at least two task reduction sequences that identify candidate COGs for their scenarios, but some students did additional task reductions. These thought patterns were used in further agent development to teach Disciple-COG how to identify strategic COG candidates.

Conclusion

In the 19th century, Clausewitz in his writings presented a theory about war that was rediscovered in the 20th century after the conflict in Vietnam ended. Since then, several professionals knowledgeable in the art of war have written to give their interpretations of Clausewitz's COG theory. In 1996, after years of effort by knowledge engineers to acquire and synthesize knowledge from COG SMEs, USAWC published the COG Monograph, a methodology for COG determination, analysis, and application. The COG Monograph along with several historical case studies formed the basis for continued development of the COG theory by teaching it to an intelligent agent called Disciple-COG. Through a partnership between USAWC, LALAB, and DARPA, students in the USAWC COG course used LALAB's Disciple-COG to develop their assigned historical scenarios and to model the way they identified their strategic COG candidates. Significant strides have been made unifying the COG theory and the learning agent technology in Disciple-COG.

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Dr. Comello is Professor of Military Studies at the Army War College. A retired Army Colonel, he was Professor of National Security Studies at the Marine Corps Command and Staff College, and Professor of Strategy Plans & Operations at the Center for Strategic Leadership. He graduated from the U. S. Military Academy, the College of Naval Command and Staff, and the National War College. He holds a Master of Science in International Affairs from George Washington University and a PhD in History from Temple University.

LTC Bowman is a graduate of the Army War College and a PhD Candidate at George Mason University. He received a Bachelor of Science degree from Ouachita Baptist University and a Master of Science degree from the Naval Postgraduate School. He was the Army Product Manager for Communications and Intelligence Support Systems, and has had a variety of acquisition, automation and tactical assignments at the Defense Intelligence Agency, the US Military Academy, and in several Army Field Artillery battalions.

Dr. Tecuci is Professor of Computer Science, Director of the Learning Agents Laboratory at George Mason University, and Member of the Romanian Academy. He received Master of Science and PhD degrees in Computer Science from the Polytechnic University of Bucharest, and another PhD degree in Computer Science from the University of Paris-South. He published over 100 scientific papers and 5 books, most of them in the artificial intelligence areas of intelligent agents, machine learning, and knowledge acquisition.

MAJ Donlon is the director of the Knowledge Engineering Group at the United States Army War College. He received a Bachelor of Science degree from the University of Delaware and a Master of Science degree from Northwestern University. His background in the Army is as an infantry officer. He now conducts applications engineering, education, and applied AI research as an Army systems engineer.

[1] COL Huba Wass de Czege, USA, "Clausewitz: Historical Theories Remain Sound Compass References; The Catch Is Staying on Course," *Army* (September 1988), 38. Brigadier General (Ret.) Wass de Czege continues to be a visionary in military affairs. In September 2000, he participated in the Objective Force Combat Service Support Workshop held at the United States Army War College.

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