ERDC/CERL TR-15-14

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A Design for Computationally Enabled Analyses Supporting the Pre-Intervention Analytical Framework (PIAF)

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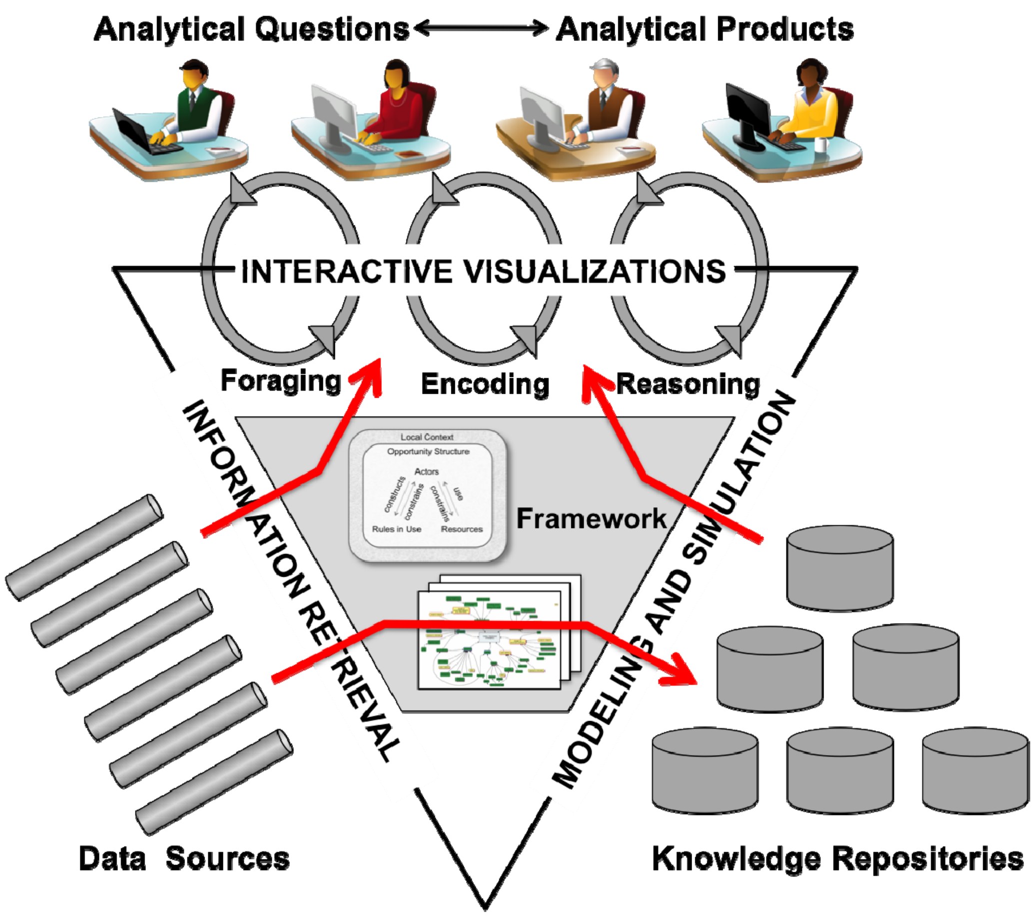
June 2015



A Design for Computationally Enabled Analyses Supporting the Pre-Intervention Analytical Framework (PIAF)

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Final report

Approved for public release; distribution is unlimited.

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under Project P2 335530, "Cultural Reasoning and Ethnographic Analysis for the Tactical Environment (CREATE)"

Abstract

The Pre-Intervention Analytical Framework (PIAF) for sensemaking includes a conceptual design and a design for computationally enabled analysis. The conceptual design, previously developed by the Engineer Research and Development Center, Construction Engineering Research Laboratory (Whalley et al. 2014), included sensemaking factor maps that are derived from peer-reviewed literature findings and organized in terms of underlying sociocultural drivers. The design for computationally enabled analysis, described here, exploits computer technology to connect the conceptual design with current military doctrine, particularly the Joint Intelligence Preparation of the Operational Environment (JIPOE). The purpose of this technology is to identify tools and methods that may facilitate analysis and decision making.

The design for this technology is shaped by two factors: (1) the "wickedness" of understanding and accounting for the influence of sociocultural factors on military operations and (2) the centrality of sensemaking to all phases of operation. Wicked problems are high-stakes, complex problems, arguably unique in each instance, and without definitive formulations or optimal solutions. Sensemaking is a human-centric, iterative process with numerous feedback loops. It involves activities including information foraging, encoding, and reasoning. These two factors suggest important requirements for tools and methods designed to facilitate analysis and decision making.

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Preface

This study was conducted for Headquarters, U.S. Army Corps of Engineers, under Research, Development, Test, and Evaluation (RDT&E) Program Element 622784 T41, "Military Facilities Engineering Technology"; Project P2 335530, "Cultural Reasoning and Ethnographic Analysis for the Tactical Environment (CREATE); Modeling and Analysis of Sociocultural Factors for Civil-Military Operations." The CREATE Work Package Manager was Timothy K. Perkins, CEERD-CNC and the Sociocultural Research and Development Program Manager was Hany H. Zaghloul, CEERD-CZT.

The work was performed by the Land and Heritage Conservation Branch of the Installations Division (CEERD-CNC), U.S. Army Engineer Research and Development Center — Construction Engineering Research Laboratory (ERDC-CERL). Significant portions of the work were completed by the Complex Systems Institute, College of Computing and Informatics, University of North Carolina at Charlotte; and the Institute for Defense Analysis in Arlington, VA. At the time of publication, Dr. Michael L. Hargrave was Chief, CEERD-CNC; Michelle J. Hanson was Chief, CEERD-CN; and Ritchie L. Rodebaugh (CEERD-TZT) was the Technical Director for Geospatial Research and Engineering. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

1 Introduction

1.1 Background

It is widely recognized that effective interaction with local populations is essential to the success of military operations. Effective interaction, however, depends on an armed force's ability to understand and anticipate how sociocultural factors influence operations. Yet, the United States Armed Forces face a critical capability gap in this area; U.S. forces are generally not proficient in accounting for sociocultural factors in mission planning and support across the full spectrum of operational phases and mission types. While advances have been made to fill this gap, too often the advances are ad hoc solutions that do not fit well into operational doctrine or leverage the best available sociocultural theory and research (Schmorrow 2011).

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) is addressing this problem as part of a research work package called the Cultural Reasoning and Ethnographic Analysis for the Tactical Environment, or CREATE. The overall intent of the work package is to establish the CREATE Analytical Framework, which is characterized by

- a strong grounding in established social science theory
- practical utility for the end user
- compatibility with military doctrine, particularly the Joint Intelligence Preparation of the Operational Environment (JIPOE)
- improved integration of mission-support activities such as intelligence, planning, and operations
- an analytical capability that connects social science theory to sociocultural inputs needed to plan and execute operations according to JIPOE requirements.

In the first phase of the CREATE work package, ERDC-CERL developed the conceptual design for these capabilities called the Pre-Intervention Analytical Framework, or PIAF (see Whalley et al. 2014). This framework guides the development of *factor maps* that are drawn from peer-reviewed literature for a given topic (e.g., the drivers of insurgency) and are organized in terms of underlying sociocultural factors. The purposes of factor maps are to

1. provide a generalized view of a given topic that can be used to quickly and effectively introduce mission personnel to the salient sociocultural factors
2. inform computational tool design by highlighting relevant factors, relationships, and social theories
3. help users explore the mission in the context of the best understandings of a given topic without having to develop detailed expertise.

The present report describes the development of a design for computationally enabled analysis that uses context and inputs provided through the PIAF and mission-specific factor maps. This capability is intended to help mission personnel formulate a more comprehensive and situation-specific approach to understanding and anticipating the influence of in-theater sociocultural factors on the outcome of military operations. The design for this capability connects the conceptual design (Whalley et al. 2014) to military doctrine — in particular, JIPOE doctrine — while suggesting tools and technologies that promote critical thinking and sensemaking activities. The purposes of the design for computationally enabled analyses are to

1. blend top-down and bottom-up analytical approaches that link theory and data with methods for exploring the application of military doctrine
2. significantly accelerate the maturation of analytical thought processes in the new JIPOE analyst, thus raising the collective quality of analytical product.
3. improve decision making by suggesting tools and methods that will promote and improve critical thinking and sensemaking, thus raising the quality of analytical product.

To summarize, the design for computationally enabled analysis is intended to focus, augment, and enhance analyst expertise, not to work around or avoid investing in it.

1.2 Objective

The objective of this study was to design a computationally enabled analytical capability for applying the PIAF and factor maps to intelligence sensemaking in support of military operations within the context of JIPOE doctrine.

1.3 Approach

The design was created by examining requirements generated by the PIAF, mapping these requirements against doctrinal processes for JIPOE, assessing state of the art information retrieval and visualization tools, and prototyping tools using these capabilities. This approach yielded a design to implement the PIAF.

To demonstrate the potential of this design, a specific analytical theme was identified: the emergence and maintenance of insurgency where a US military operation is specified.

1.4 Mode of technology transfer

Elements of the technology described in this report were demonstrated as part of a limited user test in August 2013, and other elements have been developed to proof of concept. The complexities of the PIAF and sociocultural understanding present significant additional questions that must be addressed through follow-on research and development before this analytical technology is suitable for incorporation into the PIAF. Section 7.2 outlines a sequence of studies appropriate for developing capabilities that support information foraging, encoding, and reasoning to understand the relationship between a sociocultural environment and military operations.

2 Problem Definition and Solution Requirements

The success of military operations depends on an armed forces' ability to understand and anticipate how sociocultural factors influence the outcome of military operations. Consequently, a proper understanding of a region's sociocultural context is required to address numerous questions that are of interest to U.S. armed forces. Consider, for example, how the potential for or presence of violent extremism and insurgency might affect U.S. military operations. Will host nation events or actions lead to or strengthen an insurgency? How will the level of violent extremism affect U.S. military operations? Will U.S. operations mitigate or exacerbate undesirable dynamics linked to sociocultural factors? Schmorrow (2011) contends that

> To counter violent extremism and deter aggressors, U.S. forces must understand the drivers of extremism and violence, have the capacity to forecast undesirable behaviors, and possess the tools needed to conceive and simulate COAs that will have lasting impacts.

In light of analytical questions such as these, two factors should be recognized. First, these questions are arguably "wicked" in nature. Second, forming proper understandings to such questions is largely a sensemaking process. Consequently, both factors suggest important requirements for tools and methods designed to facilitate analysis and decision-making.

2.1 Wicked problems

Rittel and Webber first proposed the notion of a wicked problem (Rittel and Webber 1973). They described wicked problems as high-stakes, complex problems that are without definitive formulations; they are problems with open solution spaces where solutions have relative quality; and, they are problems that are arguably unique in each instance. Understanding the drivers of extremism and violence, anticipating the effects of extremism and violence of U.S. military operations, and identifying the actions that could mitigate or exacerbate undesirable dynamics linked to sociocultural factors all exceed the threshold to be characterized as wicked problems. The challenges that wicked problems present to analysts and decision-makers are daunting, but problem-solving strategies have been suggested to manage these challenges. Roberts (2000) articulates three such strategies: authoritative, competitive and collaborative strategies.

Authoritative strategies for managing wicked problems emphasize a reductionist approach to problem solving. Roberts describes such strategies as ones that place problem solving under the responsibility of a few individuals as a means of reducing problem complexity. *Competitive strategies* for managing wicked problems emphasize the search for power. Here, Roberts describes such strategies as battles for supremacy among problem solvers, where such battles are means for prompting both inquiry and innovation. *Collaborative strategies* for managing wicked problems emphasize the pursuit of synergy among problem solvers. Roberts describes collaborative strategies as ones that unite forces to increase problem-solving resources while eliminating some inefficiencies and mitigating some risk — however, at the cost of increased overhead.

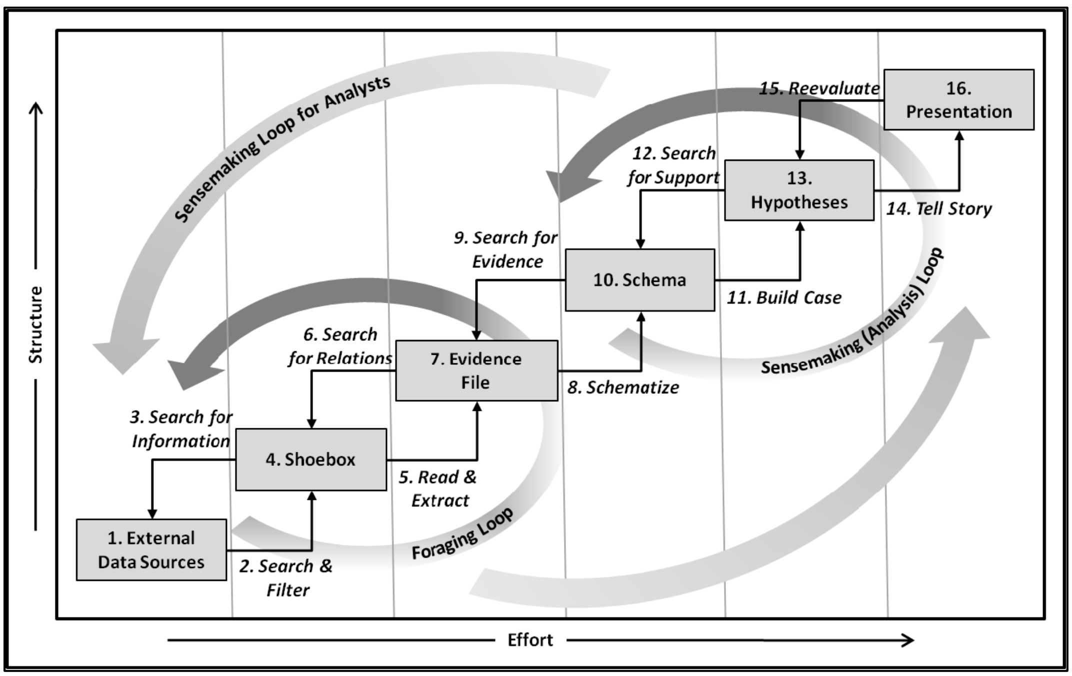
The wickedness of understanding and anticipating how sociocultural factors influence the outcome of military operations suggests several requirements for any solution. First, analysts must be able to leverage authoritative sources. Though unique in each instance and potentially contradictory (e.g., offering competing theories), authoritative sources can ground the understanding of sociocultural factors. Then, tools and methods should provide mechanisms to connect authoritative sources to the uniqueness of each situation. Second, the ability to identify and explore alternative understandings is essential. Tools and methods, therefore, should stretch analyst thinking, help analysts overcome natural biases, facilitate the exploration of alternatives and expose key assumptions. Third, collaboration and dissemination are integral activities as they can accelerate analyses while strengthening the analytical product through diversity of thought. So, tools and methods should be designed to facilitate the formation of — and communication across — communities of interest. Fourth, evaluation and validation are foundational to analysis. As a result, tools and methods should promote critical thinking and provide means to evaluate and compare analyses, both computationally and qualitatively. Finally, deep analyses must be enabled. Deep analyses move beyond surface-layer effects to uncover the broader sociocultural implications of these effects.

2.2 Sensemaking

The term *sensemaking* has several different definitions in the literature. Duffy (1995) defines it as “how people make sense out of their experience in the world.” The final report from the 2001 Sensemaking Symposium (Leedom 2001) describes sensemaking as “the process of creating situation awareness in situations of uncertainty.” Klein et al. (2006) describe it as “a motivated, continuous effort to understand connections… in order to anticipate their trajectories and act effectively.”

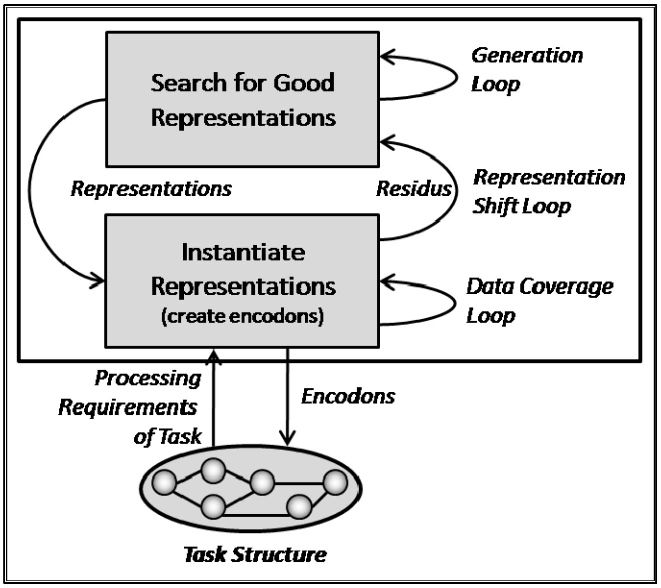
Collectively, these descriptions of sensemaking highlight several important implications. First, sensemaking is an iterative process with numerous feedback loops. Pirolli and Card (2005) illustrate this well (see Figure 1).

Figure 1. Sensemaking loop.



Second, sensemaking involves several activities including foraging, encoding and reasoning. Central to these activities is the iterative construction and refinement of representations, i.e., models, during reasoning; what Klein et al. refer to as the framing process (Klein et al. 2006). Russell et al. (Russell et al. 1993) capture this characteristic in their depiction of the Learning Loop Complex (see Figure 2).

Figure 2. Learning loop complex.

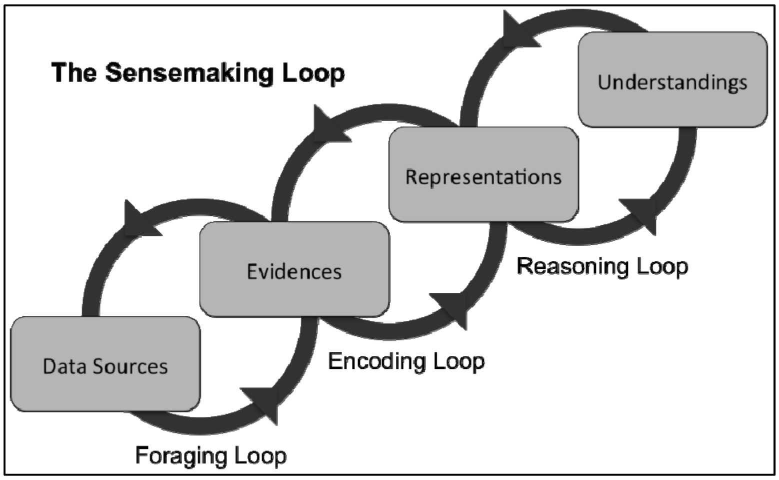


In the Learning Loop Complex, people search for a good representation; and, then, instantiate the representation — i.e., encode the data — based on the data available (i.e., data that have been foraged). Those data, called residual data, that do not "fit" the representation lead to the selection, construction or refinement of the representation. This reinforces the critical role of model representation to computationally enabled analyses, as this representation must provide affordances for the open, nonlinear, multi-dimensional and highly interdependent nature of sociocultural systems.

Third, sensemaking is largely a human-centric activity where judgment and critical thinking play essential roles. This suggests one must abandon the notion that outcomes (e.g., judgments) are the output of computational tools; rather, tools should enable the exploration of possible outcomes, facilitate human judgment and evaluate plausible futures.

Figure 3 is the sensemaking representation adopted for the design of computationally enabled analyses within the PIAF. In this representation, the progression of data to information, information to knowledge, and knowledge to understanding is clearly visible. Information, foraged from data and placed in analytical context, provides the foundational evidences to the analytical question(s). Knowledge, as representations encoded from information, emerges from relationships among concepts (Locke 1690). Understanding is synthesized from knowledge through reasoning and critical thought. This progression, however, is not necessarily linear and often highly iterative.

Figure 3. The sensemaking loop.



Considering that “U.S. forces must understand the drivers of extremism and violence, have the capacity to forecast undesirable behaviors, and… conceive and simulate COAs that will have lasting impacts” (Schmorrow 2011), this suggests clear requirements for sensemaking tools and methods (both conceptual and computational) that are designed to facilitate analysis and decision-making.

First, analysts must have access to authoritative data, information, knowledge, and understandings while decision makers must be able to leverage and benefit from these resources in the decision process. However, identification of the “best” of these analytical resources is extremely challenging for numerous reasons connected to the volume, structure (or lack thereof), heterogeneity and location of these resources. Second, capabilities that facilitate both exploration and synthesis are central to the sensemaking process. Exploration and synthesis may occur linearly, nonlinearly or by random means. Linear exploration and synthesis can occur inductively, deductively or abductively reflecting various top-down and bottom-up reasoning strategies. Nonlinear exploration and synthesis uncover inherent self-organizing and emergent properties of sociocultural systems. Random strategies provide a means for overcoming biases or local optima. Independent of the means, however, three goals are interwoven: to explore data and synthesize information (i.e., evidences); to explore information and synthesize knowledge; and, to explore knowledge and synthesize understandings. Third, timeliness is key — solutions must fit inside the decision cycle. Tools and methods, therefore, should automate the mundane, accelerate retrieval and analysis, and manage the computational complexity of the sensemaking process. Fourth, as a largely human-centric activity, tools and methods must provide interactive visualizations that promote analytical reasoning. Such interfaces should embrace the full sensemaking loop and seamlessly support foraging, encoding and reasoning throughout the analytical process. Finally, sociocultural populations exist in time and place. As such, tools and methods should enable analysts to connect the past to the present and the present to plausible futures. This requirement also shapes the products of the sensemaking loop: data, information, knowledge and understanding.

2.3 Requirements

Military operations depend on the ability to understand and anticipate how sociocultural factors influence outcomes. However, this is inherently a wicked problem. Strategies for managing wicked problems provide important insights into requirements for tools and methods designed to aid in the development of solutions. At the same time, understanding and anticipating how sociocultural factors influence military operations is largely a sensemaking process. As such, an understanding of the sensemaking loop provides additional insights into requirements for these same analytical tools and methods. Table 1 summarizes all of these requirements. The following sections illustrate how these requirements are addressed by the PIAF.

Table 1. Summary of requirements.

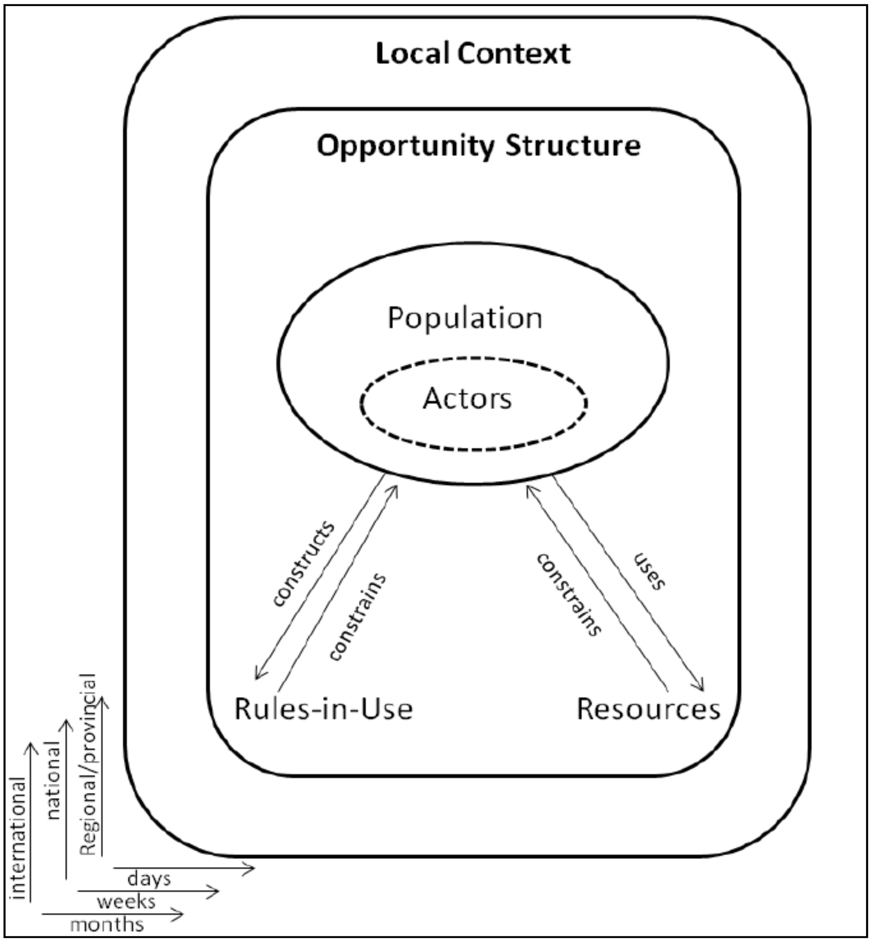
Wicked Problem Requirements	Sensemaking Requirements
Analysts must be able to leverage authoritative sources	Analysts must have access to the authoritative data, information, knowledge and understandings
The ability to identify and explore alternative understandings is essential	Capabilities that facilitate both exploration and synthesis are central (linear, nonlinear and random)
Collaboration and dissemination are integral activities as they can accelerate analyses while strengthening result	Solutions must fit inside decision cycle
Evaluation and validation are foundational	Tools and methods must provide interactive visualizations that promote analytical reasoning
Deep analyses must be enabled	Tools and methods should enable analysts to connect past to present and present to (plausible) futures

3 Pre-Intervention Analytical Framework (PIAF) Conceptual Design

The PIAF is documented in ERDC/CERL TR-14-4 (Whalley et al. 2014); this section provides a brief overview of elements of the PIAF helpful in understanding the computational design. The primary function of the PIAF is to extract and organize information most relevant to understanding social dynamics of an area. Ultimately, the PIAF aims to provide analysts and decision makers with an enhanced/accelerated ability to understand and anticipate how sociocultural factors influence outcomes across the full spectrum of military operations and mission types. The framework seeks to clarify the complexity of sociocultural dynamics as understood by subject matter experts, to leverage these best understandings either directly or indirectly through tools and methods, and to make these understandings accessible to analysts and decision makers. The result is a generalized, multilevel analytical framework that can be adapted to broad ranges of scenarios. The PIAF is designed to support information extraction and organization, and is intended to be combined with the use of social science theory to support explanation of why and how something has happened.

Attempting to understand and anticipate how sociocultural factors influence the outcome of military operations is similar to constructing a narrative about a sequence of events. However, when directed to make rapid sense of complex situations, analysts are challenged to discern relevant actors, actions or characteristics of the setting. Figure 4 depicts the principal elements of the conceptual design of the PIAF. These elements are influenced by Ostrom's Institutional Analysis and Development framework (Ostrom 2009).

Figure 4. A two-dimensional conceptual view of the PIAF structure at the relational level (Whalley et al. 2014) .



3.1 Key PIAF elements

Local context in the PIAF is scoped by both time and place and includes the system of rules-in-use, actors and resources available at that locality. These components, in turn, are filtered through an interpretive lens comprised of the historical and cultural factors specific to that locality at that moment in time. This lens contextualizes the importance of the actions of persons or groups with a common purpose, within the constraints of the local rules in use, and using the strategic resources best suited for their purpose.

Opportunity structure is the confluence among institutional and structural factors that facilitates/constrains the expression of population behaviors. In other words, the ability of a population to act is modified based on institutional arrangements and the configuration of resources.

Actors are persons or groups who can act for a common purpose. They are defined according to individual attributes as well as those attributes derived from patterns of interaction in a local context. Power relations between actors and rules-in-use provide actors with agency. Each actor has motivations that may be unique or shared with other actors. Actor motivations are the reasons and/or goals that instigate an actor to convert latent will into action in a given situation. These factors may or may not be connected to the issues that spurred a group's initial unification as a viable corporate actor. Actor attributes can evolve.

Rules in use are the rules that guide individual actor behavior as well as interactions among actors in a local context. Understanding the rules in use can reveal: "who can do what to whom and on whose authority." Rules in use are not necessary a single set of rules but often multiple, competing sets for a given local context.

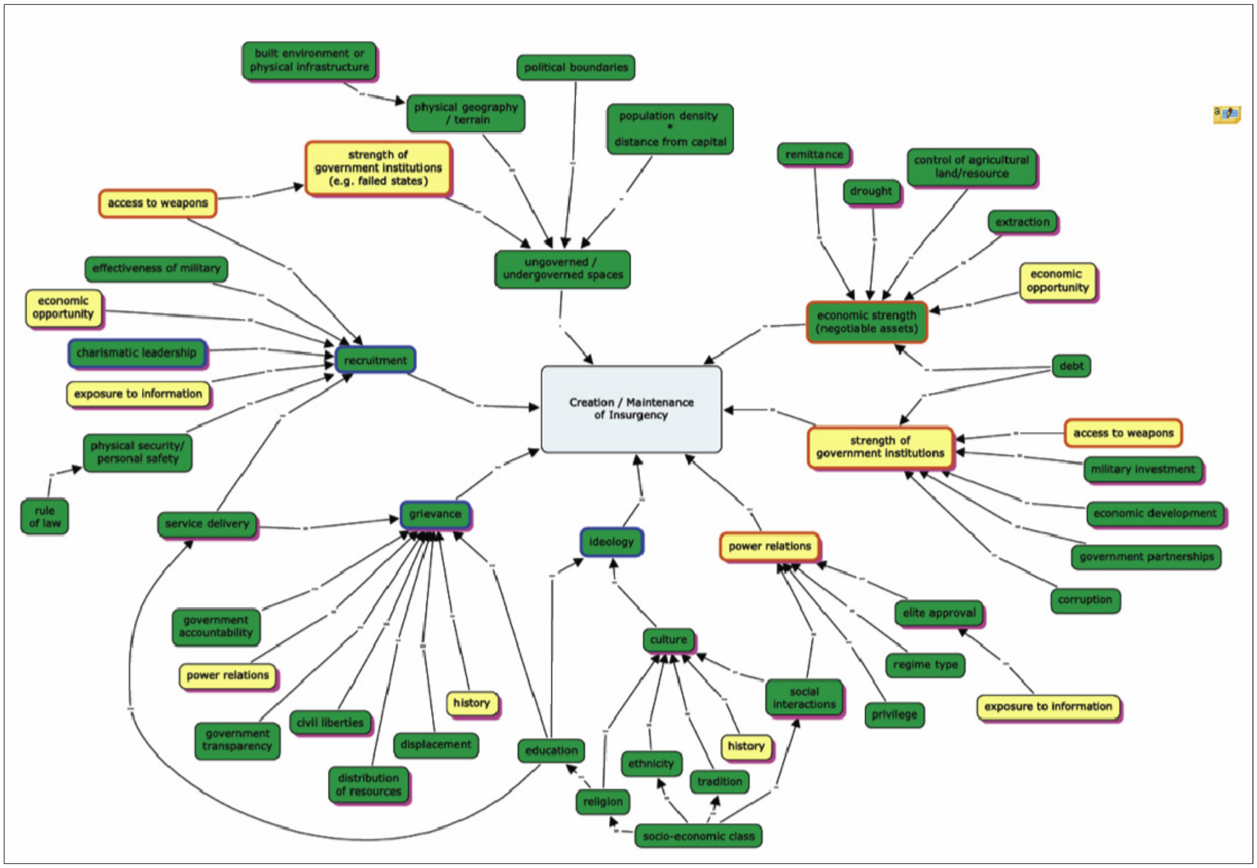
Resources in a local context are those assets — be they environmental, economic, geographic, social, or political — that carry some strategic value as perceived by the actors. Resources may be those assets that enable actors to compete to achieve some goal, or may be the contested goal itself.

The PIAF conceptual design is applied to guide the development of factor maps, drawn from peer-reviewed literature for a given topic and organized in terms of influencing sociocultural factors, linking the information extracted with relevant and potentially explanatory social science theory. The utility of these factor maps is threefold: (1) factor maps provide a generalized view of a given topic that can introduce nascent personnel quickly and effectively to influencing sociocultural factors; (2) factor maps can inform computational tool design by highlighting relevant factors, relationships and social theories for a given region; and (3) factor maps can help users explore the ideas within the best understandings of a given topic without having to become directly familiar with them. To demonstrate this utility, a factor map for insurgency in Africa — developed using the conceptual design of the PIAF — is presented in the next section.

3.2 Factor Map for insurgency in Africa

Figure 5 depicts CREATE's Analytical Framework Factor Map for Insurgency in Africa, which is explained in depth in Appendix D of Whalley et al. (2014). This map visually represents the factors that contribute to the production and maintenance of insurgency through a downward-branching hierarchical structure.

Figure 5. Factor Map for insurgency in Africa (Whalley et al. 2014, Figure D4).



The relationships between factors are supported by literature and articulated in linking phrases such as “gives rise to,” “results in,” “is required by,” or “contributes to.” The development process was guided by the conceptual design of the PIAF. The associated method involved five steps: (1) identification of concepts that may contribute to the production and maintenance of insurgency — conceptual design framework elements were used to illuminate the identification process; (2) systematic collection of literature to confirm or dismiss these hypotheses; (3) concept sorting based on how the literature said they contribute to the production and maintenance of insurgency; (4) map visualization of the concepts (i.e., factors) as they contribute to the production and maintenance of insurgency; and (5) expert review and refinement of factors and linkages based on extended literature searches.

3.3 Role of military doctrine

To be relevant to U.S. armed forces, an analytical framework must connect with military doctrine. The Joint Intelligence Preparation of the Operational Environment (JIPOE) is used to illustrate this contention (Joint Publication 2-01.3 2009), as the ability to understand and anticipate the impact of sociocultural factors in a given region is essential to the efficacy of the JIPOE process. This section summarizes the principal tenets of JIPOE. Subsequent sections will demonstrate how the PIAF facilitates sensemaking in the context of JIPOE.

JIPOE is a four-step analytical process designed to provide analytical support to decision-making in a joint operational context (see Figure 6). Table 2 summarizes the tasks associated with each step. It is easily observed that central to each step is the construction and maintenance of an understanding of the operational environment, initiated in Step 1 and explored in subsequent steps. As such, proper understanding of the sociocultural dimension of the operational environment is essential to the efficacy of JIPOE. Those tasks supported by the PIAF are italicized and boldface in this table. The next chapter will link the requirements (see Table 1) to JIPOE in the design for computationally enabled analyses within the PIAF.

Figure 6. JIPOE process cycle (adapted from JP 2-01.3, 2009, Figure II-1).

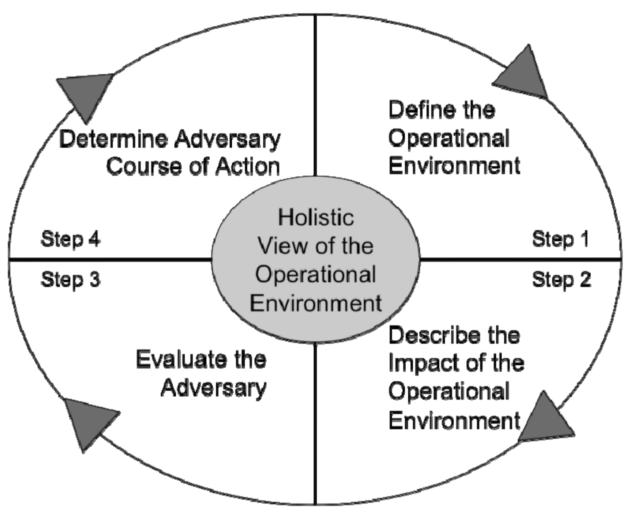


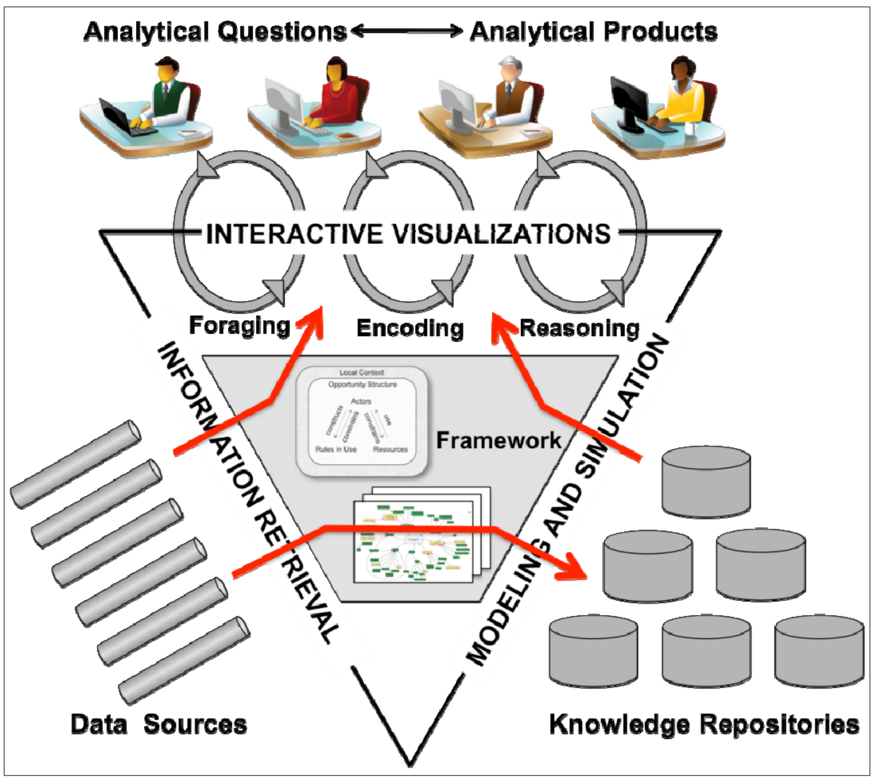
Table 2. JIPOE tasks.

Step 1	Step 2
• Identify the joint force's operational area • Analyze the mission and joint force commander's intent • Determine the significant characteristics of the operational environment • Establish the limits of the joint force's areas of interest • Determine the level of detail required and feasible within the time available • Determine intelligence and information gaps, shortfalls, and priorities • Collect material and submit requests for information to support further analysis	• Develop a geospatial perspective of the operational environment • Develop a systems perspective of the operational environment • Describe the impact of the operational environment on adversary and friendly capabilities and broad courses of action
Step 3	**Step 4**
• Update or create adversary models • Determine the current adversary situation • Identify adversary capabilities and vulnerabilities • Identify adversary centers of gravity	• Identify the adversary's likely objectives and desired end states • Identify the full set of adversary courses of action • Evaluate and prioritize each course of action • Develop each course of action in the amount of detail time allows • Identify initial collection requirements

4 Framework Design for Computationally Enabled Analyses

The design for computationally enabled analyses within the PIAF connects the conceptual design and JIPOE doctrine while suggesting tools and technologies that enable critical thinking and sensemaking. Figure 7 depicts the principal elements of this design. Central to the design for computationally enabled analyses are the elements of the conceptual design of the framework as the elements of this design are instrumental to each dimension (i.e., side) of the architecture.

Figure 7. Design for computationally enabled analyses.



The design for computationally enabled analyses is supported on each of its three sides by tools and methods for interactive visualizations, information retrieval and modeling and simulation. Information retrieval capabilities are essential to the foraging loop. Contributions from the conceptual design of the framework, however, provide opportunities to increase the efficacy of the retrieval process. Information retrieval is also connected with modeling and simulation through the encoding loop (i.e., the encoding of evidences into knowledge representations or models). Here, the conceptual design provides guidance regarding which evidences to encode into these representations. The knowledge representations can take many forms: metadata, argument models, simulation models, etc. In other words, a model is defined as an abstract representation of information and concepts and the relationships among them, potentially implemented using the PIAF conceptual design or factor map structures described in Whalley et al. 2014.

Modeling and simulation capabilities are essential to the encoding and reasoning loops. Here, modeling and simulation capabilities should be understood in the broadest sense where models are representations (conceptual, mathematical, computational or otherwise), and simulations are representations (i.e., models) implemented or interpreted dynamically over time. The role of modeling and simulation in the PIAF connects at several levels. First, models organize key dimensions of collected evidences and place those dimensions into an analytical context (i.e., connects the evidences to networks of concepts). So exploration of these models can accelerate the sensemaking process by facilitating the construction of baseline understandings of a particular analytical question. Support for such exploration can be applied to any representation, whether they are models of scholarly literature, models of the built environment or models of population behaviors. Second, modeling and simulation can give analysts better understandings of current or past states of a system (or system of systems). Analytical context, as connections among concepts, is key to this as context gives meaning to the collected evidences. Context can take many forms: spatial, temporal, social, cultural, economic, political, environmental/climate, military, functional, etc. Context can even be intellectual (e.g., argument models). Third, modeling and simulation can help analysts explain how the past and present are connected as well as hypothesize how the present may be connect to plausible futures.

The connections between modeling and simulation and the conceptual design of the PIAF are numerous. First, the elements of the framework (i.e., local context, opportunity structure, actors, rules in use and resources) identify relevant dimensions of the analytical domain to be modeled. Second, associated factor maps ground model development by focusing analysis on key aspects of the broader analytical domain. Third, framework-enhanced information retrieval tools and methods can accelerate model configuration and training. Fourth, factor maps may suggest alternative hypothesis to be explored via modeling and simulation. In short, modeling and simulation provide techniques to represent and explore analytical domains. The conceptual design of the framework enhances these efforts through semantics-based affordances.

Tools and methods for interactive visualization are key enablers both for information retrieval and modeling and simulation. Interactive visualizations leverage the power of visual perception, interactivity and knowledge structures to enhance foraging, encoding and reasoning processes. The conceptual design of the framework provides knowledge structures grounded in the analytical domain (e.g., factor maps and extensions thereof) that can be instrumental to increasing performance.

The following sections explore each dimension of the design for computationally enabled analyses within the PIAF in greater detail and describe how each dimension (1) connects to the other dimensions (2) connects to the conceptual design of the framework, and (3) connects to the requirements listed in Table 1 (section 2.3). This discussion will show that tools and methods for all three dimensions are essential to meeting the challenge of understanding and anticipating how sociocultural factors influence outcomes across the full spectrum of military operations and mission types.

4.1 Information retrieval

Information retrieval is the principal means of the foraging loop, the process by which evidences are identified and introduced into the encoding and reasoning loops. In most situations, brute force data source review is infeasible. The challenge, therefore, is twofold:

- to identify those documents that are most relevant and provide the best insight and understanding to analysts
- to uncover hidden, though relevant, insights within the sources.

Meeting these challenges suggests not only the incorporation of traditional, keyword-based information retrieval techniques, but also more advanced techniques as well. For example, semantics-based information retrieval techniques provide great promise to accelerate the retrieval process (Zhou 2008). These techniques use knowledge representations to improve relevancy calculations and the use of query-based exploration of the corpora. Furthermore, visual exploration of topic modeling results

(Ribarsky et al. 2011) and keyword extraction techniques (Monroe and Schrodt 2008) can assist efforts to discover hidden, relevant knowledge in the corpora.

Information retrieval tools and methods are essential not only for the foraging loop but also for the manner in which they inform the encoding and reasoning loops. Information retrieval can help populate models as well as help identify those aspects of the problem domain to be modeled. Furthermore, the efficacy of information retrieval tools and methods can be enhanced by interactive visualizations, as such interfaces — by design — enable novel exploration and facilitate the reasoning process.

The application of existing techniques and the development of more advanced techniques for information retrieval are motivated by problem requirements. Section 2.3 highlights several requirements that often can be best addressed through application and advances in information retrieval tools and methods. These requirements are summarized below.

4.1.1 Solutions must fit inside the decision cycle

This requirement is an overriding constraint for the problem domain as a whole. Analysis occurs at different scopes and time-scales ranging from strategic to operational to tactical. The decision speed constrains the use of any decision aid. The PIAF, therefore, must leverage tools and methods that allow it to fit inside the decision cycle. Effective information retrieval can introduce efficiencies to address this requirement while improving the resulting body of evidences.

4.1.2 Analysts must be able to leverage authoritative sources

The definition of an authoritative source is a function of the problem domain. Understanding and anticipating how sociocultural factors influence the outcome of military operations suggests that scholarly literature is an important data source for the PIAF. Effective exploitation of current scholarship, however, is challenging. For any given situation, the corpora are potentially immense and likely growing. Current information retrieval tools and methods can provide some added value by enabling the PIAF. However, more advanced information retrieval capabilities (e.g., semantics-based retrieval methods) will be required to exploit the full power of the framework.

4.1.3 Analysts must have access to the authoritative data, information, knowledge, and understandings

This requirement elaborates on the previous requirement to provide broader insight into the nature of these sources. Not all sources are identical in their level of structure, degree of homogeneity or integrity. Some sources may contain raw textual data. Other sources may be unstructured heterogeneous data; others may be structured or semi-structured. Furthermore, some sources may intermix authoritative data with deceptive data and irrelevant data (noise). The point is twofold. First, analysts must be able to derive utility from all types of data sources, including sources that may be generated by the analytical process (e.g., evidences, knowledge/models, analytical products, etc.). Techniques for markup, topic modeling and classification will be required. Second, methods to establish and maintain provenance and pedigree of the sources must be developed and/or applied. All of these techniques must account for data lifecycle concerns. Corpora are not static; rather, they are very dynamic — growing at increasing rates and evolving in both anticipated and organic ways.

4.1.4 Capabilities that facilitate both exploration and synthesis are central

Given the likely volume and complexity of the sources that could help facilitate better understandings of sociocultural factors and their potential influences on the outcome of military operations, traditional keyword-based exploration of these sources alone may be inadequate. Coupling keyword-based queries with more advanced techniques (e.g., interactive visualizations — see section 4.3) will enable analysts to explore sources and identify evidences, etc. in an accelerated manner.

The connection between information retrieval capabilities and the conceptual design of the PIAF is straightforward. The elements of the framework (i.e., local context, opportunity structure, actors, rules in use and resources) identify key evidences to be foraged as they relate to a given analytical question. In addition, factor maps can be incorporated into the knowledge representations leveraged by semantics-based information retrieval tools and methods as a means to improve relevancy calculations.

In the context of JIPOE, information retrieval tools and techniques can improve the efficacy of the following tasks:

- Identify the joint force's operational area.
- Determine the significant characteristics of the operational environment.
- Establish the limits of the joint force's areas of interest.
- Collect material and submit requests for information to support further analysis.
- Develop a geospatial perspective of the operational environment.
- Develop a systems perspective of the operational environment.
- Determine the current adversary situation.
- Identify adversary centers of gravity.
- Identify the adversary's likely objectives and desired end states.
- Identify initial collection requirements.

4.1.5 Research and development questions

This dimension of framework design suggests numerous research and development questions to consider, such as:

- How are the knowledge representations, used by semantics-based information retrieval tools and methods, constructed?
- How are unstructured and heterogeneous corpora explored efficiently?
- Which information retrieval techniques are best suited for the analytical question?
- How can information retrieval techniques help to connect evidences to subsequent representations?
- How can information retrieval capabilities be coupled with interactive visualizations to increase the effectiveness of the foraging loop?
- How can information retrieval capabilities enhance and accelerate factor map development?
- How can information retrieval tools and methods adopt authoritative, competitive, and collaborative strategies to manage wicked problems?

4.2 Modeling and simulation

Modeling and simulation capabilities are essential to the encoding and reasoning loops. Models organize key dimensions of collected evidences and place those dimensions into analytical context. Analytical context is important because it is context that gives meaning to the collected evidences. Exploration of these models, then, can accelerate the sensemaking process by facilitating the construction of baseline understandings of analytical questions. Modeling and simulation can also afford analysts better understandings or explanations of current or past states of a system (or system of systems). Furthermore, modeling and simulation can help analysts explain how the past and present are connected as well as hypothesize how the present may be connected to plausible futures.

The connection of modeling and simulation with information retrieval and interactive visualizations is clear. Development of models (i.e., the encoding of evidences into representations) depends on information retrieval techniques to identify and extract evidences. Model development also depends on interactive visualizations, as it is a human-centered process. Modeling and simulation techniques are also enhanced by effective interactive visualizations, as these techniques help analysts explore and understand models — both in terms of the phenomena they represent and the biases, uncertainties and inaccuracies they embody.

The application of existing techniques and the development of more advanced techniques for modeling and simulation are motivated by problem requirements. Section 2.3 highlights several requirements that can often be best addressed through application and advances in modeling and simulation tools and methods. These requirements are summarized below.

4.2.1 The ability to identify and explore alternative understandings is essential

The identification and exploration of alternative understandings are foundational to critical thinking (Paul and Elder 2006). It is widely understood that critical thinking is essential to effective intelligence analysis (Moore 2006). Yet, problem complexity and human biases limit an analyst's ability to identify and explore alternatives. Modeling, however, can be an effective approach to overcome both of these challenges. Models can capture complex structure and exhibit complex, emergent behavior — thus, articulating assumptions, managing complexity and providing a forum to explore alternative assumptions or representations.

4.2.2 Evaluation and validation are foundational

This requirement refers to the evaluation and validation of analytical products. Wicked problems are unique in each instance making evaluation and validation of potential solutions extremely difficult. Modeling and simulation techniques are widely accepted methods for meeting this difficulty. Models provide a focal point for analyses; they make explicit key assumptions and relations; they can be adapted or stochastic methods can be leveraged to explore competing hypotheses. However, the contention, then, often becomes, "How does one evaluate and validate the models?" This is an appropriate question, but one that can be addressed when models are adequately transparent and when model outcomes are interpreted properly. In the case of the PIAF, whether they be argument models, built environment models or population behavior models — all models are informed by the conceptual design and associated factor maps. This makes assumptions transparent. Second, models are understood in terms of plausibility, not predictability. In other word, the models provide plausible explanations for system behavior (e.g., population behavior models are interpreted in a manner that is consistent with Epstein's notion of a generative model (Epstein 2006)) — explanations that seed reasoning, not usurp it by declaring an answer.

4.2.3 Deep analyses must be enabled

This requirement highlights that sensemaking is principally a cognitive act. Deep analyses move beyond the identification of observable effects to explore their deeper implications. Since models can be viewed as knowledge representations, model processing is analogous to knowledge processing — a form of computational cognition designed not to supplant human cognition, but to enable it through semantic-level operations.

4.2.4 Capabilities that facilitate both exploration and synthesis are central

Modeling and simulation is instrumental to meeting this requirement. In this context, model exploration is a form of problem domain exploration — an essential activity for effective reasoning. Through various simulation techniques, exploration and synthesis may occur linearly, nonlinearly or by random means. Inductive, deductive, or abductive reasoning can be enabled; nonlinear phenomena can be explored; and, stochastic techniques can stretch analyses beyond local optima or biases.

4.2.5 Solutions must fit inside the decision cycle

The inherent complexity of wicked problems often necessitates computational support not just to navigate, explore and manage the complexity, but also to fit these activities inside the decision cycle. This requirement is a two-edged sword for modeling and simulation. On one edge, modeling and simulation are understood as excellent methods to enable such analyses. On the other edge, this requirement suggests important considerations for the design of modeling and simulation solutions — particularly as they relate to the encoding loop. In particular, this requirement motivates the development of rich model repositories to accelerate model development — giving analysts the ability to compose models rapidly from preexisting repositories to build simulations that reflect the observed complexities. This requirement also motivates the development of efficient techniques for the encoding of evidences (i.e., the construction of new models whether they are argument models, infrastructure models and/or population behavior models).

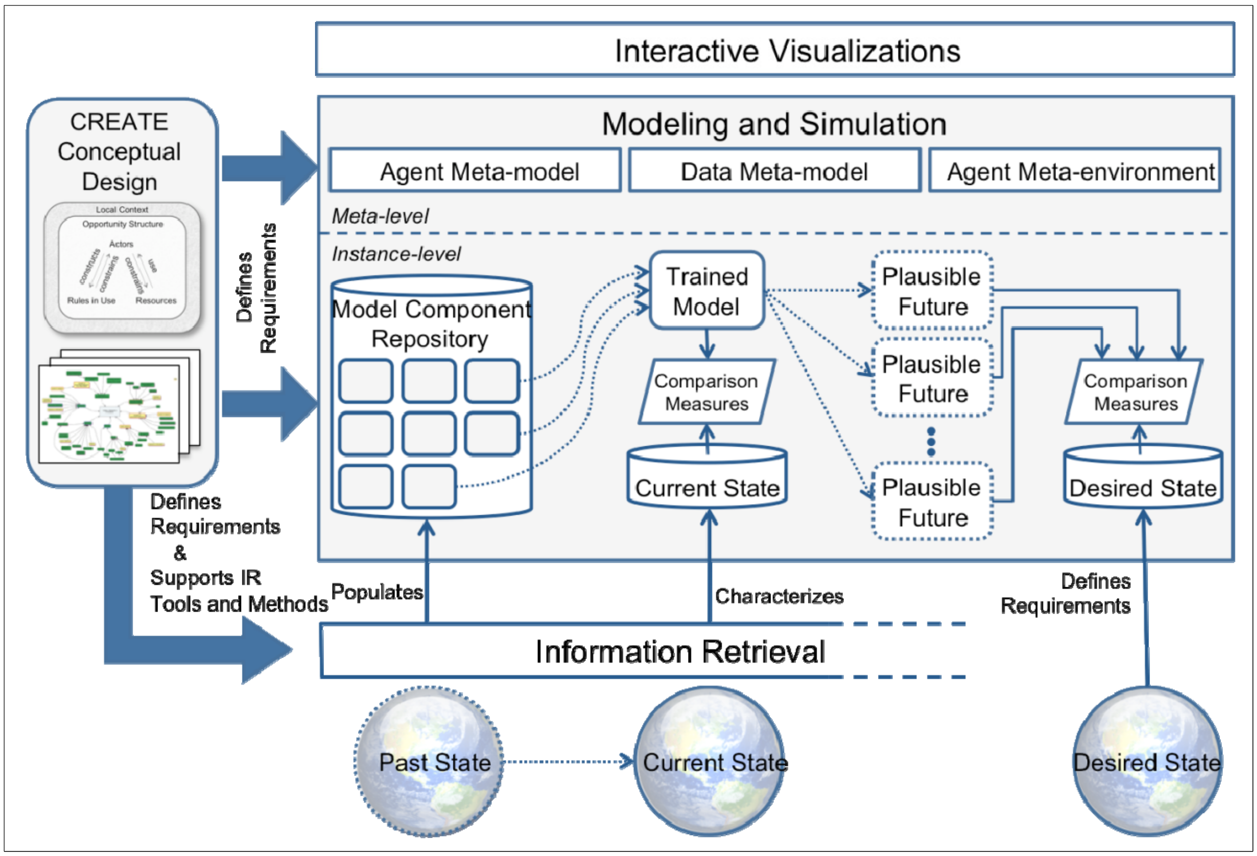
4.2.6 Tools and methods should enable analysts to connect the past and present to plausible futures

This requirement grounds the benefits of knowledge-based tools and methods. Knowledge can be viewed as emerging from the relations among concepts (Locke 1690). The relational aspect of knowledge (i.e., models) forms a basis for meeting this requirement as relations can capture narratives that reveal explanations of past trajectories and suggest plausible future trajectories. This is one of the principal functions of modeling and simulation when grounded temporally.

Viewing the above requirements collectively, the connection between modeling and simulation capabilities and the conceptual design of the PIAF can be articulated in the following manner. First, the conceptual design of the framework and associated factor maps define requirements and support information retrieval capabilities (e.g., semantics-based information retrieval) as described in section 4.1. Second, the framework and factor maps guide model component research and development. In particular, elements of the framework suggest specific component models (i.e., models of local context, models of opportunity structure). Third, elements of the framework and evidences revealed through information retrieval shape agent meta-model research and design. For example, framework elements help to identify the participants in the composed model (e.g., actors, rules in use and resources) that are instantiated and trained to a given world state.

To illustrate these connections, consider the agent-based architecture for modeling sociocultural systems shown in Figure 8. Note that in this illustration, not all models may participate in simulations. Some models may be argument models that are leveraged as knowledge structures in semantics-based information retrieval. In addition, the agent-based view of the meta-model reflects the sociocultural focus of the PIAF. Sociocultural behaviors are frequently nonlinear. As such, modeling techniques that can exhibit these self-organizing, emergent behaviors are essential. Agent-based models are widely recognized for the ability to represent and explore nonlinear behavior.

Figure 8. Modeling and simulation with the PIAF.



At the same time, non-agent-based models will likely be members of the repository as well. These models can represent other aspects of the analytical context (e.g., built environment). Furthermore, by leveraging methods for integrated modeling and simulation (Tolone 2009), these models can participate in simulations with the agent-based models and provide richer representations of analytical context.

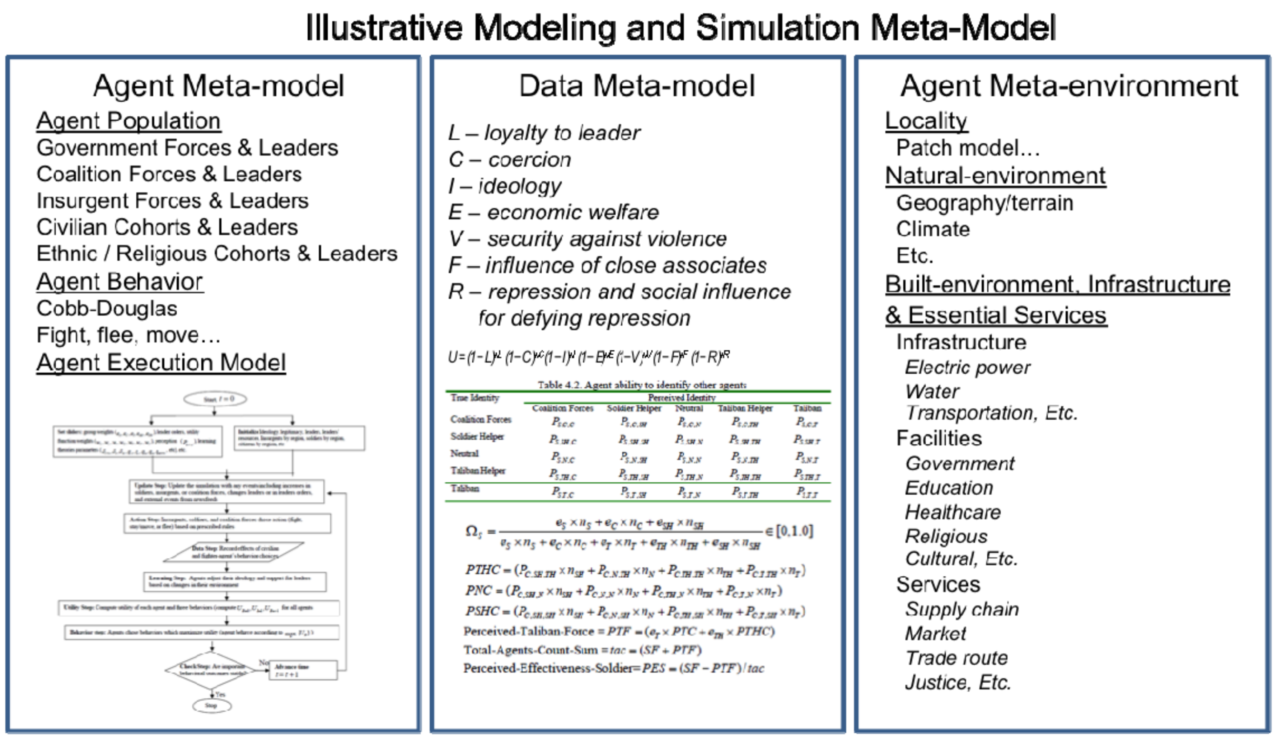
Ultimately, to meet the above requirements, a model repository approach will be required. Otherwise, the use of knowledge-based tools and methods as part of the reasoning loop will be difficult. The contention is that the encoding loop should be a continuous process that produces useful representations, which then are identified, tailored and possibly composed as they are leveraged during the decision cycle in support of the reasoning loop. This contention will likely apply equally to all models, including argument models. Populating the model repository will be an ongoing activity that will take some time to bootstrap. However, to facilitate the bootstrapping process, two techniques can be employed simultaneously. First, strategic requirements can be used to guide a top-down approach to model development. Second, models developed for specific analyses can be generalized using a bottom-up approach to model development.

Military doctrine can further illuminate the modeling and simulation dimension of the PIAF. In the context of JIPOE, modeling and simulation tools and methods can improve the efficacy of the following tasks:

- Determine the significant characteristics of the operational environment.
- Determine intelligence and information gaps, shortfalls, and priorities.
- Develop a geospatial perspective of the operational environment.
- Develop a systems perspective of the operational environment.
- Describe the impact of the operational environment on adversary and friendly capabilities and broad courses of action.
- Identify adversary capabilities and vulnerabilities.
- Identify adversary centers of gravity.
- Evaluate and prioritize each course of action.

Collectively, these tasks, combined with the elements of the conceptual design of the PIAF (see Figure 4), suggest potential refinements to the modeling and simulation meta-model (see Figure 9). These refinements correlate directly with several of the above JIPOE tasks. For example, further detail in the agent meta-environment characterizes the analytical context more richly (e.g., spatial, temporal, social, cultural, economic, political, environmental (e.g., climate), military, functional, etc.) and can enable better understandings of the operational environment to be developed. Nevertheless, actual refinements to the meta-model will emerge from practice.

Figure 9. Potential refinements emerging from JIPOE tasks



4.2.7 Research and development questions

This dimension of framework design suggests the following questions:

- How can modeling and simulation connect the past to the present and the present to plausible futures?
- How can modeling and simulation be coupled with interactive visualizations to increase the efficacy of the reasoning loop?
- How can modeling and simulation be leveraged to overcome biases and local optima within model representations?
- How can the model repository be designed to facilitate its use?
- What tools and methods are required to evaluate and validate models and simulations?
- How can fitness functions effectively measure the fidelity of models to real-world state?
- How can models be composed to build richer analytical context for analyses?
- What are effective methods for modeling sociocultural behaviors?
- How can tools and methods accelerate the encoding loop?
- How can varying model assumptions reveal model sensitivities?

- Which modeling and simulation methods are best suited for the analytical question?
- Which knowledge representations are best suited for modeling selected phenomena?
- How can model output be translated into analytical products efficiently?
- How can modeling and simulation enable the exploration of alternative futures?
- How can the efficiency and efficacy of modeling and simulation methods be improved?
- How can the efficiency v. efficacy tradeoff be managed effectively within the constraints of the decision cycle?
- How can modeling and simulation tools and methods adopt authoritative, competitive and collaborative strategies to manage wicked problems?

4.3 Interactive visualizations

The process of forming a proper understanding of how sociocultural factors influence the outcome of military operations as a sensemaking process is largely human-centric. Consequently, from a computational perspective, interactive visualizations serve an essential role within the PIAF. The relatively new field of visual analytics (Thomas and Cook 2005) provides both theoretical and empirical evidence to support this contention. As shown in Figure 7, interactive visualizations bridge core analytical capabilities (e.g., information retrieval, modeling and simulation) to end-users. Rather than being a window to the end of the analytical process, interactive visualizations are key enablers to the entire process by facilitating the foraging, encoding and reasoning loops. The potential impact of well-designed interfaces resides in their ability to leverage the power of visual perception as a means to detect patterns, correlations and relationships in general, and to provide exploratory interactions that free end-users to examine the problem space efficiently and in ways that offer new perspectives and insights.

The connection between interactive visualizations and both information retrieval and modeling and simulation is well documented in previous sections (e.g., sections 4.1 and 4.2). Interactive visualizations empower end-users to explore corpora more efficiently and effectively (i.e., the foraging loop); they enable end-users to see patterns, make correlations and define new relationships (i.e., the encoding loop); and, they provide affordances that facilitate the exploration of both models and simulations in the formation of new/better understandings (i.e., the reasoning loop).

The application of existing techniques and the development of more advanced techniques for interactive visualizations are motivated by problem requirements. Section 2.3 highlights several requirements. Since each requirement involves human participation, application and advances in interactive visualization tools and methods can help to address all of these requirements. Most of the requirements in Section 2.3 have been discussed previously in the context of informational retrieval and modeling and simulation. As indicated in the previous sections of this chapter, it is widely recognized that proper interactive visualizations enhances both. The present section highlights only three problem requirements.

4.3.1 Tools and methods must provide interactive visualizations that promote analytical reasoning

While the connection between this requirement and interactive visualizations is obvious, there are two points worth highlighting. First, interactive visualizations should accompany the entire analytical process. The implication is that interactive visualizations are instrumental not only to the development of analytical products, but also to the articulation of analytical questions. In particular, the process of translating a general question, e.g., "How do sociocultural factors influence the outcome of military operations?" into specific questions, e.g., "How does citizen sympathy for the Mombasa Republican Council affect a humanitarian assistance mission in the coastal region of Kenya?" is often non-trivial. Furthermore, the translation of specific questions into proper units of analysis is also frequently challenging. The point is that these activities — identifying the right questions, uncovering proper units of analysis — are sensemaking activities as well; thus, the sensemaking process occurs simultaneously on many different levels during the analytical process and interactive visualizations must be researched and designed with this recognition.

Second, while the power of visual perception is a central to the efficacy of human-computer interfaces, in the context of sensemaking, affordances for interactivity are equally central. Foraging, encoding and reasoning are described as loops; however, each is a cognitive dialogue — as is sensemaking as a whole. Thus, how users exchange and explore ideas, using information retrieval and/or modeling and simulation tools and methods, is equally as important as what users see. Affordances for interactivity, therefore, must be foundational to tools and methods designed to enable the PIAF.

4.3.2 Collaboration and dissemination are integral activities as they can accelerate analyses while strengthening analytical product

Recall the various strategies for managing wicked problems: authoritative, competitive and collaborative. Two of these strategies involve a plurality of participants while all require the dissemination of outcomes. Whether facing the challenge of a plurality of participants or the dissemination of outcomes, interactive visualizations have the potential to become key enablers, as information sharing is the essential to both.

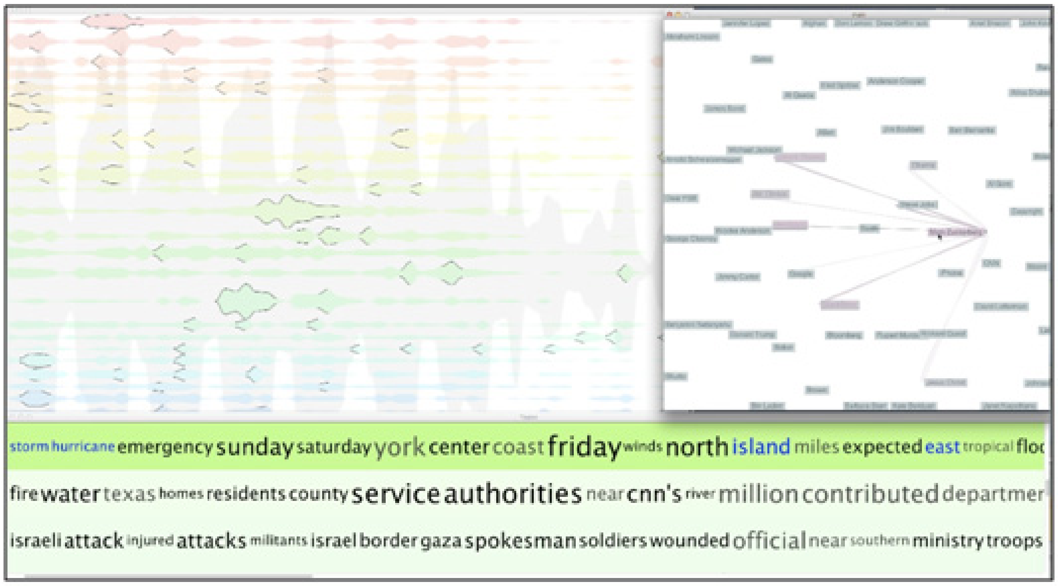
By definition, competitive and collaborative strategies require the exchange of ideas and outcomes — either for comparison or synthesis. Interactive visualizations can be the medium for such exchanges. At the same time, analytical products, synthesized from the understandings that emerge from the sensemaking process, must be developed. Interactive visualizations can provide affordances for generating these products — products that, then, become the medium for communication and the formation of communities of interest.

4.3.3 Solutions must fit inside the decision cycle

This requirement is highlighted once again because of its importance. The speed of decisions constrains the use of any decision-aid. The PIAF, therefore, must leverage tools and methods that enable it to fit inside the decision cycle. Effective interactive visualizations can provide efficiencies to address this requirement while improving the resulting analytical products.

In light of these requirements and the design for computationally enabled analyses within the PIAF, what kinds of interactive visualizations are required? The following figures highlight several possibilities. In the case of information retrieval tools and methods, interactive visualizations can help analysts make sense of large volumes of heterogeneous data including corpora of scholarly literature. Figure 10 and Figure 11 provide illustrations of interactive visualizations for exploring such corpora. Each illustration utilizes knowledge representations to facilitate the explorations of the corpora.

Figure 10. LeadLine event identification and exploration in textual data (Dou et al. 2012, reprinted with permission).



In Figure 10, topics, as collections of concepts extracted from a corpus of documents, are listed in the bottom view — each row is a topic. The right hand view is a concept map that gives connections among the extracted concepts. The left hand view contains histograms of topics depicted over time. Each topic is a separate ribbon; the width of the ribbon along the horizontal depicts the frequency of the topic over time. Each vertical slice across ribbons is a histogram of topic frequencies at a given time. The background shadow is the overall volume of all topics over time. The end user can interact with each view; however, those interactions are linked among views (e.g., selecting a topic in the bottom view will highlight its concepts in the concept map and highlight its ribbon in the time-based histogram view). The illustrations in Figure 11 and Figure 12 combine these techniques and others to facilitate the exploration of similarly large, complex corpora. Research has shown that sensemaking over large corpora can be enabled by interactive visualizations such as these.

Figure 11. STREAMIT: Dynamic visualization and interactive exploration of text streams (Alsakran et al. 2011, reprinted with permission).

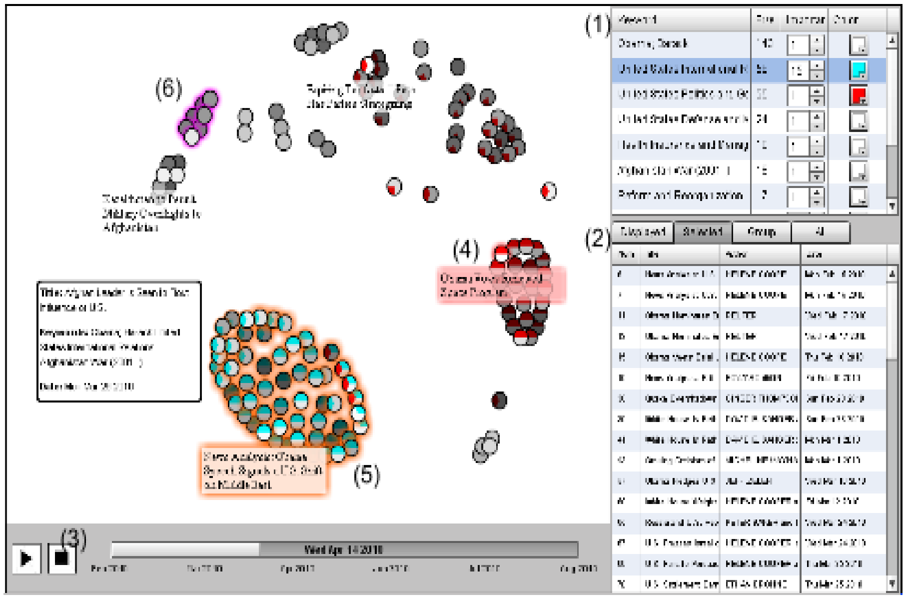
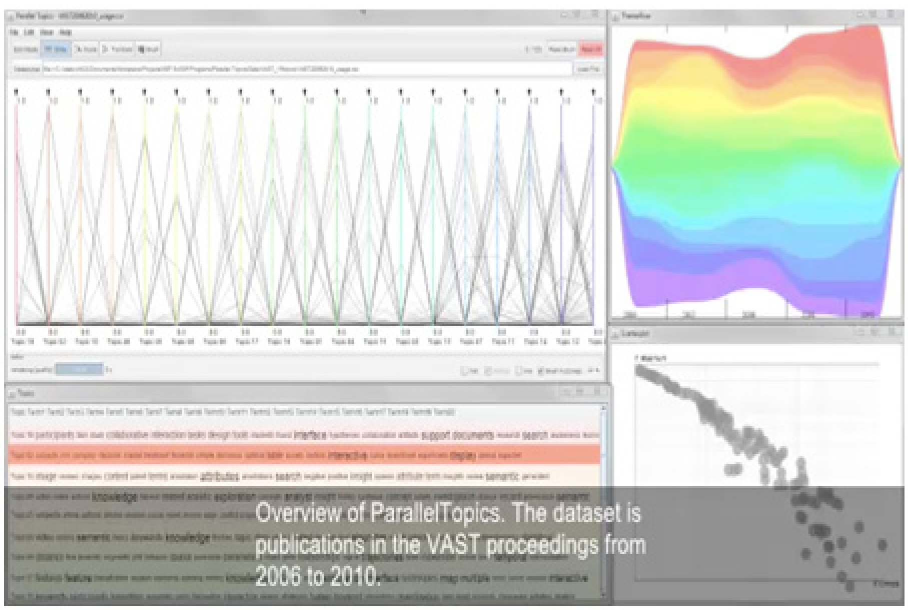


Figure 12. ParallelTopics: Exploration of VAST Proceedings 2006-2010 (Dou et al. 2011, reprinted with permission).



In the case of modeling and simulation tools and methods, interactive visualizations can help analysts explore models to better understand the structure and behavior of models, their limitations and the phenomena they represent. Figure 13 and Figure 14 provide illustrations of each.

Figure 13. Understanding the model through interactive visualizations.

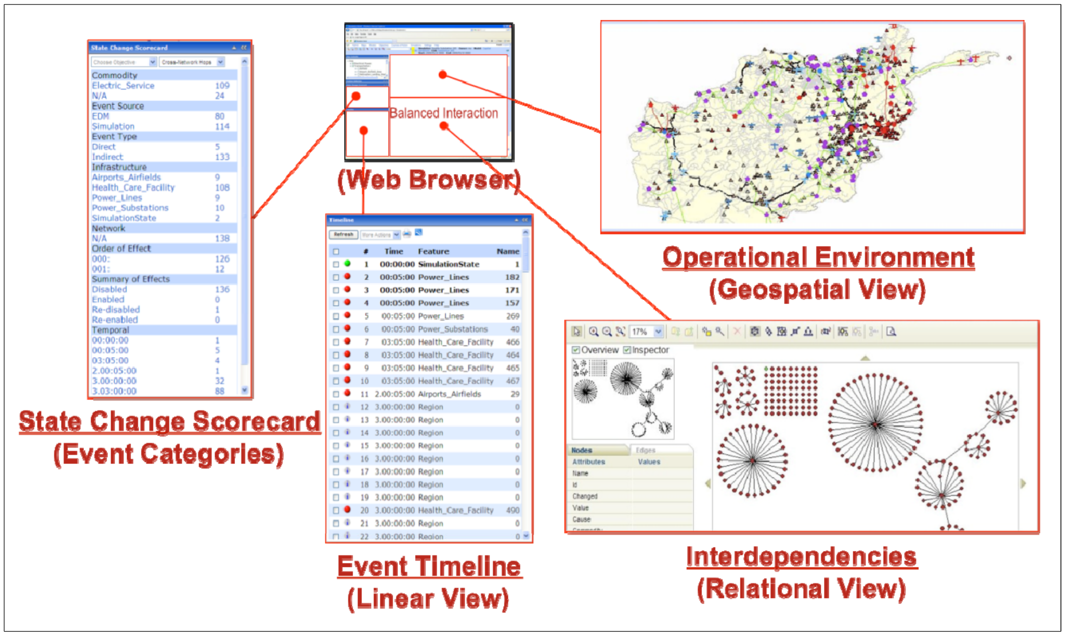


Figure 14. Interactive exploration of sociocultural modeling
and simulation (Butkiewicz et al. 2008, reprinted with permission).

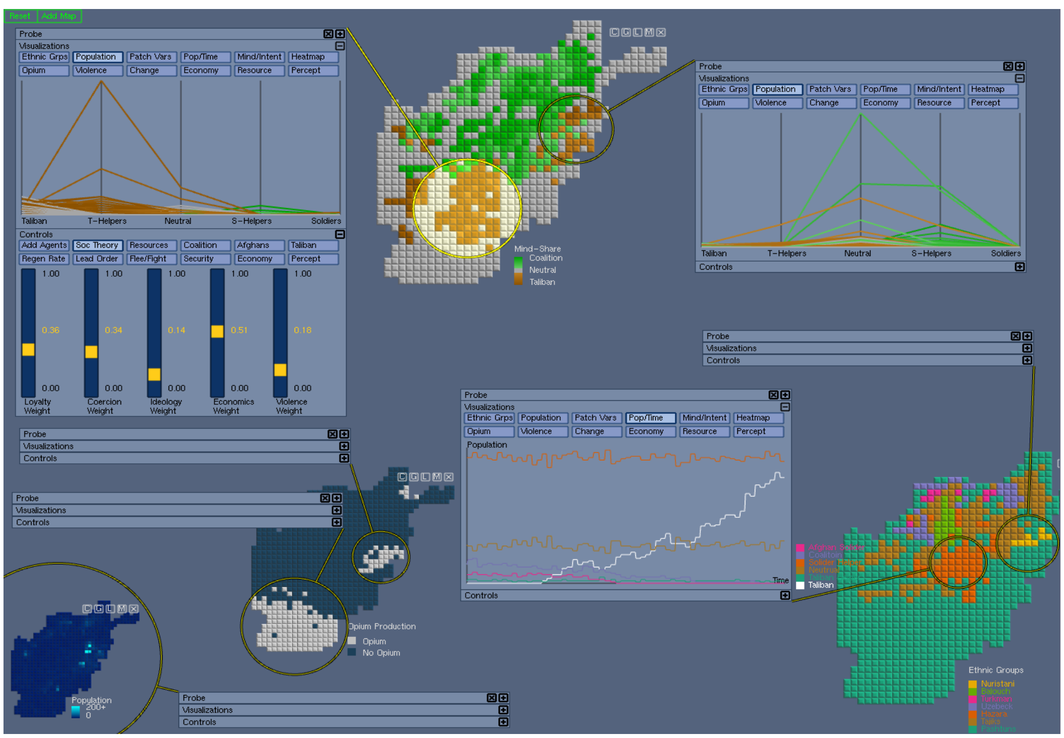


Figure 13 demonstrates capabilities that allow analysts to understand and explore the structure and limitations of their models. Figure 14 illustrates capabilities that help analysts to understand and explore the behavior of their models.

In the context of JIPOE, interactive visualizations tools and methods can improve the efficacy of the following tasks:

- Identify the joint force's operational area.
- Determine the significant characteristics of the operational environment.
- Establish the limits of the joint force's areas of interest.
- Determine intelligence and information gaps, shortfalls, and priorities.
- Collect material and submit requests for information to support further analysis.
- Develop a geospatial perspective of the operational environment.
- Develop a systems perspective of the operational environment.
- Describe the impact of the operational environment on adversary and friendly capabilities and broad courses of action.
- Determine the current adversary situation.
- Identify adversary capabilities and vulnerabilities.
- Identify adversary centers of gravity.
- Identify the adversary's likely objectives and desired end states.
- Evaluate and prioritize each course of action.
- Identify initial collection requirements.

4.3.4 Research and development questions

This dimension of framework design suggests the following questions:

- How can interactive visualizations accelerate information retrieval?
- How can interactive visualizations enable efficient exploration of large corpora independent of the data type and structure?
- Which visual representations reveal patterns and relations in large corpora?
- How can interaction uncover insights and reveal hidden connections?
- How can interactive visualizations redirect to the reasoning loop resources spent on foraging and encoding while improving the quality of analytical product?
- How can interactive visualizations facilitate effective information sharing?
- How can interactive visualizations enable model exploration?
- How can interactive visualizations compare alternative understandings?
- How can interactive visualizations represent and facilitate the exploration of the space of possible simulations?

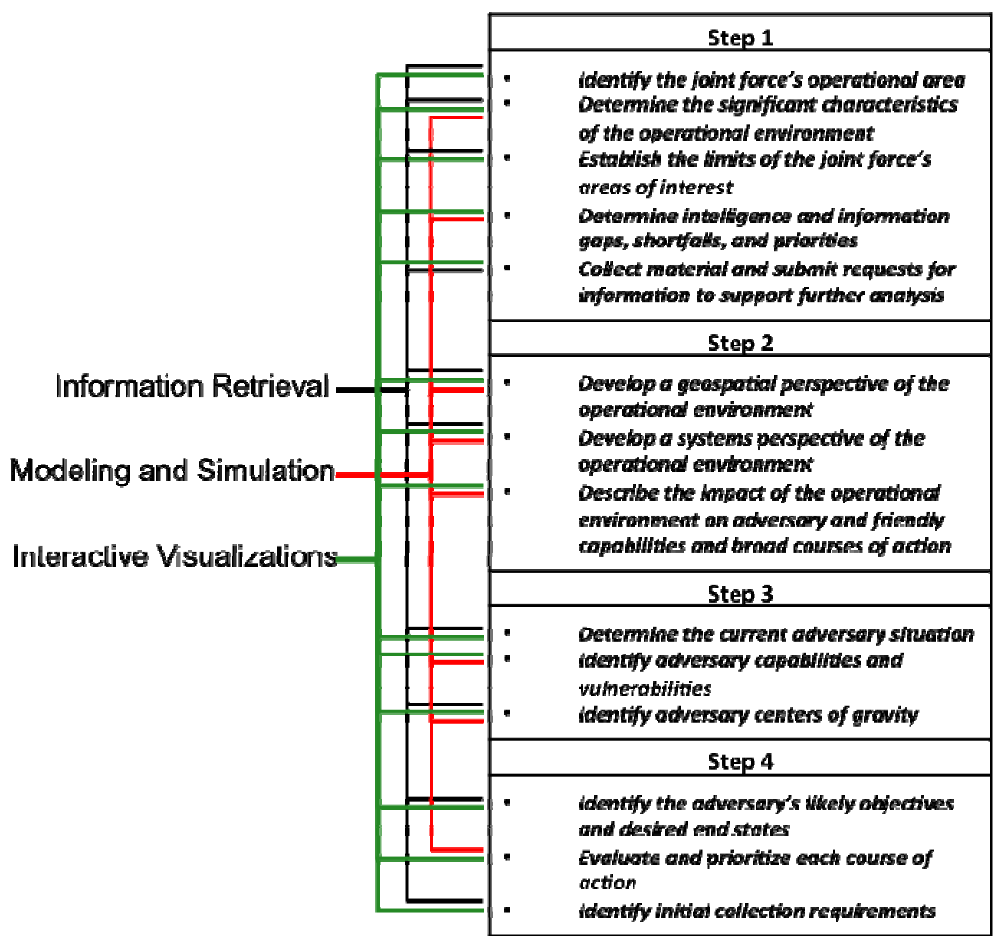
- How can interactive visualizations promote authoritative, competitive and collaborative strategies to manage wicked problems?

5 Connecting the Framework to Doctrine

The connection between the PIAF and military doctrine is illustrated thorough a vignette that outlines potential utility of the framework to the JIPOE process. The ability to understand and anticipate the impact of sociocultural factors on mission outcomes is essential to the JIPOE process. The PIAF is specifically designed for this purpose.

Recall that the JIPOE process requires (1) defining the operational environment, (2) describing the impact of the operational environment, (3) evaluating the adversary, and (4) determining adversary course of action. Each step can be enabled through computational tools and methods as articulated by the PIAF. Figure 15 shows these connections, previously discussed in sections 4.1.4, 4.2.6 and 4.3.3.

Figure 15. Computationally enabled analyses and the JIPOE doctrine.



JIPOE, scoped to a specified mission, supports decision-making in a joint operational context. As analysts execute the JIPOE process, sensemaking is the central activity. Each step of the JIPOE process can be aided by the PIAF's design for computational enabled analyses. In particular, computational tools and methods for information retrieval and modeling and simulation, both facilitated by interactive visualizations, hold the potential for managing the "wickedness" of the analyses and enhancing the product of the sensemaking process. This is evident in each step of the JIPOE process. Consider Step 1 in the following.

The process of defining the operational environment includes several tasks that can be enhanced by information retrieval capabilities supported by interactive visualizations. Some tasks appear straightforward (e.g., identifying the joint force's operational area). Others, however, are quite complex (e.g., determining the significant characteristics of the operational environment). In both cases, foraging is required. Step 1 also includes tasks that modeling and simulation can enhance. For example, determining the "significant characteristics" of the operational environment involves reasoning; and reasoning involves representations, whether cognitive or computational. Given the complexity of any operational environment, computational representations can help to identify sensitivities within the environment (e.g., common 2nd or 3rd order dependencies that cascade the impact of disruptive or constructive events); conditions that exercise nonlinearities (e.g., small input changes that suggest substantial output changes, desired or otherwise; etc.) For all of these tasks, interactive visualizations harness the power of visual perception and enable a human-centric reasoning dialogue to increase of the efficacy of the operation.

Consider, too, the output of Step 1 — a representation of the operational environment. Traditionally, this output would be an intelligence product comprised of textual summations, arguments, maps and infrastructure schematics. This same output, though in a somewhat different format, is exactly what is required for simulation-based models. For example, to construct a model for agent-based simulations one must specify an agent environment, agent populations and agent behaviors — all of which are key elements of the operational environment. The important point here, is that leveraging the power of modeling and simulation does not require new tasks in the context of military doctrine. Rather, it simply requires a computational representation. This involves a modification to the encoding activity, not a change in doctrine. Furthermore, it is common that the computational representations that result from such modification to the encoding activity provide facilities that enable the production of the "traditional" intelligent products at the push of a button.

Steps 2–4 of the JIPOE process are heavily oriented toward sensemaking's reasoning loop. The tasks associated with Steps 2-4 often presuppose that data have been collected, but further foraging may still be necessary. Here again, computationally enabled information retrieval capabilities meet these requirements. Assuming data are foraged, properly encoding and reasoning about these data become the principal challenges. Here, the elements of reason (Paul and Elder 2006) provide valuable guidance. The elements of reason (i.e., exploring alternative hypotheses; documenting assumptions; capturing evidences; explaining inferences; describing implications, etc.) are foundational elements of thought, elements that can be enabled by computational tools and methods, such as those described by CREATE.

Ultimately, the computational enabled analyses suggested by the PIAF, do not change the JIPOE doctrine; rather, they enhance its execution in obvious ways. The following section provides an illustration of the potential benefit through a case study. The purpose of the study was to evaluate the feasibility of an agent-based methodology, informed by the PIAF, to help analysts assess the likelihood of violence and demonstrations under varied conditions in the coastal area of Kenya. Once again, it is important to note that using the agent-based methodology suggested by the PIAF did not require changes to the JIPOE doctrine; rather, it works with the doctrine to enhance decision-making in a joint operational context. That is, the process of defining and describing the impact of the operational environment forage with exactly those data necessary to construct the agent environment. The principal change is how these data are encoded. These data, encoded computationally, become the foundation for model exploration and simulation, which can improve the efficacy of Steps 3 and 4. At the same time, the conceptual design of PIAF and representations it inspires provides guidance that focuses and enriches the products of Steps 1 and 2.

6 Analysis Example Using Hypothetical Mission

Violent extremism and insurgency have become common in Africa and pose a threat to U.S. interests. For success of U.S. military operations, it is essential to understand sociocultural factors as they may affect the stability of a region, and local support for or opposition to violent extremist organizations or insurgent groups. Here we will consider a hypothetical situation in the coastal region of Kenya where U.S. military support for humanitarian assistance and/or disaster relief is required. In such a situation, where a mission has been identified but military forces have not yet been committed, it would be important that U.S. armed forces acquire a valid understanding of the operational environment, including sociocultural factors. Several analytical questions could be raised:

- Will host nation events or actions lead to or strengthen an insurgency?
- How will the level of violent extremism affect U.S. military operations?
- Will U.S. operations mitigate or exacerbate undesirable dynamics linked to sociocultural factors?

To investigate these questions, an exploratory study was performed in winter 2012. It focused on possible tools and methods for modeling and simulation, given their direct connection to the reasoning loop.

The purpose of the study and the model it produced was to evaluate the feasibility of an agent-based methodology, informed by the PIAF, to help analysts assess the likelihood of violence and demonstrations under varied conditions in the coastal area of Kenya. Every effort was made to make the political and demographic situation in this part of Kenya as realistic as possible, but the model has not yet been fully calibrated to historical event data. For a more complete description see Tolone et al. (2013).

6.1 Coastal Kenya model

The Coastal Kenya model includes three types of agents:

1. Government forces

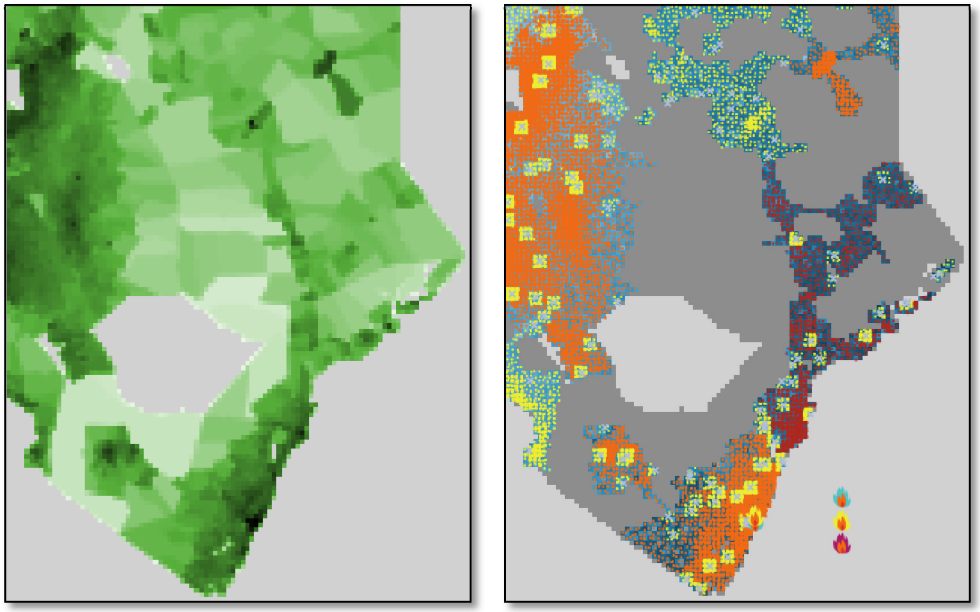
2. Opposition group leaders (i.e., one each for the Mombasa Republican Council (MRC), Muslim Youth Center (MYC), and Al-Shabaab (AS))
3. Citizens

Government agents are divided equally into two categories: “police” and “soldiers.” Police are distributed initially across districts, remain on the same district throughout the simulation, and move to the nearest violence or demonstration of greatest magnitude. Soldiers are initially distributed randomly across the entire simulation environment and move to the nearest violence or demonstration as a function of magnitude and distance. Otherwise, these agents move randomly, but still influence citizen sympathies — though police movement is restricted to their assigned districts.

The three opposition group leaders, one for each anti-government group, move randomly among territories where their group’s members are concentrated. The Al Shabaab leader may also temporarily leave the territory modeled; this represents him traveling out of the region (e.g., to Somalia).

The Coastal Kenya model is focused on citizen agent sympathies and behaviors in the coastal region of Kenya. Citizens are instantiated based on data from the coastal area of Kenya, including all of Coast Province, and the southern portions of Eastern Province, North Eastern Province and the Rift Valley. The population of the collective area is approximately 8.3 million people, with 3.4 million in Coast Province. The simulation environment represents this area with ~8500 “patches” (grids cells in the simulation space). The citizen population can range up to 40,000 simulated agents. The spatial distribution of citizens to simulation patches is initialized based on real-world census data (see Figure 16, left image).

Figure 16. Coastal Kenya Model — population density and simulation outcome.



Citizen agents are the only agents with a complex decision process. Specifically, every simulated day each citizen makes two sets of calculations (sympathy and utility) that lead to a decision: whether to demonstrate, commit violence or do nothing. The two principal outcome variables of the simulation are aggregations of these decisions and related sympathies, namely (1) the distribution of sympathies territorially among the three opposition groups and the government and (2) the territorial distribution of the two possible collective actions: nonviolent demonstrations and violence.

The choice of whether to demonstrate is assumed to be a conscious decision, based on weighing the alternatives. Accordingly, this choice is modeled for each citizen agent by calculating a relative utility value for each of the three possible behaviors. The agent chooses the behavior with the highest utility.

The other calculation that a citizen agent makes each simulated day is how to adjust its sympathy values. Because sympathy is not a behavioral choice but rather a mental state that will change with circumstances, it is modeled as a Markov process rather than via a utility function. A citizen agent's initial sympathy is given by ideology, which in turn is a function of various attributes such as its religion, age, and economic status. Sympathy is then incremented or decremented each simulated day based on events that have occurred, specifically, whether there has been a local demonstration or local violence and whether there is a local police presence.

The two outcome variables are emergent effects of change in individual citizen agents and those agents' chosen behaviors. The distribution of sympathies is initially given by the distribution of citizens' ideology, but then shifts as individual agents' sympathies change in response to local events. The distributions of the two possible collective actions, demonstrations and violence, are aggregations of the collective action on each patch. These are determined by whether the proportion of individual agents committing that action on the patch passes a given threshold.

The phenomenon of emergence in this model becomes clear from simulation runs. Simulations were executed under the following reasonable, though illustrative, collective action parameter settings and utility function weights (see Figure 17).[1]

Figure 17. Illustrative parameter settings that demonstrate emergent behavior.

Parameter Settings
MRC propensities: demonstration .5, violence .05
MYC propensities: demonstration .5, violence .05
AS propensities: demonstration .1, violence .6
Utility function weights: Sympathy .48, Repression .47, Influence .05
Number of government agents: 25

These parameter settings produced the following outcomes.

The simulation begins with no demonstrations or violence anywhere. Immediately, however, a demonstration begins wherever the MRC leader is

[1] Note that verification and validation of models of complex systems with nonlinear behaviors (e.g., sociocultural systems) is very challenging. Predictive capabilities are elusive and akin to solving a wicked problem completely. Nevertheless, modeling and simulation can help users understand better a range of plausible futures. Verification and validation of such capabilities are often evaluative in nature. When time-series data are available, models can be calibrated to a subset of the data and then evaluated against the entire corpus. Even here, when dealing with wicked problems, there are no guarantees that past trajectories can "predict" future states.

located. If the AS leader begins in certain parts of the territory, violence may begin there as well. The collective action then spreads from its initial spot or spots. Subsequently, the MRC leader may catalyze collective action in other independent locations. The spreading occurs until it fills the coastal area; it does not spread to the inland area. Occasionally, a visit by the MRCs leader may spark an independent spread of demonstrations in the inland area, but this is rare. Figure 16 (right image) depicts the spatial outcome of a sample simulation run.

If both violence and demonstrations commence initially, always demonstrations to the South and violence to the North then they will spread until they meet and then cease to spread further. If, however, violence does not begin initially, the demonstration spreads over the entire coastal area and violence never takes hold. Finally, quadrupling the number of government agents, from 25 to 100, slightly reduces the thoroughness of the spread of collective action, but does not suppress it entirely. Thus, the collective action is clearly an emergent process, somewhat anticipated but also path-dependent.

6.2 Role of information retrieval

While executing this study, numerous opportunities were identified for information retrieval tools and methods to provide value to model and simulation solutions. First, information retrieval capabilities can reveal relevant agent populations and their demographics. Second, information retrieval capabilities can help analysts characterize the simulation environment (i.e., operational environment) properly. Third, information retrieval can help analysts design the agent model (i.e., identify dependent and independent variables, define agent mobility and articulate agent decision points and methods). Fourth, information retrieval can help analysts train models and suggest potential parameter settings. Finally, information retrieval can suggest alternative hypotheses and the parameter settings that explore these hypotheses. With each opportunity for information retrieval to provide value, the conceptual design of the PIAF can play a beneficial role. The role may be advisory (i.e., offering intellectual guidance) or more computational (i.e., serving as an encoded knowledge representation leveraged in semantics-based information retrieval efforts).

6.3 Role of interactive visualizations

Results of this study show the potential benefits that could be afforded by interactive visualizations were numerous and readily apparent. For example, interactive visualizations can help analysts understand their models. This understanding includes both the parameter space as well as the design of the simulation environment. In addition, interactive visualizations can help analysts investigate simulation outcomes by providing efficient mechanisms to probe model state and observed behaviors. Analysts must understand their models, not just as a means to understand the phenomena they represent but also to frame that understanding properly through the revelation of model limitations (e.g., sparseness, biases, and uncertainties). Furthermore, interactive visualizations can offer a means for model/simulation comparison. These capabilities not only facilitate the exploration of alternatives, but also their assessment.

7 Summary and Recommendations

7.1 Summary

This report has described a more comprehensive and grounded approach to understanding and anticipating how sociocultural factors influence the outcome of military operations. The results represent an evolving methodology that combines top-down and bottom-up approaches to filling the noted gap. The analytical framework, PIAF, is characterized by strong theoretical underpinnings; a requirement for practical utility; respect for military doctrine — in particular JIPOE doctrine; capacity for bridging mission support (e.g., intelligence, planning and operations); and continuity as an analytical enabler both grounded in best understandings and applicable across the spectrum of operational phases.

The two fundamental aspects of the PIAF are its conceptual design and its support for computationally enabled analyses. This report has focused on computationally enabled analyses within the PIAF. The design for computationally enabled analyses connects the conceptual design and JIPOE doctrine while suggesting tools and technologies that enable critical thinking and sensemaking. In particular, the design for computationally enabled analyses is conceived with three-dimensions, supported on each side by tools and methods for interactive visualizations, information retrieval and modeling and simulation. Information retrieval capabilities are essential to the foraging activity. Information retrieval is also connected with modeling and simulation through the encoding activity (i.e., the encoding of evidences into knowledge representations or models). Modeling and simulation capabilities are essential to the encoding and reasoning activities. The value of modeling and simulation to the sensemaking is multifaceted. First, models organize key dimensions of collected evidences and place those dimensions into an analytical context. Second, modeling and simulation can afford analysts better understandings of current or past states of a system (or system of systems). Third, modeling and simulation can help analysts explain how the past and present are connected as well as hypothesize how the present may be connected to plausible futures.

To illustrate the potential benefits of the design for computationally enabled analyses within the framework, a specific analytical theme is identified (i.e., understanding the emergence and maintenance of insurgency in the context of JIPOE). This theme is used in various places throughout this effort to motivate the analytical problem and characterize the possible benefits of the design for computationally enabled analyses.

This report also provided a hypothetical illustration of the application of the modeling and simulation tools and methods to a study of the problem of understanding and anticipating how the potential for or presence of violent extremism and insurgent behavior might affect U.S. military operations. The report concludes by presenting a roadmap for future research and development as directed by the design for computationally enabled analyses within the PIAF.

7.2 Recommendations

Developing the design for computationally enabled analyses to support the PIAF raised several research questions. The lists provided below should be considered in future research efforts to increase the efficacy of the foraging, encoding, and reasoning loops within the decision cycle. Achieving this must be a multistep process (e.g., first new capabilities are developed; then, these capabilities are optimized for the decision cycle). But, where can efficiencies be gained and what challenges must be met to achieve these efficiencies? Analytical computational tools and methods could

- offload computational complexities from human cognition, complexities that can be solved by human cognition, but solved more efficiently with computational support
- bring order and organization to complex problems (i.e., as an authoritative strategy for wicked problems)
- promote a higher level of rigor in the analytical process through the exploration of alternatives (e.g., as a competitive strategy for wicked problems) as aids to critical thinking.
- facilitate sharing evidences, knowledge, and understandings, and provide a foundation for the formation of communities of interest (e.g., collaborative methods for solving wicked problems).

Because knowledge is organic, it represents no more than the current best understandings for a given analytical context and associated questions. The tools and methods described here should be designed in ways that connect to the knowledge domain but are independent of the dynamic knowledge content. That way, as knowledge evolves and new understandings emerge, the utility of the tools and methods are preserved.

These two factors — enabling sensemaking at the speed of decisions and computational tools that are agnostic with respect to knowledge content — motivate additional research and development. In particular, these factors suggest a trajectory that is a reverse view of the sensemaking process. Better understandings are a product of the reasoning loop, and are primarily represented as modeling and simulation and interactive visualization capabilities. Reasoning leverages encoded knowledge, which is populated from evidences foraged, and is primarily represented as information retrieval capabilities. As discussed in section 4.2, modeling and simulation capabilities can take many forms: argument modeling, population behavior modeling, infrastructure and essential services modeling, among others. Sections 4.1.5 (R&D questions for information retrieval), 4.2.7 (R&D questions for modeling and simulation), and 4.3.4 (R&D questions for interactive visualization) each identify many research questions that will contribute to successfully applying models and simulations in support of military operations. Listed below are recommendations for next-step modeling and simulation R&D studies to advance the state of the art:

- Research and design a modeling and simulation framework for richer characterizations of the operational environment including:
  - Articulation of agent meta-model, data meta-model and agent meta-environment.
  - Description of interface(s) with data portals accessed using information retrieval techniques.
  - Description of life-cycle management for modeling and simulation.
  - Design of methods for inserting threat Courses of Action (COA) into models (i.e., connecting with JIPOE doctrine).
- Design flexible, extensible architecture for end-to-end modeling and simulation methodology, connected to JIPOE doctrine and processes.
  - Modularize the current meta-model (e.g., create a synthetic library).
  - Design a relevant model repository to support rapid model composition in the construction of agent models (both agent populations and agent behaviors) and agent environments (comprised infrastructure and essential services models and possibly natural environment models).

    - Design a model composition methodology to construction population behavior models and integrated models of the population environment.
- Research and design initial fitness functions for the simulation outcomes based on measurable outcomes of key model variables.
    - Develop how the fitness function number is used to score the success of the simulation against a goal (i.e., end state / commander's intent) or to compare model instances against desired/undesired objectives.
    - Develop measures of comparison for state characterizations — e.g.,
        * How is the commander's intent measured in simulation end-states?
        * How are simulation outcomes evaluated?
- Research and design efficient methods for threat Course of Action specification and execution (current process is manual).
- Research and design capabilities to:
    - Integrate new data sources or technologies for data capture
    - Incorporate near-real time data
    - Utilize such data to calibrate simulations
    - Learn from deviations from reality.
- Develop a framework for verification, validation and evaluation of the modeling and simulation tools and methods.
- Research and design a methodology for sensitivity analysis of various simulation runs under various circumstances.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
June 2015

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
A Design for Computationally Enabled Analyses Supporting the Pre-Intervention Analytical Framework (PIAF)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
622784 T41

6. AUTHOR(S)
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5d. PROJECT NUMBER
P2 335530

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
P.O. Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CERL TR-15-14

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Headquarters, U.S. Army Corps of Engineers
441 G Street NW
Washington, DC 20314-1000

10. SPONSOR/MONITOR'S ACRONYM(S)
HQUSACE

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Pre-Intervention Analytical Framework (PIAF) for sensemaking includes a conceptual design and a design for computationally enabled analysis. The conceptual design, previously developed by the Engineer Research and Development Center, Construction Engineering Research Laboratory (Whalley et al. 2014), included sensemaking factor maps that are derived from peer-reviewed literature findings and organized in terms of underlying sociocultural drivers. The design for computationally enabled analysis, described here, exploits computer technology to connect the conceptual design with current military doctrine, particularly the Joint Intelligence Preparation of the Operational Environment (JIPOE). The purpose of this technology is to identify tools and methods that may facilitate analysis and decision making.

The design for this technology is shaped by two factors: (1) the "wickedness" of understanding and accounting for the influence of sociocultural factors on military operations and (2) the centrality of sensemaking to all phases of operation. Wicked problems are high-stakes, complex problems, arguably unique in each instance, and without definitive formulations or optimal solutions. Sensemaking is a human-centric, iterative process with numerous feedback loops. It involves activities including information foraging, encoding, and reasoning. These two factors suggest important requirements for tools and methods designed to facilitate analysis and decision making.

15. SUBJECT TERMS
sociocultural factors; military operations; analysis; methodology; Pre-Intervention Analytical Framework (PIAF); sensemaking

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER *(include area code)***
Unclassified	Unclassified	Unclassified		56	