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The State of The Art and The State of The Practice

Title of Paper:
Assessing Self Organization and Emergence in C2 Processes

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Abstract

We are interested in investigating if we can properly assess whether or not emergent and self organizing capabilities will really improve command and control. To this end, the following questions seem paramount:

1. How does one predict that a capability is about to emerge or self organize?
2. 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?
3. What types of knowledge are required to enable agents to be able to exhibit emergent capabilities or self organizing capabilities?

The primary conclusions of this research are:

1. That we should develop a rigorous assessment process, capable of predicting and evaluating both emergent and self organizing capabilities.
2. That much more theoretical work and development is necessary to produce emergent and self organizing capabilities which can be relied upon in a military context.
3. Our primary research goal should be to validate how "Critically interacting components self-organize to form potentially evolving structures exhibiting a hierarchy of emergent system properties" [1].
4. That the agents expected to exhibit the self organizational and emergent capabilities must be able to learn and have access to multiple knowledge types.

Introduction

We are interested in evaluating the practical usefulness of self organization and emergence with respect to warfighting command and control. The field of self-organization seeks general rules[2] 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.

We will begin by defining the terms "self organization" and "emergence" and by paying attention to leading researchers in the field such as John Holland [3] who has stated that "any serious study of emergence must confront learning". Thus this author will assume that in order to learn, self organizing entities must have access to knowledge, which forces us to evaluate the types of knowledge required for self organization and emergence. This in turn raises interesting questions such as what kinds of knowledge should self organizing entities require to be able to function at all?

The paper will also focus on what process mechanisms attract the actors to different entities with which to self organize and then what happens to the entities themselves.
For example:

1. When does an entity lose its old identity and become something else (threshold crossing)?
2. Will an entity ever relinquish its new identity and revert back to its old self (reverse threshold crossing)? Can a butterfly revert back to a caterpillar again after the caterpillar "emerged" into a butterfly (Persistence of the new emergence)?
3. Are the old components still usable after the old components "emerge" into something else or is only the emerged "entity" usable"?
4. Is it possible to predict when self organization will occur if at all?
5. Is it possible to predict when capabilities will emerge if at all?
6. Under what conditions will these self organizational and emergent phenomena occur?
7. What are the environmental attributes that will be conducive to nurturing self organization and emergence?
8. What are multiple self organizational possibilities in a given process context, can an entity self organize in more than one way, if so which one will happen first?
9. What are the boundaries of emergent capabilities in terms of realistic expectations? Should we expect agents to "emerge" into medical experts capable of giving first rate medical diagnosis by simply "acquiring medical knowledge"? Or are we really talking about domain specific agents emerging into "smarter" agents? (Medical domain, ISR domain, C2 planning domain, etc.)

Definition of 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) [4].

<u>Definitions of Self Organization</u>[5]

1. The essence of self-organization is that system structure often appears without explicit pressure or involvement from outside the system. In other words, the constraints on form (i.e. organization) of interest to us are internal to the system, resulting from the interactions among the components and usually independent of the physical nature of those components. The organization can evolve in either time or space, maintain a stable form or show transient phenomena. General resource flows within self-organized systems are expected (dissipation), although not critical to the concept itself. The elements of this definition relate to the following attributes:

    - Critically Interacting - System is information rich, (implies a knowledge store), neither static nor chaotic
    - Components - Modularity and autonomy of entity 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

2. And from Wikipedia: What is self-organization?

    a) The evolution of a system into an organized form in the absence of external pressures.

    b) 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.

    c) The introduction of correlations (pattern) over time or space for previously independent variables operating under local rules.

Typical features include (in rough order of generality):

a. Absence of external control (autonomy)
b. Dynamic operation (time evolution)
c. Fluctuations (noise/searches through options)
d. Symmetry breaking (loss of freedom/heterogeneity)
e. Global order (emergence from local interactions)

f. Dissipation (energy usage/far-from-equilibrium)
g. Instability (self-reinforcing choices/nonlinearity)
h. Multiple equilibria (many possible attractors)
i. Criticality (threshold effects/phase changes)
j. Redundancy (insensitivity to damage)
k. Self-maintenance (repair/reproduction metabolisms)
l. Adaptation (functionality/tracking of external variations)
m. Complexity (multiple concurrent values or objectives)
n. Hierarchies (multiple nested self-organized levels)

3. 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 (no controls change)
4. From Wikipedia also - Self-organization refers to a process in which the internal organization of a system, normally an open system, increases automatically without being guided or managed by an outside source. Self-organizing systems typically (though not always) display emergent properties.

<u>What kinds of entities self organize and what do they look like (what attributes do they possess?</u>

For this discussion I will focus on agents in a process whether human or software – Ferber [6] 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.

The following are attributes of a Multiple Agent System:

The term "multi-agent system [7] 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.

Definition of attractor

The states or regions in a self organizational agent state space to which agents are drawn, in the case of multiple attractors the agents could possibly exhibit confusion or self organize around the wrong attractor.

Definition of Emergence

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. Whereas merging means the combination, immersion, fusion of two separate entities, emerging means the opposite.

The Oxford Companion to Philosophy, 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)”.
There is no consensus among 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.[8]

Properties of Emergence [9]

"Emergent Properties: An emergent behaviour or emergent property can appear when a number of simple entities (agents) operate in an environment, forming more complex behaviors as a collective. A single ant cannot build a nest but the swarm can. The property itself is often unpredictable and unprecedented, and represents a new level of the system's evolution. The complex behaviour or properties are not properties of any single such entity, nor can they easily be predicted or deduced from behaviour in the lower-level entities. The shape and behaviour of a flock of birds or school of fish are good examples.

One reason why emergent behavior occurs is that the number of interactions between components of a system increases combinatorially with the number of components, thus potentially allowing for many new and subtle types of behaviour to emerge. For example, the possible interactions between groups of molecules grows enormously with the number of molecules such that it is impossible for a computer to even count the number of arrangements for a system as small as 20 molecules.

On the other hand, merely having a large number of interactions is not enough by itself to guarantee emergent behavior; many of the interactions may be negligible or irrelevant, or may cancel each other out. In some cases, a large number of interactions can in fact work against the emergence of interesting behaviour, by creating a lot of "noise" to drown out any emerging "signal"; the emergent behaviour may need to be temporarily isolated from other interactions before it reaches enough critical mass to be self-supporting. Thus it is not just the sheer number of connections between components which encourages emergence; it is also how these connections are organised. A hierarchical organisation is one example which can generate emergent behaviour (a bureaucracy may behave in a way quite different to that of the individual humans in that bureaucracy); but perhaps more interestingly, emergent behaviour can also arise from more decentralized organisational structures, such as a marketplace. In some cases, the system has to reach a combined threshold of diversity, organization, and connectivity before emergent behaviour appears.

Systems with emergent properties or emergent structures may appear to defy entropic principles and the second law of thermodynamics, because they form and increase order despite the lack of command and central control. This is possible because open systems can extract information and order out of the environment.

Emergence helps to explain why the fallacy of division is a fallacy. According to an emergent perspective, intelligence *emerges* from the connections between neurons, and from this perspective it is not necessary to propose a "soul" to account for the fact that brains can be intelligent, even though the individual neurons of which they are made are not. The concepts of are central to a deeper understanding of emergence" [Kim99].

Types of emergence and their features

The following table attempts to summarize Fromm's[10] work concerning types of emergence and their attributes. This table is extremely useful in simplifying yet bounding the discussion of emergence.

Features of Emergence (entire table composed from Fromm's work)

Type	*Name*	*Examples*	*Predictability*	*Comments*
I	*Nominal, planned, or Intentional, no feedback, Feed forward only*		*Predictable*	*Associated with the maximal causal connectivity. Intended emergence's drawback is the lack of flexibility or adaptability, as in a top down control as in a state planned central economy, however, well defined and planed objects are reliable and act in the same manner each time*
Ia	*Simple, Intentional/Nominal Emergence*	*Function of a machine is an emergent property of its underlying parts, Function of Software is an emergent property of the underlying code, information of a sentence is an emergent property of the sounds and how words are arranged,*		*Brittle and lacks flexibility, but reliable*
Ib	*Simple, Unintentional Emergence*	*Thermodynamic properties like pressure, volume, temperature*		*Emergent physical properties like an avalanche or a wave-front*
II	*Weak, includes simple, top down feedback from the macroscopic to the microscopic,*	*A swarm or shoal of fish is an emergent property which influences the motions of each participating animal,*	*Predictable in Principle, but not in every detail, since it involves top down feedback it is also known as "downward causation" (Bedau97)*	*The feedback is only positive when the members can distinguish between different scales, microscopic objects tend to have a repulsive effect, whereas macroscopic objects have an attractive effect , Direct interaction is when the agents influence each other directly but not necessarily the environment or the total system, an example of this is the so called "flocking trick" where the agents maintain a rule set which insists upon avoiding contact, (repulsion)Indirect interaction occurs when the agents change the state of the total system and the environment through their individual behavior, the so called "pheromone trick" is an example*

IIa	***Weak Stable Emergence***	***Swarm Intelligence, Flocking behavior of fish and birds, foraging in ants, Wikipedia, Linux, optimal process of goods in an economy,***	***Predictable in Principle, but not in every detail***	***Negative feedback imposes constraints on the actions of the agents, exhibits downward causation due to top down feedback, inflation is a negative feedback***
IIb	***Weak Unintentional Instable Emergence***	***Bubbles or crashes in the stock market, fads, crazes, celebrity effect***	***Predictable in Principle, but not in every detail***	
III	***Multiple***		***Multiple emergences, either a particular emergence is not predictable or exhibits chaotic behavior***	***Time delayed feedback is not considered in this listing of emergent types***
	III A Emergence with multiple feedback	***In humans, short term positive feedback results in blind imitation while long term negative feedback results in careful consideration, when stocks are rising, imitators will have an incentive to buy which will raise the stock price, but eventually the belief that a stock has "peaked", and the knowledge that bubbles pop, will end up deterring buyers (negative feedback), emerging stock prices cannot be relied upon***	***Multiple emergences, either a particular emergence is not predictable or exhibits chaotic behavior***	***Short range activation (positive feedback) coupled with long-range inhibition (negative feedback)***
	III B Adaptive emergence with multiple feedback	***Sudden scientific or mental revolutions, abrupt, unsteady, changes and jumps in complexity***	***Multiple emergences, either a particular emergence is not predictable or exhibits chaotic behavior***	***Changes due to massive catastrophes, or a sudden dramatic challenge in the environment, accelerating the transitions to higher forms of complexity, or to mass extinction of the existing objects, cognitive catastrophes caused by mental barriers***
IV	***Strong Emergence and Supervenience Strong emergence can be defined as the appearance of emergent structures***	***Systems, not individual agents are the result of strong emergence. Life is a strong emergent property of genes,***	***Not Predictable in Principle, gateway or breakthrough event (Gell-Mann94)***	***Maximal form of emergence is associated with the minimal form of causal connection. The highest/ strongest form of emergence is related to supervenience, a step before transcendence. No magic processes,***

	on higher levels of organization and complexity, macroscopic level is independent from microscopic level	***genetic code, and nucleic/amino acids. Culture is a strong emergent property of memes, language, and writing systems***		***no mystical processes, no supernatural powers, no unscientific processes, or anti-scientific processes, strong emergence is the crossing of the barrier of relevance. It is often related to very large jumps in complexity and major evolutionary transitions***

Do self organizing entities need knowledge and what types of knowledge do they need?

Agents must be able to acquire knowledge, learn, make decisions, establish hierarchies between themselves, and communicate with each other [11]. Thus the types of knowledge required are diverse. The following itemization is an attempt to categorize knowledge by types [12] that may be useful to a particular agent rather than have each agent attempt to manage all possible 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.

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.

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.

Blackler's [13] categories of knowledge

Embrained knowledge

- dependent on conceptual skills and cognitive ability
- 'knowing that' (rather than' knowing how')
- common perspective in AI, KM, etc

Embodied knowledge

- 'action-orientated'
- 'knowing how'
- practical thinking
- tacit
- 'situated'

Encultured knowledge

- 'shared understandings'
- based on 'acting with'
- tacit
- represented in practices and language

Embedded knowledge

- resides in systematic routines
- maybe 'ritualized'
- represented in configurations of materials and processes
- 'working orders'

Encoded knowledge

- conveyed by' signs' and' symbols'
- represented textually and digitally
- decontextualized and abstract
- significant in 'technologies of representation'

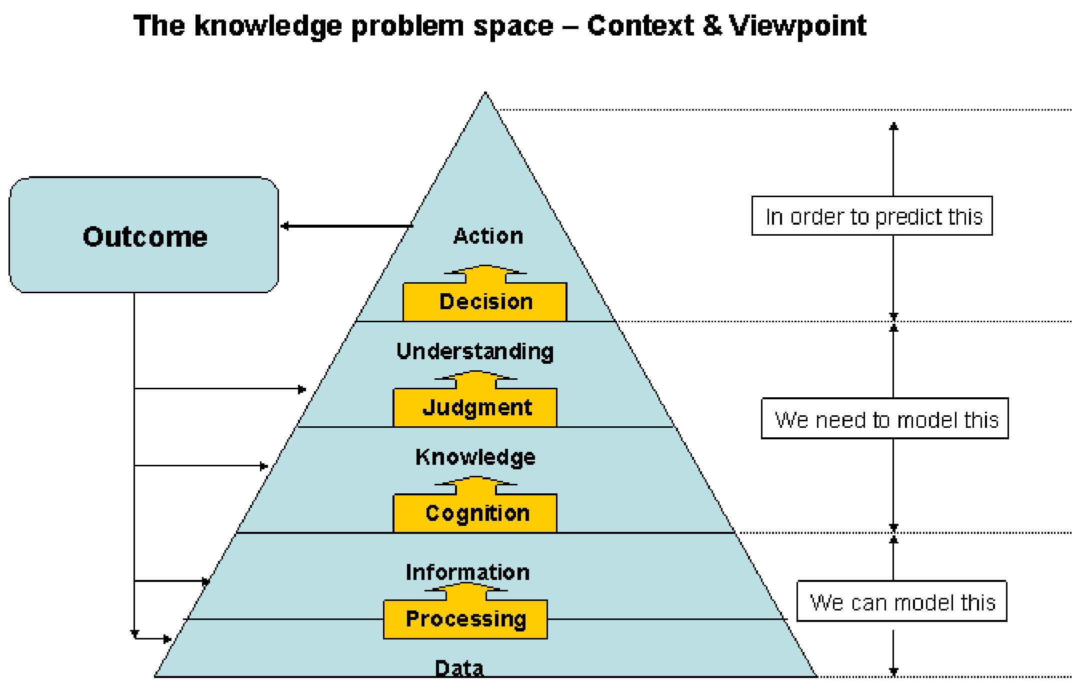


Figure 1 – The Knowledge Modeling Gap[14]

The previous knowledge types illustrate the complexity involved in any analysis of the above graphic. We not only must decide which knowledge types are relevant, but also how should each type be modeled in the context of the above model's goal of improving agent understanding so that superior decisions will result. The modeling itself is outside the scope of this short paper, but a few comments are needed. The gap in the middle is where modelers have trouble translating the information collected into knowledge, thus inhibiting agent "understanding". The fear being that poorly modeled knowledge results in poor understanding and thus poor judgments. Gaps in agent knowledge representations and in agent understanding appear to limit the complexity of what we can expect to emerge through self organization. For example, suppose that the particular knowledge domain is network and software architectural knowledge, can we expect agents with access to an architecture knowledgebase to be able to evolve or exhibit emergent architectural behavior given an architectural information ecosystem? Can we expect architectural agents to compose a "bullet proof "secure Service Oriented Architecture? Suppose that the domain is mission planning? Do we really wish to say that "self organization" has reached a point of composing "competent" or human equivalent mission plans? Any serious theory of assessment proposed for evaluating emergence and self organization must articulate clear and obvious boundaries of what are the realistic capabilities of such architecture or mission planning entities.

Setting the predictability expectation – Using the concepts of Complexity Theory – How do we know when something is about to self organize or emerge, can it be relied upon by the Warfighter?

The current scientific theory related to self-organization is Complexity Theory, which states:

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

But how do we know when or if an emergence or self organization is about to occur? Is there a threshold which can be identified and monitored which can indicate that a capability is about to "appear"? If there is such a threshold, can we be sure that it will be activated when needed? Just how reliable are self organizing and emergent processes? In Moffat's [15] complexity paper, he identifies a "critical point for self organization" which corresponds to a particular fitness value. This attempts to define a critical point of self organization against a fitness factor. I have two comments, first in processes requiring multiple self organizations to occur, there may well be multiple fitness values which could be achieved by the same self organizing resources or agents. This means that "multiple basins of attraction" (the states (the attractors) in a self organizational agent state space to which agents are drawn) could simultaneously exist forcing confusion among the actors rather than self organizing; possibly causing a deadly delay in making a decision as to which basin should be serviced first? Second, in evolutionary computation, particularly genetic algorithms used to model cellular automata behavior, the fitness value is usually provided. Here that does not seem to be the case. During Katrina, several events occurred which cast doubt on the completeness of the formulation for self organizational expectations. Many members of the New Orleans police fled, thus leaving fewer actors to self organize. Communications (their GIG) failed after power outages, primarily due to a lack of satellite phones years after the September 11, 2001 terrorist strikes. Thus, critical infrastructure needed to permit self organization and knowledge creation and transfer disappeared. Instead of the network becoming the centerpiece for self organization to occur, it became a primary focus for failure, a giant single point of failure with no apparent adequate backup systems. How does Network Centric Warfare (NCW) theory adjust for infrastructure failures which corrode the basis of the NCW approach?

Defining the basics for a Self Organization or Emergence Assessment Process

It seems that any assessment methodology designed to predict the success or failures of self organization and emergent capabilities must target at least the following major process phases:

1. First that the actors will actually repeatedly self organize and are adequate to accomplish the task given the same process stimulus (Predictability).
2. That the process agents will respond to both stimuli and other multiple input types appropriately.

3. That the actors or agents will not be "tricked" by another basin of attraction and self organize around a false optimal in a different part of the state space, thus destroying repeatability and predictability.
4. That the self organized actors will actually understand the task, or have the ability to acquire the knowledge necessary to successfully execute the task
5. That the agents will actually execute the task successfully
6. That the self organizing process agents will "manage process inputs in a queue like fashion" preventing agent overload and confusion.
7. An agent based methodology or "fitness criteria" must exist to validate that the process input set has been properly transformed into the proper process output set. Repeatability testing must be an attribute of these agents. In a more advanced setting or follow-up paper, it may be interesting to attempt to "allow the process agents to evolve verification capabilities".

But here we are confronted with a serious issue that is true now even for human actors: for process inputs which differ in type or frequency, the probability that any given set of process resources can retrain themselves by acquiring and applying new knowledge in short periods of time is very low. In my Abstract model paper[16] I called this "mechanism realignment latency"; this issue must be modeled and simulated to better understand the way ahead. Even if the agents had access to explicit knowledge, internalizing the knowledge so that "skills" appropriate to the new task may emerge seems at best a trial and error process.

<u>Defining a simple hypothetical abstract self organizational model for command and control which will exhibit type 1 A or simple intentional emergence after self organization occurs</u>

I would like to propose for further research and analysis the following hypothetical model. I believe that a command and control model utilizing self organization which satisfies the primary dictum " Critically interacting components self-organize to form potentially evolving structures exhibiting a hierarchy of emergent system properties" can be primitively modeled as follows:

First, clearly define a simple process set, attractor set and environment in which the agents must select the appropriate attractor to be drawn to.

Second, develop the "attractor rules" which will "force a particular agent instantiation to be drawn to it."

Third, develop a set of attractor formation rules (controls for the attractors).

Fourth, develop minimum agent attributes and capabilities, which are independent of any particular process.

Fifth, the agents must be able to seek out attractors or seek a particular state space (attractor basin) based upon some rule set.

Sixth, the agents will respond to a process input type known as an "agent stimulus". The agent stimulus will cause the agents to begin early self organizational phases and to possibly go into "learn mode" by seeking knowledge.

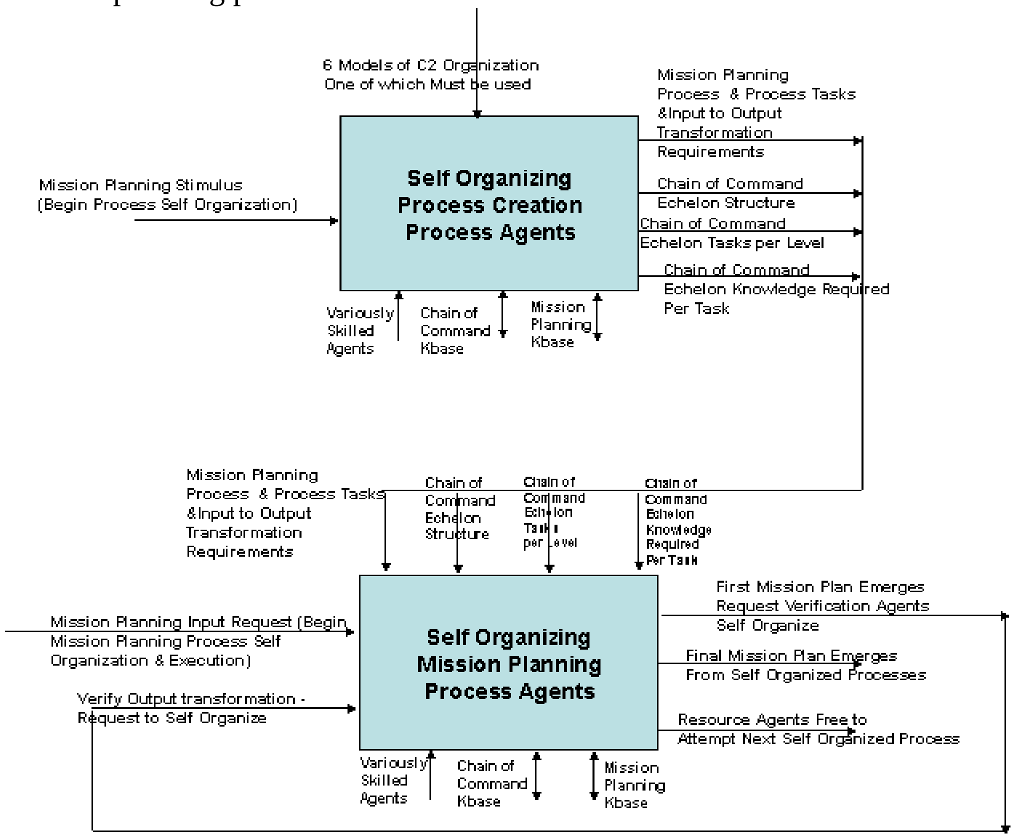
Seventh, after stimulus reactions and learning, the agents will complete self organization within a process context after receipt of a valid input type.

Eighth, the newly self organized process will begin executing the process steps and transform the input into the correct output sets or states.

Ninth, the agents and the process will be able to recognize “completion states” and stop transformation of the inputs, returning to an idle condition awaiting the next stimulus. Tenth, the process verification agents will analyze the success or failure of the process transformation of input to output created by the self organized entities.

Relationship to Command and Control (C2)

Continuing the hypothetical example, suppose that we are attempting to examine the self organizational behavior of “organization creation agents” and “C2 planning agents”. Looking at the graphic below we see two processes: a process creation process and a mission planning process.



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 identified by Dr. Alberts[17] are all possible valid forms of arrangement. They are:

a. Control free - World War II – German – Mission Specific
b. Selective control – Israeli – Mission Specific
c. Problem Bounding – British Army – Objective Specific
d. Problem Solving – American Army – Objective Specific
e. Interventionist – Modern Soviet – Order Specific
f. 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? Or should another self organizing process select the optimal model from which to form the chain of command echelon needed to support the model? I have depicted such a possible process set in the above graphic. According to Moffat and Mason[18], the following are capabilities required of C2 agents: Sense its local environment and construct an internal representation - a perception - of the external world; Plan its own behaviour, based on the current perception of the external world; Exchange information with other agents. The graphics below are also from Moffat and Mason's work. If we maintain a "process context", we should be able to understand what we are asking the process to "self organize into". The primary question here is that if we do not instruct the agents (the purpose of the process controls for the organization agents), then they could in theory self organize into anything. In other words which of the 6 models listed above might appear given a particular stimulus for the agents? The figure below indicates that a combination of models may also "emerge" given that the agents may have been granted "unbridled evolutionary freedom". We must conclude that rule based self organization to produce type 1a emergence may be too restrictive and that another more robust form of adaptive self organization (limited rule sets at best) is required. It seems that the number of rules required to support C2 echelon self organization for a given process stimulus would cover a very large state space. We also must conclude that the prudent methodology needed for the next generation of self organizational experimentation with C2 echelon creating agents will require the techniques promised by evolutionary computation.

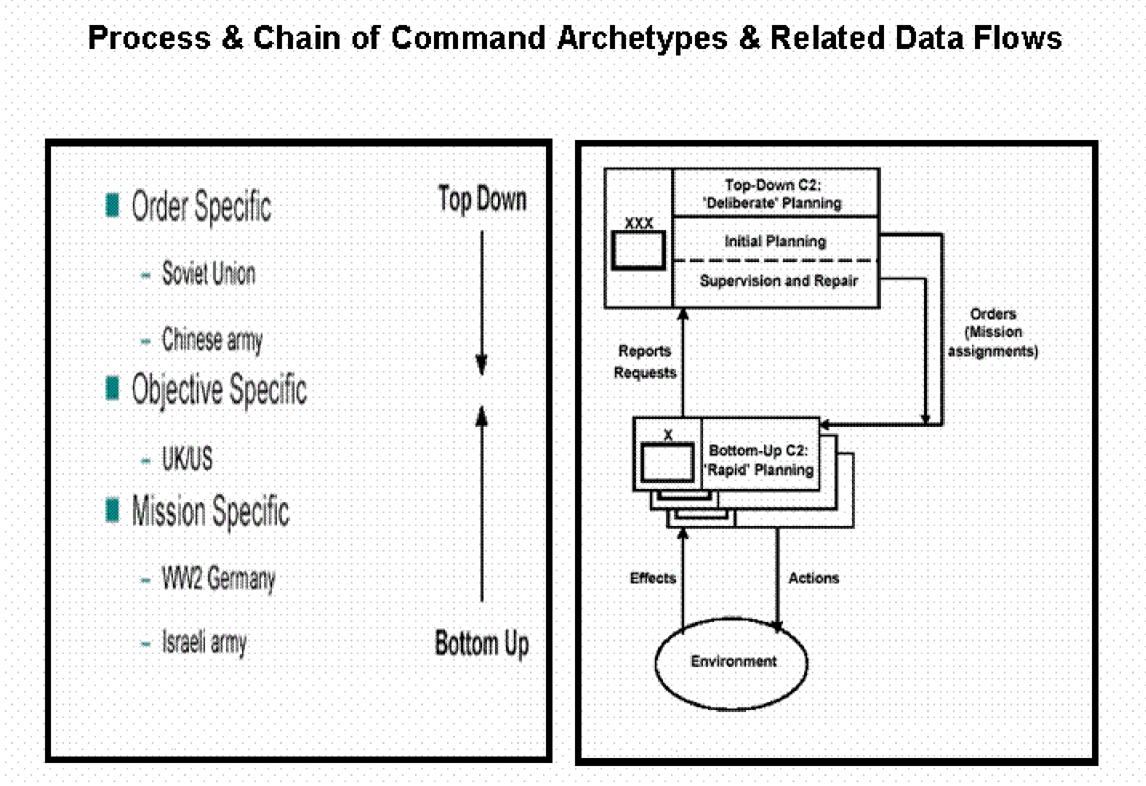


Figure 2 – Moffat[19] and Mason's depiction of C2 top down and bottoms up planning models

The combined graphics in figure 2 depict the C2 structure capabilities as related to top down or bottoms up planning methodologies. Given one of the 6 C2 models depicted, the agents must "self organize" into the proper related echelon structure and the agents at each echelon level must "learn" the appropriate mission planning skills or acquire the proper knowledge required for their echelon in the particular C2 model selected. Once we have arrived at this point, this permits us to model a certain level of understanding required for the agents.

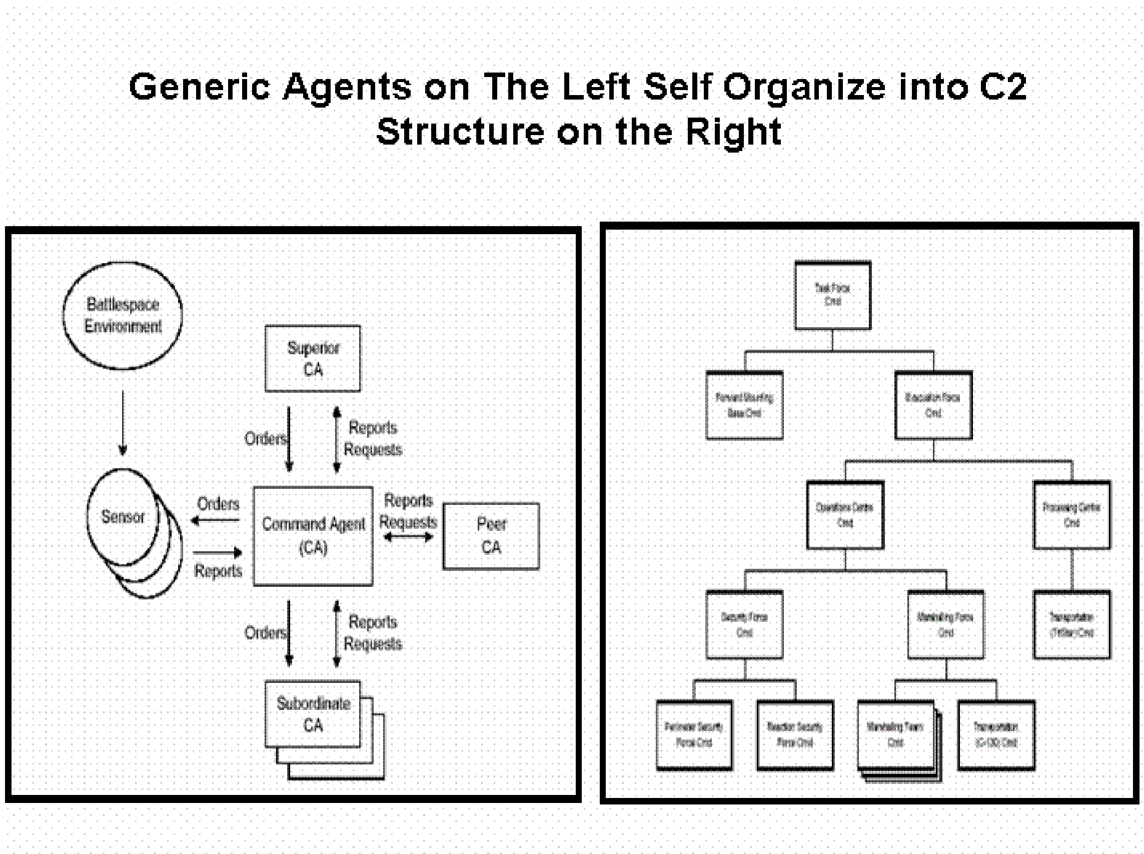


Figure 3 – depicts a self organized instantiation of command agents into a "command echelon structure" (also from Moffat and Mason's work cited above) Given a set of process inputs and stimuli, each agent at the echelon level should next be capable of producing a "mission plan" given one of the six models as a frame of reference. Assuming that a form of the German model "self organized", the agents should now begin to acquire the knowledge necessary to create the plan segments appropriate for their echelon level. Assuming that the agents do actually perform the planning tasks, and also assuming that a "plan aggregation" agent is present to fuse the plan into a coherent whole, the "mission plan" created by the agents would "emerge" from the aggregate of all the echelon planning agents. While no single agent in this example can create an entire plan, the agents acting collectively can, after they self organize into the echelon structure depicted in figure 3. Thus, the agents "self synchronize" to create the process output product, namely the mission plan. In other words, the process framed entities self organized into echelon organizations and "a mission plan emerged". This example would be tantamount to intentional or type 1a emergence after self organization. But the real

problem for follow-on research remains how do we actually know that the agents will "really self organize" into a proper structure, and how do we really know that the echelon agents will then create a useful mission plan? Obviously, we do not know this for certain. What we need is a predicative mechanism or a self organization and emergence assessment technique in order to validate that the agents will self organize at all or exhibit any emergent "mission planning capability.

Relevant Research [20]

Interesting research in this field has been pursued by Sims, Goldman, and Lesser of the University of Massachusetts Amherst. Their experiment focused on the premise that in large scale organizations, centralized control is not feasible. Their approach is to attempt self organization through a "bottoms up" approach of Coalition formation. Agents negotiate iteratively to enable managers to refine their coalitions and adapt dynamically to environmental changes. A coalition of agents is formed with each agent containing varying degrees of information (local and social), the coalition is then tested to determine how information content affects the resulting organization. The self organization occurs in stages of discovery, maintenance, and negotiation. Their results demonstrated that self-organization occurs best when communications between the agents is "free", a second result showed that social information increased the utility of the organization over local information.

Other relevant research includes: "Agent Based Model of Auftragstaktik: Self Organization in Command and Control of Future Combat Forces[21]", "Agent Based Modeling Approach to Quantifying the Value of Battlefield Information[22]", "Agent Coalitions[23]", "Information Oriented Organizations[24]", "Task Oriented Organizations[25]"

Conclusion

We have discussed the categories, types, and attributes of self organization and emergence. It seems that before the DoD embarks down this path, that a robust assessment process for the evaluation of emergent and self organizational capabilities should be developed. We have suggested attributes and capabilities that agents must have in order to exhibit self organization and emergence. Type 1a emergence, seems the only practical research target at this time. Focusing upon intentional or nominal emergence will hopefully give a deeper understanding of what must occur for these C2 organizational and planning agents to successfully self organize. This author also is very tempted to conclude that "emergence" is a much deeper phenomenon than the Latin derivative "appears" implies. Appearing means or implies that an "observer" is present. If DNA mutates and a sixth finger appears or emerges, the parents may be "surprised" at the emergence of the additional finger but the actual cause is really that the mutant DNA is simply being transcribed. Nothing really magically appeared. Plus the parents "knew" that the correct structure of a human hand should contain five fingers. Suppose that a plant had a mutated DNA sequence which allowed it to process more sunlight. Did the increased photosynthesis capability emerge if no human being ever notices it? Or did simple and common evolutionary phenomena occur that resulted in an increase in the plant's capability? If humans do not notice the additional capability does anything "really emerge"? And if humans do notice, do they then proudly proclaim their discovery

of the new emergent capability and await their Nobel announcement? We must be prudent and patient with ourselves such that lethargy does not replace serious scientific analysis. Whether or not there actually exists a phenomena as "emergence" that occurs because of clear scientific processes is not at all obvious.
This author also arrives at the same conclusion as John Holland [26]: "We would have to prove that emergent phenomena ***will*** occur when these sufficient conditions are met", from page 239. And also page 232, under cognitive examples "our abysmal ignorance of most aspects of cognition presents a serious deterrent to our understanding of emergence". We're nowhere near the end of the exploration of emergence", page 221.
The Goals of C2 process and NCW capability design in terms of "real usability of these concepts must include the following:

1. Predictable, stable and reliable emergence and self organization.
2. Self organization and emergence must apply to processes, organization, systems, software, and individual agent capabilities.
3. It is imperative that self organizational theory and emergence theory co-evolve with NCW and C2 process assessment theory in order to achieve any meaningful improvement in the state of the art or state of the practice of self organizational C2 or emergent C2 behaviors.
4. Assessment methodologies and processes must focus on positive emergence and self organizing capabilities as well as negative self organization, and negative emergence.
5. A "Process Instrumentation and Metrics Theory" must be a key component of any assessment theory expected to be capable of successful prediction of useful emergent capabilities or self organizing capabilities
6. The processes and resources expected to exhibit self organizational and emergent phenomena must have access to the knowledge which will enable such behaviors within the actors. The knowledge must be of the proper types as described in the sections above concerning the relationships between knowledge types and categories of self organization and emergence.
7. Reliability and predictability seem to evolve as key requirements for any potential use of self organization and emergent capabilities. The DoD must be able to have reliable capabilities before entering combat situations with such entities.

In closing, repeating the following quotation from John Holland seems appropriate: "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"

References

1. Lucas, Chris, "Quantifying Complexity Theory", http://www.calresco.org/lucas/quantify.htm
2. Lucas, Chris, Self Organization, FAQ, ©1997 Chris Lucas, version 1 (draft) 24 May 1997
3. Holland, John, H., "Emergence", Perseus Books, 1998

4. Morin, Edgar. 1977. La Methode I: la Nature de la Nature. Paris: Seuil. See also, Kelly, Sean. 1988. "Hegel and Morin: The Science of Wisdom and the Wisdom of the New Science." In The Owl of Minerva: Biannual Journal of the Hegel Society of America. Vol. 20, 1. pp.1-67
5. Self-Organizing Systems (SOS) FAQ, Frequently Asked Questions Version 2.98 June 2005, USENET Newsgroup comp.theory.self-org-sys
6. Ferber, J.,1999. "Multi-Agent Systems: an Introduction to Distributed Artificial Intelligence." Reading, MA, Addison-Wesley.
7. Pawloski, Joel S., March 2001 "Modeling Tactical Level Combat Using a Multi-agent System Design Paradigm" (GI agent)
8. Holland, John, H., conclusion in "Emergence – From Chaos to Order":
9. Kim, Jaegwon "Making Sense of Emergence" (1999), *Philosophical Studies* 95, 3-36.
10. 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
11. Kewley, "Agent Based Model of Auftragstaktik: Self Organization in Command and Control of Future Combat Forces", Center for Army Analysis, Proceedings of the 2004 Winter Simulation Conference
12. Stephens, Robert, Knowledge modeling and representation, http://www.cems.uwe.ac.uk/~rstephen/courses/UQC833hm/week6/lecture.html
13. Blackler, F., 1995, Knowledge, Knowledge Work and Organizations: An Overview and Interpretation, Organizational Studies
14. Kewley and Larimer, "Agent Based Modeling Approach to Quantifying the Value of Battlefield Information", Phalanx V 36, 2003
15. Moffat, James, "Complexity theory and Network centric Warfare", CCRP Press, September 2003
16. Lenahan, Jack "An Abstract Process and Metrics Model for Evaluating Unified Command and Control, A Scenario and Technology Agnostic Approach", CCRP CCRTS, June 2004
17. Dr. David S. Alberts and Dr. Richard E. Hayes, "Command Arrangements for Peace Operations", national defense university, ndu Press Book, May 1995, page 39.
18. Moffat, James, Mason, Colin "AN AGENT ARCHITECTURE FOR IMPLEMENTING COMMAND AND CONTROL IN MILITARY SIMULATIONS", *Proceedings of the 2001 Winter Simulation Conference B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, eds*.
19. Moffat, James, Mason, Colin "REPRESENTING THE C2 PROCESS IN SIMULATIONS: MODELLING THE HUMAN DECISION-MAKER", *Proceedings of the 2000 Winter Simulation Conference J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, eds.*
20. Sims, Goldman, and Lesser, "Self-organization Through Bottom-Up Coalition Formation", AAMAS, 2003
21. Kewley, "Agent Based Model of Auftragstaktik: Self Organization in Command and Control of Future Combat Forces", Center for Army Analysis, Proceedings of the 2004 Winter Simulation Conference

22. Kewley and Larimer, “Agent Based Modeling Approach to Quantifying the Value of Battlefield Information”, Phalanx V 36, 2003
23. Shehory and Kraus, “Agent Coalitions”, (ICJAI’95)
24. Goldman and Rosenschien, “Information Oriented Organizations”, (Agents’99);
25. Horling, Benyo, and Lesser, “Task Oriented Organizations”, (ICMAS’01)
26. Holland, John, H., “Emergence”, Perseus Books, 1998