PACS.i - A Complexity Theory based Framework for Battle Management

Ravindra V Joshi
Research Scholar, Department of Computer Science and Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, Kanyakumari District, Tamil Nadu, India.
E-mail: rvjoshi18@hotmail.com

N. Chandrashekhar
Professor, Department of Computer Science and Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, Kanyakumari District, Tamil Nadu, India.

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Abstract

A Platform based on Complexity Theory will consist of domain specific framework, dynamics, and systems. PACS.i is a framework through modern combat missions can be conveniently managed. PACS stand for Planner, Analyst, Commander and Soldier. While Planner and Analyst define pre and post battle view, soldier models frog's view of combat in execution and commander bird's view of same. These roles should handle Population, Spatial, Temporal and Causal dynamics (with their sub-classes). Also four types of Systems - regular, complex, chaos-based and stochastic can realize these architectures with varied benefits and losses. This paper explores the relation between roles, dynamics, and systems. PACS.i framework is result of synergy between all three of these.

Keywords

Battle Management, PACS.i Framework, Peer Communication Protocol.

Introduction

Modern battles have to be managed in complex manner. Highly sophisticated and automated weapons, rapidly changing environments, missions planned with element of surprise as central theme make it difficult to handle in conventional manner. In fact, these combat missions are of complex nature and need such treatment. We explain one such framework, PACS which is Complexity Theory based for handling modern combats. This framework was originally formed when author presented one of the paper as poster in IRISS convention (Ravindra V Joshi and N Chandrashekar, 2019). PACS is derived from the name Planner, Analyst and Commander and Soldier. These are spelt out of order for phonetic convenience. Right order is Planner-Soldier-Commander and Analyst. Their roles are explained briefly below:

1. **Planner:** Planner (Sun Tzu, 2010) is responsible for assigning each soldier his role in the mission, objectives he has to accomplish 4D (3D + Time) map with which he can navigate the space, peer communication protocol and protocol for communication with commander.
2. **Soldier:** Soldier is the one who fights it out in battlefield. In current age of autonomous weapons, soldier need not necessarily be human, but a robot, a UAV or any such system.
3. **Commander:** Commander is the central authority who receives information from all the soldiers, builds global situation awareness and distributes commands among all soldiers. His role is information centric.
4. **Analyst:** Once Mission is completed, analyst analyzes the data. He may use advanced techniques Deep Neural Nets. Since DNNs (Vivienne Sze *et al.*, 2017) give outputs whose justification is obscure, another component may be added which is known as Explanatory AI module.

Complexity Theory is about dynamics (James Moffat, 2003). Mainly, following dynamics are identified. Population dynamics concerns itself about collecting sample or creating population for research. Structure Dynamics about robustness and scalability of structure. Temporal dynamics deals with how system will grow wrt time. Time may at an instance or evolutionary. Finally cause-effect dynamics or causal dynamics will determine cognitive (being aware of situation) and utility based (purposeful action). This framework is shown in Figure 1.

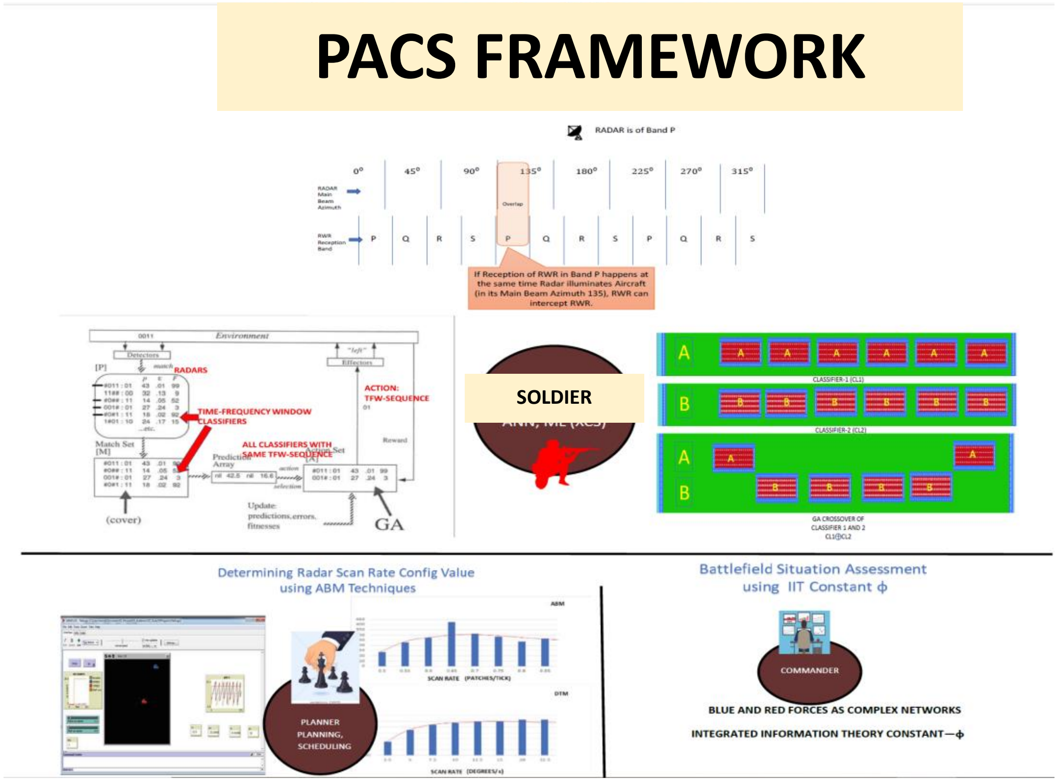

Figure 1 PACS Framework

Table 1 Dynamics vs PACS Roles

Sl. No.	Attribute (Claudius Dros, 2008)	Deterministic	Complex	Chaotic	Stochastic
1.	Population Dynamics	MODERATE	HIGH	LOW	MODERTE
2.	Structural Dynamics (Scalability)	LOW	HIGH	LOW	LOW
3a.	Temporal Dynamics-1 (Instantaneous)	LOW	HIGH	LOW (in Certain Regions)	HIGH (within Estimated Margins)
3b.	Temporal Dynamics – 2 (Evolutionary Growth)	LOW	LOW	LOW	MODERATE
4a.	Causal/Utility Based Dynamics	HIGH	LOW	LOW	LOW
4b.	Causal/Cognitive Dynamics-1 (Mining/Recognizing Patterns)	MODERATE	LOW	LOW	HIGH
4c.	Causal/Cognitive Dynamics -2 (Explanatory Intelligence)	LOW	MODERATE	LOW	LOW

Weaver, 1948 in a classic paper in 1947, introduced a system of “Organized Complexity”. Such system would be different “Disorganized Complexity”. Today we call the former Complex Systems and latter Stochastic Systems. In between the two a Chaotic System is also introduced. In this paper we study how each of the system is applied dynamics of each Role. Section 2, 3, 4 and 5 address Planner, Soldier, Commander and Analyst respectively. Section 6 discusses the results and concludes with future work.

Planner

Planning Ravindra V Joshi and N Chandrashekar, 2018 is not very new, in fact it was widely used in WWII itself, then it gave birth to a new discipline called Operation Research. Simple Problems starting from Transport and Assignment Problems grew on the support of Linear Dynamic Programming and became Strong. Also, there are different kinds of planning. Most familiar part of planning is Path or Motion Planning. Also known as Path Generation Problems, this class addresses how an object or group objects should navigate in space, typically in presence of obstacles. An important idea that got developed here was of Domain Independent Planning. Set of techniques that can be applied to any domain were formalized and strengthened. Many practices ranging like State Space Planning, Graph Based Planning, Constraint driven Planning and Propositional Logic based Design are also in practice.

Scheduling is a related problem to planning. If planning tries to find out solution in tasks, scheduling tries the order in which resources should be assigned to these tasks. Both are related. In scheduling, there are mainly two classes: Deterministic and Stochastic. In Deterministic model, all the details about Jobs, their resource requirements, arrival times etc., are known in advance. In stochastic model, they are discovered as time progresses. Common concepts like Jobs, Flow Shop, Release Time, Due Time etc., Scheduling is so common that it occurs from OS Task scheduling to on board resources scheduling to Project Scheduling.

1. Population Dynamics

When combat needs to be modeled, different entities and actors of self and enemy are generated by actor. Different Human, System, Carrier (like Tank, Aircraft) and Weapon/Ammunition (Missiles), Sensors and Combat Elements like Radars/Electronic Warfare (David Adamy E W, 2020).

Regular Planning Techniques are not very strong in Diverse Population Generation. Most of them rely on hand coding with some uniform distribution of parameters. Design Patterns like Abstract Software Factory and Software Factory facilitate creation of objects confirming to certain characteristics but they have different context.

Complexity Theory is strong for generation of rich and diverse population. Extensive body of work exists in the field of cellular dynamics using which population is generated. Random Boolean Networks are established constructs used for these purposes. RBNs consist of a set of nodes and edges with Boolean values that is 1's and 0's. Nodes will also boolean truth-tables based on all the incoming edges. Thus, the network as whole defines a set of Boolean.

2. Spatial Dynamics

These dynamics captures Concepts, Relations, Structure between members of the population. It is static These are essentially a static model, where a frozen world is observed by moving around it. Conceptual structure of whole combat is important to Planner. Both self and enemy forces are modeled by planner are connected into a network and plan is formed to achieve the objectives. Network/Graph is the preferred data structure used to model the structure. Specialized algorithms like Shortest Path Algorithms can be used to identify spots of vulnerability and robustness. Techniques like Fault Tree Analysis, Reachability Analysis, and Petri net analysis are done for Vulnerability or conversely, Robustness analysis by (Lazaros Moysisa, 2019).

Since Planner assumes *a-Priori* knowledge of entire battlefield, it will be difficult to scale beyond this knowledge. For example, it is difficult to use a 100 vs 100 soldiers plan and use it in 1000 vs 1000 battle. One way to counter to this localize the design, and replicate design in large numbers assuming local design is general enough. Many of times, this has worked, and equal number of times it has back-fired. Generally, if it is known that scaling will be a requirement regular planning approach should not be first option.

3. Temporal Dynamics

In Temporal dynamics, the changes that are being observed in the world, rather than in observer. Dynamics generally has two types, Linear and Non-Linear. In linear dynamics, to put simply world will change only a small in small amount of time. Hence it will be predictable over a long period of time also. This is done by one step at a time, predicting a little future after every small time interval based on previous interval. But these will fail in non linear dynamics as in a small interval, and a small difference in input values (even a small error) can make output go on totally wrong path. Once on wrong trajectory, deviation will only amplify resulting in even more divergence. Thus, out of bound, incorrect paths will result from seemingly minor, small inaccuracies. For this reason, non-linear dynamics is supposed to be exceedingly difficult to model and manage than linear.

In non-linear dynamics behavior manifested by system is often called as emergent behavior as it cannot be attributed to any of constituents of the systems.

In case of regular planner, linear dynamics is the preferred approach. For most of the time the planning will be done a-priori that is before the battle. Though uncertainties are involved they are resolved using some assumptions and planning is done. So, there will be little or no scope for emergent behavior.

4. Causal Dynamics

Causal Dynamics recognizes A Mission is a purposeful activity. Purposeful attempts will be executed to maximize benefits against continuously changing real Mission conditions. Goal of Planning is to optimize the responses of various friendly forces under different conditions of Mission Plan. Optimization may be wrt to achieving objectives, spending resources, or minimizing loss of lives to self's armies. These optimization techniques are described below.

- **Cognitive Dynamics**

In Cognitive Dynamics, an entity continuously explores and reacts to environment and knows how to survive. In the current context, survival may involve dominating the enemy and his territory also. One important part of cognitive system is that it models itself also. For example, when a frog program sees a car rushing towards it, it senses that "it" is in danger. Two types of Cognitive Models are used in practice.

First one is Symbolic, where entities are modeled by a set of attributes and behaviors of external world. Most of the modern world, including OO Modeling, PROLOG Logic Modeling etc., follows this path only. AI Guru, Marvin Minsky also advocated same approach. Right from perceiving the external world, building situation awareness and projecting it to near future and based on the possibilities deciding course of actions all of these are covered by Cognitive Dynamic Systems. Generally, Cognitive Systems are modelled after brain. Highly analytical, semantic systems modeled by Regular Systems will not be strong enough to model them. Neither is totally chaotic or random. For such systems, complex adaptive dynamics systems will provide appropriate framework.

- **Utility Based Dynamics (Optimization)**

Cognitive Dynamics may recognize sensing of environment and modeling self for acting it. Causal Dynamics describes the way information is transformed as series of Cause and

Effects as it passes through various nodes in information path. This model argues that no change can happen by itself, there should be an external force acting on it. Hence it tries to establish a series of cause and effect chains, and use the same knowledge in achieving *"survival"*. There are two main forms of Causal Dynamics, Cognitive and Mission Dynamics

a) Optimization at an Instance

Optimization is an important dimension of Many approaches to optimization have been taken from decision theory. Main classes are single and multiple objective optimization problems. In Single Objective Optimization only one parameter is maximized/minimized among many. Inflecting maximal damage to the enemy maybe also objective. On the other hand, Multiple Objective Optimization concerns with multiple objectives at same time. Inflicting maximum damage to enemy while maintaining minimum casualties to self is Multi Objective.

Single Objective Optimization Problem is generally modeled primarily a mathematically which has to be maximized (minimized is obtained by negation sign). Associated with it will be a set of constraints. Again, constraints can be grouped into equality and inequality constraints. Finally, a parameter vector, along with their ranges is also a part of input specifications. Many techniques are used to solve such problems. In direct analytical techniques, mathematical techniques like Integration are applied to find the solution. After computers have become popular, numerical techniques, discrete methods like Finite Element Analysis are also very frequently used in recent days to solve these techniques. Also, Simulation Techniques like Discrete Time/Event Simulation can be readily used.

b) Optimization Across Evolution

Regular Plans will not evolve. At best, they improve over multiple iterations by explicit changes. But the very data structure and algorithms used are such that they open-ended in nature. The read inputs and generate outputs. Even shorting output to input will not yield as very soon they are driven to (software) saturation.

In some advanced techniques a combination of cognitive as well as evolutionary approaches is uses. Evolution based on Self-Organized-Criticality (Per Bak *et al.*, 1988) and Integrated Information Theory Planning. Here, the whole mission is carried out in such a way that number of conflicts with certain attritions (casualties) vs number of conflicts follows power-law distribution. When such planning is used in conjunction with Integrated Information Theory 3.0 a cognitive as well as evolutionary plan will be prepared. For such kind of planning Complexity Theory will provide correct Framework. The relations can be summarized as follows:

Table 2 Planner vs Systems

Sl. No.	Role	Attribute	Regular	Complex	Chaotic	Stochastic
1.	Planner	Population (Diversity) Dynamics [Syntactic vs Pattern (Pattern-Oriented]		v	v	
2.		Structural Dynamics [Robust vs Scalable]	v	v		v
3.		Temporal Dynamics [Linear vs Nonlinear] [Predicted vs Emergent]		v	v	v
4.		Cognitive Dynamics [Connectionist vs Symbolic]				v
5.		Mission Dynamics [Instantaneous vs Evolutionary] [Local vs Global]		v [Global]		v [Local]

Soldier

Soldier is the primary entity of battle. They are one which shed sweat and blood in the battleground and probably, even the goal of achieving mission's objectives. It can be member of Population Soldier, Carrier (Tank, Fighter Aircraft, Ship, Submarine), Guided Missiles, Torpedoes, and information specific entities are Sensor (Radar, Sonar), Sensor-Suppressor (Jammer, Active Protection System). These entities are best modeled by Agents in complexity theory. Agents can improve any of above, but more. In general, it can model anything that can perceive and act.

1. Population Dynamics

Regular Methods try to model these entities as Planning activities. Soldiers (and other artifacts) are modeled as objects with their attributes and operations. In some frameworks, all the entities can be captured in an XML format and they can be initialized to Object Oriented Models using eXtended Markup Language (OO-XML) parsing library. For example NET serialization framework. JSON (Java Script Object Notation) is another popular method. Population Generation in such models is not very algorithm friendly. Same Software Factory like methods are followed.

Challenge for Complex Systems (let us restrict to RBNs) is to generate different types of networks representing each type of soldier entity. For example, soldier's job may be to moving forward, and if an adversary found, attacking. While this pattern may be common to all soldier entities, the domain, the speed with which it moves, attack and defense capabilities, remaining health/fuel etc., varies from type to type. Their perspective will be of Frog's eye view of world. eXtended Classification System (XCS) (Martin V *et al*., 2002) algorithm proposes an elegant population generation problem based on initial problem definition. It liter fills population by probabilistically creating each species with desired characteristics.

Chaotic system can check whether the initial configuration of population is stable or not by projecting them into future and build bifurcations. If there are unstable regions model has to be returned.

Stochastic Population Generation will be a technique to one of the above techniques. However, System Noise of various actors should start getting defined here. Measurement Noise also will be one of the parameter that will be modeled.

2. Structural/Spatial/Relational Dynamics

The number of actors involved will be too many to represent each one and compute each one individually in regular model. So, they are treated in groups or clusters. Sensing and Controlling is done on groups rather than individuals.

Complex Systems are well equipped to handle such scenarios. They come out particularly strong when there are large number of particles. Idea here is to model each of the entity/actor as an agent, but only essential aspects that are relevant to the problem. Consider Agent Based Modeling, a very popular method among practitioners of Complex Systems Community. Here the domain or world is displayed as a grid. Basic actors agents (active entities), patches (passive entities) and a set of rules defining next state given current state of the grid.

Complex Systems are self-similar in nature. This implies that attributes and operations, response to stimuli etc., are same in case of Complex Systems, irrespective of Scale. Essentially they are fractal in nature how scalable complex network has to be built. But it should be noted that increased scalability does not mean increased robustness. More scalable system can be less robust, in fact. Suitable trade-off measures have to be applied.

3. Temporal Dynamics

Regular Methods try to solve the mechanisms using analytical methods and evaluate equations at later t. At best they may evaluate using numerical methods. But these are shown to be error-prone for nonlinear systems.

Complex Systems use combination of cognitive and evolutionary approaches to determine future trajectory. XCS is one such method. Here reinforcement-based learning method will assign fitness to members of population genetic algorithm will evolve or not. Ravindra V Joshi and N Chandrashekar, 2019 describes an application of this algorithm for military requirements. It discusses how Probability of Intercept can be optimized using the algorithm. The challenge in POI optimization is to intercept as many as radars as possible, while Radar Warner is rotating in Frequency domain and Radars are rotating in Spatial Domain. A combination of Reinforcement and Genetic Algorithms are used to optimize Probability POI. This is typical of Complex System Management methods.

Chaos theory will tell whether results in a particular area are stable or not. Let r be a parameter on which fixed points will emerge. As r varies from one end to another end, bifurcations and chaotic regions will be emerging. Lyapunov constants can also be used to check whether system is susceptible to chaos or not.

Stochastic Models are most useful for the role of Soldier. Since soldier essentially operates in real time, reacting to events happening around him/her and at the same time keeping himself on track and moving towards goal, statistical estimation and tracking algorithms like Kalman Filter are very natural him. Also very relevant are results based on statistical machine learning, where result is readily derived from patterns without trying to build deeper symbols.

4. Causal Dynamics

At *cognitive dynamic level*, as detailed out in XCS method, Reinforcement techniques are widely used. Reinforcement are half-way between Cognitive and Utility based dynamics (as in Utility based agents). They just not sense external environment, also associate a reward or penalty for the decision taken based on whether the result of the decision was positive or negative. When seen over large number of steps, correct steps would be assigned more weight wrong decisions. Regarding Ubd, or Utility based dynamics, finding maxima at local instance will involve normal statistical techniques. Optimization across mission requires more deliberation.

It should be noted that both cognitive and missionary approaches will be required when missionary dynamics are analyzed for a soldier. Most suitable cognitive data structure for soldier is neural network, that too tuned at executing a task. Now, widespread usage of Deep Neural Networks and Recurrent Neural Networks becoming a reality. RNNs are relevant to time series kind of applications.

Information Theoretic approach is another perspective from which cognitive aspects of the systems can be explored. Here, Integrated Information Theory (specifically, IIT 3.0) (Masafumi Oizumi) specifies a constant denoted by φ (small phi) which represents the integrated information a mechanism (i.e., a soldier) perceives.

On the other hand, evolutionary dynamics try to optimize over a period as against at given point of time. As explained earlier, in XCS algorithm, this is achieved by using Genetic Algorithm component. Thus, at soldier level, primarily cognitive (reinforcement) and evolutionary (genetic algorithm) govern behavioral model. The relations can be summarized as follows:

Table 3 Soldier vs Systems

Sl. No.	**Role**	**Attribute**	**Regular**	**Complex**	**Chaotic**	**Stochastic**
1.	Soldier	Population (Diversity) Dynamics [syntactic vs pattern oriented]		v	v	v
2.		Structural Dynamics [Robust vs Scalable]	v	v		v
3.		Temporal Dynamics [Linear vs Nonlinear] [Predicted vs Emergent]		v	v	v
4.		Cognitive Dynamics [Connectionist vs Symbolic]				v
5.		Utility Based Dynamics [Instantaneous vs Evolutionary] [Local vs Global]		v [Local]		v [Local]

Commander

Command and control (C2) is defined a "set of organizational and technical attributes and processes. [that] employs human, physical, and information resources to solve problems and accomplish missions" to achieve the goals of an organization or enterprise. The basic idea behind C2 (or still modern C4ISRN) is that one or more centers will be monitoring the operations of whole army from background. They will assess the status of situation and risks associated, and based on that disseminate commands throughout the force.

Assuming a single commander scenario, his job would be to collate information from all the soldiers and distribute it back.

1. Population Dynamics

There can be two types of Commanders and Centralized or De-Centralized. In Centralized architecture, which also will have hierarchical architecture, information from front-end soldier to back-end commander through a hierarchy of intermediate officers. Similarly command will flow back. In decentralized commander scenario, the hierarchy will be flattened and virtually, every soldier will think like commander himself.

2. Spatial/Structural/Relational Dynamics

In Hierarchical relationship, Commander and Soldiers are related by one ore more levels of hierarchy. Different topologies like, Star, Tree or Graph (Forest) can be used to connect all soldiers to commanders. Edge soldiers strictly execute orders. They have little autonomy. They would be given a plan, whenever deviation from plan occurs, it needs to be communicated to higher command and wait for further commands. Further commands can be received only after received from commanders.

Another architecture is decentralized. In stark contrast to previous one, here each soldier is empowered to take decision on his own. The team organization is more or less flat. Hierarchy is almost absent, multi level hierarchy is definitely not present.

Decentralized Systems are more easily scalable than centralized ones. This is obvious due to the fact that, in centralized model, addition of one extra node will involve addition of many more links. Deletion of links if node is deleted. In decentralized approaches, remarkably, addition/deletion of nodes will not depend on existing number of nodes. This can be big advantage during real time battle management.

3. Temporal Dynamics

For commander, the evolution of combat force should be visualized as one pattern rather than as collection of individuals and small teams. When approached through a total analytical perspective, Lanchester' s equations characterize the dynamics of battle force through the time.

$$\frac{db}{dt} = -L_r * (\frac{dr}{dt})$$

$$\frac{dr}{dt} = -L_b * \left(\frac{db}{dt}\right)$$

Let B0 and R0 be initial force strengths of the two armed forces. As time passes by Blue force reduces *at the rate* Red Force multiplied by Lethality of Red force (Lr) and vice versa. This simple pair of differential equations the temporal dynamics fairly well.

The model can be slightly changed to introduce Reinforcement in between. The timing of reinforcement can be based on battle state. When such change is introduced, state space of battle forces is said to enter a non-monotonic phase. This non-monotoni city is believed to be presence of chaotic behavior in the mode.

The Complex dynamics is defined Self Organized Criticality. As (Per Bak *et al*., 1988) defined in their classic work, steps move in steps, called avalanche. The system moves to a critical point. At that slight change results catastrophe, causing rapid realignment of forces. System moves to the points of through successive catastrophe. Though we cannot invite catastrophe in normal sense for the sake of increased fitness, we can go for it, if it does not involve physical or material casualties. Aim is just to reconfigure across all scales. The changes suggested in this model, esp. if done with specific split, combine rule for networks, chaotic behavior should is resolved and the state-space evolution should become monotonic.

4. Causal Dynamics

Commander has unique set of issues to address. Important among them are, how to become aware global situation? How to map them to global decisions? How to break these commands and disseminate among relevant stakeholders? Each front-end entity/soldier will have a piece of information sensed by him independent of others. First task is to collect data from each one of them and build *situation awareness*, by doing multi-sensor data fusion. For handling chaotic data there are Chaotic Neural Networks.

Integrated Information Theory, defines certain metrics at System level also. For example, IIT constant Φ (big PHI) (Masafumi Oizumi *et al.*, 2014) how well information is integrated at System itself. While Φ indicates quantitative aspect of information, qualia refer to qualitative aspect of information.

At stochastic level, Cause and Effect are determined by Kalman Gain kind of metric. It indicates how much system model (actual input output definition and their covariance's) has to be relied. It builds on the properties of Statistical Mechanics, a foundation of modern physics by connecting thermodynamic properties to microscopic materials. The relations can be summarized as follows:

Table 4 Commander vs Systems

Sl. No.	Role	Attribute	Regular	Complex	Chaotic	Stochastic
1.	Commander	Population (Diversity) Dynamics [syntactic vs pattern oriented]	v	v		
2.		Structural Dynamics [Robust vs Scalable]	v	v		
3.		Temporal Dynamics [Linear vs Nonlinear] [Predicted vs Emergent]	v	v	v	
4.		Cognitive Dynamics [Connectionist vs Symbolic]		v		v
5.		Utility Based Dynamics [Instantaneous vs Evolutionary] [Local vs Global]		v [Global]		v [Global]

Analyst

Analysis, activity of analyst is an integral and important part of Combat management. As we have seen, any combat or mission requires planning before it can begin. Similarly, after a mission has ended, it has to be analyzed to check what went well and what not so well. Generally, this will be conducted in de-briefing session. But fully or partially analyzing tools will be of immense help. Key input for analysis is recording that has happened during execution of mission. Data thus recorded, would be analyzed to understand key events, cause and effect relations which will act as inputs for next round of planning.

1. Population Dynamics

Population will be same as that of Planner. Recorded data is analyzed with reference to plan.

2. Spatial/Structural/Relational Dynamics

Most common format of Recorded Data would be<RecNo, Timestamp, Event>. If same framework records events from multiple systems, the template may be<RecNo, System, Event>. This event can run quite deep into the hierarchy. Suppose there is a Target Identification Module of Radar Data Processor. The signal would have travelled all the way from Antenna, RF-Rx Buffer, Radar Signal Processor, Radar Data Processor. Recording should record all the events along this path.

Analysis is not split it Serila or Parallel analysis, or Centralized vs Decentralized Analysis. Common Practice is to use sequential, centralized analysis. However, Neural Networks (NNs) and especially Deep Neural Networks (DNNs) are used quite often. But, that is for the purpose of cognition

3. Temporal Dynamics

Since the focus is on reconstruction of Past identification of causes of effects, Temporal Dynamics plays limited role for analyst. Power law distribution in data can be key indicator critical states. Similarly non linear dynamic analysis can identify the stable regions.

4. Causal Dynamics

In analysis, causal dynamics (or dynamics of cause effects) plays a significant role. Primary Data Analysis may consist of aggregating, classifying and grouping data. At this stage, visualization will play an important role. Analysis and Visualization together, will result in interactive analysis of data. This is also called as “Pivoting”. Next step in formalism is Fault Tree Analysis or Petri net analysis will help to assess the impact of failure of any individual risk and also probabilities associated with it.

Using statistics to derive relations in heaps of recorded data is nothing new. Many programs have been written to find structure in recorded data. Programs, called Deep Neural Networks, have emerged in recent which are extremely efficient in making sense of available data sets and patterns. They very effectively mimic the behavior implied in data. For example, they all the aspects of a radar is reliable modeled by a deep neural network. But DNNs have a problem too. They are extremely sensitive to noise. Slight noise in input will drive to different decision altogether. Another problem is that nobody understands why DNN gave a particular choice or division. A new branch called Explanatory AI has developed to solve this problem. IIT can contribute meaningfully at analysis level. IIT clearly draws out, what each mechanism or system perceiving in integrated way. Thus, IIT specific snapshots are also recorded, they help in justifying the system. Primary tool of Analyst is Causal Dynamics and he is supported by all its forms. The relations can be summarized as follows:

Table 5 Analyst vs Systems

Sl. No.	Role	Attribute	Regular	Complex	Chaotic	Stochastic
1.	Analyst	Population (Diversity) Dynamics [Syntactic vs Pattern Oriented]	v			
2.		Structural Dynamics [Robust vs Scalable]	v	v	v	
3.		Temporal Dynamics [Linear vs Nonlinear] [Predicted vs Emergent]	v	v	v	
4.		Cognitive Dynamics [Connectionist vs Symbolic]		v		v
5.		Utility Based Dynamics [Instantaneous vs Evolutionary] [Local vs Global]		v [Global]		v [Global]

Discussion

A Role based framework PACS was introduced and compared against four types of approaches. Regular where solution is derived by analytically solving the problem. Complexity Theory based approach combination of network (graph), cognitive and evolution-based approaches are used. These techniques are applied to Population, Structural, Temporal, Cognitive and Utility Based Dynamics. Results obtained for each of Planner, Soldier, Commander and Analyst are combined. The results are as indicated below:

Table 6 Consolidated PACS Roles vs Systems

Sl.No.	Role	Regular	Complex	Chaotic	Stochastic
1.	Planner	1	4	2	4
2.	Soldier	1	4	2	5
3.	Commander	3	5	1	2
4.	Analyst	3	4	2	2
5.	Total	8	17	7	13

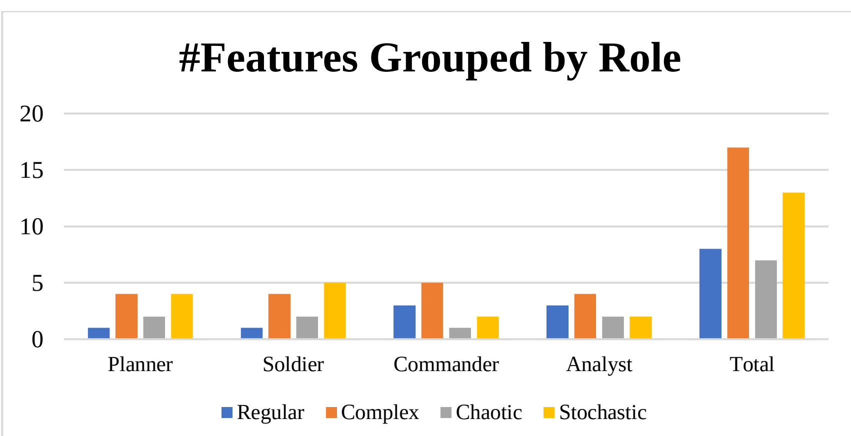

Figure 2 Consolidated PACS Roles vs #Features

As clearly seen in the analyzed data, Complexity Approach stands out from other approaches. Its nearest competitor is Stochastic modeling. But this chart can be misleading. Regular or deterministic modeling comes bundled with minimal features for all roles. This, being rather negative attribute, may imply that the configuration is simple and good enough for most of simple scenarios. In fact number of systems that employ regular system models are maximum in practice. Chaos System model will be limited in plotting out troubled areas. It maps areas which are inherently unstable, where results cannot be relied. Another comment is about stochastic systems. Contribution of stochastic systems in suspiciously small for Commander. This is because large number of participants will cancel each others' noise giving rise to (pseudo) deterministic behavior at macro level. Also, it can be noted that, at soldier level, stochastic (Kalman filter based) systems are based which observe, estimate and track each soldier separately. However, it is at Commander's level Complex Systems stand out. Here the situation awareness of entire battle has to be experienced by commander. This comes in emergent manner, not as "brick-by-brick" mechanism. Commander gets the insight which is "more than sum of parts" a classic quote in theory. It also helps in interpreting recommendations made by stochastic systems like machine learning algorithms or DNNs.

This shows how battle can be visualized and managed in terms of PACS framework. The framework is built on Complexity Theory. It shows various dynamics of the theory like Population, Spatial, Temporal and Causal (Cognitive, Utility based) dynamics can be applied roles. It also evaluates how different system models like regular, complex, chaos and stochastic model as envisioned. We tend to continue this work by incorporating this model in larger framework. Final idea is to develop product lines with the help of these frameworks. PACS will be one important framework of such platform.

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