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Ontology Development for Military Applications

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"Discussion without definition is impossible."
-- Sir Edward Grey, Great Britain's Foreign Minister World War I

Abstract

In order for Artificial Intelligence (AI) to become truly useful in high-level military applications it is necessary to identify, document, and integrate into automated systems the human knowledge that senior military professionals use to solve high-level problems. The skeletal structure for this work is provided through the development of an ontology. This paper presents brief overviews first on ontology development and then on the levels of war that senior military leaders deal with. This is followed by a description of the ontology development done for a course of action critiquing agent as part of the Defense Advanced Research Project Agency (DARPA) High Performance Knowledge Bases (HPKB) program. A military course of action is a preliminary candidate plan for how a military organization might attempt to accomplish an assigned mission. Course of action development is done at each level of war, strategic, operational and tactical, but this agent was developed to support the lowest, which is the tactical level. The paper next describes the expansion and extension of the course of action ontology required to represent the military concept of center of gravity used at the strategic level, which is

the highest of the levels of war. This later work is a part of the DARPA Rapid Knowledge Formation (RKF) program being investigated by the George Mason University Learning Agent Laboratory and the Knowledge Engineering Group at the United States Army War College (USAWC).

Ontologies

Guarino and Giaretta (1995) noted that the term "ontology" had at least seven distinct meanings in the literature, and their work explained the implications of each interpretation for the knowledge engineering community. At the end of their paper, they suggested a set of definitions that we find appropriate for our work. First, an ontology is a logical theory which gives an explicit, partial account of a conceptualization. Second, a conceptualization is an intentional semantic structure that encodes the implicit rules constraining the structure of a piece of reality. These two definitions give additional detail to Gruber's (1993) early definition of ontology, which was "a specification of a conceptualization."

Ontologies are essential for developing and using knowledge-based systems. Every knowledge model has an ontological commitment (Noy and Hafner, 1997), that is, a partial semantic account of the intended conceptualization of a logical theory. Thus the AI community has adopted ontology development as a pre-requisite to building knowledge-based systems. The ontology captures that set of concepts used to describe the knowledge for the system.

Ontology development and use is an important area of research in AI (Van der Vet and Mars, 1998). Most research on ontologies focuses on what one might characterize as domain factual knowledge, but there is a segment of ontology research that seeks to represent, use and share knowledge about problem-solving methods, which is also important in knowledge-based system development (Chandrasekaran et al., 1999).

Ontology research in the context of building knowledge-based systems has led to an organization of the knowledge base into an ontology and a set of problem solving methods (Tecuci et al., 2000a). The ontology provides a representation vocabulary with which to describe the facts and the concepts in a problem domain, meaning, the different kinds of objects in the problem domain, the properties of each object, and relationships existing between objects. These descriptions are also part of the ontology. The terms from the ontology are used to represent the problem solving methods (rules, cases, etc.) needed by the knowledge-based system to solve the problems for which it was designed.

The ontology is the more general component of the knowledge base, being characteristic to an entire domain, such as the medical, or military domains. A domain ontology specifies terms that are useful in a wide range of different applications in that domain. For instance, a military ontology would include specifications of military units and of military equipment that are very likely to be included in the knowledge base of any agent developed for a particular military application. Moreover, there is generally wide agreement in any mature domain on the basic terms of that domain. This allows one to reuse ontological knowledge that was previously developed, in order to build a new knowledge base, rather than starting from scratch.

The problem solving methods represent the specific component of the knowledge base. They are not only specific to a particular application in a given domain, but they are even specific to a particular subject matter expert. Consider, for instance, a rule-based agent that assists a military commander in critiquing courses of action with respect to the principles of war and the tenets of army operations (an agent that will be referred to again in this paper). The rules will identify strengths and weaknesses in a military course of action, and will obviously be domain specific. Moreover, they are very likely to include subjective elements that are based on the experience of a specific military expert.

The Levels of War

Three authors frequently quoted in lectures at the USAWC are Sun Tzu (400 BC), Carl von Clausewitz (1832), and Baron Antoine-Henri Jomini (1862). Their individual works though written in antiquity have been translated and published in the 20th Century because the concepts therein are deemed to be as valuable to military leaders today as when they were first described.

While the basic nature of war is constant, the means and methods of combat have evolved through time. Military operations of tomorrow will not be conducted in the same way they are today, and today's operations employ means and methods that are radically different than those of the past. However, one aspect of military operations that has remained relatively constant is the view that they occur at three different levels each with its own means, methods, and ends. These levels are tactical, operational, and strategic (FM 100-5, 1993). The tactical level is the lowest level of war. Its focus is the military application of unit combat power through the use of fire and maneuver that are basic actions for the execution of battles and engagements. Actions at the operational level imply a broader dimension of time and space – when, where, and under what conditions to engage or refuse to engage the enemy in battle. As Tzu (400 BC) put it, "Invincibility lies in the defense; the possibility of victory in the attack. One defends when his strength is inadequate; he attacks when it is abundant (p. 85)". The operational level of war uses campaigns and major operations to attain strategic objectives. The strategic objectives are defined by national political objectives; war is after all a political action of last resort. Thus the strategic level, the highest of the three levels, can be thought of as the art of winning a war; the operational level can be thought of as the art of winning a campaign; and the tactical level can be thought of as the art of winning a battle.

During World War II, the beach landings on Okinawa and the ensuing battles were at the tactical level of war. Three months after the landings, when the island was secure and ready to be used as a launching point for strategic bombing of the Japanese homeland, a key step in winning the war, marked the completion of the operational level Okinawa Campaign. During the course of the Okinawa Campaign, the large number of American casualties shocked President Truman and influenced his strategic level decision to drop the first atomic bomb on the Japanese homeland to hasten the end of the war.

Course of Action Application

Courses of action are outlines of plans for the manner in which a military force might attempt to accomplish a mission. Course of action development is done at each level of war. It is general military practice for a staff to generate several courses of action for a mission, and then make comparisons of those courses of action based on factors such as the principles of war and the tenets of military operations. After listening to the staff and receiving their recommendation, the commander of the combat unit makes the final decision as to which course of action to use for the mission. Course of action development at the tactical level of war is often done in haste. Both the staff’s planning and the commander’s decision making are likely to be affected by combat stress, fatigue, hunger, and other environmental factors. Decision making can be decisive in combat and the United States military strives to select commanders based on proven ability to make good decisions under the most adverse conditions. Knowledge based systems, used as decision aids that are unaffected by environmental factors, could prove to be critical tools for military commanders and their staffs.

The goal of the HPKB research program was to produce the technology needed to rapidly construct large knowledge bases that provide comprehensive coverage of topics of interest, are reusable by multiple applications with diverse problem-solving strategies, and are maintainable in rapidly changing environments (Gunning and Burke, 1996). The approach taken by George Mason University researchers was based on the Disciple apprenticeship multi-strategy learning theory, methodology and shell for rapid development of knowledge bases and knowledge-based agents (Tecuci, 1998). The Disciple learning agent shell consists of a learning and knowledge acquisition engine as well as an inference engine and supports building an agent with a knowledge base consisting of an ontology and a set of problem solving rules. One of the DARPA HPKB challenge problems was to construct a critiquing agent that could evaluate military courses of action for ground combat operations, with respect to the principles of war and tenets of Army operations. To address the HPKB course of action challenge problem, Disciple was extended (Tecuci et al., 2000) and used to develop the Disciple-COA agent (Figure 1).

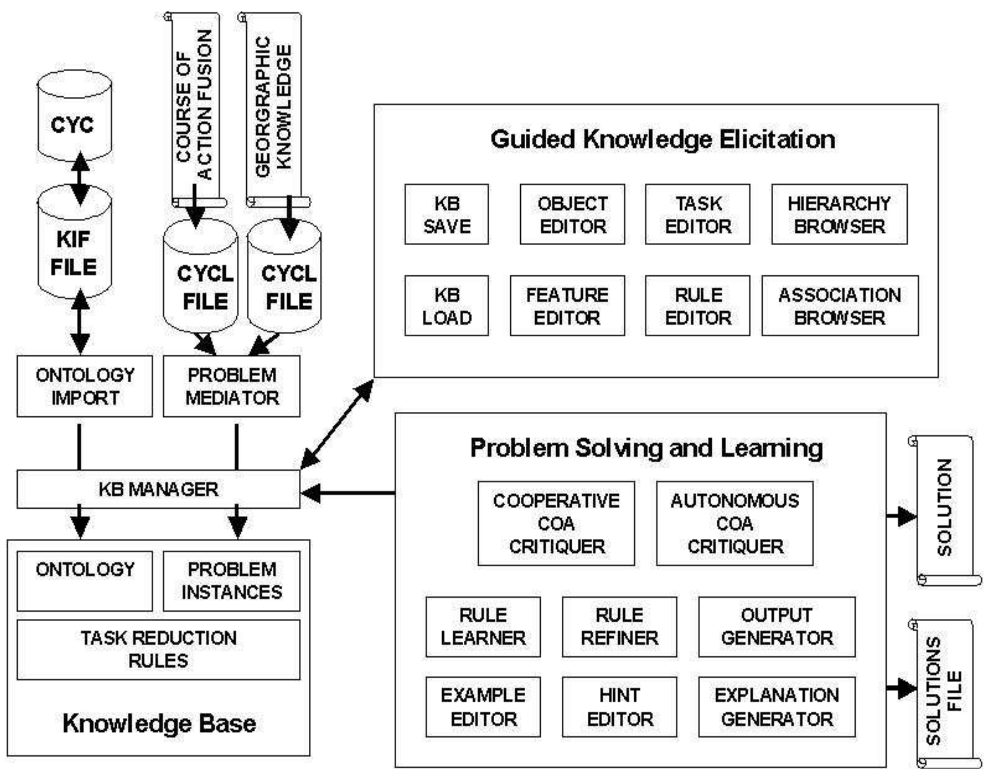

Figure 1. The Architecture of Disciple-COA

Disciple's ontology includes objects, features, and tasks, all represented as frames, according to the knowledge model of the Open Knowledge Base Connectivity protocol (Chaudhri et al., 1998). The objects represent either individuals or sets of individuals. The objects are hierarchically organized according to the instance-of / type-of and subclass-of / superclass-of generality relationships. For Disciple-COA, an initial ontology was defined by importing the ontology built by Teknowledge and Cycorp for the courses of action challenge problem. The imported ontology contained the vocabulary needed to represent courses of action, and all HPKB participants working on the challenge problem shared it. A fragment is given in Figure 2.

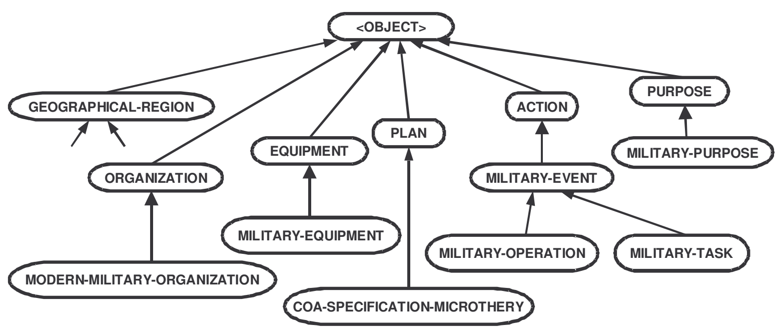

Figure 2. Fragment of top level elements of the imported military domain ontology.

The ontology was refined and extended for the Disciple-COA agent using the ontology building tools of Disciple shown in the top right side of Figure 1. Figure 3 shows that a high level element from Figure 2, MILITARY-TASK, has a substructure in which concepts and instances are described by specific values and features.

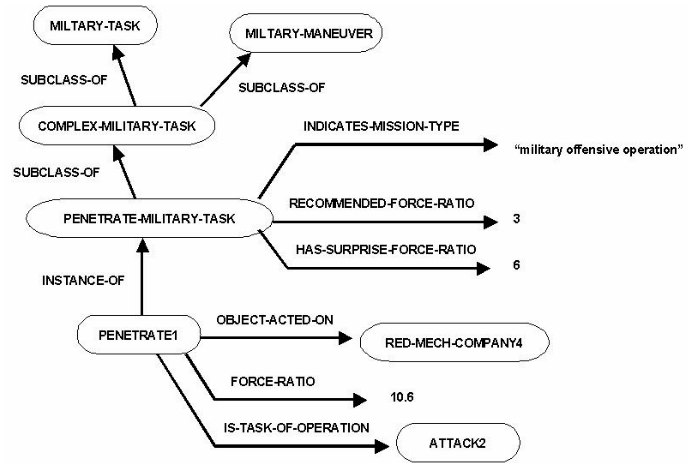

Figure 3. Additional ontology development using Disciple-COA.

As part of the HPKB program, Disciple-COA and the other course of action critiquing agents were evaluated using five scenarios of increasing difficulty. The impressive results of this evaluation can be found in Tecuci et al. (2000a). In addition, George Mason University researchers conducted a one-week knowledge acquisition experiment using Disciple-COA at the U. S. Army Battle Command Battle Laboratory in Fort Leavenworth, Kansas (Tecuci et al., 2000b). This experiment took four military professionals experienced in both the tactical and operational levels of war but having no prior knowledge engineering experience and gave them approximately sixteen hours of training in AI and the use of Disciple-COA. Then starting with a knowledge base containing the complete ontology of objects and features in Disciple-COA but no rules, the military professionals were asked to train the agent to critique courses of action based on two principles of war – offensive and security. The agent training sessions lasted about three hours, and each expert, without measurable assistance from a knowledge engineer, successfully built 26 rules and 28 tasks. The results of this test were also impressive.

With the HPKB evaluation results and those obtained at Fort Leavenworth, knowledge engineers in the Center for Strategic Leadership at the USAWC felt it was time to suggest that Disciple's focus be migrated toward the more difficult military problems found at the operational and strategic levels of war. This is being done with the cooperation and support of DARPA through its RKF program (Burke, 1999).

Center of Gravity Application

One of the most difficult and often vexing problems that top military leaders face at the strategic level of war is the determination and analysis of the center of gravity (COG) for an opposing force. Clausewitz (1832) introduced the concept of a center of gravity as “the hub of all power and movement, on which every thing depends” (p. 595). USAWC Faculty members have debated the meaning of Clausewitz’s words for many years. It is a controversial concept with several contentious issues. Each US military service (Army, Navy, Marines, and Air Force) has a different view of it, perhaps biased by their different perspective of the strategic and operational levels of war. To facilitate further study, the Center for Strategic Leadership convened a working group of subject matter experts to attempt to give definition to the concept. These subject matter experts also worked with USAWC students (U. S. Army, U. S. Air Force, as well as International Fellows from the Egyptian, German, Philippine, Royal Thai, and Venezuelan militaries) interested in the problem. What emerged from this effort was published in a monograph entitled *Center of Gravity: Determination, Analysis, and Application* (Giles and Galvin, 1996). The monograph has an accompanying process chart. Based upon this work, it is clear that the center of gravity concept can be applied at both the strategic and operational levels of war. At the strategic level of war, the center of gravity determination is essential for maintaining focus on strategic goals, for allocating and using military resources, and for winning the war. Correctly identifying the strategic center of gravity is critical to the success of military campaigns at the operational level. Thus the strategic center of gravity helps identify the operational center of gravity.

The ontology development for the center of gravity application builds on what was done for the course of action application. The course of action ontology provides an extremely important starting point, but the expansion of this ontology for center of gravity determination and analysis is extensive and complex because of the much greater coverage required for the new domain. Figure 4 presents "Step 1" of the Giles and Galvin monograph process chart. It has an immediate impact on any knowledge engineer having to do the ontology development for such a process. In just one category, "Economic Factors" for example, there are a plethora of objects, features, tasks and rules that can be added to the ontology used in Disciple-COA. This is to say that concepts such as MODERN-MILITARY-ORGANIZATION and MILITARY-TASK in the Disciple-COA ontology are still needed, but now it is likely that concepts such as GROSS-DOMESTIC-PRODUCT, ECOMONIC-DEPENDENCY-ON-IMPORTED-FOSSIL-FUEL, ELECTRICAL-PRODUCTION-CAPABILITIES, and more are also needed. The question is which of these concepts are needed in the majority of scenarios that the agent will face and therefore should be part of an initial ontology. Human subject matter experts face the same problem; however, through experience and study, these experts have developed a framework of concepts that they quickly consider as they "Assemble Relevant Data."

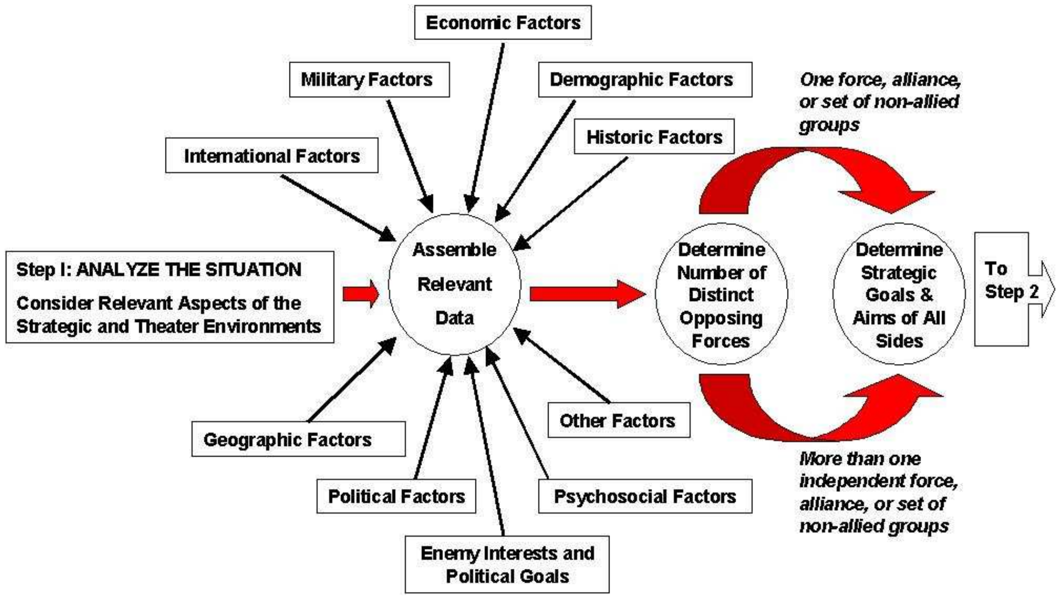

Figure 4. Step 1 of the center of gravity determination process.

USAWC faculty members continue to both study and teach center of gravity determination and analysis using the basic model provided by the monograph. In an elective course devoted to the concept of center of gravity, students study military and crisis scenarios and do strategic and operational center of gravity determination for each opposing force in a selected scenario. Taking this same approach, knowledge engineers have begun the process of initial ontology development by studying two separate military campaigns, the World War II invasions of Okinawa and Sicily. It is important to understand that instances of military actions very specific to the Okinawa Campaign, for example, are similar to instances in current day situations. These instances belong to concepts that must be captured in the basic ontological development if they are not found ready for import from ontology repositories such as CYC (Lenat, 1995). For example, the motorboat Kamikaze attacks against US Naval vessels during the Okinawa Campaign are not unlike the modern-day motorboat terrorist attack recently directed against the USS Cole. A common element of both applications was the use of surprise, a principle of war understood by Disciple-COA. Yet another profound commonality between the two is found in religious beliefs, a "relevant" Psychosocial Factor, which must be introduced into the ontology.

The Disciple methodology appears to be ideally suited for use in this domain and the USAWC environment. Disciple provides a wide range of flexible tools for ontology, knowledge base and agent development and the USAWC has the necessary domain expertise and scenarios. Consequently, knowledge engineers from the Center for Strategic Leadership will work with USAWC students taking the elective course entitled "Case Studies in Center of Gravity Determination" during the spring term. Each student in this class is required to select a historical campaign or contemporary planning scenario and do strategic and operational center of gravity determination for each of the opposing forces. They will use a newly developed feature of Disciple that will allow them to describe the selected scenario in a natural user-Disciple dialog. Based on this dialog, Disciple will extend and populate a generic ontology for center of gravity determination and analysis. The ontologies developed in this way will be used by the USAWC students in a subsequent elective course entitled "Military Applications of Artificial Intelligence" to further develop and train Disciple-COG agents.

The USAWC is fortunate to have among its faculty several members of the original working group that produced the center of gravity monograph. These subject matter experts will be asked to evaluate the results produced by Disciple-COG.

Conclusion

Ontology development is critical to the creation of successful knowledge-based systems. The military has numerous problem domains at the tactical, operational, and strategic levels of war where knowledge-based systems have been and can be deployed. DARPA through its HPKB program supported the development by researchers at George Mason University of

Disciple-COA, a tactical course of action critiquing agent. All participants in the HPKB program shared an initial ontology developed by Teknowledge and Cycorp. The built-in ontology tools found in the Disciple shell enabled further ontology development. The evaluation results for Disciple-COA were impressive and caused knowledge engineers at USAWC to recommend for DARPA's RKF program that Disciple be focused on the strategic level problem of center of gravity determination. George Mason University researchers agreed with this recommendation. DARPA subsequently approved it, and ontology development for Disciple-COG is underway.

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References

Burke, M. (1999) *Rapid Knowledge Formation (RKF) Program Description,* http://dtsn.darpa.mil/iso/ programtemp.asp?mode=331

Clausewitz, C. (1832) On War. Translated by M. Howard and P. Paret (1976) Princeton University Press: Princeton, NJ.

Chandrasekaran, B., Josephson, J., and Benjamins, V. (1999) What Are Ontologies, and Why Do We Use Them? *IEEE Intelligent Systems*, 14, 1, 20-26.

Chaudhri, V. Farquhar, A., Fikes, R., Park, P. and Rice, J. (1998) OKBC: A Programmatic Foundation for Knowledge Base Interoperability. *Proceedings of the Fifteenth National Conference on Artificial Intelligence (AAAI-1998)*, 600-607, AAAI Press: Menlo Park, CA.

FM 100-5 (1993), US Army Field Manual 100-5, *Operations*, Headquarters, Department of the Army, Washington D.C., 1-3.

Giles, P. and Galvin, T. (1996) Center of Gravity: Determination, Analysis, and Application. Center for Strategic Leadership: Carlisle Barracks, PA.

Gruber, T. (1993) A Translation Approach to Portable Ontology Specifications. *Knowledge Acquisition*, 5, 2, 199-220.

Guarino, N. and Giaretta, P. (1999) Ontologies and Knowledge Bases: Towards a Terminological Clarification. In *Towards Very Large Knowledge Bases: Knowledge Building and Knowledge Sharing*, N. Mars (editor), 25-32, ISO Press: Amsterdam, The Netherlands.

Gunning, D., Burke, M. (1996) *Rapid Knowledge Formation (RKF) Program Description,* http://dtsn.darpa.mil/iso/ programtemp.asp?mode=331Gunning, D., Burke, M., High Performance Knowledge Bases (HPKB) Program Description, http://dtsn.darpa.mil/iso/index2.asp?mode=9

Jomini, A. (1862) *The Art of War.* Translated by H. Mendell and W, Craighill (1971) Greenwood Press: Westport, CN.

Lenat, D. (1995) CYC: A Large-scale Investment in Knowledge Infrastructure. *Communications of the ACM*, 38, 11, 33-38.

Noy, N. and Hafner, C. (1997) The State of the Art in Ontology Design: A Survey and Comparative Review. *AI Magazine*, 18, 3, 53-74.

Tecuci, G., Boicu, M, Marcu, D., Bowman, M., Ciucu, F. and Levcovici, C. (2000a) Rapid Development of a High Performance knowledge Base for Course of Action Critiquing. *Proceedings Seventeenth National Conference on Artificial Intelligence (AAAI-2000) and the*

In *Proceedings of the SouthEastern Regional ACM Conference*, Atlanta, GA, March 16-17, 2001.

Twelfth Innovative Applications of Artificial Intelligence Conference (IAAI-2000), 1046-1053, AAAI Press: Menlo Park, CA.

Tecuci, G., Boicu, M., Bowman, M., Marcu D., Shyr P., and Cascaval C., (2000b) "An Experiment in Agent Teaching by Subject Matter Experts," *International Journal of Human-Computer Studies*, 53:583-610.

Tecuci, G. (1998) *Building Intelligent Agents*, Academic Press: San Diego, CA.

Tzu, S. (400 BC) *The Art of War.* Translated by S. Griffith (1981) Oxford University Press: New York, NY.

Van der Vet, P. and Mars, N. (1998) Bottom-Up Construction of Ontologies, *IEEE Transactions on Knowledge and data Engineering*, 10, 4, 513-526.

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