Applications of Complex Systems to Operational Design

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Simon distinguished between the declarative logic of the natural sciences, concerned with how things are, and the normative logic of design, which is concerned with how things ought to be [Simon 1996]. According to Simon, everyone who devises courses of action aimed at changing existing situations into preferred ones is engaged in designing. Where traditionally design was associated with giving form to tangible artifacts, this broader conception recognizes that design also applies to more abstract entities. Services, interfaces, networks, projects, and even discourses are legitimate subjects for design [Krippendorff 2006]. The topic of this paper is the design of the operations of an organization, which compared to traditional design concerns in architecture and industrial design, are fundamentally fluid, dynamic, and open systems. Consequently, complex systems theory contains important insights for operational design. This paper uses examples from military operations to illustrate complex systems applications to operational design. We show how an appreciation of complex systems has been captured in U.S. Army doctrine on design, leading to the most significant change in the Army operations process in over a generation. We then identify further opportunities to build on this success within the Army. The implications are quite general, and apply to the design of business and interagency operations.

1 Introduction

Much of the complex systems literature is concerned with the *science* of complex systems. We know quite a lot about the collective behavior of complex systems, such as social insect colonies, gene regulatory networks, and social networks. We know rather less about how these insights apply to the improvement of social systems. Questions of improvement are inherently systemic: if improvement is assessed only with respect to the part, there is no guarantee that local improvement will not make the whole system worse [Churchman 1968]. Questions of improvement are also questions of design: they conform to a normative rather than a declarative logic [Simon 1996].

The earliest theories of design were developed by architects. Research into design methodology as a broader topic common to architects, engineers, industrial designers, and urban planning is often traced back to the first Conference on Design Methods in London in 1962 [Cross 2006]. Early models of the design process were elegant, logical, and bore little if any resemblance to what designers actually did [Lawson 2006]. Consequently, design research in the 1970s and 1980s moved away from building rational models of the design process to develop participatory methods of design, and to articulate the unique contributions of designers in situations involving uncertainty, instability, uniqueness and value conflict [Cross 2006]. This helped establish design as a discipline, and encouraged its application in new and more abstract fields. Krippendorff traces a trajectory of the expanding applicability of design from products to services, interfaces, networks, projects, and discourses [Krippendorff 2006]. Design is now often portrayed as a broad approach to understanding and transforming human situations that blends analytic and intuitive thinking [Martin 2009].

In this paper, we will be concerned with the subject of operational design; that is, the design of actions taken by an organization to improve a problematic situation experienced by a social group. Frank Lloyd Wright famously observed that a doctor can bury his mistakes but an architect can only advise his client to plant vines. Wright's observation underscores just how little influence an architect has on a building after its construction. Although this leaves architects open to criticism for their mistakes or lack of foresight, it also permits a very useful simplification. In most circumstances, the architect can approximate their environment as a closed system. In contrast, an operational designer establishes an ongoing relationship with the affected social group. The interactions of an operational designer are iterative and exhibit a greater degree of reversibility than the design decisions of an architect. The operational designer is part of the social system they are designing, and must conceive of their environment as open to flows of energy, matter, and information.

Operational design thus conceived is a problem of complex systems design. The purpose of this paper is to explore this intersection between the interdisciplinary fields of complex systems and design. We will draw on examples of operational design from the military domain. Western militaries have developed a number of sophisticated approaches to operational design in the last decade in response to the complex challenges of contemporary operations. Section 2 examines the relationship between complexity and military operations. Section 3 describes concepts for operational design developed by Australian, Israeli, and U.S. Armies over the past decade. Section 4 identifies opportunities for incorporating further insights from complex systems into operational design. Section 5 concludes with broader implications for the design of other governmental agency and commercial operations.

2 Complexity and Military Operations

2.1 Complexity is an enduring feature of military operations

> …in war, as in life generally, all parts of the whole are interconnected and thus the effects produced, however small their cause, must influence all subsequent military operations and modify their outcome to some degree, however slight. In the same way, every means must influence even the ultimate purpose.
>
> —Carl von Clausewitz [1984]

Clausewitz's influence on Western military thinking has ensured that Western militaries, and particularly land forces, have been self-aware of the sheer complexity of war since *On War* was published in 1832. Clausewitz [1984] insisted that war does not follow its own logic, but is an instrument of policy. As such, no military action can be evaluated in isolation, and has meaning only within its political context. Restated in modern terms, war is an open system, and the information relevant to its description is as unbounded as the political system that generates the conflict.

Clausewitz also appreciated the nonlinearity of war. He described the role of interaction, friction, and chance on the battlefield. Beyerchen [1992] showed that these concepts align with key concepts from nonlinear science, including positive feedback, instability, entropy, and chaos. According to Beyerchen, Clausewitz "perceived and articulated the nature of war as an energy-consuming phenomenon involving competing and interactive factors, attention to which reveals a messy mix of order and unpredictability" [Beyerchen 1992].

2.2 Complex systems theory influences modern operational art

While it is arguable that Clausewitz anticipated some developments within the nonlinear sciences, the science of his time was of course Newtonian. In 1996 and 1997, the U.S. Marine Corps updated their key doctrinal publications to describe the nature of war using complex systems concepts. The U.S. Marine Corps also funded a nine year program of international workshops for complex systems modeling, named Project Albert (see for example [Hoffman & Horne 1998]).

The U.S. Army's School of Advanced Military Studies (SAMS) began teaching complex systems theory at about the same time it was introduced into U.S. Marine Corps doctrine (see for example [Schneider 1996]). SAMS was established in 1984 as a graduate school to educate military officers on the operational level of war. The acknowledgement of an operational level of war linking strategic goals with tactical action had been introduced in U.S. Army doctrine (known as AirLand Battle) two years earlier [United States Army 1982].

The operational level was based on the theory of operational art developed by the Soviet military theorists, especially Svechin and Tukhachevsky, between the two world wars. Napoleonic warfare between 1805-1815 was seen as ideally consisting of a single decisive battle, such as Napoleon's victory at Austerlitz: short, sharp, and achieving a strategic outcome [Epstein 1992]. The Soviet theorists recognized that decisive battle in modern industrial warfare was unlikely, and seeking it could lead to the trench warfare stalemate of World War I. To restore movement on the battlefield, the Soviets introduced operational art, which integrated multiple parallel and sequential tactical actions to achieve a strategic goal.

Operational art involves the synthesis of a complex purposeful whole composed of distributed and dynamic components. More simply, *operational art designs a system*. The motivation for the rediscovery of operational art in the U.S. included Vietnam and the Cold War. The AirLand Battle doctrine writers were part of the Vietnam reform movement. Among other issues, in Vietnam there was a failure to convert tactical success into strategic progress. At the same time, the Cold War context involved planning for conflict on a large scale. The maneuver of large formations required the grouping of battles and operations into campaigns in order to match the Soviets' ability to sequence operations over the full depth of the battlefield. SAMS was at the center of the introduction of operational art into U.S. Army theory, doctrine, and education. Consequently, complex systems theory had immediate relevance to the operational level of war, as well as to theoretical research at SAMS.

Outside the U.S., in 1994 Israeli Brigadier General Or initiated a Special Task Force to investigate a perceived lack of generalship within the Israeli Defense Force (IDF). The review resulted in the founding of the Operational Theory Research Institute (OTRI) in 1996 under the leadership of Brigadier General (Res.) Tamari and Brigadier General (Res.) Naveh. Naveh's research into Soviet operational art connected Tukhachevsky's Deep Operations theory with its roots in systems theory. In comparing Russian definitions of operations with von Bertalanffy's concept of the universal system, Naveh concluded that "one can rightly claim that the operational level is the implementation of the universal system in the military sphere" [Naveh 1997]. Additionally, whereas Clausewitz advocated defeating the enemy by the physical destruction of their source of power, Tukhachevsky advanced a theory for disintegrating enemy forces through operational shock. Deep operations involved simultaneous disruption of the enemy's configuration over its entire depth, integrating physical strike, cognitive surprise and deception, and momentum (operational tempo and density) [Naveh 1997]. In addition to the classical Soviet operational art, U.S. developments in operational art were taught at OTRI. The influence of complex systems could be found in OTRI's application of swarming and network theories to urban operations [Weizman 2006a].

The Australian Army also made important contributions to the application of complex systems theory to military operations. Within the Future Land Warfare Branch of Australian Army Headquarters, Brigadier Kelly and Lieutenant Colonel Kilcullen led the development of *Complex Warfighting* [Australian Army Headquarters 2004], the capstone future operating concept for the Australian Army. *Complex Warfighting* characterized the future operating environment as complex, diverse, diffuse, and lethal, describing a conflict ecosystem with an increasing variety of state and non-state actors. In response to the challenges of complex warfare, the future operating concept envisaged small, highly autonomous, modular combined arms teams, capable of swarming and reconfiguring in different ways.

3 Military Responses to Complexity

3.1 The natural response to complexity is adaptation

In 2006, the publication of *Adaptive Campaigning* [Australian Army Headquarters 2006] built on the framework of *Complex Warfighting* to recognize that the appropriate response to complexity is adaptation. *Adaptive Campaigning* introduced the concept of operating across five simultaneous, interdependent and mutually reinforcing lines of operation. The purpose was to recognize that traditional military combat actions alone could not be decisive in complex warfighting: to cause an attractor change to a new stable society, multiple concurrent actions are required. *Adaptive Campaigning* described an adaptive cycle for operations consisting of four steps: act, sense, decide, adapt.

Adaptive Campaigning provided the Australian Army with a new framework for campaign planning, which was immediately tested in Iraq and Afghanistan. The commander of the first Reconstruction Task Force (RTF), Lieutenant Colonel Ryan, explained how this new approach was applied. "Possessing this 'human map', continually updated using complex adaptive systems theory, equipped the commanders and staff with insights into the dynamics of the province and the ability to assess the impact of RTF projects on the various local actors" [Ryan 2007]. In addition to enhancing the RTF's operational adaptation, the concepts from *Adaptive Campaigning* were used to implement counter-adaptation operations against the Taliban, aimed at disrupting their ability to adapt.

The commander of the RTF 3, Lieutenant Colonel David Wainwright, also the lead author of *Adaptive Campaigning*, applied complex systems theory to military operations within the framework of *Adaptive Campaigning*. The campaign plan developed six interdependent lines of simultaneous and sequential operations to build indigenous Afghan capacity towards self-reliance (see Figure 1 for a graphical reconstruction of the campaign plan). The headquarters developed an adaptation cycle to implement Wainwright's concept for analysis-led reconstruction operations.

In a recent study of the Australian Army's application of *Adaptive Campaigning* during RTF 3 in Afghanistan and Overwatch Battle Group (West) 1 in Iraq, Major Bassingthwaighte concluded that "…using Adaptive Campaigning as a framework in context with a particular situation and mission results in a workable campaign plan that can guide tactical action that supports the strategic objective" [Bassingthwaighte 2011]. Bassingthwaighte cited examples during Operation Spin Ghar in Afghanistan and during an incident at the Al Khidr Police Service in Iraq where the campaign plan provided the rationale for adapting tactial actions in a changing environment to improve coherence with the strategic goal [Ibid].

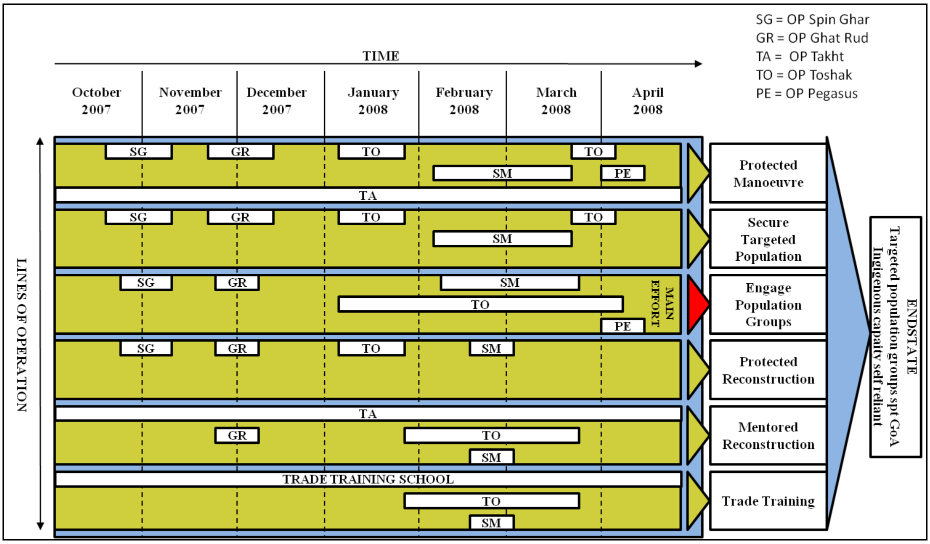


Figure 1. Campaign plan for the operations of RTF 3, courtesy of [Bassingthwaighte 2011].

In 2008, the Chief of the Australian Army, Lieutenant General Ken Gillespie, launched the Adaptive Army initiative, which included the biggest restructuring of the Army since 1973 [Australian Army Headquarters 2008]. The objective was "…improving the quality and timeliness of information flows throughout Army in order to enhance Army's adaptation mechanisms at all levels. [Ibid]" The Army was reorganized into two Commands responsible for adapting at different time scales. This extended the application of complex systems principles from operational design to organizational design, and provided a better fit between the operations and structures of the Australian Army for complex operations.

3.2 Reframing enables a deeper form of adaptation

Since its inception, Israel's OTRI had been developing a novel approach to operational design. Naveh's theory of Systemic Operational Design (SOD) presented a fundamental challenge to the prevailing paradigm of Western military theory, which he characterized as driven by the industrialization of war, obeying a linear order and binary logic [Naveh 2005]. Naveh emphasized a form of adaptation that required reframing the operational artist's theory of reality in order to create new forms of maneuver. This new way of thinking, first outlined by the Special Task Force in 1994 [Naveh 2007a], was tested in 2002 when Brigadier General Kokhavi, commander of the Israeli Defence Force 35 Paratrooper Brigade and graduate of OTRI, designed the Nablus and Balata components of Operation Defensive Shield. The following remark during Kokhavi's war council provides an illustration of how the brigade reframed its thinking about urban operations.

> The prevailing maneuver paradigm is about geometrical order, physical cohesion, and massed firepower. Its conceptual coherence is embodied in its formal simplicity. Moreover, since the similar patterns of space are being utilized by the competing symmetric contenders, the rationale of emerging operations is deterministic and the problem of self-orientation, both geographically and cognitively, by individual tactical

commanders is a minor challenge. Once we shift from modes of action based on presence to modes of action based on disappearance, and from maneuver framework reflecting Euclidean geometry to maneuver framework reflecting geometry of complexity we magnify the space for exploiting potential, yet at the same time we pull the cognitive challenges for warfighters to new extremes. Since every unit commander is an autarkic fractal component within an emerging fractal system, the cognitive problem of self-orientation becomes three fold. First one has to refer, at every moment of the evolving operation his relative position to the geography. Second, one has to refer, at every moment of the evolving operation, his relative position to sister units functioning within the relevant operational space. And, thirdly, one has to draw, at every moment of the evolving operation, the systemic implications from his positioning in relation to the logic of the emerging maneuver as a whole. The first is about navigation, the second is about orientation, and the third is about systemic awareness. I mean awareness not in the sense of recent American clichés but a cognitive quality implying synthesis. Therefore, we need to prepare navigation aids, to invest in developing common spaces of understanding in the fighting units, and to design a command architecture enabling dynamic learning in action [Naveh 2005].

Kokhavi describes how his infestation strategy "inverted the geometry" of the urban space in order to walk through walls:

…this space that you look at, this room that you look at, is nothing but your interpretation of it. […] The question is how do you interpret the alley? […] We interpreted the alley as a place forbidden to walk through and the door as a place forbidden to pass through, and the window as a place forbidden to look through, because a weapon awaits us in the alley, and a booby trap awaits us behind the doors. This is because the enemy interprets space in a traditional, classical manner, and I do not want to obey this interpretation and fall into his traps. […] I want to surprise him! This is the essence of war. I need to win […] This is why that we opted for the methodology of moving through walls… Like a worm that eats its way forward, emerging at points and then disappearing. […] I said to my troops, "Friends! […] If until now you were used to move along roads and sidewalks, forget it! From now on we all walk through walls!" [Weizman 2006b]

While the tactic of entering buildings through holes blasted in the walls rather than through doors or windows is common in urban operations, the novelty of Kokhavi's design was in the scale on which this occurred, and the decentralized command and control architecture for the infestation operation.

Further applications of SOD in Israel included Kokhavi's design for the evacuation of settlements in Gaza in 2005, and the Northern Storm contingency for a campaign against Hezbollah, which was designed between 2002-2005 under the leadership of Major General Gantz [Naveh 2010]. Beginning in 2003, the IDF rewrote their doctrine, the core of which was inspired by SOD. The new doctrine was officially published in April 2006, just before the July 2006 Israel-Hezbollah war. Following the failure of the IDF to meet any of their strategic objectives during the war, there was a rush to assign blame to the politicians, the Chief of Staff, the Air Force, the Army, as well as the way the war was planned, communicated, and executed [The Economist 2006]. The new doctrine was criticized as being "too complicated, vain, and could not be understood by the thousands of officers that needed to carry it out" [Matthews 2008]. U.S. historian Matt Matthews drew the following conclusion from his study of the 2006 war.

Shimon Naveh's SOD has come under much criticism for being nearly incomprehensible to those who were charged with its implementation. The core of SOD may not be without

> merit, but it is useless if it cannot be understood by officers attempting to carry out operation orders using SOD terminology and methodology.

Naveh acknowledged that SOD was difficult to understand, but that "…wars are very hard to fight and yet we go and fight them…. If you're serious about your profession, then you'll go through it" [Naveh 2007b]. He noted that the generals who orchestrated the 2006 "ill-conceived and poorly executed campaign" [Naveh 2007a] were not advocates of the OTRI approach but those who, in the words of Dov Tamari, had been "seduced by the belief that fighting a war can eliminate a threat" [The Economist 2006]. Certainly, the air-dominated "effects-based operations" approach that the IDF initiated the conflict with was fundamentally different to the SOD strategy articulated in the Northern Storm contingency campaign design. Nevertheless, Matthews' warning about the potential for complicated language to reduce the clarity of military orders was persuasive, particularly in the U.S.

3.3 A simplified design methodology

The U.S. Army Capabilities Integration Center[1] (ARCIC) introduced concepts mirroring the Australian and Israeli responses to complex warfighting to the U.S. Army. In 2005, the U.S. Army was re-examining its approach to the Iraq war and searching for fresh thinking. SAMS students coached by Naveh successfully used SOD to formulate a creative approach to campaign design within the Unified Quest wargame. Following a five-part Senior Leader Forum on operational art and design, ARCIC published a pamphlet *Commander's Appreciation and Campaign Design*, which asserted that the "…study of interactively complex systems must be systemic rather than reductionist, and qualitative rather than quantitative, and must use different heuristic approaches rather than analytical problem solving" [Department of the Army 2008]. The pamphlet distinguished between the cognitive functions of design as an application of operational art to problem framing, and the cognitive functions of detailed planning as a more procedural approach to problem solving.

While continuing to support the Unified Quest wargames, SAMS developed a curriculum to educate design, and began to formalize the design methodology [School of Advanced Military Studies 2008]. The SAMS curriculum included a significant component of systems thinking and complex systems theory, and the SAMS student text on design noted: "Complex systems provides an understanding of the sources of complexity, as well as new approaches to coping with complexity by becoming more adaptive. Designers can leverage the complex systems approach to deal with complexity over time" [Ryan *et al.* 2010].

The influence of Australia's *Adaptive Campaigning* is evident in the U.S. Army's Capstone Concept, *Operational Adaptability* [Department of the Army 2009]. The central idea of the capstone concept, operational adaptability, explicitly links complexity, adaptability, and operational design through idea of developing the situation through action (called 'Adaptive Action' in *Adaptive Campaigning*):

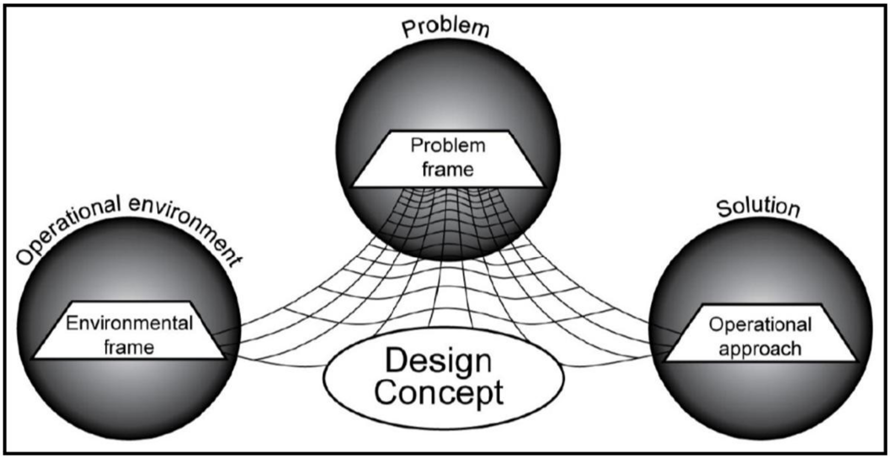
> *Develop the situation through action.* Because technology cannot deliver everything that leaders and units must learn about the environment and enemy organizations, Army forces must be prepared to develop the situation through action…. Because of the complexity of

[1] The U.S. Army Capabilities and Integration Center was previously U.S. Army Training and Doctrine Command Futures Center until it was renamed in 2006.

> the environment and the continuous interaction with adaptive enemies, understanding in armed conflict will never be complete…. Leaders must be adept at applying design as a methodology for framing problems [Department of the Army 2009].

This concept of developing the situation through action – stimulating the system in order to learn as well as to transform – was a significant departure from the previous Army Capstone Concept published in 2005. The 2005 version also acknowledged complexity, but proposed that the solution would be found in "full spectrum dominance," "decisive operations," and "Network-Enabled Battle Command," which attempted to control complexity and uncertainty through the use of information and communications technology. The director of ARCIC, General McMaster, noted that the biggest change to the Capstone Concept was "recognizing some of the limitations in technologies that were designed to improve situational understanding and situational awareness" [Harlow 2009].

In 2010, the U.S. Army updated its Field Manual on the Operations Process, *FM 5-0*, to include a chapter on the design methodology. While the underlying ideas were derived from Naveh's SOD, the U.S. Army design methodology considerably simplified the language of design, and integrated design within the Army operations process. It defined design as "…a methodology for applying critical and creative thinking to understand, visualize, and describe complex, ill-structured problems and develop approaches to solve them" [United States 2010]. The design methodology illustrated in Figure 2 was first described in [Banach and Ryan 2009]. The methodology iterates between three cognitive spaces focused on understanding the environment, the problem(s), and potential solutions. The following four paragraphs briefly describe these three cognitive spaces and the significance of reframing in



design.

Figure 2. Army design methodology.

In the environmental space, designers frame the environment by consciously choosing the perspective from which a complex situation will be made sense of. Designers review, and if necessary reframe the guidance they are given by higher authorities, and map out the dynamic and interactions and relationships between relevant actors within a social network. The environmental frame also considers the dynamics of the system: the history, current state, and future goals of the actors within their cultural context, to appreciate systemic tendencies and potentials for change. The recognition of potential enables designers to construct a desired end state, which articulates a set of conditions that are within the potential of the system.

In the problem space, designers focus on the difference between the current and desired systems. Problem framing involves constructing three systems. The system of opposition is a collective of agents that will actively oppose the transformation towards the desired attractor. The system of support is a collective of actors that will work together to achieve the desired attractor. The system of energy is the set of resources that flow through the system, enabling both the system of support and the system of opposition. Both the system of opposition and system of support are conceived broadly: often, parts of our own organization work against the desired transformation, and can be considered part of the system of opposition. Appreciating the rationale of those who oppose us provides an external perspective for evaluating our own strategic logic. The problem frame expresses the set of problems the designers will address in terms of the underlying tensions within the system and the additional tensions created by transformative change.

In the solution space, designers develop an operational approach to resolve the set of problems surfaced in the problem frame. The operational approach should be an integrative solution that addresses the underlying causes and tensions identified within the problem frame. The operational approach gives tangible form to the strategic logic for transformation. This connects theory with practice. In addition to articulating the pattern of simultaneous and sequential actions to transform the system, the operational approach also specifies how the designers will continue to learn about the system.

Reframing ensures that the design methodology is adaptive. Because war is an open system, any “solution” is assumed to be temporary in nature. To account for this and avoid confirmation bias, designers continually challenge the relevance of their understanding of the environment and the problem(s). When novel patterns emerge that erode the explanatory value of the current design, the designers must reframe their understanding of the problem, which leads to new solutions. Consequently, design is iterative and continuous throughout an operation, and is integrated with planning, preparing, executing and assessing the operation.

A notable application of design in the U.S. by Captain Porter and Colonel Mykleby (a student of Naveh) proposed a new grand strategic narrative for the U.S. “In one sentence, the strategic narrative of the United States in the 21st century is that we want to become the strongest competitor and most influential player in a deeply inter-connected global system, which requires that we invest less in defense and more in sustainable prosperity and the tools of effective global engagement” [Mr. Y 2011]. The design, developed from within the Pentagon and published under the pseudonym Mr. Y, reframed the strategic narrative from control in a closed system to credible influence in an open system. This logic then argued for the replacement of Kennan’s containment theory (first published under the pseudonym X) with sustainment: credible global influence based on internally sustainable development. The authors have initiated grass roots sustainment movements in counties across the U.S. to grow bottom-up solutions to national strategy challenges identified in their strategic narrative.

4 Opportunities for Harnessing Complexity

4.1 Complex systems techniques are applicable throughout design

We have seen that significant insights from complex systems theory have already been incorporated into Australian, Israeli, and American approaches to operational design. The growing awareness of the utility of complex systems theory, not just for describing complexity, but for transforming systems in the presence of complexity, opens the door for the application of further complex systems techniques to operational design.

According to the U.S. Army design methodology, designers strive to transform existing conditions towards a desired end state. In a dynamical system, transformation requires a change in attractor. From a complex systems perspective, designers should not aim for an end state (since end implies finality, state implies static, and ‘end state’ implies reverse planning from a point target). Rather, designers should seek transformation by moving the system’s state out of the current basin of attraction to within the basin of attraction of a more desirable attractor. In this idealization, tactical action is an injection of energy away from the current attractor, while strategy alters the manifold of the dynamical system. Strategy affects the underlying network of positive and negative feedback loops to create new desirable attractors, deepen the wells of existing desirable attractors, reduce the stability of undesired attractors, and create repellers to steer the system’s state away from undesired regions of phase space. Operational art involves aligning strategic manipulation of the context with focused tactical action to push the state of the system across the threshold separating an undesirable basin from a more desirable basin. Dynamical systems theory provides a richer conceptual framework for constructing attractors rather than end states and transforming the current state towards a more desired pattern of behavior.

4.2 Techniques for modeling complex social systems

During environmental framing, complex systems theory enables designers to appreciate variety, and leverage sources of variation within the system to improve adaptability. As Axelrod and Cohen observe, “[t]he Complex Adaptive Systems approach, with its premise that agents are diverse, is well suited to design projects… It builds in the default assumption that there is variety within a population that could matter” [Axelrod and Cohen 2000]. As well as variety, complex systems emphasizes bottom-up and informal sources of order within the system. For example, the success of “the surge” in Iraq was due to exploiting the self-organizing Sunni uprising in addition to top-down changes to the strategy.

Designers require complex systems techniques to help identify and model the self-organizing dynamics of social systems. Gharajedaghi [2006] identifies four broad perspectives for mapping systems that he claims are mutually exclusive and collectively exhaustive: structure, function, process, and context. However, researchers in the field of business process modeling have identified information as a distinct additional perspective [List and Korherr 2006]. Complex systems theory, conceived widely, offers useful tools for each of these five perspectives. Network theory and cellular automata provide insight into structure; iterated function systems and 'black box' functional flow block diagrams represent function; genetic algorithms, reinforcement learning and system dynamics models represent process; agent-based models can incorporate each of these perspectives and place them in context; and almost all measures of complexity are related to the information embedded in and/or processed by a system. Together, these techniques enable designers to appreciate from multiple perspectives the relationship between the calculus of individual agents (their rule sets) and the collective behavior that emerges from the dynamic interactions between agents.

4.3 Multidimensional problem framing

During problem framing, complex systems theory helps designers to avoid binary, zero-sum representations of problems in favor of a multidimensional perspective.

> Multidimensionality is probably one of the most potent principles of systems thinking. It is the ability to see complementary relations in opposing tendencies and to create feasible wholes with infeasible parts…. Using a multidimensional representation, one can see how the tendencies previously considered as dichotomies can interact and be integrated into something quite new. The addition of new dimensions makes it possible to discover new frames of reference in which opposing sets of tendencies can be interpreted in a new ensemble with a new logic of its own [Gharajedaghi 2006].

Complex systems theory shows how design variables that are often traded off against one another can create synergies when combined from a multidimensional and multi-level perspective.

For example, the U.S. Central Command's Air and Space Operations Center is currently facing a design tradeoff between being adapted for the current fight (low-intensity, decentralized counterinsurgency operations in Afghanistan and Iraq) versus being adaptable for potential future threats (such as high-intensity, large-scale conventional operations at very short notice). Both extremes of the tradeoff are unsatisfactory. The current centralized structure maintains readiness against the most dangerous threat but is inefficient for supporting decentralized operations in Afghanistan. Restructuring to better match the low-level autonomy of the land forces in Afghanistan would be more effective, but creates unacceptable vulnerabilities in the case of unanticipated high-intensity conflict in the region. A multidimensional approach recognizes that there are some functions that can be decentralized to improve current operations, some central overheads that must be maintained to deter and counter future threats, and many ways to improve the agility of the Air and Space Operations Center to allow rapid switching between regional priorities.

4.4 Designing for emergence

Complex systems theory contributes novel architectures for the operational approach. One example is indirect design. Rather than designing the exact form for tactical action, the environment within which tactical decisions are made is designed. This includes specifying the purpose, constraints and rule sets to guide action. Most importantly, indirect design concentrates on designing mechanisms for adaptation in a changing environment. The selection of action is left to tactical commanders on the ground, who can adapt their action to the local context. In this situation designers create the conditions for the emergence of a successful design. As the designers observe the emerging patterns, they can refine the constraints and rule sets to exploit new opportunities and counter threats.

A similar concept already exists in military theory: *auftragstaktik*, or mission command, communicates intent but not detailed control between a superior and subordinate. However, complex systems theory adds insights on how to design development environments, how to connect multiple scales within the system, and how to accelerate adaptation. Indirect design presents the possibility of designing for emergence.

4.5 Simple rules, second-order adaptation, and multiscale assessment

As was discussed above, reframing in design is intimately connected with the concept of adaptation. However, complex systems theory emphasizes the value of simple rules, contributes the concept of second order adaptation, and informs assessment within operational design. Complex adaptive systems usually follow simple rule sets. This is because complicated rule sets do not generate behavior that is qualitatively any more complex, and simple rules can be adapted more rapidly in a changing context. Second-order adaptation applies adaptation (variation, selection, and replication) to the adaptation process itself. Designers that experiment with new methods for reframing, select methods that improve relevance, and replicate those methods by sharing them with other designers are utilizing second-order adaptation to continuously improve their capacity to design.

Complex systems theory enables designers to assess the effectiveness of their design across multiple temporal and spatial scales. Assessment of improvement is often averaged over space and assumes incremental progress over time. These assumptions do not hold in general for complex systems. Self-organization generates patterns that maintain themselves far from well-mixed spatial averages, while phase transitions produce nonlinear and often discontinuous progress over time. Instead of using average, incremental movement in a positive direction to drive feedback to adapt the operational design, a complex systems approach requires a nonlinear, multiscale, dynamic model that connects a network of measures throughout the system and its environment. The model provides an explicit theory of reality that allows designers to make sense of observed spatial patterns and aggregate these in a nonlinear way. It connects strategic, operational, and tactical assessment such that the strategic assessment is not merely the sum of tactical measurements. The model does not need to be perfect. As long as it is subject to an adaptive process, it will be increasingly effective over time.

5 Conclusion

In this paper, we have seen how military theorists have acknowledged complexity and responded effectively through the design of adaptive operations. We then explored ways in which complex systems theory applies throughout design: modeling complex social systems; multidimensional problem framing; designing for emergence; and using simple rules for intervention, constructing second-order adaptive mechanisms, and multiscale assessment frameworks.

It would seem that these approaches to operational design developed within the military domain have broader applicability and could be tailored to the design of other governmental and commercial operations. For interagency operations, where no single agency is in charge and different organizational interests and cultures create a high degree of internal complexity, there is an obvious need for design. Businesses also operate in a highly competitive and often rapidly evolving environment, and can benefit from operational designing to connect strategy and execution. The military experience reveals the central cognitive tension between developing deep, nuanced understanding versus constructing relatively simple and clearly communicable interventions to learn about and improve conditions in a complex, open system. A design that creatively resolves this tension between theory and practice is, in a word, elegant.

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