The IW Joint Operating Concept (JOC) lists counterterrorism, unconventional warfare, foreign internal defense, counterinsurgency, and stability operations as IW operations and activities recognizing overlaps between them and applications outside the population-centric IW operational environment (OE) (U.S. Joint Staff, 2010). The uniting feature of all of these operations is that the kinetic actions of traditional combat, while present, are insufficient for prosecuting or describing the operations. Human, social, cultural, and behavioral (HSCB) actions and understanding are required and often dominate.

Operations Research analysts must carefully model and analyze the Irregular Warfare (IW) domain in order to provide accurate recommendations and assessments. Managing the complexity of the IW domain requires scoping the problem and assigning useful consistent descriptions. Semantic Web ontologies provide a means for formalizing descriptions of the IW domain.

ONTLOGIES

Ontologies provide a structure for holding our knowledge about a domain and for using that knowledge. We have been increasing our use of ontologies to support modeling and simulation (M&S) and analysis within the Department of Defense (DoD) in the last half dozen years.

An ontology is one tool for describing a domain of knowledge about the world. There is some fluidity in ascribing the title “ontology” to descriptions. Error! Reference source not found. (based on McGuinness, 2003) illustrates a spectrum of description formality, with the dotted vertical line dividing line non-ontologies (on the left) and ontologies (on the right). Lee Lacy describes ontologies as formally described collections of terms and their relationships. A very important subset of ontologies consists of those that are machine-readable. The Web Ontology Language (OWL) provides a method for encoding ontologies so that they are machine-readable (Lacy, 2005). The relationships form a structure and the terms form a controlled vocabulary for describing the domain.

The formal “is-a” requirement (from Error! Reference source not found.) implies a structure: what are the things that an element of the ontology might be one of? Naturally, the choice of the structure depends on the domain in question. It would be convenient if, in each case, there were a single, obvious, “correct” answer. Generally, there are several possibilities, with no clear rationale for making a choice.
Fortunately, ontologies, unlike strict taxonomies, can have more than one structure and elements can have an “is-a” relationship with multiple structures and with multiple categories within a structure. It should be noted that “is-a” is not the only structure-forming relation. The “part-of” and other relations (lower right in Error! Reference source not found.) also induce structures that may be included in an ontology. For example, a “pie” can be described as having a “crust” and a “filling” (parts of the pie), as well as having sub-types such as “apple pie,” “cherry pie,” etc. (is-a relations). The domain and the use of the ontology will determine the nature of the relations that are used.

REPRESENTING THE IW DOMAIN WITH ONTOLOGIES

In 2010, the U.S. Army Training and Doctrine Command (TRADOC) Analysis Center (TRAC) asked for a metric ontology of irregular warfare (IW). Hartley and Lacy formed the team that developed the ontology. We divided world as shown in Figure 2. The IW OE (i.e., the “IW world”) is made up of actions, environment, and actors. The actors are natural and human (individual and collective) entities, with identities, relationships, decision making processes, etc., who perceive/are influenced by the state of the world. They perform actions, which are interventions, events and ongoing processes that affect the operational environment (the actors, environment, and actions). The state of the operational environment at any given time is described by state variables (metrics) that give states of being, contexts of actions and protocols for actions. The state variables are classified using a PMESII+ (political, military, economic, social, information, infrastructure, kinetics, environmental) structure.

This work focused on creating an ontology of the state variables or metrics, shown in the right-hand part of the figure. TRAC used that ontology to enhance their existing model (previously developed through compilation of several extant IW metric taxonomies) to more robustly represent the IW OE. TRAC also used the ontology to structure and examine links between various operational Lines of Effort (LOEs) metrics and metrics elements (Hartley and Lacy, 2011). The ontology enabled TRAC to develop LOEs associated with each key actor/faction within the scenario being represented (Hartley and Lacy, 2011).
Subsequently, Hartley expanded the ontology into a total ontology (including the actions, environment, and actors of the figure) of irregular warfare and used it to improve his DIME/PMESII VV&A Tool (Hartley, 2009/2011; Hartley, 2011b). The ontology defines the IW elements and their connections and provides the basis for a “connectivity check” within a model’s sub-elements. It does not, nor is it intended to, describe the specific interactions among the various model elements of IW; however, it does allow for checking as to whether all the components that are desired are, in fact, represented. It should be used as the basis for coordinating the use and creation of multiple models of irregular warfare. It can also be used to identify gaps in social theories (Hartley, 2012).

In 2012, TRAC contracted for work to extend the metric ontology into a complete IW ontology. Dean Hartley also led the team in this effort. Recognizing that use of the “LOE” doctrinal terminology is typically only used by U.S. Department of Defense (DoD)/Coalition military forces and agencies, Hartley’s work focused on bringing to TRAC an expanded ontology and creating ontological generalizations of the LOEs, called Goal-Task-Owner (GTO) Sets, for use by significant non-DoD parties to IW (Hartley and Lacy, 2013). Figure 3 illustrates the large number of actors (Owners), each with its own agenda (sets of Goals and Tasks) that may be present in a large IW operation. Any model or analysis of the situation needs to take all of these into account.

![Figure 3. Potential Range of Actors and Agendas in an IW](image)

This latest part of the ontology has just been completed and distributed. We foresee numerous uses in the future.
USING ONTOLOGIES WITH M&S IN IW ANALYSIS

In 2007, the Office of the Secretary of Defense (OSD) used the Oz wargame integration toolkit to record the first IW Analytical Baseline in the Department of Defense, The Africa Study. In the Africa Study, moves of a wargame were entered into multiple social simulation models that determined the effects of the moves. With Oz, the research team described the actions, actors, and whole of government moves in an OWL ontology at the strategic level of war. The categorization of moves into the general and specific categories of the machine-readable ontology facilitated machine analysis of trends in the game (Duong and Pearman, 2013).

In 2010 U.S. Army TRAC sponsored SIMmiddleware as a key element within TRAC’s ongoing development of the IW Tactical Wargame (TWG). SIMmiddleware, a continuation of Oz by the same inventor (Deborah Duong), took the application of ontologies to simulation analysis a step further by giving ontologies an active role in the integration of simulations. An inference engine acting on the ontologies computed move translations between social models and recognized simulation states, such as indicator states and measures of effectiveness, important to the study question. In the TWG analysis, SIMmiddleware expressed the conceptual model of the study as the “hub” of ontologies arranged into a hub and spoke design (Figure 4). The spokes were the ontologies that represent the native objects and relations of the different social models of the study, including the Nexus Cognitive Agent simulation to model key leader networks, and the Cultural Geography simulation to model popular support and infrastructure. Translation ontologies translated back and forth between the concepts of the conceptual model of the study and the concepts of the simulation models. These translation ontologies were probabilistic ontologies that used Bayesian inference to translate moves that did not have an exact definition, or when resolutions were crossed from a more general to a more specific move.

The “hub and spoke” design facilitates modular integration of disparate models with diverse languages into a single consistent language of the study, which clearly demarcates what is being studied and what is not. To know what goes into a conceptual model of a study, there is a rule of thumb: If a difference between models matters to the results of the study, then that difference should appear in the conceptual
model, else it is just an implementation difference which serves the same function, and therefore is not part of the modeled concept. By defining the terms of what is under study, ontologies flag inconsistencies, or the use of a concept not under study, helping to bound the study for analysis (Duong and Bladon 2012, Duong 2012).

In the TWG analysis, ontologies were also used to define simulation states, such as indicators and measures of effectiveness, important to the strategies of the wargamers. By keeping a record of the decision points, branches and sequels, and goals of the wargamer’s strategy, the ontology noted information that was used to automate the wargame in multiple constructive runs for Monte Carlo analysis. The hierarchical arrangement of the ontology, from general down to specific, provided a variety of views on what happened in the wargame, facilitating the analysis of trends. For example, within the IW TWG analysis the mutual information score was measured between indicators and wargamer actions at several levels of generality in the ontology to find out what actually triggered wargamer decisions at the right level of generality. The many levels of generality of the ontology helped to define simulation states that mattered to the study question, eventually to be put into a Markov Process that summarized the trends of multiple simulation runs (Duong and Bladon 2012, Duong 2012).

In 2013, U.S. Army TRAC sponsored a study of modeling Civil Military Operations, which included research on how ontologies may support Verification, Validation, and Accreditation (VV&A) of social simulations and their federation in a study. SIMmiddleware was enhanced with a Shum ontology that defines conceptual support for a theory. This ontology kept track of every time trends in a social simulation supported the social theory that they were supposed to represent. If the output of the social simulation matched the trends that would be expected in the social theory, the model would be considered more valid. However, to be valid, a social simulation must also match real world processes through the social theory it represents. Ontologies assisted here too: the Markov Processes that summarized the trends of multiple runs of the simulation could be measured against real world data put in another Markov Process, using a probabilistic distance, to find an objective “validation” score. Ontologies helped in the comparison by offering multiple levels of generality to describe the simulation state for comparison across multiple dimensions (Duong and Pearman 2013).

ONTOGONY APPLICATION

Starting in 2007, TRAC collaboratively undertook an extensive research effort to examine the current state of capabilities to examine and analyze Doctrine, Organization, Training, Materiel, Leadership (DOTML) change and conduct of operations decisions associated with the IW OE. TRAC performed an extensive literature review, including (but not limited to) Galula (1964), Cordesman (2005 and 2007), Stephen Downes-Martin (2010), Paul K. Davis (2009), Glenn & Gayton (2008), Kilcullen (2010), and Hartley (numerous items). TRAC also extensively leveraged prior work such as

- Office of the Secretary of Defense Cost Assessment and Program Evaluation (OSD CAPE),
- Defence Science and Technology Laboratory (Dstl) United Kingdom Ministry of Defence (UK MoD),
- U.S. Marine Corps Combat Development Command Operations Analysis Division (MCCDC OAD),
- Joint Staff J8,
- the TRADOC G2 Intelligence Support Activity (TRISA),
- ongoing analysis in current operations, Iraq: Operation Iraqi Freedom (OIF) and Afghanistan: Operation Enduring Freedom (OEF).

From that early research emerged the metric-state-vector concept for capturing the current state of the IW OE to facilitate analysis. An examination of the existing constructs that identified and grouped such metrics led to a decision to group metrics in a PMESII taxonomy that could also be rearranged, as necessary, into metrics informing progress toward lines of effort (LOE) desired end-states. The initial
consolidation of metrics clearly indicated that a taxonomy would not be sufficient to adequately represent the metrics and their relationships within any grouping – an ontology was required. Ontologies lend themselves well to the essential elements of analysis (EEA) and Measures of Performance/Effectiveness (MOP/MOE) structure central to Army and DoD analyses. They additionally enable the concept of decomposition; the method of breaking down elements of the OE to levels where the interactions and effects can be reasonably understood – then re-aggregating those elements to the level(s) required to effectively inform decisions. Both the decomposition and the re-aggregation are greatly enabled by understanding the key relationships between the environmental elements and the metrics, leading to a much more robust and nuanced understanding of the OE. An important concept was using the metric-state-vector concept to attempt to understand movement between the states, identify possible tipping points (Gladwell 2009), and attempt to reduce the range of “black swan” possibilities or their impacts (Taleb 2007 and Perla 2008).

CONCLUSIONS

Attempting to solve problems without an understanding of the key elements involved, their relationships, and potential second and third order impacts is typically challenging. Within an environment as complex as irregular warfare, attempting such is fraught with risk. Without robust representations of the range of elements and interactions within an IW OE, decision analysis efforts may not adequately support senior leader decisions concerning equipping forces, organizing forces, and conducting operations within the IW OE. Semantic Web ontologies provide a means for formalizing descriptions of the IW domain and of particular models of the IW domain. It is recognized that the capture of the “complete” range of elements and interactions is not possible. However, this effort has sought to capture the most relevant elements and relationships, identify associated metrics, and anticipate metric variation in order to provide a structural construct wherein effective analysis associated with the IW OE can be attempted. Operations within IW OEs are not going away anytime soon. The analytic community must continue to expand its capabilities to support related decisions.

REFERENCES


Duong, Deborah Vakas and Jerry Pearman. 2013. “Data Processing for Mitigation: Data Interfaces for Input, Output, and Translation between Models” in Sociocultural Behavior Sensemaking: State-


