A Complex Systems Approach to the Design and Evaluation of Holistic Security Ecosystems

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A conceptual model for the design and evaluation of Holistic Security Ecosystems is introduced together with a proof of concept test bed for exploring the social, cognitive, geographic and informational dynamics in the emergence of such large scale interdependent meta-organizations. The model is based on recent developments of the holonic paradigm of cross-organizational workflow coordination and decision making. Focused on the dynamic, on-the-fly creation of targeted, short-lived meta-organizations that work towards achieving a common goal (crisis resolution) the model guarantees optimal coordination and decision making at various levels of resolution across the holarchic levels of the organization.
Keywords. Holonic Enterprise, Command and Control (C2), complex interdependent networks, Complex Adaptive Systems (CAS), network-enabled operations, Emergence of Robust Structure.

1 Introduction

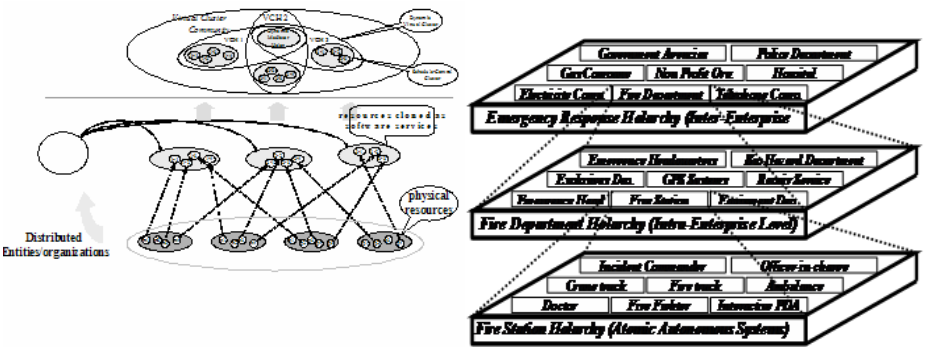
The new security challenges of the 21st century are qualitatively different than in the past. Due to the complexity of such operations military forces find themselves collaborating with numerous other 'partner' organisations to achieve a

common goal. This has imposed new demands on capacities and capabilities; and consequently requires new models to understand key issues and evaluate options. Successful modeling must consider human and organisational factors, which are currently not adequately addressed; certainly not at a meta-organisational level. The problems the military forces and their 'partners' encounter in operations are often messy, intractable, and dynamic; spilling across the problem-solving and management boundaries of single organisations or established cross-sector forms. The environment may often border on the chaotic and uncontrollable, but it may be possible to influence it in a predetermined direction if approached properly. This will require effective collaborative problem solving on the part of partnering organisations for which their "common goal" is more accurately a commonality of elements which bind them together in collective action. It is generally the intent of these partnering organisations to retain their autonomy while "joining forces" to achieve shared goals. The resulting tensions between autonomy and partnering lead to ambiguity and complexity in the meta-organisational (i.e. the collective set of entity organisations and interrelationships) structure or form. These tensions must be reconciled in order to achieve both individual and shared objectives. Participants are pushed into activities that are beyond traditional areas of competence and they are stressed when encouraged simultaneously to build inter-organisational linkages and to protect organisational autonomy. In these instances, both cooperative and competitive behaviour will likely be observed. The persistence of "coordination" as a problem in operations indicates a deeper issue than merely the need to "coordinate" tasks, which relates to the nature of the relationships amongst entities within a meta-organisation and whether or not the set of relationships and consequent meta-organisational form promotes or hinders collective decision-making. In recognition of this problem, theories on "robust networking" have been advanced but require not only shared information but shared understanding and intent as well. It is rarely argued any longer that technology drives social change; instead a more holistic approach is advocated in which "information technology" is comprised not only of physical artefacts but also the social relations around those artefacts.

In this paper we propose a complex systems approach to the emergence of holonic organizational structure – as meta-organizational structure (system of systems) integrating various players (multi-level organizations, individuals, devices and the ICT systems and communication networks linking them) while balancing autonomy and cooperation in the drive towards a common goal (crisis resolution) in emergency response-related military operations.

2 On Emerging Robust Structure Through Architecture and Protocols

For a decentralized organization to function as an organization-and not just as a collection of disconnected elements – the components must interact within a shared environment, typically internal to the organization. The components



(a) Reconfigurable Holarchy with Dynamic Mediator

(b) Emergency Response Holarchy

Figure 1: Emerging Robust Holonic Structure

can no longer simply report up their respective chains of command and expect insightful decisions to issue magically from the top. The components must interact among themselves and find their own ways of collaborating through the environment.

Command and Control (C2) is the military term for the structures and processes though which an entity (i.e., an organization, a system, an organism, etc.) operates. Every entity (military, business, social, political, biological, hardware, software) has a C2 structure. Much of an entity's C2 structure is often recorded in its constitution, by-laws, policies and practices manuals, or design documentation - if it has any of these. Virtually no entity has a complete statement of its C2 structure. A fundamental question to be faced by any discussion of C2 is: what are the requirements for which a C2 design is the answer. That is, what meta-behavioral properties or qualities do we want an organization/system to have? Among the list of possible requirements are the ability to choose actions which will further the system's interests, the ability to act effectively to perform a specific function (sometimes known as execution), the ability to respond to the unknown, the ability to act at the appropriate time scale depending on the situation, the ability to recover from injuries, etc.

From a complex systems perspective, C2 can be built into the architectural requirements determining the components and their interactions through protocols encapsulating the policies and governance rules, which thus will shape the structure of such an organization. Governance refers to the creating of conditions for ordered rule and collective action [9], and focuses on centrally controlling major societal functions to reduce chaos and preserve overall system optimal functionality with respect to all its participants. The C2 mechanism lays the foundation for emerging robust structure [10] in the timely deployment of dynamic, short-living organizational structures needed in emergency response military operations, Fig. 1 a. b. Robustness stems from system's ability to reconfigure its structure to accommodate various disturbances while maintaining

its functionality in a range of acceptable behaviors. This is achieved via a 'plug-and-play' flexible architecture in which components can be easily interchanged to take over the functionality of broken ones [13].

[1] makes a strong argument regarding the role of architecture and protocols in the evolution of complex systems - in particular in the capacity to develop resilience through robust structure. Protocols define how diverse modules interact and architecture defines how sets of protocols are organized. The concepts of architecture and protocol is completely compatible with the challenge of developing new ways to organize human effort beyond the classic industrial control hierarchy. While we have tend to explore inter-organizational architectures for collaboration across a wide range of efforts, there have been far few efforts to explore the architectural design space within an organization. Our standard architectural framework has been the control hierarchy and protocol is hierarchic authorizations.

Doyle's deep analysis of biological and technological robustness concludes that selection acting at the protocol level could evolve and preserve shared architecture, thus enabling interchangeable 'plug-and-play' of components, which in turn facilitates structural reconfiguration. This is in tune with our previous result [10] while deepening and fleshing out what makes auto-catalytic sets, the fundamental units of self-reproductible complex systems architecture [7]. The basic auto-catalytic set (holon) within the underlying architecture/protocol lays the foundation for emerging (robust) structure and preserving it during the dynamics of purposeful organizational deployment in the chaos of crisis [11].

Ecologies and economies framed by suitable architecture components are defined by the workings of the protocol allowing integration of components parts. Mastering protocol and architectural design at the 'primal' autocatalytic set / holon is thus crucial in ensuring resilient deployment, given that it is the protocol that creates the dynamics of organizational boundary. Resilience of a social ecosystem is defined as the capacity of the system to absorb disturbances while maintaining its function, structure, identity and feedbacks [15]. Resilience depends the capacity of the organization to re-organize over spatial and functional scale [4] via adaptive governance [2].

The participants in a military operation may be described as species within a social ecosystem [3] specialized to achieve both their own goals and those of the greater organization [4]. Such organizations are characterized by:

- the participants' ability to negotiate between autonomy and cooperation in a drive (attractor) towards a common goal,
- a coordinated workflow process that triggers the formation of high-level organizational structure (patterns of collaborative clusters) through low-level interactions between participants, and
- a capacity to organize over spatial and functional scale [15] to maintain resilience against attack.

3 Holistic Security Ecosystems (HSE)

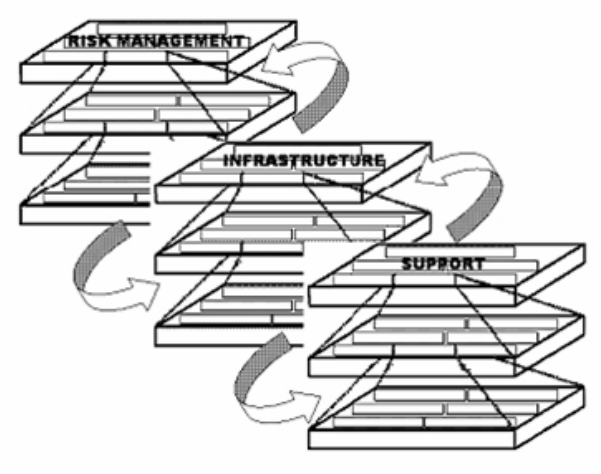


Figure 2: Holistic Security Ecosystem

We build on the holonic enterprise and emergency response holarchy concepts, Fig. 1 to define a *holistic security ecosystem (HSE)* as an emergent short-living meta-organization dynamically created in response to an emergency event by bringing together several otherwise stand-alone dispersed organizations [14]. The HSE is a meta-organization of interdependent specialized Risk, Support ad Infrastructure Holarchies, Fig. 2 working in synergy through a shared environment – most fundamentally a communication network - which adds one more dimension (C) to the Command and Control – making the operational coordination across an HSE a C3. C3 is facilitated by a shared environment, including common resources as well as implicit and explicit rules of behavior. Management of the interactions between these organizations has to undertake multifaceted challenges (cultural, professional, coopetition, trust in a new temporary authority, etc) which require careful crafting of the basic architecture and protocol elements to enable resilient flexible functionality in an unpredictable dynamic environment. Such an organization is subject to either gradual or abrupt change. Gradual change is characterized by a steady progression in organizational change, whereas abrupt change is characterized by unpredictable actions and consequences [5]. In the case of an attack, periods of abrupt change increase in frequency, duration and magnitude.

To increase the flexibility of military units approaches such as net-centricity have been proposed, which imply a significant decentralization of authority – individual components of an organization are given as much autonomy as possible. Yet virtually all organizations remain hierarchical to some degree, thus the holonic heterarchical structure suits well the purpose of balancing autonomy of low-level holons with the authority of a chief executive / unity of command

encapsulated in the HSE via a dynamic mediator [13] Fig. 3 enabling authority to be dynamically allocated at various levels in the chain of command as well as within one level (in case e.g. the chief executive needs to be replaced). The executive (mediator) is given the authority and responsibility to use some assigned resource(s) – typically more than s/he can control on his or her own-to achieve some objective.

One may look at an organization's operational structure as a reflection of its strategy for allocating resources. This opens the perspective of using market models to reconfigure the organizational structure via the harmonious flow of resource allocation tuned to respond optimally to the crisis at hand. Markets (and most innovative environments) allocate resources in a bottom-up fashion. It is primarily the autonomous agents that decide how resources will be distributed. They make that decision when they make their individual decisions about what to buy. Similarly, "power to the edge" implies that the power to allocate resources is vested primarily with the lowest level elements-those at the edge, away from the power centers. This approach opens the possibility of tuning the bottom-up emergence of robust structure via market models [8].

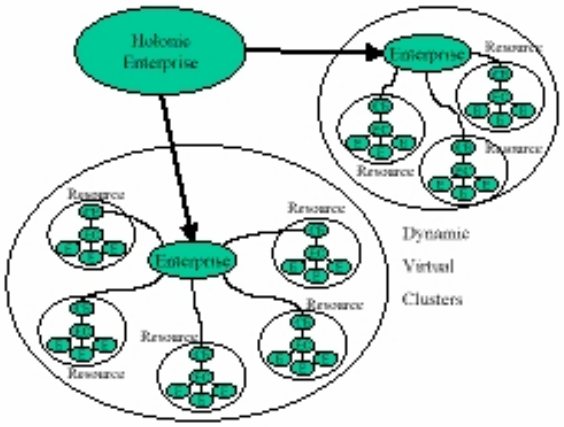


Figure 1 – Dynamic Virtual Clustering Pattern in the Holonic Enterprise

Figure 3: Delegation of Command via Dynamic Mediator

When tuning the resilience of HSEs via resource allocation it is important to realize that entities capable to acquire their own resources from sources outside of themselves (and from outside of any larger organization of which they are a component) can be far more autonomous than entities that acquire their resources from higher levels within a hierarchical resource allocation framework. Thus, a niche for independence/autonomy in a holarchy can be created by outside suppliers which will thus create a buffer accommodating eventual resource scarcity strains that may lead to cascading failures otherwise. Such external sources un-

dertaking eventual unexpected loads in case of unexpected disturbances enforce organization's resilience.

4 Modeling and Simulation Testbed

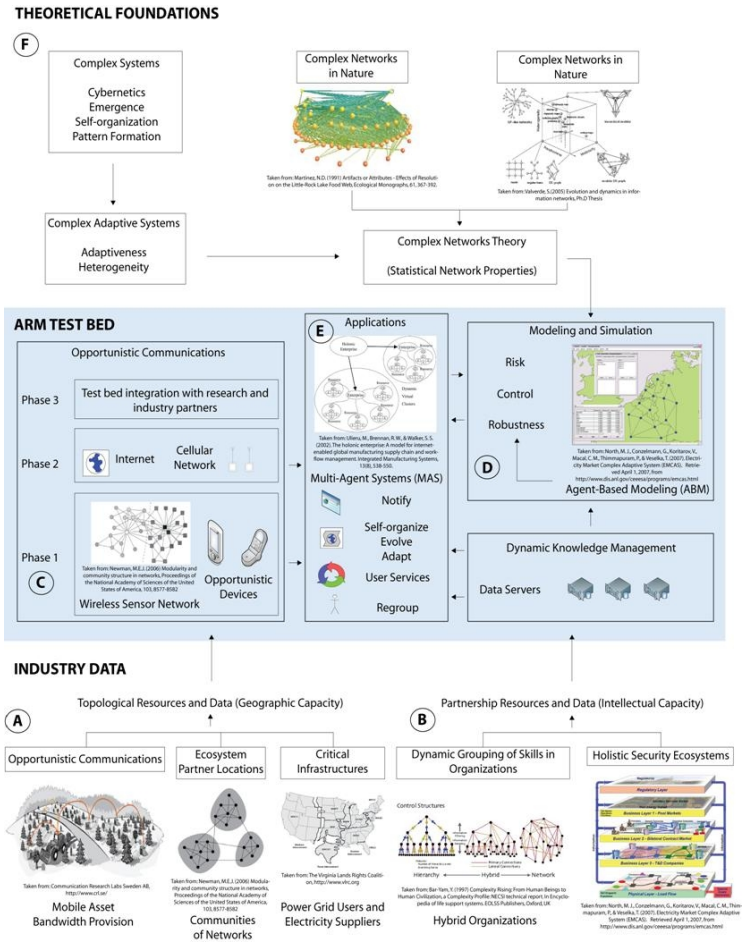


Figure 4: Adaptive Risk Management Testbed

Among the major challenges facing the deployment of such dynamic interdependent meta-organizations, we mention: How are decisions made about both allocating existing shared resources and investing in new shared resources? How to craft rules that govern both behavior and the use of shared resources? Once made, how are these rules enforced? How are they changed as circumstances change? To address these challenges we are working on the development of

a conceptual model for the emergence (dynamic creation) of HSE via collaborative resource exchange among participants. This boils down to the modeling and analysis of interdependent network-enabled hybrid complex systems consisting of organizations, departments, individuals, information and physical entities and the dynamics of their cascading effects under various conditions and strains. Simulations on the adaptive risk management (ARM) testbed available in our lab, Fig. 4 [12] enable an understanding of the dynamics of criticality occurrence within the Holistic Security Ecosystem for a wide range of operating scenarios.

The conceptual model (B in fig. 4) encompasses two capacities:

- The **geographical capacity** of the organization addresses which resources ("partners") are located where at any given time. On our testbed the geographical placement of organizational partners is modeled through the Wireless Sensor Network (C in Fig. 4), where every sensor represents the location of a collaborative partner.

- The **intellectual capacity** of the organization consists of the specialized skills available through different partners in the organization. An indication of responsiveness, focus area of employees etc. would be typical examples of intellectual capacities.

The geographical intellectual capacities represent the organization and its partners as a network, whose entities are processing by the modeling and simulation module (D in Fig. 4).

The HSE Testbed (Fig. 5) is being used to run various configurations of HSE under various conditions and strains with various factors impacting the workflow coordination and decision-making throughout the meta-organization to enable understanding of the dynamics of criticality occurrence within the HSE under various operating conditions / scenarios of mission critical activities. Through simulations, existing social networks are "mapped" into the holonic model to investigate the strengths and resilience of various HSE configurations, thus determining their suitability to address various crisis models. This enables mapping of various HSE configurations to the crisis types for which the particular meta-organizational structure works best. Validation of resulted HSE configuration – crisis type mappings on 'in-vivo' simulation exercises for various instantiations of scenarios (taking e.g. pandemic mitigation or Vancouver Olympics scenarios an various crisis possibilities within the particular scenarios) will provides essential feedback for the model improvement.

5 Conclusions and Future Work

We will extend the holonic model by integration of various aspects impacting the flow of decision-making and functionality of the meta-organization (professional decision-making, cultural impact, trust in such short-life mission-oriented organizations, etc.). Analysis and identification of the impact and interdependencies between various key factors in the extended model transcending cul-

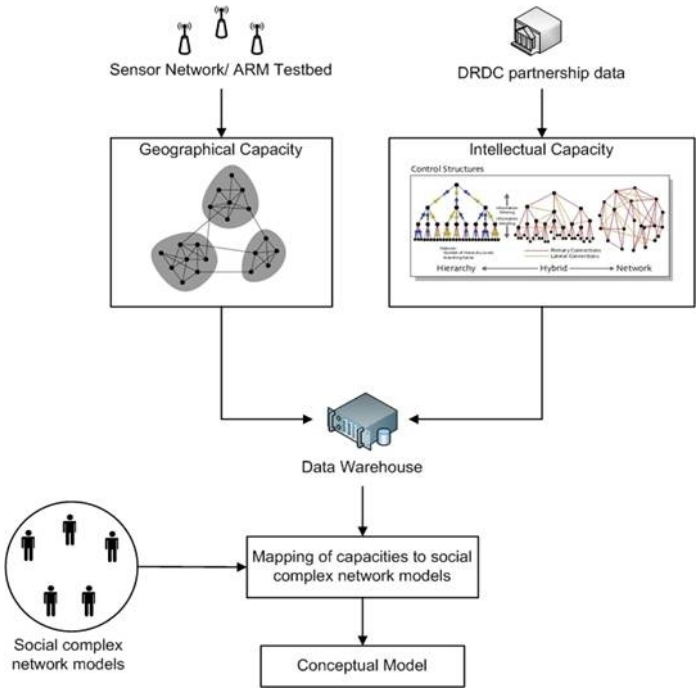


Figure 5: Holistic Security Ecosystem Simulation Testbed

tural, professional, psychological, sociological etc. dimensions will be used to tune the resilience of the HSE by identifying eventual cascading effects with emphasis on the weakest points/links, to determine counteracting (strengthening) measures. This will result in a methodology of design for resilience of HSE laying the foundation of a template for harmonious inter-organisational operations coordination in highly dynamic, short-living mission-critical crisis relieving meta-organizations encompassing methods to optimise interactions and communication linkages among participants.

Integrating the simulations results into a 'strategic thinking process' will enable a change of culture in the design and deployment of integrated HSE (with a-priori identified risks and potential cascading criticalities strengthened and an anticipatory ability of the impact of various dynamics of interdependent factors) which would lead to a seamless reorganization of the HSE in patterns of resilience under various strains and internal disturbances – that will enable it to keeping its operational flow unobstructed through the chaos of various crises. If taken to the next level – this could lead to an overall benchmarking of strategic thinking for self-transformation to help organizations adapt to the high dynamics of our world by considering interdependent factors while better focusing on relevant strength in overcoming limitations, [6].

We must ensure that today's solutions are not tomorrow's problems - and

key to this is our capacity of agile response directed by wise strategy. We hope that the proposed conceptual model and testbed will facilitate 'wise strategy' deployment by crafting emergent robust structure in dynamic meta-organizations.

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