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Multiscale Representation Phase I

Yaneer Bar-Yam
New England Complex Systems Institute

Reviewed by
Jeffrey R. Cares
Alidade Consulting

Reported to
John Q. Dickmann and William G. Glenney, IV
Chief of Naval Operations Strategic Studies Group

Tasks:

4.1.1. Initial Investigation. Investigate the principal system concepts including scale-based information valuation and process dynamics.

4.1.2. Concept Definition. Provide a thorough analysis of the scale-based dynamics of information in the context of military operations.

4.1.3. Evaluation Framework. Develop a general framework for evaluating the CROP concept, to include the constraints of limited resources (humans, machines, bandwidth, collectors, knowledge, time) suitable for defining, in the abstract, solutions to the information dynamics problem. This framework will be used in further efforts (including Fleet Battle Experiments) to evaluate the CROP and similar concepts.

Introduction

Many innovators have asserted that the US military must have networked forces to successfully conduct operations in the Information Age. This assertion is based on a general belief that traditional means of locating enemy forces, passing command and control information and amassing data for decisions will necessarily improve by the connection of dis-contiguous parts into a networked whole. There are now scores of networked concepts, including Network Centric Warfare (US Navy),[1] the Future Combat System (US Army),[2] the Dynamic Air Tasking Order (US Air Force), Sea Dragon (US Marine Corps) and Joint Vision 2020 (Joint Chiefs of Staff).[3] These concepts contain elements that are themselves networked subsystems (indeed, much of the recent spate of military innovation began with talk of a System of Systems).

The notion of a networked force does not specify, in and of itself, how distributed information is to be shared between networked parts. However, in various suggested strategies for implementation of network concepts it is assumed that information can be gathered and coherently presented by a single system. Although there are many competing visions, they all share the main characteristics of the Common Relevant Operational Picture (CROP) concept. The CROP concept suggests that all the militarily relevant information about a battlespace can be collected in a single repository and displayed in a single presentation architecture that is available for and can be tuned to the preferences and scope of authority of individual commanders at all levels as well as individual soldiers, airmen, marines and sailors.[4,5]

Since the purpose of the CROP is to collect sensory information and describe the military environment, whether or not it will successfully fulfill its promise is less a question of engineering design than it is a matter of system description. For most Information Age military contexts, the systems that must be described are complex systems. For the purpose of this discussion, a complex system is a system of interacting components whose collective behavior cannot be easily inferred from the behavior of the parts in isolation. Therefore, a scientific understanding of descriptions of complex systems is fundamental to successful development of concepts such as the CROP. Central to this scientific understanding is the notion of multiscale representations. Multiscale representations provide an analysis tool for the linkage of information and action. Multiscale representations treat information as an enabler of effective function and avoid the generic, universal information representation that, as will be discussed later, does not work in complex contexts.

The motivation behind military network concepts may be traced to the dramatic growth of networks in non-military contexts. There is, however, a difference between the military concepts and civilian practice. Civilian networks are often organically grown through distributed mechanisms and the information remains distributed and incoherent to unified presentation. Generally, the military concept of networks promotes a coherently and globally accessible system that is centrally conceived, centrally engineered, and centrally integrated.[6] Similar attempts at central design in civilian contexts (such as the Microsoft Network), failed to generate the success of the inherently distributed network systems. Accelerating the growth of military information networks requires a much more systematic and fundamental understanding of the relationship between network structure and function.

Two directions for future work based upon this first stage project include: (1) the development of multiscale representation analysis of military contexts and the implications for force structure and information management and (2) the development of an organic growth "enlightened evolutionary engineering" strategy for military networks based upon extensive "mental gaming" of actual military contexts.

Task 4.1.1

The foundation for the use of multiscale representations involves specific development of methods for analysis of system capabilities. Among the essential concepts developed are:

There is a finite complexity of any entity at a particular scale. One must choose a scale at which to observe a system. Here scale refers to the level of detail, not the scope. For example, one can observe and describe an Army division at the fire team, squad, company, or battalion level. System detail above and below the selected scale is represented by more abstract descriptions than is available at the scale of observation. In other words, to detail the squads in a company means you have chosen the squad, not the company, scale of observation; similarly, to say that a battalion consists of one or more companies defines the battalion at the company, not the battalion scale. The complexity of an entity is a function of the scale of observation.[7]

This finite complexity implies a limitation in the diversity of contexts that can be dealt with by the system. It also implies a limitation in the information flow that can be responded to by the system. Continuing the previous example, observing an Army division at the division level means that squad level activities are abstracted in the detail. The Commanding General of the division, therefore, is ill suited to focus on squad level contexts, such as small units tactics, orders or movement. Likewise, a Squad Leader is ill- suited for command of the entire division. As a general principle, information flows and decisions in complex systems are extremely sensitive to scale. Decisions and information flows must match the scale of observation; otherwise, limitations in decisions and information flows confound the system. An effective analysis of military operations requires describing the impact that can be achieved by enemy and friendly forces at each scale of a potential or ongoing encounter. The ability of a system to deliver impacts at a particular scale depends both on force composition and on the C^4ISR system that it employs. Any large scale force is composed of finer scale forces coordinated to achieve a large scale impact. In the simplest case, the scale of impact of a force involves the delivery of multiple shots in a coherent fashion. The ability to deliver coherent firepower can be achieved by simple coordination, but this is not the same as the ability to deliver measured amounts of firepower at specific targets. In complex military missions (examples include Vietnam and Kosovo), the finer scale forces cannot act in simple coherence and be effective. Complexity of operation involves delivery of diverse shots to diverse and distinct targets with multiple shots directed at targets which require multiple hits to satisfy mission objectives. The scale and complexity necessary to overcome a particular enemy force is dictated by the scale-dependent structure of the enemy force itself, and the scale-dependent structure of the battlespace (terrain, etc.), as well as the complexity of objective constraints (political, etc.). Thus, for example, centralized targeting may be effective in relatively simple large scale conflicts, but is not effective in highly complex encounters. The C^4ISR system should be designed to determine effective mission objective based firepower, and to coordinate its delivery, while the military structure must be designed to deliver this firepower.

Of particular relevance to systems involving human beings, including military ones, is the finite complexity of a human being at the scale of interaction between human beings. The limitation on the complexity of response of a human being is a key "human factor" that is relevant to the design of hybrid human/machine systems. Specific implications for the nature of effective design are to be discussed in various examples and below in progress reported toward task 4.1.2.

Task 4.1.2

In this project, specific attention has been made to the application of multiscale analysis to 21st Century Warfare and the comparison of traditional warfare with prospects for Network Centric Warfare. The focus, however, is on analysis of the CROP concept as a guiding principle for developing the information structure of networked forces.

The opportunities for communication in traditional military contexts have been limited. Experience with the effects of limited information, along with the explosion of information networks in society, has led to a general belief that creating networks that provide a ready access to information will lead to substantially improved effectiveness. Counter to this notion, the limitation of an individual human being's complexity suggests that information flow may not be helpful (and may even be dangerous) in a context where real-time response is necessary and action based upon relevant information can be impaired by spurious information, i.e. distraction. Even when relevant information can be extracted from an information rich source, substantial delay in response will result from the filtering process.

Some military innovators have suggested that the system must be designed like the "all-points-connected" networks of individuals in social systems (an example of which is the Internet). Such architectures may allow the development of more functionally oriented sub-networks of individuals through trial and experimentation over extended periods of time. When action is coordinated through such a network, limited sets of individuals and communications are involved. Whether a specific communication is built upon a network design through hardware or software is not essential, what is essential is that information relevant to specific acts is communicated effectively when rapid response is necessary.

The limitation in the complexity of response of an individual human being can be readily recognized in the context of information rich environments. Whether we consider the possibility of a person paying attention to multiple conversations at a party, or multiple channels of television simultaneously, limitations are well known scientifically (and fairly obvious to the lay person through everyday experience). While these examples show that an individual has an ability to focus attention on the relevant information in a "noisy" environment, this ability has limitations and any noise filtering accelerates exhaustion. Moreover, in hazardous or demanding environments distraction results in degraded attention.

The objective of this research is to provide a context for recognizing the role of information in action and response to environmental demands and challenges associated with specific tasks. *Our conclusions can be stated immediately: The CROP concept as articulated violates a basic principle of information distribution in complex systems. The central task of a sensor system is to provide* ***relevant*** *information Increasing the availability of* ***potentially relevant*** *information must be carefully weighed against the damage due to distraction by irrelevant information.* While this statement is natural and intuitive, even obvious, we emphasize this as the primary conclusion of our study precisely because the CROP concept, as articulated, fundamentally violates this concept. Indeed, the CROP concept, while justified as the basis of the new networked military systems design, contrasts with other concepts of networked and distributed information systems (both real and imagined). *Instead, it corresponds to the concept of a centralized data processing system.* We note that the objective of multiscale representations is to determine the information relevant to a particular observer's scale. Therefore, the concept of a multiscale representation can provide substantial guidance about building more effective concepts of information distribution in a networked system. While such guidance is beyond the scope of the present project, we conclude this document with suggested research program to apply multiscale representations for the development of networked information systems that can replace the CROP concept.

Typically, information about the local environment is the most relevant, and information about remote locations is less relevant. In a command hierarchy, relevant information is information at the scale at which a commander must make decisions. At more senior levels of command, coarser scale information may require aggregation of finer scale information. As in the traditional saying, "can't see the forest for the trees," there is a great difficulty in recognizing the larger scale behavior from the details. Thus, the accessibility or exposure to such details does not necessarily enable effective action.

Consider the flood of e-mail messages that occupy substantial attention of each individual today. In the context of an interactive effort, the usefulness of e-mail is clear. However, in the context of time sensitive tasks with life and death consequences, such distractions are inappropriate. An open network, sometimes envisaged by planners, would be even worse, corresponding to having everybody see everybody else's email. At an even greater extreme, where mobile sensors are flooding a network with real-time video from many sources, attention to such an information flow is highly unrealistic.

A more careful understanding of information in complex systems suggests that the most important task of an information processing system is not collecting it (in fact, in many complex cases, this is the most trivial task). Discarding irrelevant information is the most important task, yet it is a task which is often most difficult. As an illustration, in the case of human perception we know that people do not have eyes in the back of their heads. This reflects the fundamental tradeoff that is being discussed: while information that is lost can, at times, be important, even life-saving, the importance of reserving attention for the information which is more likely to be important is essential and thus the tradeoff of ignoring substantial amounts of potentially useful information is being made by the biological system.

The availability of information can thus be seen to be detrimental in many cases. The imagined concept that somehow our attention will be drawn to precisely the piece of information that is relevant to our next action cannot be assumed. The process of design of a system to provide the relevant information must be carefully considered since *there is no generic network design that will provide a general solution to this problem.* This is the difficult task that is usually not recognized when conceptualizing information systems, or when recognized it is not adequately resourced when acquiring new sensor and information systems. Multiscale representations can provide the fundamental understanding necessary for examining strategies to identify the relevance of information in the context of specific tasks as well as the understanding necessary for effective development of future operational concepts that are centered on information intensive missions and functions. Application to specific tasks requires substantial "mental gaming" as well as direct testing of scenarios. Such scenario testing would involve teams of individuals performing specific tasks in challenging (complex) environments requiring coordinated behaviors.

Task 4.1.3

This section suggests a general framework for evaluating the CROP concept, to include the constraints of limited resources (humans, machines, bandwidth, collectors, knowledge, time) suitable for defining, in the abstract, solutions to the information dynamics problem. This framework can be used in further efforts (including Fleet Battle Experiments) to evaluate the CROP and similar or substantially distinct concepts.

The framework recognizes *scale* as the most fundamental characteristic of Information Age command and control. This is in stark contrast to other more tangible characteristics from Industrial Age command and control such as speed, reliability and security, all of which can trace their inception to modes of communication and models of the environment that depend on the delivery of physical messages rather than implicit meaning. A collection of messages (particularly messages containing positional information about an enemy) does not guarantee an understanding of the importance of the messages at scales coarser than the messages themselves. *Scales, then, are a set of perspectives from which the framework focuses attention on an Information Age command and control system.*

The evaluation framework requires identification of the particular scales from which the environment will be observed. For typical Industrial Age military contexts, these scales can be usefully defined using the existing levels of command. An area for future research is to identify what these scales will be in Information Age warfare processes.

Our analysis is guided by the recognition that an information system cannot be evaluated without an understanding of the function or task that it serves, and particularly the structure and function of the system that uses this information. A general framework for evaluation of the CROP concept can be based upon the principles of multiscale representation once the following key question is addressed: Is CROP and the related networked information system designed to serve the conventional command and control hierarchy, or is this system designed to replace the command structure with another? If it is to serve the existing command structure, then it must act to filter information by scale aggregation so as to allow effective functioning rather than to expose commanders to irrelevant information. If it is to change the command control system, then the evaluation framework requires joint analysis of command structure and the information structure in the context of expected mission objectives. In this project, we confine ourselves to describing the evaluation framework of the CROP concept as supporting structure to the existing command and control systems and organizations. We also discuss the context and reasons for extensions of this Phase I project that generalize this analysis to consider alternate command and control structures, organizations and technology architectures and their suitability for complex missions (see below).

The conventional command hierarchy assumes or demands aggregation of information as a natural outcome of the limited information flow between levels of command. Each commander is responsible for recognizing and reporting the limited information (such as enemy geo-location or own-force logistics data) that is essential for higher-level commanders to evaluate and respond to as aggregate information. Aggregation of information requires military specific understanding of both strategy and tactics in the context of military confrontation. Once orders are received, each commander is responsible for obtaining relevant environmental information that affects the manner of execution and interpreting the actions necessary for execution through orders to lower level commanders or soldiers in the field.

The CROP concept, as currently articulated, does not recognize the essential nature of the aggregation of information. At this time, computer based systems are not capable of the pattern recognition processes that are necessary for such information aggregation. More specifically, pattern recognition based abstraction is the product of military experience in the context of military operations. The translation of information to a coarser scale often entails identification of broad patterns and trends, creation of metaphors and symbols or re-interpretation of the information based on history, calculation or hunch. In short, in complex environments, translation from finer to coarser scales frequently requires fabrication of information that is not explicitly contained in the physical manifestation of the environment. Since computer systems are not, in themselves, capable of such aggregation at this time, human designed methods of information aggregation must be contained within (through electronic implementation) or in conjunction with (through human action) the CROP design. Development of the necessary filters of information and their representational abstractions in the form of auditory or visual displays should be considered a challenging task. This task is essential to the success of CROP.

The most basic framework for analysis of specific CROP implementations should be the analysis of the implementation of transparent aggregation of information. This aggregation should take the form of auditory or visual information flows that represent the necessary information at the scale needed for the commander response. Several levels of *focus* that limit distraction at the expense of potentially relevant information should be available. The information provided in such aggregated information displays must be guided by military intuition and experience, not just by technological feasibility.

While the gathering of and representation of information is the essential role of CROP, our evaluation framework points out the essential and complementary task of interpreting coarse scale information in the form of military goals, objectives and commands, in terms of actions in the context of specific environmental contexts. This corresponds to the detailing of coarser scale information into the fine scale. The translation of information to a finer scale often entails interpretation from broad patterns and trends to particular, singular events, deciphering of metaphors and symbols or relevance of collective determinations to individual histories, calculations or hunches. In short, in complex environments, translation from coarser to finer scales frequently requires interpretation of implications about the physical world in general to the details of physical things in particular.

Understanding multiscale representations is a fundamental prerequisite for building an effective fighting force dependent upon large quantities of information. This knowledge must be fully integrated into new concepts, technological design and acquisition decisions, experimentation, gaming and simulations of future combat. The guiding concepts for information systems and force design should capitalize on the multiscale nature of information, decisions and hierarchy in Information Age competition. This includes the analysis of strengths and weaknesses of friendly and enemy forces.

The CROP evaluation framework we have described adopts the CROP in the context of conventional military control. The challenge of applying this analysis to Information Age

Warfare must not only recognize the importance of information aggregation, it must recognize the inherent complexity of Information Age Warfare contexts through the environmental, enemy and political components. Indeed, we might define Information Age Warfare as those contexts in which the demands of complex military operations exceed the information flow capacity of the conventional military structure. While this appears to be the key opportunity for CROP based concepts, the current CROP concept is not well suited for this task precisely because it does not recognize the need for information filtering and the limitations on human information flow in real time response.

If the warfare environment is complex enough, then

— collecting detail at fine scales does not guarantee a meaningful picture at coarser, composite scales.

— broad patterns from coarser scales do not guarantee a meaningful local picture at finer, distributed scales.

The CROP concept as defined does not solve these problems of information flow and representation. By not addressing these problems, the CROP fails to address the key role of information for networked forces engaged in Information Age Warfare. The information flow problems must be solved by changes in the command structure. The reason for this is an impossibility of abstraction in a complex context where individual actions do not aggregate to create collective behaviors in a simple way. Dis-contiguous distributed forces betray very little information in the physical location; deeper questions of intent and the dynamics of maneuver are contained in higher scale patterns. In this context, the relationship between scale and command level in the military hierarchy do not apply. The application of military force in this context requires new force structures in conjunction with radically different information systems to achieve the necessary aggregation of force behavior.

A multiscale analysis and the resulting evaluation framework must then focus on an examination of the decisions required at each important scale in Information Age command and control systems. These decisions must be matched to the command structure capabilities. For existing military contexts, these decisions often depend on physical attributes of the environment and the location of enemy and friendly forces.

An example is the archetypal Course of Action (COA) analysis. In many Industrial Age contexts, defensive decisions depended on which Avenue of Approach (AOA) an enemy might choose during an attack. A commander might consider the three most likely AOAs, and label each of these a COA. Then the commander would array forces to counter one or all of the COAs, leaving a reserve to commit once the enemy's particular COA was determined. A decision tree could be constructed from this analysis, with each decision in the tree depending on such physical considerations as AOA trafficability assessments, enemy location data or the state of friendly defensive positions. In the context of Information Age Warfare, where forces may be more mobile, more dispersed, more hidden by context or constraint and stealthier than previously, the variety of decisions and number of possibilities is many orders of magnitude greater and the standard COA analysis must be generalized for distributed decision-making and aggregation. An area for future research is to determine the types of Information Age decisions appropriate to each level in a command hierarchy.

Attendant to determining the appropriate scales and the useful decisions at those scales are measurements of the environment that will aid in making the decisions. By definition, an observer will search for information in the environment at the scale of observation. Insofar as there is physical evidence at that scale which helps with the decision, direct, explicit observation of the physical world is appropriate. Where the information is more implicit, observers (and, as a function of hierarchy, the entire chain of command) must find indirect physical evidence that translates into information that helps with a decision. An example of the former is determination of the center of mass as well as the speed and direction of an armored division on maneuvers in support of archetypal COA analysis. An area of future research is determination of the coarser scale patterns, structures and behaviors that translate physical measurement at a finer scale to decisions at a coarser scale. A mature evaluation framework would also allow for replication of finer scale instances from coarser scale patterns.

As a concluding note, since there is no generic network design that will provide a general solution to the problem of multiscale function, development of a framework to evaluate concepts such as the CROP is highly context dependent. In other words, while the concept of multiscale representations may be general, application of multiscale representations to a CROP concept within a specific network design is greatly impacted by the design of the network and the nature of the combat tasks. For this reason, development of the framework to any more than the general statements contained in this section will require *in situ* research during such events as Fleet Battle Experiments, war games or other high context activities.

Conclusions and Extensions of the Multiscale Analysis beyond the CROP

The focus of this report on the implications of multiscale representations for the CROP concept led to the centrality of the limitations of human complexity on the structure and function of an information network. In the context of more specific CROP designs, the framework of multiscale representations provides a mechanism for evaluating CROP concepts through the comparison of the system (human and machine) capability in aggregation of information, and commander capability in responding to this information.

The importance of this subject extends beyond the analysis of CROP to the analysis of the environmental complexity, the force structure, and the command and control of the force structure in view of specific mission objectives. Thus, a more systematic evaluation of multiscale representations in the context of military applications would discuss the effectiveness of military command and control structures in the context of complex mission objectives. Complex mission objectives are the context of difficult 21st century military challenges for which new information technologies are most relevant.

Thus, the application of multiscale representations to a second phase project should be pursued. In the context of pursuing this project, preliminary efforts have been made to consider both information aggregation, and multiscale complexity of military structure. The results of these investigations have been described in oral reports to the Chief of Naval Operations Strategic Studies Group and the Newport Center for Information Age Warfare Studies and would be the basis for extending this work in a second stage project. These reports are outlined below.

Additional Report topics:

First Oral Report:

1. Introduction to complex systems and patterns of collective behavior
2. Multiscale representations and force aggregation
3. Tradeoff between large scale and complex operations.
4. Control structure analysis for the coordination of complex response
5. Application of multiscale analysis to the 21st Century plans for littoral warfare
6. Multiscale representations and the 21st Century Warrior

Second Oral Report

1. Review of first oral report
2. Implications of multiscale analysis of control structures for large-scale engineering
3. Enlightened evolutionary engineering

References:

1. D. S. Alberts, J. J. Garstka, F. P. Stein, Network Centric Warfare, DoD C4ISR Cooperative Research Program (1999)

2. Future Combat Systems: http://www.darpa.mil/fcs/

3. Joint Vision 2010: http://www.dtic.mil/jv2010/jv2010.pdf

4. U.S. Joint Forces Command (USJFCOM) definition---Common Relevant Operational Picture (CROP): CROP is a presentation of timely, fused, accurate, assured, and relevant information that can be tailored to meet the requirements of the joint force and is common to every organization and individual involved in joint operations. http://www.ijwa.org/J9/j9_main.htm

5. Ref. 3, p. 16: "the capability to collect, process, and disseminate an uninterrupted flow of information,…" p. 18: "Improved command and control, based on fused, all-source, real-time intelligence…".

6. Ref. 3, p.32: "The implementation process will integrate ongoing initiatives, such as the Joint Requirements Oversight Council, Joint Warfighting Capabilities Assessments, and Advanced Capabilities Technology Demonstrations (ACTD), to promote the integrated development of operational capabilities."

7. Y. Bar-Yam, Dynamics of Complex Systems, especially Chapters 8 and 9.

8. P. J. Hiniker, 4th International Command and Control Research and Technology Symposium, 1998,http://www.dodccrp.org/Proceedings/DOCS/wcd00000/wcd0006f.htm