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ANTICIPATORY UNDERSTANDING OF ADVERSARY INTENT: A SIGNATURE-BASED KNOWLEDGE SYSTEM

Dennis K. Leedom, Ph.D.
Evidence Based Research, Incorporated
1595 Spring Hill Road, Suite 250
Vienna, VA 22182
(703) 893-6800 ext 397
DLeedom@EBRInc.com

Robert G. Eggleston, Ph.D.
US Air Force Research Laboratory
Warfighter Interface Division
Wright-Patterson AFB, OH 45433
(937) 255-8764
Robert.Eggleston@wpafb.af.mil

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ABSTRACT

This paper outlines the recent development of a new ontological framework for modeling the intentional behavior of an adversary relative to its long-term strategic goals within a complex and emergent battlespace. Motivated by recent military doctrine and knowledge management literature, the paper describes how an adversary and its battlespace environment can be represented by four classes of knowledge: (1) battlespace artifacts, (2) cause-effect system models, (3) tactical episodes, and (4) strategic agenda hypotheses. While the first two classes represent the battlespace in terms of logico-scientific knowledge, the latter two classes provide a form of narrative knowledge essential to sensemaking in the real world. As these forms of knowledge are dynamically integrated over time, they provide the basis for (1) structural identification of behavior signatures that link adversary intentions and capability with observed actions and (2) transactional identification of battlespace weaknesses and emergent opportunities that can predict future adversary actions. The ontological framework represents a new paradigm–one that dynamically constructs the meaning and interpretation of battlespace artifacts, systems, episodes, and organizational agendas on an as-needed basis. This new and powerful approach overcomes the limitations of existing knowledge representation methods by addressing operational context as the explicit subject of analytical inquiry.

INTRODUCTION

This report summarizes the development by Evidence Based Research, Incorporated, of a holistic knowledge system that can be used to construct and maintain anticipatory awareness and understanding of an adversary operating within a complex and emergent political, military, economic, social, information, infrastructure, physical, and time (PMESII-PT) battlespace. Various classes of knowledge within this framework can be connected to represent a unique behavior signature of an adversary. In turn, this signature paradigm serves as an analytical framework for developing various types of anticipatory inferences regarding the future behavior of the adversary. This research was carried out in support of the U.S. Air Force Research Laboratory.

THE COMPLEX AND EMERGENT NATURE OF THE BATTLESPACE

The complex and emergent nature of modern military operations are highlighted in the US Army's new doctrine on insurgency and counterinsurgency operations. As such, they serve as a benchmark for constructing a knowledge system capable of identifying, tracking, and predicting patterns of adversary behavior over time. As noted in this new doctrine, *"…an insurgency is an organized, protracted politico-military struggle designed to weaken the control and legitimacy of an established government, occupying power, or other political authority while increasing insurgent control. …Political power is the central issue in insurgencies and counterinsurgencies; each side aims to get the people to accept its governance or authority as legitimate. Insurgents use all available tools—political (including diplomatic), informational (including appeals to religious, ethnic, or ideological beliefs), military, and economic—to overthrow the existing authority. This authority may be an established government or an interim governing body. Counterinsurgents, in turn, use all instruments of national power to sustain the established or emerging government and reduce the likelihood of another crisis emerging."* (US Army, 2006)

The doctrinal process of operational design sets the requirement for constructing a signature-based knowledge system. Operational design combines the art of command with the science of control to provide a framework of understanding for operational and tactical action. From a knowledge framework point of view, it provides context for determining (1) what is to be known about an adversary and the battlespace environment, (2) how these entities should be interpreted in light of a Joint commander's mission, and (3) how these entities can be manipulated to achieve the Joint commander's strategic and operational intent.

However, the concept of operational campaign design has evolved in modern times in response to the complex and emergent nature of the battlespace. In traditional force-on-force combat operations against the organized military forces of a nation state, operational design is approached in a somewhat linear, phased fashion that begins with an expression of the strategic end state to be achieved and culminates with the planning of specific tactical tasks that, when executed, create the battlespace conditions corresponding to this end state. In more recent operations, the complex and emergent nature of the battlespace dictates a more dynamic approach to constructing and adjusting an operational design over time.

To see how this challenge can be approached in a systematic manner, we consider the US Army's doctrinal structure for specifying an operational design. The general framework of operational design includes three knowledge construction steps: (1) framing the problem, (2) formulating the design, and (3) refining the design. The knowledge elements that are linked together in this figure define what must be known and understood about an adversary and the larger battlespace environment in order to successively target specific effects against that adversary.

REPRESENTING THE BATTLESPACE WITH DIFFERENT CLASSES OF KNOWLEDGE

In the present research, we focus on defining those classes of knowledge that must be developed in order to frame the operational problem and formulate the operational design of an organization acting within a complex and emergent PMESII-PT battlespace. These classes of knowledge—extending from end state to lines of operation/effort—constitute the core elements of a holistic, self-referent, and focused framework of operational awareness and battlespace understanding. Finally, we apply this analytical concept in reverse-engineering manner to represent and understand the intentional behavior of an adversary.

End State Conditions – The Need to Represent State Variables

At a strategic level of analysis, *end state* is expressed in terms of a broadly defined set of *conditions* to be achieved within the battlespace by the operational campaign. The terms "end state" and "conditions" imply the need to think about the battlespace in terms of state variables. On the one hand, these state variables must describe some meaningful aspect of the battlespace that can be observed, measured, and assessed. Presumably, these state variables reflect one set of values at the beginning of an operational campaign and a different (desired) set of values at the culmination of the campaign. One the other hand, these state variables must relate to the strategic objectives that define a military organization's mission. Thus, they constitute a specific set of operational relevant state variables –perhaps only a few out of the many possible state variables that could be potentially defined within the battlespace. Given the complex nature of the battlespace and its relevant PMESII-PT dimensions, it is likely that some state variables might be empirically quantified along an interval or ratio measurement scale, while others will necessarily be subjectively defined using a nominal or ordinal measurement scale. In either case, the importance of including relevant state variables cannot be overemphasized since they provide the primary metrics for assessing operational progress.

Centers of Gravity – The Need to Represent Battlespace Cause-Effect Systems

According to military doctrine, a *center of gravity* is the source of power that provides the moral or physical strength, freedom of action, or will to act. Since the loss or neutralization of a center of gravity ultimately results in defeat, the concept of a center of gravity provides analytic utility for designing an operational campaign. Centers of gravity generally constitute a complex system of capabilities and influences within the modern battlespace. As noted in US Army Field Manual 3-0, "*Modern understanding of the center of gravity has evolved beyond the term's preindustrial definition. Centers of gravity are now part of a more complex perspective of the operational environment. Today they are not limited to military forces and can be either physical or moral. Physical centers of gravity, such as a capital city or military force, are typically easier to identify, assess, and target. They can often be influenced solely by military means. In contrast, moral centers of gravity are intangible and complex. They are dynamic and related to human factors. Examples include a charismatic leader, powerful ruling elite, religious tradition, tribal influence, or strong-willed populace. Military means alone are usually ineffective when targeting moral centers of gravity. Eliminating them requires the collective, integrated efforts of all instruments of national power.*" (US Army, 2008)

The notion of a center of gravity implies the need to think about the PMESII-PT battlespace as an interconnected system of systems that mutually interact with and influence one another. In general, constructing the battlespace in terms of cause-effect system models allows analysts to formally define specific cause-effect relationships that potentially serve to alter the state of the battlespace. Some of these cause-effect systems can be formally defined in terms of *intentional work systems*. An intentional work system model can be used to describe any organization that exerts efforts to bring about purposeful state change within an operational environment. Intentional work systems are described in terms of an interrelated set of intentions, effects, capabilities, and resources that are used to bring about specific state changes within the operational environment. In the present case, adversary organizations are appropriately described as intentional work systems. Another class of systems that might be considered includes *battlespace ecosystem systems*. An ecosystem system comprises some operationally relevant entity within the battlespace—*e.g*., a host nation government, a provincial district, a cultural or ethnic population group, or a national economy—that represents a functional cause-effect relationship which can be influenced or manipulated by one of the intentional work systems. Given their general nature, battlespace ecosystem systems provide an analytic context (*i.e*., an influence model) for (1) defining operationally relevant state variables and (2) defining cause-effect pathways through which work systems can bring about change. The representation of some entities (*e.g*., a host nation military force, a small transnational terrorist group, or a neighboring state) as either a formal work system model or an ecosystem system model is an analytic choice that depends upon its perceived importance to a military organization's framework of understanding. Finally, the term "ecosystem" is used in this instance to denote that fact that all entities within the battlespace mutually influence one another to dynamically produce various states of equilibrium and disequilibrium.

Operational Approach – The Need to Represent Tactical Episodes

As defined in military doctrine, *operational approach* describes the manner in which a military organization intends to influence a center of gravity. Operational approaches can include both (1) direct influences focused on center of gravity strength and (2) indirect influences that focus on a series of decisive points while avoiding center of gravity strength. Operational approaches are further divided into two classes: *defeat mechanisms* and *stability mechanisms*. Defeat mechanisms are directed primarily at an adversary center of gravity in order to neutralize that adversary's capability to wage an operational campaign. According to US Army Field Manual 3-0, "*A defeat mechanism is described in terms of the physical or psychological effects it produces. Defeat mechanisms are not tactical missions; rather, they describe broad operational and tactical effects.*" Defeat mechanisms include the destruction, dislocation, disintegration, and isolation of an adversary's primary resources and capabilities. These types of influences are commonly considered in traditional force-on-force combat operations against the organized military force of a nation state. However, they can also be employed in representing modern insurgency organizations. In either case, they may be used in combination to produce reinforcing effects that are greater than the sum of the individual effects.

Analytically, the concept of an operational approach implies the need to formally represent state change transactions within the PMESII-PT battlespace. This idea is closely related to representation of the battlespace in terms of cause-effect systems; however, there is an implied sense of action. Whereas cause-effect system models represent the potential for state change, actual state change occurs in the form of specific *tactical episodes*. Here, a tactical episode narrative can be used to depict an action, event, or emerging condition that produces a specific set of effects (state changes). The changes are brought about by the actions or influence of one or more defined work systems within the battlespace. These actions or influences are targeted against specific artifacts within the battlespace to produce a set of *direct effects*. However, because these artifacts are linked with other artifacts through the various system models, these same actions and influences can produce *second-order effects and consequences*.

Decisive Points – The Need to Represent Bracketed Artifacts

A *decisive point* is a geographic place, critical factor, function, or system element that, when acted upon or influenced, produces the effect intended by the commander. Decisive points associated with traditional combat operations tend to be physical in nature –*e.g*., a military force's reserve units, a port facility, or a distribution network. Decisive points associated with stability and counterinsurgency operations tend to be more abstract in nature –*e.g*., repairing a water treatment plant, securing an election, providing electrical and sewer services, or providing health care and economic aid to families. In either case, a decisive point represents an artifact within the PMESII-PT battlespace that is deemed by the commander to be of major importance to a defined center of gravity.

From an analytic point of view, the concept of decisive points requires us to represent the battlespace in terms of specific artifacts. These artifacts can be either physical or concrete in nature, or they can be more abstractly defined. Concrete artifacts typically represent physical objects within the battlespace, while abstract artifacts typically represent some feature of the battlespace deemed relevant for describing operational progress. The important point to make here is that they are assigned contextual significance by the commander because of their functional association with a center of gravity. Hence, in terms of constructing a knowledge system, we are primarily interested in representing only those artifacts that are deemed to be operational significant –not every possible artifact within the battlespace. In the present research, we define operationally significant artifacts as being *bracketed artifacts –i.e.*, they are bracketed or singled out for attention because of their perceived operational significance. A second characteristic of bracketed artifacts is our ability to associate specific state variables with each artifact. By associating specific state variables with a bracketed artifact, we enable the artifact to be accounted for in an analytic (rather than purely descriptive) manner.

Finally, we consider the complex, interconnected nature of the modern battlespace and note that actions, events, and emerging conditions can produce both direct and indirect state changes. Our ability to analytically track both direct effects and second-order effects and consequences derives from our representation of the PMESII-PT battlespace as an interconnect set of work system models and ecosystem system models. In turn, these models are simply sets of bracketed artifacts that have been functionally associated in terms of their respectively state variables (a term that we shall define later as *dependency equations*). Thus, in order to ultimately link decisive points with centers of gravity and end state conditions, we must analytically account for both (1) the battlespace artifacts directly acted upon by different work systems and (2) those artifacts that serve to describe the ecosystem systems that propagate these effects throughout the PMESII-PT battlespace.

Lines of Operation and Lines of Effort – The Need to Represent Strategic Agendas

Military doctrine defines a *line of operation* or *line of effort* as a conceptual bridge that links a series of discrete tactical actions, events, or emerging conditions to a purposeful objective. In this sense, they represent elements of a military organization's strategic agenda. Lines of operation are geographically oriented in time and space in relation to an adversary. They connect a series of decisive points that lead to control of a geographic or military force-oriented objective. Traditional combat operations are typically designed using lines of operation. By contrast, lines of effort link multiple tasks using the logic of purpose (cause-effect) to focus efforts toward establishing operational and strategic conditions. Lines of effort are constructed where positional reference to an adversary has little or no relevance, and where it is appropriate to coordinate military actions with other instruments of national security. Stability and counterinsurgency operations are typically designed using lines of effort that connect a series of decisive points to political, economic, social, information, or infrastructure objectives. Finally, multiple lines of operation and lines of effort can be designed, planned, and executed in parallel with one another to achieve an integrated strategic purpose. As noted in US Army Field Manual 3-0, "*Commanders use both lines of operations and lines of effort to connect objectives to a central, unifying purpose. Lines of operations portray the more traditional links between objectives, decisive points, and centers of gravity. However, lines of operations do not project the operational design beyond defeating enemy forces and seizing terrain. Combining lines of operations and lines of effort allows commanders to include nonmilitary activities in their operational design. This combination helps commanders incorporate stability tasks that set the end state conditions into the operation. It allows commanders to consider the less tangible aspects of the operational environment where the other instruments of national power dominate.*" (US Army, 2008)

From an analytic perspective, lines of operation and lines of effort represent a unifying framework for modeling a military organizations intentional process of designing, planning, executing, monitoring, assessing, and adjusting an operation. As such, they provide the operational context for determining the operational significance of bracketed artifacts, work systems, ecosystem systems, and episodes discussed earlier. That is, artifacts, systems, and episodes become operational significant to the Joint commander if they are associated in some meaningful way with one of his constructed lines of effort. For example, specific battlespace artifacts become operationally significant if they represent a decisive point or constitute a functional element of one of the defined center of gravity systems that link effects with key end state conditions (*i.e.*, state variables). Battlespace systems become operationally significant if they represent a center of gravity or one of the linking systems that connect effects with key end state conditions. Episodes become operational significant if they result in change to one of the key end state conditions.

Holistic, Self-Referent, Focused Nature of a Battlespace Knowledge System

As defined through current military doctrine, end state conditions, centers of gravity, operational approach, decisive points, and lines of operation/effort constitute a holistic, self-referent system of constructed knowledge for planning, executing, monitoring, assessing, and adjusting an operational campaign. Together, they reflect a military organization's visualization of the battlespace relative to its intentional mission goals. This knowledge system is self-referent in the sense that each element of knowledge is mutually dependent upon the other constituent elements for its contextual definition and operational significance. Over time, emergent events and conditions within the battlespace will dictate the need to add, delete, or modify specific elements within the knowledge system. However, as these changes occur, the organization must act to bring other parts of this knowledge system into alignment so as to maintain coherence and sense of purpose. Finally, it can be seen from the preceding discussion that a military organization's framework of operational awareness and understanding constitutes a purposeful knowledge system. Rather than simply reflecting a massive, encyclopedic body of facts, information, and knowledge about a particular region of the world, the knowledge system just defined represents a focused vision (or model) of the battlespace relative to a strategic agenda.

Modeling an Adversary – Reverse Engineering an Adversary's Operational Design

While military doctrine mainly uses the concept of operational design to frame the battlespace in terms of a specific operational campaign, it is important to consider that this same generic framework can be applied to describe the intentional behavior of an adversary within the battlespace. Hence, as one attempts to understand the strategic motivation underlying an adversary's behavior, it becomes useful to view the battlespace from the adversary's point of view. That is, we frame the behavior of an adversary organization in terms of its desired end state conditions, its perceived centers of gravity, its operational approaches, its perceived decisive points, and its constructed lines of operation or lines of effort. While the details of an adversary's operational design might differ from those of a western military commander, the basic classes of knowledge elements contained in an operational design are still relevant and useful.

A HOLISTIC FRAMEWORK OF LOGICO-SCIENTIFIC AND NARRATIVE KNOWLEDGE

In order to develop a knowledge system that is consistent with modeling the intentional behavior of an adversary, we must formally consider the types of knowledge classes that, when appropriately linked, represent an emerging adversary signature. Development of these knowledge classes is motivated in part by current theories of knowledge management, and in part by the preceding discussion of operational design. We begin this examination with a brief discussion of two complementary types of knowledge—logico-scientific and narrative—that must be effectively combined to produce a workable knowledge system. Next, we introduce four specific classes of knowledge and show how they fulfill a unique ontological role within a holistic knowledge framework.

Two Contrasting Forms of Knowledge

In reviewing the current research literature on information management and knowledge management, one is struck by a pervasive ambiguity of definitions regarding the fundamental nature of human knowledge. Much of this ambiguity arises from the philosophical foundation that dominates science and engineering today, including past research on signature analysis. This foundation emphasizes what Jerome Bruner (1986) calls *logico-scientific knowledge*. Standing in contrast to this type of knowledge is *narrative knowledge* that is more commonly used in everyday life. Although complementary in nature, these two forms of knowledge are irreducible to one another. According to Bruner, efforts to reduce one to the other, or efforts to ignore one at the expense of the other inevitably fail to capture the rich diversity of thought. In his outline of these two forms of knowledge, Bruner makes certain distinctions that are important to consider in the study of adversary behavior:

Objective of Knowledge: The objective of logico-scientific knowledge is the establishment of universal truth, whereas the objective of narrative knowledge is the endowment of meaning and intentionality to experience.

Nature of Knowledge: The nature of logico-scientific knowledge is empirically validated truth, whereas the nature of narrative knowledge is verisimilitude.

Method of Knowledge Construction: Logico-scientific knowledge is constructed through sound argument, formal logic, tight analysis, and proof, whereas narrative knowledge is constructed through association, storytelling, intuition, and inspiration.

Key Characteristics of Knowledge: Logico-scientific knowledge is theory-driven, abstract, context-free, ahistorical, objective, and coherent, whereas narrative knowledge is meaning-driven, context-sensitive, historical, intentional, and sometimes paradoxical.

Because logico-scientific knowledge serves as the epistemological foundation for much of the systems engineering sciences, it is accepted unquestioningly by most systems engineers engaged in signature analysis. Indeed, the very concept of the scientific method comes out of, and is indistinguishable from, these ideas. Extending beyond the development of scientific knowledge, the concept of logical positivism has been applied more recently to all human knowledge and reflected in current data fusion research, information mining technologies, and semantic web technologies (*cf*. Steinberg et al, 1999; Davies (ed.) *et al*, 2003; Veltman, 2004; Seifert, 2006). Logico-scientific knowledge has served well the needs of the industrial age where emphasis was placed on physical science theories and the design and analysis of mechanical systems. Unfortunately, this tradition does not characterize knowledge as it is created and applied in the complexity and wickedness of everyday life. Thus, as society has moved from the industrial age, to the information age, and to the knowledge age, logico-scientific knowledge no longer serves as an adequate framework for studying complex problems involving human behavior.

Because narrative knowledge does not conform to the principles of scientific knowledge, its formal study in an analytical sense presents a new and unique challenge. Nevertheless, we are compelled to address this type of knowledge if we are to understand the types of intentionality factors that influence adversary behavior. As noted above, narrative knowledge deals explicitly with intentionality as it is constructed and represented within a work system organization. Here, Bruner argues that narrative knowledge ties intentionality together with action –thus reflecting a "dual landscape" of actions on one level and their meaning or significance on another level. In this sense, narrative knowledge serves to help organize logico-scientific knowledge in a manner that gives it contextual meaning. Thus, it becomes necessary for us to capture both types of knowledge in our constructed framework of operational awareness and understanding.

We must approach the definition of narrative knowledge from a social constructivism point of view. This view holds that meaning is established by each individual based on their unique experience and set of interests. Central to the definition of this type of knowledge are the philosophical ideas of relativism, nominalism, and autopoiesis. Because this tradition serves as the epistemological foundation of much of the social sciences, it is little understood or ignored by most systems engineers. Yet, as is well known by both psychologists and corporate managers, the principles reflected in this alternative tradition often provide a better explanation or model of human behavior in everyday life (Brown *et al*, 2005).

Pursuing these ideas a bit further, relativism implies that humans always understand and evaluate specific beliefs (*i.e*., facts, assertions, and theories) in terms of their historical and cultural context. Thus, the roles of truth and language are reversed from that posited in the logico-scientific tradition. The logico-scientific view begins with the idea that absolute truths exist in the world and await discovery by man. Language is then shaped to provide a unified means of articulating this truth so that it can be shared. In contrast, the narrative tradition begins with the existence of language that is acquired through personal experience, and then argues that it is language that shapes and organizes our individual understanding of plausible truths. For example, George Lakoff and Mark Johnson argue that much of our thinking is metaphorical in nature as we attempt to interpret current experience in terms of previous experience (Lakoff & Johnson, 1980). While some individuals might view metaphorical thinking as being limited to poetic imagination and rhetorical flourish, Lakoff and Johnson have found that it plays a central role in how people mentally structure their perception of the world around them, how they get around in the world, and how they relate to other people in the world.

Closely related to relativism is the idea of nominalism. This concept rejects the logico-scientific position that artifacts in the world can be objectively assigned to specific types and groups on the basis of commonly shared characteristics. By contrast, nominalism holds that artifacts labeled by the same term have nothing more in common except their assigned name. In short, nominalism denies the existence of universals. Such an idea fits with the tradition of social constructivism since it philosophically argues that the described characteristics of artifacts have no place to exist other than in the minds of individual perceivers. In a more practical sense, nominalism underscores the need for analysts to establish a common ground of understanding before they can effectively interact.

The concept of autopoiesis comes to us from the work of biologists Francisco Varela and Humberto Maturana. As noted by these authors, an autopoietic system is one that is organized as a network of self-sustaining processes that continuously regenerate the system as a self-contained entity –*i.e*., one that cannot be described by using dimensions that define another space (Varela *et al*, 1974). Examples of an autopoietic system include the biological cell that is made up of various nucleic acids and proteins, and is organized into bounded structures such as a cell nucleus, cell membrane, and cytoskeleton. Specifically, the concept of autopoiesis is said to define the dynamics of non-equilibrium systems operating in a larger open system. Extending this concept to the structure and organization of human knowledge (Maturana & Verela, 1980) argued that the state of understanding of an individual actor is considered to be in non-equilibrium as the actor operates within the world (the larger, open system). Thus, to say that an individual actor's state of understanding is autopoietic is to highlight the self-referent and self-sustaining nature of that mental framework –*i.e*., it is self-adjusted on the basis of personal experience in order to enable the actor to maintain a cohesive and functional identity.

While each of these tenets—relativism, nominalism, and autopoiesis—offer us general insight into the constructive nature of narrative knowledge, it is the more recent concept of sensemaking that applies these ideas to an organization and shows more explicitly how knowledge relates to action. Sensemaking as a concept has principally evolved through the work of Karl Weick that began in the 1970s and has continued through the present (*cf*. Weick, 1977; Weick, 1993; Weick, 1995; Weick & Sutcliffe, 2001). In its most simplified form, sensemaking can be defined as an ongoing process by which actors within an organization consensually construct and coordinate a system of understanding and action. The logico-scientific tradition sees knowledge as an accumulated, but static framework of propositions, meanings, facts, and truth values. By contrast, current theories of sensemaking view knowledge as a dynamic, ongoing, and negotiated achievement that is distributed among a set of actors. As such, it yields insight into how we must analytically represent narrative knowledge.

Adding to this view is the work of Gary Klein whose research on sensemaking has led to his concept of sensemaking as a continuous interplay between hypothesized frameworks of understanding and empirical evidence gleaned from the operational environment (Klein *et al*, 2007). Klein's data/frame model of sensemaking is driven by a number of ideas that are consistent with the preceding discussion. These ideas can be summarized in terms of the following four guiding principles:

Congruence: Human actors make sense of a situation by engaging in two concurrent mental processes: fitting available data into a framework of understanding and molding a framework of understanding around the data. Sensemaking usually ceases when the data and frame are brought into congruence.

Practicality: Human actors focus on the development of practical understanding and prediction in a situation, not the development of formal systems of knowledge in a scientific sense. In order to achieve a functional understanding of a situation, human actors engage in abductive reasoning (*i.e*., selecting a hypothesis that best explains available evidence) as well as logical deduction.

Parsimony: Human actors seek to develop understanding based on a minimum of data. Only a few key anchoring features (features that symbolize the typicality of the frame) are required to trigger the recall of a specific frame. Human actors develop understanding on an "as needed" or "just-in-time" basis, rather than attempting to build a full or comprehensive mental model of a situation or phenomenon.

Richness: Experts employ the same reasoning strategies as novices. What distinguishes their performance is their ability to employ a richer repertoire of cause-effect connections.

The two types of knowledge just discussed (logico-scientific versus narrative) represent complementary ideas regarding the nature of knowledge. Thus, both views have merit relative to the construction of a knowledge system that can be used to understand the behavior of an adversary within a socially-defined battlespace. Perhaps, the simplest way to describe how these two forms of knowledge stand in relation to one another is in terms of an organization's know-what versus know-how. The know-what of an organization describes its awareness of objects, events, and conditions within its work environment –a form of knowledge that is generally developed in a logico-scientific manner. By contrast, the know-how represents the accumulated wealth of action-oriented experience within an organization that can effectively apply the know what to solve goal-driven problems. Accordingly, it is developed in a narrative manner. In the words of John Seely Brown, "*Know-how embraces the ability to put know-what into practice. It is a disposition, brought out in practice. Thus, know-how is critical in making knowledge actionable and operational. A valuable manager, for example, is not simply one who knows in the abstract how to act in certain circumstances, but who in practice can recognize the circumstances and acts appropriately when they come along. That disposition only reveals itself when those circumstances occur.*" (Brown & Duguid, 1998) Thus, any type of signature-based knowledge system must accommodate forms of knowledge that are empirically acquired and logically structured, as well as forms of knowledge that are more socially constructed in nature.

Having presented a brief review of relevant ideas in knowledge management, we next turn to the definition of four specific classes of knowledge elements that will provide the ontological building blocks of awareness and understanding for modeling and analyzing the behavior of an adversary. As will be seen, they represent a blend of the logico-scientific and narrative approaches to defining knowledge.

Artifact Knowledge

This class of logico-scientific knowledge formalism describes *a specific, bracketed artifact* that is constructed by the analyst to represent an operationally relevant part of an adversary work system or the surrounding battlespace ecosystem. Artifact knowledge tends to be atomistic and universal or context-free in nature, although it might reflect the particular vernacular of a given perspective or domain of expertise. Artifacts include physical objects, events, actions, and conditions within the battlespace, as well as abstracted constructs that enable the analyst to describe relevant intentions and capabilities of an adversary work system or relevant features of the battlespace ecosystem with which the adversary interacts. Artifacts specifically correspond to one or more of the PMESII-PT dimensions of the battlespace, thus enabling analysts to eventually track which aspects of the battlespace are being accounted for within the signature-based knowledge system. While it is recognized that the battlespace reality consists of a myriad of potentially definable artifacts, artifact definitions offer a means for simplifying and focusing this reality into a workable analytic model. Being based upon analyst judgment, they reflect those objects, events, actions, conditions, and abstracts constructs considered essential for analytically characterizing the battlespace.

From an ontological point of view, artifact knowledge represents the basic building blocks of higher forms of awareness and understanding. It is considered to be atomistic in nature in the sense that they represent the lowest level of battlespace decomposition within the knowledge system. Although it represents a form of logico-scientific knowledge, artifacts are considered to be socially constructed in nature in the sense that each artifact is uniquely defined by the analyst on an "as needed" basis to describe some aspect of the battlespace. However, in order to provide some degree of structure and order, basic artifact classes defined within the knowledge system serve as a guide or template for creating new artifact signatures. Each of these artifact classes specify the types of narrative information and state variables that must be included in the construction of a given artifact type –*e.g.*, a provincial population group allegiance to the host nation government, a host nation government border security enforcement, or a provincial district political participation. When associated with a strategic agenda, artifacts can be designated—under certain conditions—as a decisive point in the operational campaign design of an adversary. Structurally, a decisive point artifact can logically represent a critical obstacle that must be successfully influenced in order for the adversary to achieve some line of operation or line of effort. Transactionally, an artifact can become an emergent decisive point if its state has reached a tipping point relative to one of the adversary's lines of operation or lines of effort.

Artifacts are analytically defined in several complementary ways to uniquely characterize them and provide for their organized use within a system of knowledge. This reference definition can be socially constructed based on analyst expertise; however, once constructed, it serves to ensure consistent use of the artifact within the knowledge framework. A *verbal description* articulates the basic characteristics of the specific artifact that uniquely identify and distinguish it along one or more of the PMESII-PT dimensions of the battlespace. One or more associated *state variables* provide operational definition and quantification to an artifact. If the parent artifact reflects multiple dimensions, then several artifacts will be required to separately represent each relevant PMESII-PT dimension. Each state variable is defined in terms of a semantically-anchored measurement scale that can be nominal, ordinal, interval, or ratio in nature, depending upon the degree to which it can be perceived or apperceived by the analyst. State variables enable computational forms of analysis, as discussed later in this paper. An artifact's *pedigree* includes any socio-cultural shaping factors or other ancillary information that informs the community of users about the manner in which the artifact was constructed and added to the knowledge system. Pedigree information serves to insure proper use of the constructed artifact by other analysts as they use its definition to construct higher forms of operational awareness and understanding (*e.g*., systems, tactical episodes, and strategic agendas).

From an operational design point of view, artifacts fulfill a variety of roles. First of all, they represent the analyst's judgment as to what objects and features are considered operationally relevant to the framework of battlespace awareness and understanding. They can be used to functionally define adversary work systems and battlespace ecosystem systems. In some cases, these systems will represent a defined center of gravity. In other cases, these systems will be used to define an operational approach. Specific artifacts can be designated as a decisive point (*i.e*., the point at which an action, event, or emerging condition alters the battlespace in some significant manner). Finally, the state variables associated with these artifact signatures serve to (1) represent an important endstate condition, (2) represent an intermediate cause-effect mechanism, or (3) highlight an important second-order consequence.

Cause-Effect System Knowledge

This class of logico-scientific knowledge formalism constitutes a *system of artifacts* that is constructed by the analyst to functionally describe an adversary work system, other work system, or operationally relevant part of the PMESII-PT battlespace ecosystem. Systems are described in terms of their general purpose, the constituent artifacts that make up the system, and the functional relationships that link these artifacts in meaningful cause-effect ways. System definitions can reflect functionality and cross-connections across multiple PMESII-PT dimensions of the battlespace. These relationships define the potential for work (state change) relevant to a given perspective or domain of expertise. Each of these aspects of a system is socially constructed by analyst judgment according to the perceived complexity of the battlespace –*i.e*., there is no fixed or standard set of systems that must be included within the knowledge framework. While it is recognized that the battlespace reality consists of a myriad of complex functional relationships, system definitions offer a means for simplifying and focusing this reality into a workable analytic model of one or more adversaries, other political entities, and the battlespace environment within which they operate. Being based upon analyst judgment, system definitions are subject to modification and refinement over time as new evidence is accumulated and new perspectives are considered. System definitions can be modified to reflect (1) a different composition of artifacts and (2) a different functional relationship among these artifacts. New systems can be added or existing systems deleted if the evolving state of the battlespace so warrants.

Cause-effect system models are analytically defined in several complementary ways to uniquely characterize them and provide for their organized use within a system of knowledge. This reference definition can be socially constructed based on analyst expertise; however, once constructed, it serves to ensure consistent use of the system model within the knowledge framework. A system's *verbal description* articulates the basic set of bounded artifacts that uniquely identifies and distinguishes a system within the framework of battlespace awareness and understanding. As a socially constructed definition, this description bounds the system in terms of its interdependent elements (artifacts) and holistically describes their arrangement in terms of purpose, work functions, inputs, and outputs. A system is existential in nature, representing the analyst's experiential bracketing of a specific cause-effect relationship within the PMESII-PT battlespace. *Directed network graphs* provide the means for visualizing the functional associations and overall structure of a cause-effect system. Directed arcs connecting the constituent artifacts are labeled to indicate the general nature of the association defined to exist between each artifact pair. The resulting graph structure enables analysts to holistically visualize each defined system and its connection to other systems within the battlespace. *State variable dependency equations* are used to computationally define cause-effect relationships among the state variables associated with the constituent artifacts comprising a system. In addition, these equations can also reference state variables associated with other systems within the knowledge framework. In each case, a dependent state variable is computationally defined in terms of one or more independent state variables. Cross-dimensional effects and consequences are modeled by linking state variables along one of the PMESII-PT dimensions with one or more state variables representing other dimensions. As will be discussed later, the addition of a tactical episode to the knowledge framework triggers a recalculation of all state variable dependency equations in order to represent the propagation of effects across the battlespace. A system's pedigree includes any socio-cultural shaping factor or other ancillary information that informs the community of users about the manner in which the system was constructed and added to the knowledge framework.

From an ontological point of view, each system represents a type of functional model that—when integrated with other systems to form a holistic understanding of the battlespace—enables the analyst to represent a purposeful set of cause-effect mechanisms or pathways. System definitions reflect the analyst's declaration of operationally relevant work mechanisms and cause-effect relationships within the battlespace –in short, how the battlespace is "wired together" in both an intentional and functional sense. Importantly, it should be noted that system definitions (*i.e*., models) describe the potential for transactional changes within the battlespace. Actual change, however, is described by episode signatures, another class of signature formalism discussed later. Thus, system definitions represent the analytic means by which the influence of actions, events, and emerging conditions are propagated through a network of interconnected state variables that ultimately move the battlespace toward or away from an identified set of end state conditions. When associated with a strategic agenda, systems can be designated as a center of gravity in the operational campaign design of an adversary. In this role, the system definition contains the artifacts and state variables representing the end state conditions of the line of operation or line of effort.

Tactical Episode Knowledge

This class of narrative knowledge formalism constitutes a *battlespace transaction* that is constructed by the analyst to functionally describe an action, event, or emergent condition that alters one or more state variables within the PMESII-PT battlespace ecosystem in an operationally significant manner. That is, they link Bruner's dual levels of actions and meaning/significance to provide a plausible explanation for why and how the state of the battlespace evolves over time. Tactical episodes are described in narrative or schema-like fashion to provide a plausible explanation for each observed action, event, or condition in terms of (1) the battlespace systems or artifacts responsible for its enactment, (2) the targeted set of battlespace artifacts acted upon, and (3) the resulting state variable changes associated with this transaction. Each aspect of a tactical episode is socially constructed by analyst judgment according to the perceived dynamics of the battlespace. While it is recognized that the battlespace reality consists of a myriad of on-going interactions, tactical episode definitions offer a means for simplifying this reality into a workable analytic model. Being based upon analyst judgment, they reflect those transactions considered essential for analytically characterizing battlespace changes over time.

In order to distinguish these various forms of battlespace enactment, the following classification scheme has been adopted within the knowledge framework. An *action* represents a form of battlespace enactment carried out by a formally defined work system (*e.g*., an adversary or other organization that has been modeled in terms of specific work capabilities and intentions). An *event* represents a form of battlespace enactment carried out by one of the battlespace ecosystem system models (*e.g*., a host nation government, population group, or other entity that is represented only in causal form). An *emergent condition* represents a form of battlespace change that cannot specifically be attributed to either a formal work system or battlespace ecosystem system (*e.g*., an influx of refugees, an increase in unemployment, or a natural disaster)

Each tactical episode represents a set of operationally significant state variable changes that—when associated with specific strategic agenda—enables the analyst to represent the evolution of the battlespace in operationally explainable ways. Whereas cause-effect system models (described previously) represent the potential for transactional changes to the battlespace, tactical episodes document the instantiation of actual changes over time. State variable changes associated with a specific tactical episode represent the direct effects of an action, event, or emergent condition. The new state variable values are then entered (as independent variables) in the state variable dependency equations to compute the second-order effects and indirect consequences of the action, event, or emergent condition throughout other PMESII-PT dimensions of the battlespace. Thus, a tactical episode serves as a trigger for propagating a broad set of state variables changes across the battlespace.

Tactical episodes are analytically defined in several complementary ways to uniquely characterize them and provide for their organized use within a system of knowledge. This reference definition can be socially constructed based on analyst expertise; however, once constructed, it serves to ensure consistent use of the episode within the knowledge framework. A tactical episode's *verbal description* bounds the observed action, event, or emergent condition in terms of the enacting system/artifact, the targeted system/artifact, and the resulting state variable changes. A tactical episode is existential in nature, representing the analyst's experiential bracketing of a specific transaction within the PMESII-PT battlespace. *Directed network graphs* provide the means for visualizing the structural relationships existing among enacting systems/artifacts and targeted systems/artifacts that define a tactical episode. Directed arcs connecting the constituent systems and artifacts are labeled to indicate the dynamic nature of the transaction connecting each pair. The resulting graph structure enables analysts to holistically visualize each defined tactical episode and its transactional connection to specific systems and artifacts within the battlespace. *State variable value changes* are manually entered by the analyst to describe the transactional effects of the action, event, or emergent condition on a designated set of artifact state variables already defined within the knowledge framework. Depending upon the complexity of the tactical episode, state variable changes can be specified along any of the PMESII-PT dimensions of the battlespace in order to represent cross-over effects –*e.g.*, a military action produces a change in a political artifact or social artifact. The choice of which state variables to modify is based on analyst judgment and the complexity of the PMESII-PT battlespace. A tactical episode's *pedigree* includes any ancillary information that informs the community of users about the manner in which the episode was constructed and added to the knowledge system.

Although not formally defined to be a part of a tactical episode, the knowledge system automatically computes the second-order effects and indirect consequences of an action, event, or emergent condition at the time it is added to the framework of operational awareness and understanding. As each tactical episode is appended to the framework, the state variable backplane register is updated on the basis of the state variable dependency equations specified as part of the various system definitions. Additionally, tactical episodes serve as evidence that can either support or contradict the various strategic agenda hypotheses developed by the analysts. This assessment is expressed in the form of an evidence likelihood ratio. As new tactical episodes are added to the knowledge framework, their respective evidence likelihood ratios are used to adjust the current belief strength associated with each strategic agenda hypothesis.

From an ontological point of view, tactical episodes fulfill a variety of roles. First of all, they represent the analyst's judgment as to what is considered operationally relevant transactions over time within the battlespace. They also serve to directly instantiate operational approaches relative to specific decisive points and end state conditions associated with a defined line of operation or line of effort. Tactical episodes can represent defeat mechanisms, stability mechanisms, or any other type of cause-effect mechanism considered operationally relevant by the analyst. As discussed next, a strategic agenda (a purposeful set of lines of operation or lines of effort) is defined in terms of potential decisive points and end state conditions. If the targeted artifact of a tactical episode corresponds to one of the decisive points associated with a strategic agenda, then the episode is declared to be operationally relevant to that strategic agenda. In turn, the direct and indirect state variable changes associated with the tactical episode enable the analyst to adjust the values of the end state conditions defining the strategic agenda. Over time, these adjustments produce a pattern of operational progress that can be assessed for each line of operation or line of effort comprising the adversary's strategic agenda.

Strategic Agenda Knowledge

This class of narrative knowledge formalism expresses the operational agenda of an adversary. This form of knowledge ties together a sequence of tactical episodes to form a meaningful story. Agendas place system knowledge and tactical episode knowledge within an intentional framework that provides a plausible explanation of how actions, events, and emergent conditions support the achievement of specific work goals. Like episodes, strategic agendas are narrative in nature; however, they represent a higher or more strategic level of narrative. In the present research, strategic agendas are comprised of a *line of operation* or *line of effort* that is hypothesized to intentionally describe a specific facet of an adversary's operational design. As appropriate, they can be defined for other identified work systems within the battlespace –e.g., a host nation government. Together with a cause-effect system model definition (described earlier), strategic agenda hypotheses provide the means to completely describe an adversary in terms of organizational structure, control relationships, work capabilities, and operational campaign design.

Ontologically, agendas constitute the highest form of contextual knowledge within the knowledge framework and enables analysts to conduct inferential reasoning with regard to an adversary's operational campaign strategy. Strategic agendas are described in terms of (1) a single center of gravity system that represents the operational focus of the line of operation or line of effort; (2) an operational approach that identifies a general cause-effect pathway for influencing this center of gravity; (3) a sequence of documented tactical episodes (actions, events, or emergent conditions) that instantiate the operation approach; and (4) a set of desired end state conditions that are measured in terms of key state variables selected from the various battlespace ecosystem models. Each of the key state variables are designated as having a critical (or tipping point) value that defines the point of achieving operational success along the line of operation or line of effort.

Each aspect of a strategic agenda is socially constructed according to the analyst's judgment by relating the other three classes of knowledge in meaningful ways. System definitions and artifact structurally form a strategic agenda hypothesis. Over time, a strategic agenda hypothesis is empirically instantiated by evidence accumulated in the form of tactical episodes. Episodes serve to both (1) alter the key state variable values in an operationally significant manner and (2) adjust the belief strength of the line of operation or line of effort. At the same time, strategic agendas provide the context for interpreting the operational significance of these other classes of knowledge. That is, artifacts, systems, and tactical episodes reflect operational significance to the degree that they are functionally or structurally associated with one or more strategic agendas.

Strategic agendas are analytically defined in several complementary ways to uniquely characterize them and provide for their organized use within a system of knowledge. This reference definition can be socially constructed based on analyst expertise; however, once constructed, it serves to ensure consistent use of the episode within the knowledge framework. A strategic agenda verbal description articulates the hypothesized line of operation of line of effort comprising the strategic agenda. This hypothesis describes a specific aspect of the adversary's operational campaign in terms of desired end state conditions, perceived center of gravity, and operational approach. A strategic signature is both existential and dynamic in nature inasmuch as it (1) existentially defines a perceived objective of the adversary and (2) instantiates that perception over time with accumulated evidence. *Directed network graphs* provide the means for visualizing a hypothesized line of operation or line of effort in terms of (1) the system designated as a center of gravity, (2) the key state variables within this system representing the end state conditions, and (3) a series of tactical episodes instantiating the operational approach. Tactical episodes (directly or indirectly influencing the values of one or more of the key state variables) are added to the network graph over time as accumulated evidence. These episodes serve to adjust the belief strength of the line of operation or line of effort by means of the Bayesian analysis method described later in this paper. *Key state variables* designated as corresponding to the end state conditions for the line of operation or line of effort are computationally tracked over time to provide a sense of operational progress being achieved along a specific line of operation of line of effort. This knowledge element quantifies the key state variables designated within the directed graph network. Each key state variable is assigned a designated critical (or tipping point) value that defines operational success relative to the line of operation or line of effort. *Belief strength* represents the degree of accumulated evidence supporting or contradicting the hypothesized line of operation or line of effort. As described later, the belief strength value is computed in an inferential manner using a Bayesian statistical procedure. A strategic agenda's pedigree includes any socio-cultural shaping factors or other ancillary information that informs the community of users about the manner in which the agenda was constructed and added to the knowledge system.

From an operational design point of view, strategic agendas provide high-order narrative insight into the structure and status of an adversary's operational campaign. As discussed later in this paper, they represent a dynamic type of behavior signature that—once defined—can be used to anticipate future adversary actions and states of the battlespace. By combining the elements of operational design into a formalized hypothesis, strategic agendas enable analysts to interpret the relative operational significance of systems, artifacts, and state variables representing the battlespace. In turn, this level of understanding supports anticipatory awareness of an adversary –*i.e.*, the centers of gravity, operational approaches, and targets likely to be associated with future actions, events, and emergent conditions within the battlespace. Strategic agenda hypotheses are constructed in relationship to the other knowledge classes. System definitions represent associated centers of gravity of interest to the adversary, as well as other elements of the battlespace ecosystem through which the adversary achieves its influence. Each of the system definitions are, in turn, comprised of artifacts defined by the analysts. Tactical episodes represent the battlespace actions, events, and emergent conditions that (1) modify the state of the battlespace ecosystem and (2) provide evidentiary support for each of the strategic agenda hypotheses.

FORMS OF REASONING AND ANALYSIS

Before proceeding with a discussion of how this framework can be used to dynamically construct adversary signatures, it is useful to identify two complementary approaches that can be used to develop anticipatory awareness and understanding. We broadly categorize these approaches as structural and transactional in nature. *Structural anticipation* derives from a logical analysis of the relationships that exist among the artifacts, system models, and strategic agendas within the framework of knowledge. In essence, structural analysis anticipates future adversary behavior by connecting adversary intentions with adversary capabilities to reveal likely areas of operational emphasis. Structural analysis is relatively static in nature inasmuch as it focuses on the operational campaign design of the adversary –*i.e*., what is the adversary attempting to achieve, how is the adversary attempting to achieve it, and with what means is the adversary pursuing these goals?

One technique that is particularly useful for structural analysis is *morphological analysis* (Richey (2002). Morphological analysis is a generalized method for structuring and analyzing complex problem fields that are (1) inherently non-quantifiable, (2) contain genuine uncertainties, (3) cannot be casually modeled or simulated, and (4) require a judgmental approach. It can be employed in wicked problem situations to address complex issues that have not yet been expressed in a well-defined form or structure. The power of morphological analysis derives from its ability to holistically address complex problem fields rather than simply analyzing one particular aspect of a situation that might be easily quantified or modeled. Thus, it is specifically suited to the study of complex socio-technical problem fields such as those found in recent stability operations and counterinsurgency operations. Traditionally, morphological analysis has been applied principally to the problem of planning complex socio-economic programs that must consider many dimensions and variables (Ritchey, 2006). Central to this form of application has been the need to reduce a large combinatorial planning problem down to reasonable size by identifying and eliminating incompatible combinations of variable. In this manner, morphological analysis is conducted up front to reduce the number of combinations and options that must be formally considered during the more detailed planning process. In the present research, however, we are interested in using morphological analysis to dynamically construct operationally relevant behavior signatures. Specifically, we use of morphological analysis to visualize the operational significance of various combinations of artifacts, systems, episodes, and agendas after other forms of analysis have been completed. In turn, these signatures can then be used to (1) characterize an adversary in some unique way and (2) anticipate future intentions and actions of that adversary.

By contrast, *transactional anticipation* derives from a dynamic analysis of emergent trends and opportunities reflected within the state of the battlespace. Specifically, transactional analysis focuses on the manner by which tactical episode narratives alter key artifacts and state variables within the battlespace. In essence, transactional analysis presumes an adaptive adversary that is able and willing to shift operational emphasis in order to influence key state variables that are near their tipping points. Transactional analysis is dynamic in nature inasmuch as it constantly seeks to reveal newly emergent patterns of system vulnerabilities and weaknesses within the battlespace –*i.e*., which of the adversary's various lines of operation or lines of effort are likely to receive increased emphasis in order to exploit a specific battlespace vulnerability or weakness? Together with structural analysis, transactional analysis is autopoietic in nature inasmuch as it constantly seeks to maintain a coherent framework of explanation that links meaning with action. From an operational point of view, transactional analysis is more relevant to asymmetric forms of warfare where an adversary seeks to exploit different pathways of influence within a complex PMESII-PT battlespace.

Transactional analysis is supported by the use of a Bayesian statistical method that enables analysts to update the belief strengths of each strategic agenda hypothesis on the basis of supportive and contradictory evidence represented in each tactical episode. The term "Bayesian" derives from the fact that this class of methods is based on the use of Bayes' theorem. This theorem enables one to infer the posterior likelihood of a hypothesis on the basis of (1) the prior likelihood and (2) the conditional probability of observing a piece of evidence if the hypothesis is actually true. In the present research, we transform this relationship into an expression involving a term we define as the *evidence likelihood ratio*. An evidence likelihood ratio is simply a comparison of two estimated probabilities: (1) the likelihood of seeing a specific tactical episode if the strategic agenda hypothesis is true versus (2) the likelihood of seeing that same episode narrative if the hypothesis was not true. In practical terms, this ratio reflects the degree to which a specific tactical episode supports versus contradicts a given strategic agenda hypothesis. Large values of this ratio (~10) correspond to evidence that is highly supportive of a specific hypothesis, while low values (~0.1) correspond to evidence that is highly contradictory. A ratio value of 1.0 indicates neutrality. Of course, in the presence of multiple hypotheses, this ratio must be estimated individually for each separate strategic agenda hypothesis. [Note: for the sake of mathematical simplification, each strategic agenda is assumed to be statistically independent.]

BEHAVIOR SIGNATURES DEFINED

In order to apply the concept of a behavior signature to today's complex and emergent battlespace, we must broaden our understanding and definition of this construct from its traditional use in past decades. The following discussion addresses this concern from three perspectives: (1) the narrative nature of behavior signatures, (2) the nature of anticipatory awareness and understanding provided by signatures, and (3) the analytical definition of behavior signatures within the context of the present knowledge framework.

The Narrative Nature of Behavior Signatures

In order to better understand the narrative nature of behavior signatures, one must begin with a fundamental definition of their nature and purpose in the real world. In this regard, a signature is considered to be an observable artifact, pattern, relationship, or other phenomenon from which one can draw a meaningful inference of some sort. Typically, a signature is thought to represent some distinguishing characteristic of an observable artifact, pattern, relationship, or other phenomenon that is of interest to the analyst. Signature analysis involves the use of inferential logic of the following form: If ***S*** is a distinguishing characteristic of artifact ***A*** and ***S*** is observed to be present, then it follows that ***A*** must be present.

With regard to military, interest in signature analysis has traditionally focused on detecting the existence, location, and operational status of specific types of weapons platforms or military units. In each case, it is presumed that the weapon platform or military unit can be detected and classified on the basis of one or more distinguishing electromagnetic signals. These signals can be either passive (*e.g*., reflected radar or sonar returns) or active (*e.g*., search or tracking radar signals, telecommunication transmissions, infrared emissions) in nature. One specific form of intelligence support to military commanders deals explicitly with the spectral signatures of potential targets –i.e. measurement and signature intelligence (MASINT). By contrast, a desirable feature of new weapons platforms within the US military is the existence of a low operational signature characterized by low acoustic, heat, electromagnetic, or noise emissions (Williams & O'Braskey, 2002; US Army, 2004). More recently, the term operational signature has been used in a broader sense to denote the detectable operational characteristics uniquely associated with an adversary unit in unconventional warfare (Jones, 2006). The lack of a clear operational signature has been cited as an issue in tracking and targeting the activities of al-Qaeda ("Fact file." 2007).

The term operational signature has also been used in other fields to denote a particular set of observable characteristics that can be used to infer the presence of a specific artifact. For example, analysis of a seismic waveform (*e.g*., shape, polarity, amplitude, frequency, and phase) can be used by geophysicists to identify the likely location and size of oilfield deposits. A similar analysis of thermal emission and reflection radiometer data has been used to detect the presence of potential oilfields (Nasipuri *et al*., 2006). In the field of computer security, counter-forensic privacy tools that are used to delete traces of sensitive data on computer hard drives are said to leave their own identifiable operational signature (Geiger & Cranor, 2005). Similarly, the term genetic signature has been used in medical research to identify specific DNA genetic sequences that—when present—indicate that a person has a higher likelihood of contracting a specific type of disease later in life ("The genetic signature." 2006).

In applying the concept of signatures in the present research, we must address two related analytic issues. The first issue deals with the nature of what is being detected or inferred. As illustrated by the signature examples just cited, there has been a tendency in the past to use the concept of signatures only in relationship to physical objects –*i.e*., a weapon system, military unit, oilfield, or a DNA structure. However, as suggested by the preceding discussion of operational design, we are interested in inferring the existence of a broader set of ontological elements. Specifically, we would like to be able to infer the intentions, operational strategy, and capabilities of an adversary –ontological elements that are more abstract, yet nonetheless important to constructing a framework of operational awareness and understanding. Thus, we must interpret the concept of a signature more broadly relative to things like centers of gravity, lines of effort, and so forth. The common characteristic that links each of these signature elements is their narrative significance –*i.e.*, the notion that these elements of knowledge are contextually linked by narrative declarations and hypotheses.

The second issue deals with the dynamic nature of the battlespace. The fact that we are interested in constructing a signature involving behavior suggests that we must deal with action, events, and emergent conditions within the battlespace. This aspect of signatures suggests that we must incorporate narratives into our signature definition. Narratives imply more than simply the movement of a definable object through three-dimensional space, as in the traditional case of radar or sonar signatures. Narratives imply both intentionality and consequence, two aspects of inference traditionally dealt with only at higher levels of intelligence fusion (Steinberg *et al*, 1986). Since our knowledge framework incorporates these aspects of knowledge, it is only natural that our construction of behavior signatures must involve both intentionality and consequence.

Given these two issues, the nature of the modern battlespace requires us to adopt a broader interpretation of signature analysis than has been characteristic of past efforts. In this regard, past examples of signature analysis typically focused on the real-time identification and characterization of specific physical objects –*e.g.*, weapon systems, military units, etc. In this context, this type of logico-scientific knowledge provided limited utility to commanders in their attempts to engage an adversary's military force. In the present context, however, narrative knowledge system is seen to provide contextual understanding at both an operational and strategic level of analysis. By expanding our focus to include various forms of narrative knowledge, the resulting analytic framework can provide deeper insight regarding (1) the potential impact of specific adversary capabilities on key centers of gravity, (2) the likelihood of specific second-order consequences across each of the PMESII-PT dimensions of the battlespace, (3) the identification of potential leverage points and influence pathways, (4) the likely intentions of an adversary, and (5) the operational approaches likely to be taken by an adversary, to name just a few. By tracking tactical episodes and assessing their impact on the structure and state of the battlespace, analysts can begin to (1) detect shifts in adversary strategy and tactics, (2) assess the relative degree of progress in defeating specific adversary lines of effort, and (3) identify emerging opportunities and risks within the PMESII-PT battlespace. In turn, each of these areas of deeper insight enables us to have greater anticipatory understanding of an adversary operating within a complex and emergent battlespace. Thus, the incorporation of both logico-scientific and narrative forms of knowledge into a holistic framework represents a new paradigm for signature analysis –one that moves beyond simply predicting the existence of specific objects within the battlespace to a level of anticipatory awareness and understanding that enables analysts to project alternative futures within the battlespace.

The Nature of Anticipatory Awareness and Understanding

We employ the term *anticipatory* rather than *predictive* in the sense that complex problem spaces are rarely, if ever, predictable in an objective, deterministic sense. Rather, we can only speak of anticipating future areas of behavioral and outcome emphasis because of three factors that are intrinsic to the modern battlespace. First, we are largely dealing with social systems where free will and intentionality precludes human social behavior from being reduced to a set of mechanical relationships. Second, the modeling of this behavior across the various PMESII-PT dimensions of the battlespace can only be subjectively approximated in terms of general causal dependencies. Finally, the intentional nature of the modern PMESII-PT battlespace forces us to holistically address behavior and outcome in terms of operational relevance –*i.e.*, what might be relevant behavior and outcome in one context is not necessarily relevant when one or more of the contextual factors evolves or changes.

Applying these ideas to our holistic knowledge system, we focus on the specific elements of knowledge that can be linked in signature form to provide anticipatory insight into an adversary's operational campaign design. As illustrated in Figure 1, these elements include adversary motivations, adversary capabilities, and battlespace opportunities:

Adversary Motivations – Understanding the intentions and operational approach of an adversary provides insight into the *motivations* that govern future behavior and outcomes. In the present system design, we maintain this knowledge in the form of hypothesized strategic agendas that represent the intentions and operational approach of an adversary. Over time, tactical episodes serve to update (1) the belief strength of each strategic agenda and (2) the key state variable values that represent operational progress along each strategic agenda.

Adversary Capabilities – Understanding the work capabilities and organizational structure of an adversary provides insight into the *capabilities* that enable or delimit future behavior and outcomes. In the present system design, we maintain this knowledge in the form of a work system model (a linked set of artifacts) that represents an adversary's work capabilities and controlling organizational elements.

Battlespace Opportunities – Understanding potential vulnerabilities and obstacles in the centers of gravity perceived by an adversary provides insight into the *opportunities* that trigger future behavior and outcomes. In the present system design, we maintain this knowledge in the form of state variables defined within various cause-effect system models that comprise the battlespace ecosystem. These variables include key state variables associated with ecosystem systems designated as centers of gravity by an adversary. Still other state variables represent potential leverage points through which second-order effects and indirect consequences can eventually influence the key state variables. A state variable reflects a battlespace vulnerability or obstacle whenever it represents an operational decisive point vis-à-vis the adversary's campaign design –*i.e.*, it (1) reaches a value at or near its tipping point or (2) represents a critical obstacle along one of the adversary's lines of operation or lines of effort.

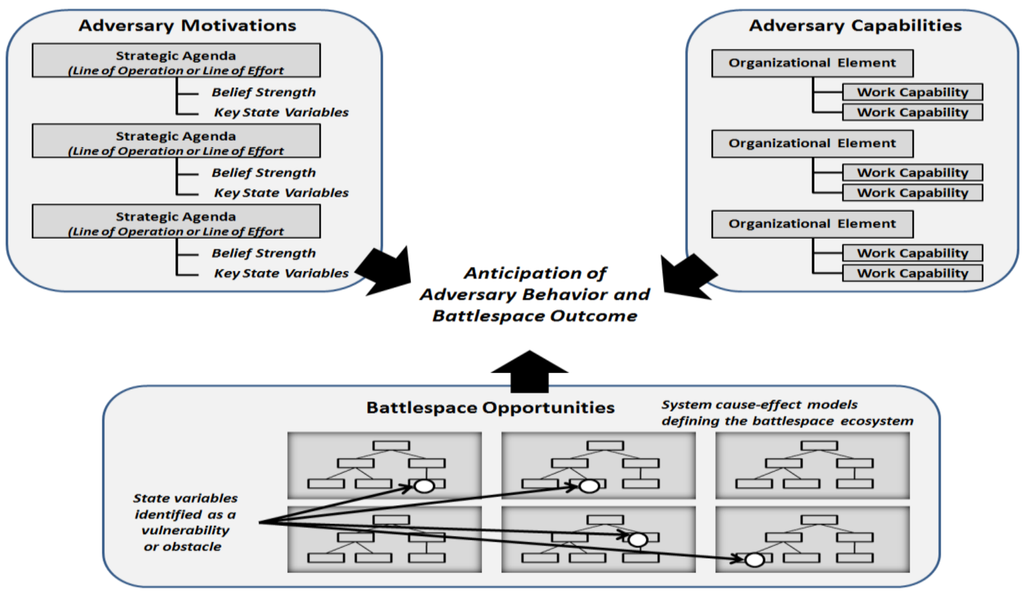

Figure 1 Knowledge Elements Defining Anticipatory Awareness and Understanding

The Analytical Definition of Behavior Signatures

We are now at a point where we can formally define behavior signatures in the context of our holistic knowledge framework. This definition expands the general definition given earlier in this report and adapts it to the specific nature of a complex and emergent battlespace. Specifically, we adopt the following definition:

A behavior signature is a *dynamically constructed narrative* that uniquely characterizes an adversary at a given point in time in terms of a *hypothesized strategic agenda* that is (1) organizationally supported by a *defined work system*, (2) functionally associated with *systemic cause-effect relationships* within the battlespace ecosystem, and (3) instantiated over time by a series of *observable tactical episodes*. A behavior signature enables the anticipation of future adversary intentions and actions to the extent that the contextual framework of knowledge underlying its construction remains valid over time.

Our definition of a behavior signature follows the general architecture of the holistic, self-referent knowledge framework developed in this report. In comparison to previous signature definitions discussed earlier, it is more temporal and intentional in nature –thus reflecting its just-in-time construction and enabling its use for anticipating future adversary intentions and actions. We next illustrate how behavior signatures are developed and maintained over time within a complex and emergent battlespace.

CONSTRUCTING AND EXPLOITING ADVERSARY BEHAVIOR SIGNATURES OVER TIME

Having introduced the concepts of structural and transactional analysis in the preceding section, we are now in a position to discuss how they can be combined into a holistic analytic strategy to construct meaningful behavior signatures of an adversary.[1] In short, this strategy involves three basic tasks. The first task involves the construction of a holistic, self-referent framework of artifacts, work systems and battlespace cause-effect systems, and hypothesized strategic agendas that represent an adversary's operational campaign design. As presented earlier, this framework of knowledge provides the general basis for structurally analyzing the battlespace. The second task involves the development of tactical episodes that are used to dynamically adjust the values of state variables defined within this framework along with the belief strengths associated with each hypothesized strategic agenda. The addition of tactical episodes to the knowledge framework provides the narrative basis for transactional analysis of the battlespace.

The third task involves the application of morphological analysis to reveal operationally significant patterns and relationships that comprise various behavior signatures. The use of morphological analysis provides a systematic approach to visualizing and highlighting both static and dynamic features of an adversary's operational campaign and the battlespace within which it unfolds. In turn, these highlighted signature patterns and relationships serve to suggest future areas of operational emphasis by an adversary –i.e., they provide anticipatory awareness and understanding of the adversary vis-à-vis the specific nature of its operational campaign and the state of the PMESII-PT battlespace. Through transactional analysis, analysts can identify (1) high belief strength values that suggest a strong pattern of operational emphasis, (2) key battlespace artifacts whose state variables represent either tipping points or critical obstacles along a specific adversary line of operation or line of effort, or (3) other artifacts that can act as leverage points for adversary action (*i.e*., their state variables influence via the dependency equations one or more key state variables associated with the adversary's desired end state conditions). At the same time, structural analysis illuminates key linkages that connect adversary intentions, adversary capabilities, and battlespace opportunities. Emergent inconsistencies within the structural framework can serve as indicators of strategy change –*i.e*., episodes that do not clearly conform to existing strategic signatures, systems, or key artifacts. Together, these various forms of signature analysis provide anticipatory awareness and understanding in a complex and emergent battlespace. The general form of this structural analysis is suggested in Figure 2.

Following the approach outlined by Ritchey (2006), the table shown in Figure 2 lists the various dimensions of knowledge that must be structurally connected to form a behavior signature. Each column within this table represents a different dimension of knowledge. The first three columns represent knowledge about the adversary, while the last three columns represent knowledge about the battlespace. Cells within each column reflect signature elements extracted from the holistic knowledge system.

As each tactical episode is added to the morphological table, it is logically connected across the table to form a plausible explanation of the event, action, or emergent condition. The arrows connecting these specific knowledge elements represent but one of many combinatorial possibilities. However, this specific configuration represents the analysts' best judgment as to why and how the tactical episode occurred. As episodes are added to the holistic knowledge system, they serve to (1) modify various state variables throughout the framework of signatures and (2) adjust the belief strengths of each strategic signature hypothesis. Following the definition given earlier, Figure 3 also illustrates the concept of an adversary behavior signature. Essentially, a behavior signature can be defined from a set of tactical episodes that are (1) specifically linked with other battlespace and adversary characteristics and (2) supportive of a specific strategic agenda hypothesis. The structure of such a signature is illustrated by the shaded cells connected by dashed arrows in Figure 2.

An adversary signature reflects a particular association of a strategic agenda hypothesis with the other knowledge elements depicted across the morphological table illustrated in Figure 2. This general signature paradigm can now be used as an analytical framework for developing various types of anticipatory inferences regarding future adversary behavior. In the next several figures, we illustrate different forms which this analysis might take. In Figure 3 we depict the combined use of structural analysis and transactional analysis.

[1] The knowledge framework outlined in this paper has been analytically applied to the study of real-world insurgency groups operating in Lebanon and the Federally Administered Tribal Areas of Pakistan. These illustrations are documented in technical reports available only upon request submitted to the second author and approved by the US Air Force.

In this case, the belief strength of a specific line of effort has risen to a very high value, indicating a strong pattern of operational emphasis. Again, the structural framework used with this morphological analysis can be used to trace linkages from this line of effort back through to an identified center of gravity system and its key battlespace artifacts. Identification of these artifacts suggests areas of likely future action by the adversary.

Strategic Agenda	***Organizational Element***	***Operational Work Capability***	***Center of Gravity System***	***Key Battlespace Artifact***	***Tactical Episode***
Agenda 1 Operational Approach Belief Strength	Org Element A Leadership and C^2 Resources	Work Capability 1 Classes of Effects Belief Strength	Battlespace Sys A Constituent Artifacts	Artifact 1 State Variables	Tactical Episode A State Variable Changes Evidence Likelihoods Ratios
Agenda 2 Operational Approach Belief Strength	Org Element B Leadership and C^2 Resources	Work Capability 2 Classes of Effects Belief Strength	Battlespace Sys B Constituent Artifacts	Artifact 2 State Variables	Tactical Episode B State Variable Changes Evidence Likelihoods Ratios
Agenda 3 Operational Approach Belief Strength	Org Element C Leadership and C^2 Resources	Work Capability 3 Classes of Effects Belief Strength	Battlespace Sys C Constituent Artifacts	Artifact 3 State Variables	Tactical Episode C State Variable Changes Evidence Likelihoods Ratios
Agenda 4 Operational Approach Belief Strength		Work Capability 4 Classes of Effects Belief Strength	Battlespace Sys D Constituent Artifacts	Artifact 4 State Variables	Tactical Episode D State Variable Changes Evidence Likelihoods Ratios
Agenda 5 Operational Approach Belief Strength		Work Capability 5 Classes of Effects Belief Strength	Battlespace Sys E Constituent Artifacts	Artifact 5 State Variables	Tactical Episode E State Variable Changes Evidence Likelihoods Ratios
		Work Capability 6 Classes of Effects Belief Strength	Battlespace Sys F Constituent Artifacts	Artifact 6 State Variables	Tactical Episode F State Variable Changes Evidence Likelihoods Ratios
			Battlespace Sys G Constituent Artifacts	Artifact 7 State Variables	
			Battlespace Sys H Constituent Artifacts	Artifact 8 State Variables	
				Artifact 9 State Variables	
				Artifact 11 State Variables	
				Artifact 12 State Variables	
				⋮	

Shaded cells connected by arrows define an adversary behavior signature

Figure 2 Development of an Adversary Behavior Signature

Strategic Agenda	***Organizational Element***	***Operational Work Capability***	***Center of Gravity System***	***Key Battlespace Artifact***	***Tactical Episode***
Agenda 1 Operational Approach Belief Strength	Org Element A Leadership and C^2 Resources	Work Capability 1 Classes of Effects Belief Strength	Battlespace Sys A Constituent Artifacts	Artifact 1 State Variables	Tactical Episode A State Variable Changes Evidence Likelihoods Ratios
Agenda 2 Operational Approach Belief Strength	Org Element B Leadership and C^2 Resources	Work Capability 2 Classes of Effects Belief Strength	Battlespace Sys B Constituent Artifacts	Artifact 2 State Variables	Tactical Episode B State Variable Changes Evidence Likelihoods Ratios
Agenda 3 Operational Approach Belief Strength	Org Element C Leadership and C^2 Resources	Work Capability 3 Classes of Effects Belief Strength	Battlespace Sys C Constituent Artifacts	Artifact 3 State Variables	Tactical Episode C State Variable Changes Evidence Likelihoods Ratios
Agenda 4 Operational Approach Belief Strength		Work Capability 4 Classes of Effects Belief Strength	Battlespace Sys D Constituent Artifacts	Artifact 4 State Variables	Tactical Episode D State Variable Changes Evidence Likelihoods Ratios
Agenda 5 Operational Approach Belief Strength		Work Capability 5 Classes of Effects Belief Strength	Battlespace Sys E Constituent Artifacts	Artifact 5 State Variables	Tactical Episode E State Variable Changes Evidence Likelihoods Ratios
		Work Capability 6 Classes of Effects Belief Strength	Battlespace Sys F Constituent Artifacts	Artifact 6 State Variables	Tactical Episode F State Variable Changes Evidence Likelihoods Ratios
			Battlespace Sys G Constituent Artifacts	Artifact 7 State Variables	
			Battlespace Sys H Constituent Artifacts	Artifact 8 State Variables	
				Artifact 9 State Variables	
				Artifact 11 State Variables	
				Artifact 12 State Variables	
				⋮	

Associate strategic agenda emphasis with organizational element, work capability, center of gravity, and relevant battlespace artifacts

Figure 3 Likely Areas of Future Action Consistent with an Emphasized Line of Effort

In the next example shown in Figure 4, we illustrate the identification of a decisive point represented as either a tipping point or obstacle. In the case of a tipping point, the analysts have discovered that one of the key state variables has reached a value at or near a desired end state condition identified within one of the adversary's lines of effort. By logically connecting these knowledge elements across the table, the analysts are able to explain why this specific battlespace artifact (and its state variable) represents a tipping point in the adversary's operational campaign. In a similar fashion, the identified artifact might represent a critical obstacle defined within the line of effort's operational approach. Again, contextually connecting these elements across the table allows analysts to explain the operational importance of this artifact. At the same time, the structural connection of this decisive point to an existing center of gravity enables analysts to further identify other artifacts that might be the likely focus of future action by an adversary. Finally, in Figure 5, we illustrate the case where a new tactical episode cannot be plausibly linked with either an identified center of gravity or a strategic agenda. In this case, the combined use of structural and transactional analysis alerts the analysts to the need to reexamine the holistic knowledge system and to possible add a new strategic agenda hypothesis to explain this emergent pattern.

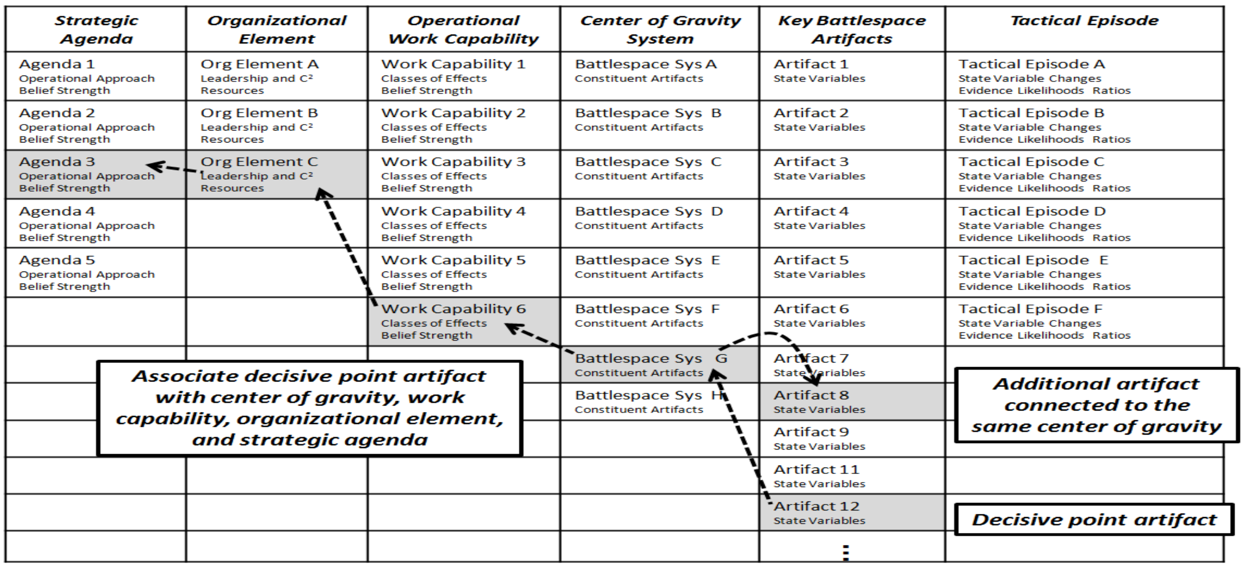

Figure 4 Plausible Explanation of a Decisive Point and Its Implications for Future Action

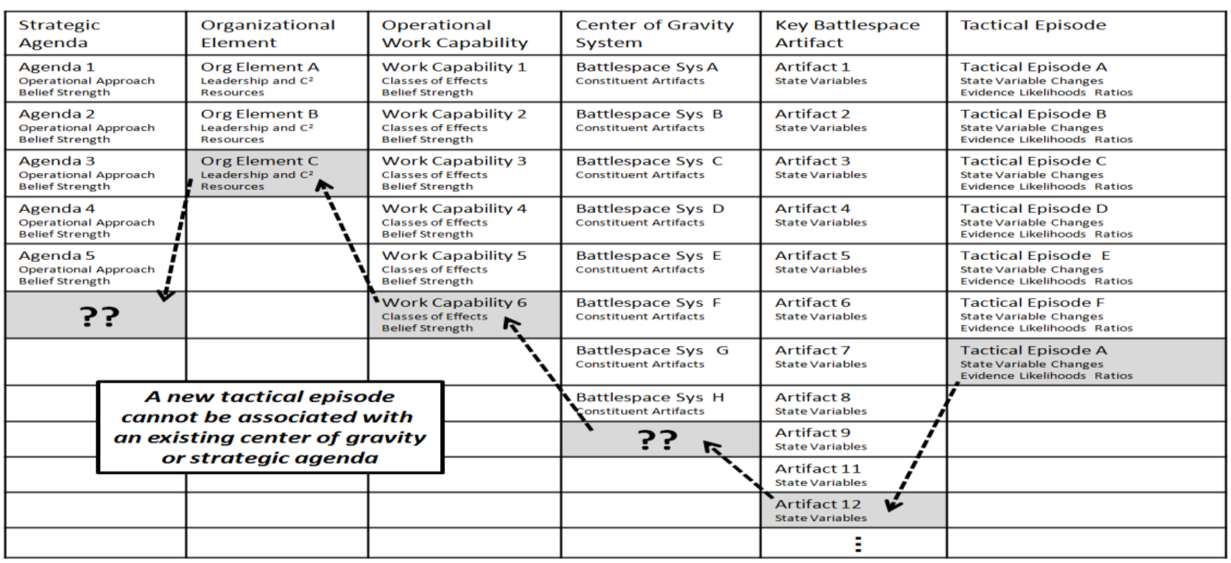

Figure 5 Emergent Pattern Suggesting the Need for a New Strategic Agenda Hypothesis

IMPLICATIONS FOR KNOWLEDGE REPRESENTATION

While the social sciences have developed descriptive theories of narrative knowledge and its role in organizational sensemaking, little of this work has been successfully translated into useful analytical tools that can provide a rigorous and quantitative basis for predictive analysis. However, work conducted by EBR over the past several years for the US Air Force Research Laboratory has produced a new ontological language and framework for representing operational campaigns in terms of a holistic combination of logico-scientific and narrative knowledge. As briefly outlined in this paper, this framework analytically characterizes an intentional work system organization and its operational environment in terms of four interconnected forms of knowledge: (1) artifacts and state variables, (2) cause-effect systems, (3) tactical episodes that change state values, and (4) strategic agendas that link these other forms of knowledge into meaningful lines of effort. Once constructed as an autopoietic web of knowledge definitions, the framework enables dynamic, as-needed contextual interpretation of each element of knowledge, as well as both structural and functional analysis of their relationships. In contrast to existing methods of knowledge representation, knowledge elements can be examined from individual social perspectives, rather than being assigned fixed and universal meaning. This enables analysts to explicitly address context as a subject of inquiry, rather than either ignoring social perspective as a cognitive bias or source of noise or handling it as a metadata or semantic appendage (*cf*., Jansen, 1993; MacGregor & Ko, 2003; Khriyenko & Terziyan, 2006).

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