# 2006 Command and Control Research Technology Symposium

## The State of The Art and The State of The Practice

## Title: Assessing Self Organization and Emergence in C2 Processes

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# Agenda

- Introduction
- Self Organization
- Emergence
- Relationship between self organization and emergence
- Knowledge and understanding required by self organizing agents
- C2 example
- Conclusion

# Introduction

- We are interested in investigating if we can properly assess whether or not emergent and self organizing capabilities will really improve warfighting. To this end, the following questions seem paramount:
  - How does one predict that a capability is about to emerge or self organize?
  - How does one know or assess if a newly self organized or emergent capability will be better or worse than the capabilities currently available in a process?
  - What types of knowledge are required to enable agents to be able to exhibit emergent capabilities or self organizing capabilities?
- The field of self-organization seeks general rules about the growth and evolution of systemic structure, the forms it might take, and finally methods that predict the future organization that will result from changes made to the underlying components. Emergence anticipates the appearance of capabilities or properties not presently available.

# Definition of the organization:

- **Organization:** An organization can be defined as an arrangement of relationships between components or individuals which produces a unit, or system, endowed with qualities not apprehended at the level of the components or individuals. The organization links, in an inter-relational manner, diverse elements or even events or individuals, which henceforth become the components of a whole. It ensures a relatively high degree of interdependence and reliability, thus providing the system with the possibility of lasting for a certain length of time, despite chance disruptions (Morin, 1977).

# Self Organization Definitions

- The evolution of a system into an organized form in the absence of external pressures.
- Process centric self organization occurs when, in a particular process, given a new task type, the resources (mechanisms) and process steps re-arrange themselves to successfully perform the new task without being so instructed
- A move from a large region of state space to a persistent smaller one, under the control of the system itself. This smaller region of state space is called an attractor.
- The introduction of correlations (pattern) over time or space for previously independent variables operating under local rules.
- The field of self-organization seeks general rules about the growth and evolution of systemic structure, the forms it might take, and finally methods that predict the future organization that will result from changes made to the underlying components
- Source: Wikipedia & Self-Organizing Systems (SOS) FAQ, Frequently Asked Questions Version 2.98 June 2005, USENET Newsgroup comp.theory.self-org-sys

# Self Organization Attributes

- Critically Interacting - System is information rich, neither static nor chaotic
- Components - Modularity and autonomy of part behaviour implied
- Self-Organize - Attractor structure is generated by local contextual interactions
- Potentially Evolving - Environmental variation selects and mutates attractors
- Hierarchy - Multiple levels of structure and responses appear (hyperstructure)
- Emergent System Properties - New features are evident which require a new vocabulary
- Source: Ferber(99)

# Self Organization Features

- Typical features include (in rough order of generality):
  - Absence of external control (autonomy)
  - Dynamic operation (time evolution)
  - Fluctuations (noise/searches through options)
  - Symmetry breaking (loss of freedom/heterogeneity)
  - Global order (emergence from local interactions)
  - Dissipation (energy usage/far-from-equilibrium)
  - Instability (self-reinforcing choices/non-linearity)
  - Multiple equilibria (many possible attractors)
  - Criticality (threshold effects/phase changes)
  - Redundancy (insensitivity to damage)
  - Self-maintenance (repair/reproduction metabolisms)
  - Adaptation (functionality/tracking of external variations)
  - Complexity (multiple concurrent values or objectives)
  - Hierarchies (multiple nested self-organized levels)
  - Source: Wikipedia

# What kinds of entities self organize?

- For this discussion I will focus on agents in a process whether human or software – Ferber defines agents as having the following properties:
- An agent is a physical or virtual entity
- (a) which is capable of acting in an environment,
- (b) which can communicate directly with other agents,
- (c) which is driven by a set of tendencies (in the form of individual objectives or of satisfaction/survival function which it tries to optimize),
- (d) which possesses resources of its own
- (e) which is capable of perceiving its environment (but to a limited extent),
- (f) which has only a partial representation of this environment (and perhaps none at all)
- (g) which possesses skills and can offer services,
- (h) which may be able to reproduce itself,
- (i) whose behavior tends towards satisfying its objectives, taking account of the resources and skills available to it and depending on its perception, its representations and communications

# Ferber also ascribes the following attributes to a Multiple Agent System

The term “multi-agent system” (or MAS) is applied to a system comprising the following elements:

- (1) An environment, E that is a space which generally has a volume.
- (2) A set of objects, O. these objects are situated, that is to say, it is possible at a given moment to associate any object with a position in E. These objects are passive, that is they can be perceived, created, destroyed and modified by the agents.
- (3) An assembly of agents, A, which are specific objects representing the active entities of the system.
- (4) An assembly of relations, R, which link objects (and thus agents) to each other.
- (5) An assembly of operations, Op, making it possible for the agents of A to perceive, produce, consume, transform, and manipulate objects from O.
- (6) Operators with the task of representing the application of these operations and the reaction of the world to this attempt at modification, which we shall call the laws of the universe.

# Emergence Definition

- The Cambridge Online Dictionaries say to emerge means “to appear by coming out of something or out from behind something” or “to come to the end of a difficult period or experience”,  whereas, Emergence is simply “the *process* of appearing”.
- A property of a system is emergent, if it is not a property of any fundamental element

# Emergence – Alternative Definitions

- **The Cambridge Online Dictionaries say *to emerge* means "to appear by coming out of something or out from behind something" or "to come to the end of a difficult period or experience", whereas emergence is simply "the process of appearing".**
- **A property of a system is emergent, if it is not a property of any fundamental element**
- **Emerge is the opposite of merge**
- **The words emergence and to emerge have the Latin origin *emergere* which means to rise up out of the water, to appear and to arrive. The Latin verb *emergere* comes from *e(x)* "out" + *mergere* "to dip, plunge into liquid, immerse, sink, overwhelm", i.e. to emerge is something like the opposite of to merge. Emergence is derived from the present participle of emergere, *emergens*. Whereas merging means the combination, immersion, fusion of two separate things, *e*merging means the opposite.**
- **The Oxford Companion to Philosophy [Honderich95] defines emergent properties as unpredictable and irreducible: "a property of a complex system is said to be 'emergent' just in case, although it arises out of the properties and relations characterizing its simpler constituents, it is neither predictable from, nor reducible to, these lower-level characteristics".**
- **Explanatory emergence means "the laws of the more complex situations in the system are not deducible by way of any composition laws"**
- **Descriptive emergence means "there are properties of 'wholes' (or more complex situations) that cannot be defined through the properties of the 'parts' (or simpler situations)".**

# Emergence Taxonomy - Overview

- Type I Simple/Nominal, without top-down feedback
  - Ia Simple Intentional
  - Ib Simple Unintentional
- Type II Weak, including top-down feedback
  - IIa Weak (Stable)
  - IIb Weak (Instable)
- Type III Multiple, with many feedbacks
  - IIIa Stripes, Spots, Bubbling
  - IIIb Tunneling, Adaptive
- Type IV Strong
- Source: Fromm, Jochen, Emergence Perspectives - From Section 4.2 of “Types and Forms of Emergence”, Distributed Systems Group, Electrical Engineering and Computer Science Group, Universitat Kassel, Germany

# Emergence Discussion

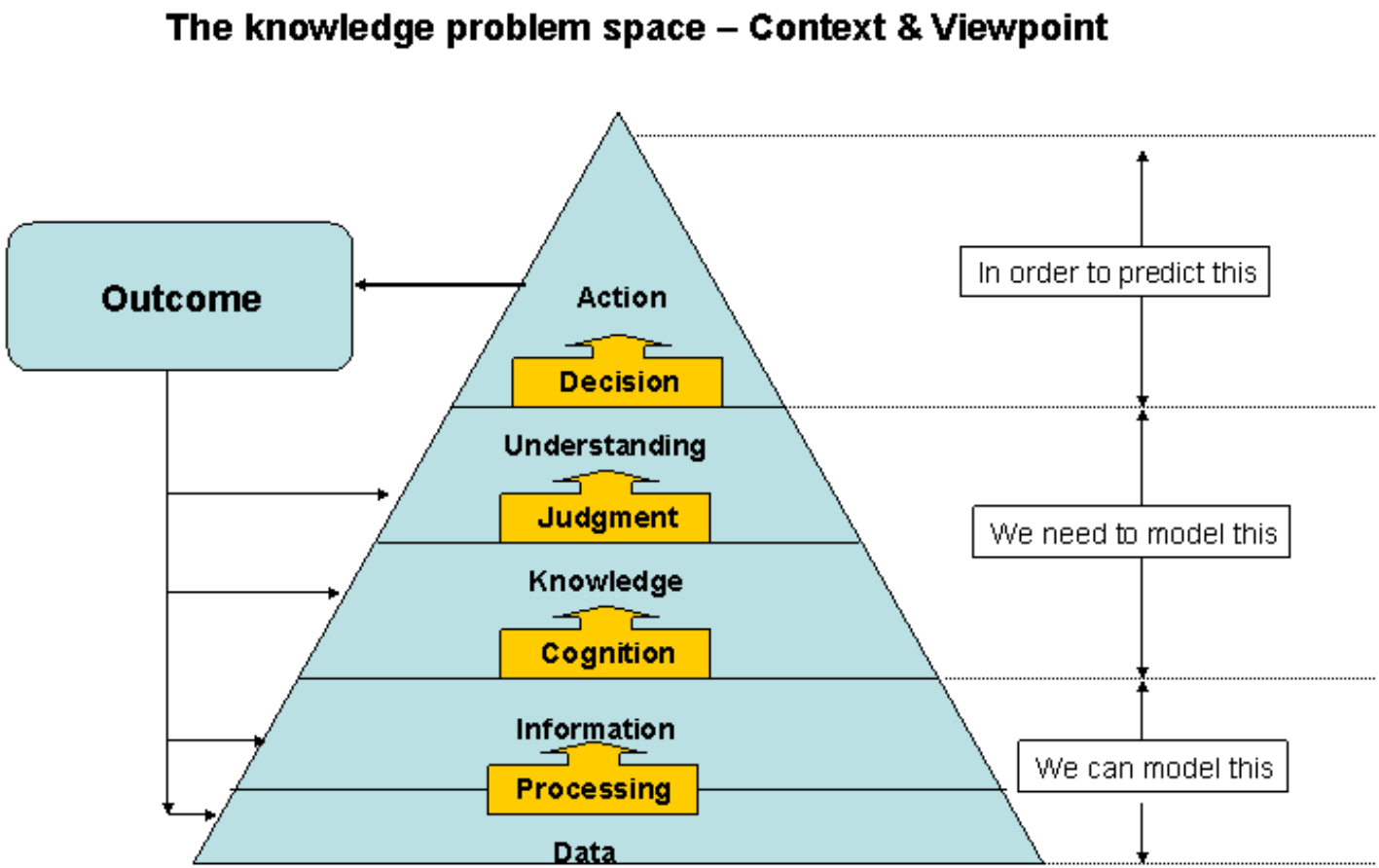
- There is no consensus amongst scientists as to how much emergence should be relied upon as an explanation. It does not appear possible to unambiguously decide whether a phenomenon should be classified as emergent, and even in the cases where classification is agreed upon it rarely helps to explain the phenomena in any deep way. In fact, calling a phenomenon *emergent* is sometimes used in lieu of any better explanation.
- Source: Holland, John, H., conclusion in “Emergence – From Chaos to Order”

# Relationship of Self Organization to Emergence

"Critically interacting components self-organize to form potentially evolving structures exhibiting a hierarchy of emergent system properties"

- Source: Lucas, Chris, "Quantifying Complexity Theory", http://www.calresco.org/lucas/quantify.htm

# What knowledge and understanding relationships would C2 agents require to be successful?

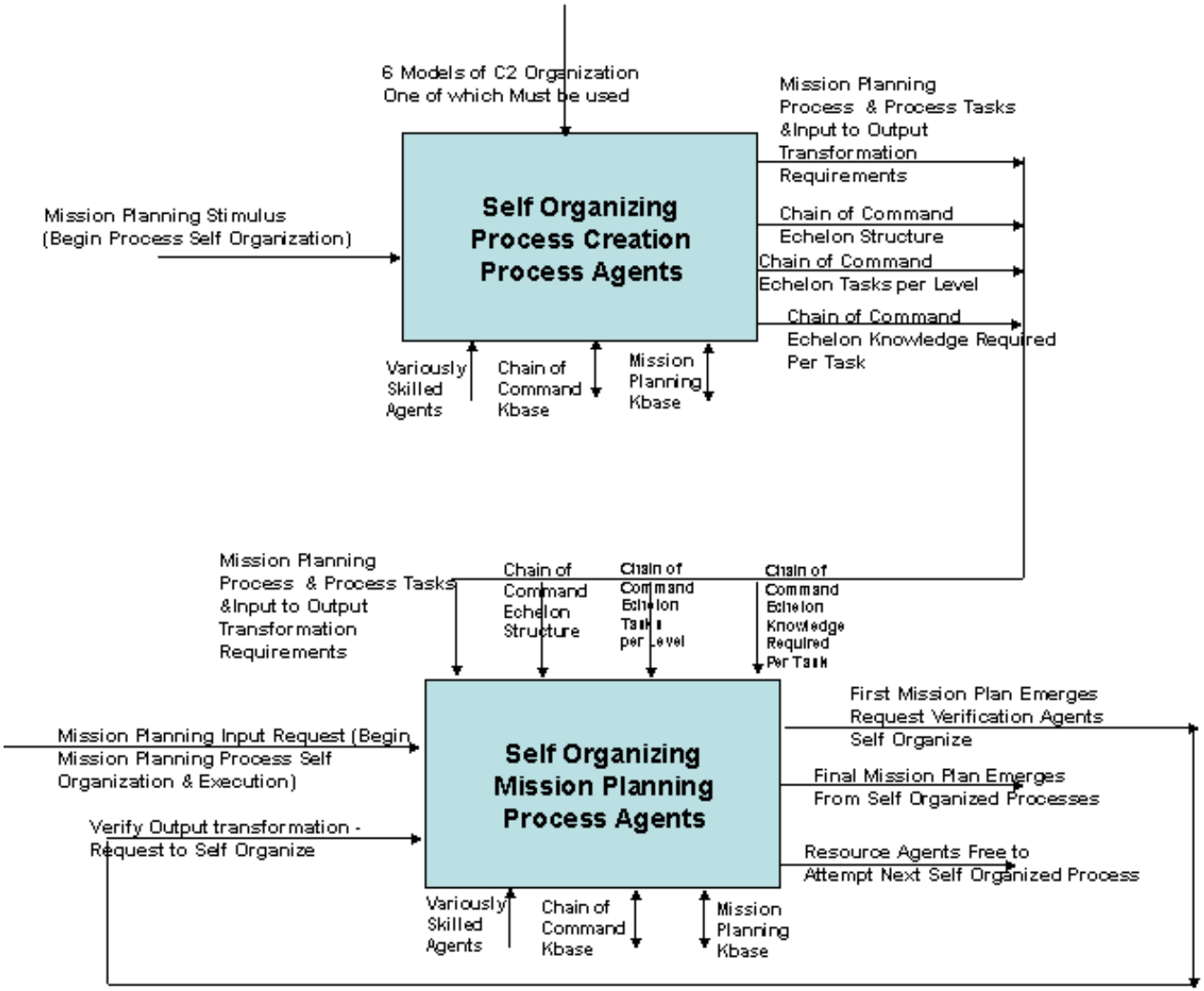



**Source of graphic is Kewley and Larimer's:**
**"Agent Based Modeling Approach to Quantifying the Value of Battlefield Information", Phalanx V 36, 2003**

# Agent Knowledge Types

- ***Theoretical knowledge***
  - Daniel Bell stated that the 'axial principle' of post-industrial society is the codification of theoretical knowledge and its centrality for innovation.
  - Innovations start from theoretical premises
  - Knowledge is the starting point for action
- ***Tacit knowledge***
  - Polanyi distinguished *tacit* from *explicit* knowledge: personal knowledge embedded in individual experience and involving such intangible factors as personal belief, perspective and values.
  - Explicit knowledge can be formalized, but tacit is informal, action and discourse orientated: *acting with* rather than *acting on.*
  - Tacit knowledge may be the real key to getting things done.
- **Implicit knowledge**
  - *Knowledge that can be articulated but hasn't.*
  - *What a competent practitioner can infer readily from a task, problem or scenario.*
  - *That which can be elicited and represented by a competent analyst.*
  - *In so doing, implicit knowledge became explicit knowledge.*
- ***Explicit knowledge***
  - Fact based, publicly available and beyond dispute.
  - Possibly recorded in documents, also includes scientific and technical knowledge, common understandings, the 'right way of doing things' and socially accepted norms.
  - Easily verbalizable, and stated in the form of rules or notes. Includes knowledge of organizational structures, business rules, etc
  - Easiest to deal with as it is easily articulated, communicated and represented in formal languages.

# C2 Example of Attractors and Process Self Organization

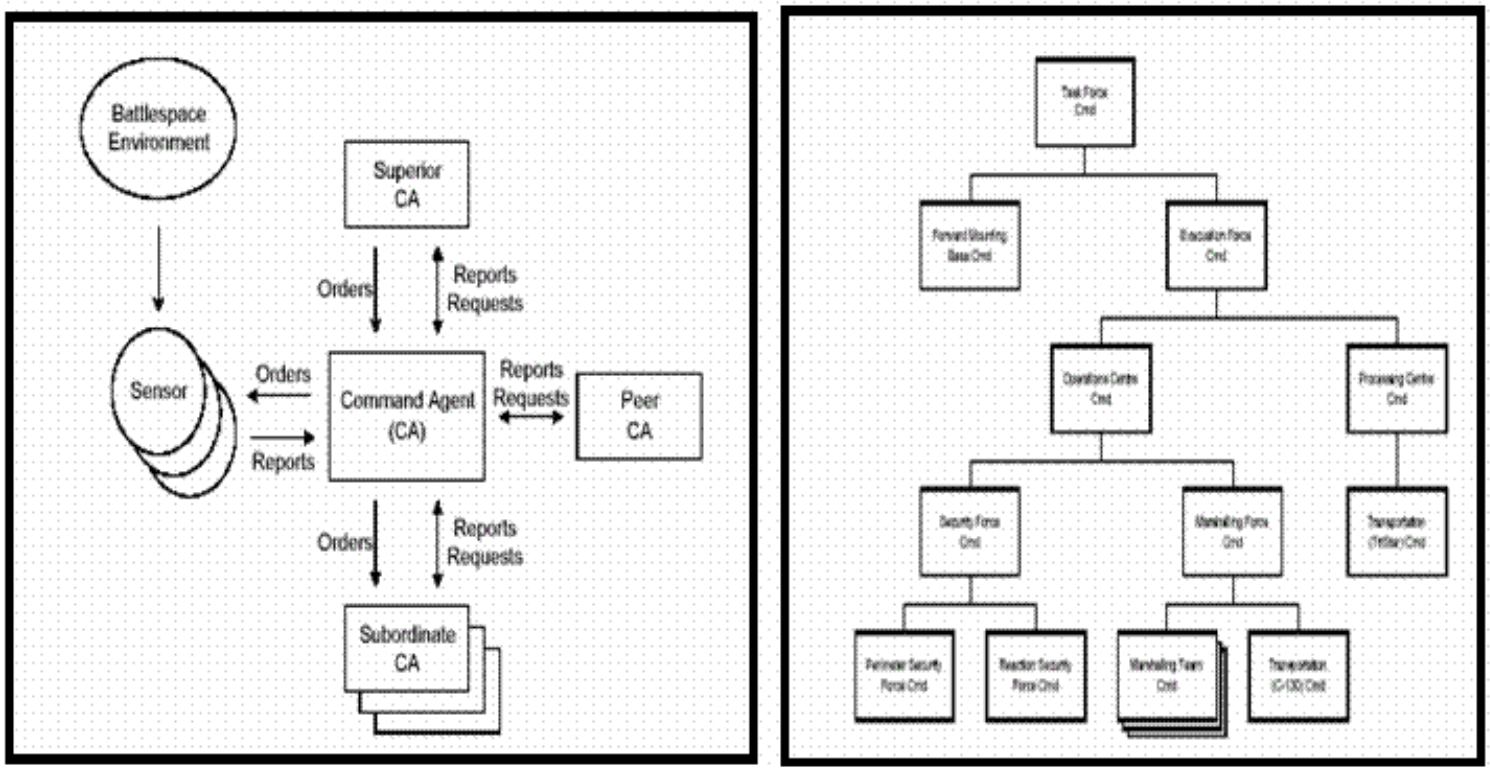


# C2 Example of Attractors and Process Self Organization (Discussion Continued)

- Let's suppose that the process creation agents may form a command and control structure as an output of their process. Now also suppose that the six archetypical command and control types (six possible attractors) identified by Dr. Alberts are all possible valid forms of arrangement. They are:
  - Control free - World War II – German – Mission Specific
  - Selective control – Israeli – Mission Specific
  - Problem Bounding – British Army – Objective Specific
  - Problem Solving – American Army – Objective Specific
  - Interventionist – Modern Soviet – Order Specific
  - Cyclic – Chinese Army - Order Specific
- Which C2 organization would be formed by the agents? Should the agents be "directed" to form a particular type? Should we (humans) interfere and "tell" the agents (by process control rules) that only the German control free model is acceptable?

# C2 Example of Attractors and Process Self Organization (Discussion Continued) – the “plan” should emerge from “planning agents” at each echelon of the self organized structure

## Generic Agents on The Left Self Organize into C2 Structure on the Right




**Source of graphic is Moffat and Mason’s:**
**“AN AGENT ARCHITECTURE FOR IMPLEMENTING COMMAND AND CONTROL IN MILITARY SIMULATIONS”**
**2001 Winter Simulation Conference**

# Conclusions

- The primary conclusions of this research are:
  - That our goal should be to validate how “Critically interacting components self-organize to form potentially evolving structures exhibiting a hierarchy of emergent system properties”
  - That we should develop an assessment process, capable of predicting and evaluating both emergence and self organization.
  - That much more theoretical work and development is necessary to mature stable and reliable emergent and self organizing processes and capabilities, prior to granting serious consideration for military use.
  - That the resources and agents expected to exhibit the self organizational and emergent capabilities must be able to learn and have access to multiple knowledge types in order to be successful.