Antifragile Criticality of Complex Intelligent Strategic Systems - A Framework for Thinking

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Abstract

The Complex Intelligent Strategic Systems (CISS) are emerging in the Sixth Wave of Innovation (years 2020-2045). Discovering, defining, describing, designing, developing, deploying, and deducing (7Ds) of CISS will have unprecedented demands, stresses, unknowable future impacts and failure potentials. Increasingly CISS will be safety, security, business or mission critical. CISS have substantial decentralization, higher embedded/ambient algorithmic intelligence, inherently conflicting, unknowable and diverse operational needs and requirements, continuous evolution, deployment and learning; heterogeneous, inconsistent, and changing elements and erosion of people-system boundary. We propose that antifragile mechanisms should be conceived, designed and built into these systems ab-initio. CISS lifecycle aspects including Value, Inventiveness, Manned-Unmanned Teaming (MUM-T), Computational Emergence, multi-level Design, Computational Engineering, Adaptive System Infrastructure, Adaptable and Predictable System Quality - need an integrative thinking framework. Classical thinking dimensions – Analytical, Logical, Value, Inventive, and Systems thinking (ALVIS) need to be synergized with the sixth wave of innovation dimensions of Scale, Computational, Algorithmic and Network (SCAN) thinking. We also speculate the emergence of a need of Quantum and Nano (QN) thinking within this decade. We propose and describe ALVIS-SCAN-QN thinking framework for 7Ds of CISS for achieving antifragile criticality (AFC).

Keywords: Antifragile Criticality (AFC), Complex Intelligent Strategic Systems, Increasing Intelligence of technical systems, ALVIS Thinking, SCAN Thinking, QN-Thinking, Sixth wave of Innovation, TRIZ

1. Introduction

When Richard Feynman was delivering his famous lectures on physics in 1962 and wrote “we do not yet know all the basic laws: there is an expanding frontier of ignorance” in the USA, it is unlikely that he would have heard of Generich Altshuller - the Soviet prisoner released after Stalin’s death from Siberian confinement in 1954. Altshuller was discovering the laws of evolution of technical systems through painstaking analysis of thousands of patents which was to result in the Theory of inventive problem solving (TRIZ in Russian parlance). It is indeed the fate of our world that multiple directions are taken for exploration and development in de-coupled social, political, and cultural societies – as USA and USSR were after World War II – without open exchange of learning and knowledge. Feynman states that laws of nature are approximate and, "… at each stage it is worth learning what is not known, how accurate it is, how it fits into everything else and how it may be changed when we learn more" [1]. This is indeed the process of continuous learning, understanding and creation of new knowledge. Despite its explanation by Darwin, in the 19th Century, acceptance of evolution by natural selection as a possible model of explanation of the progress of cosmos is relatively a recent phenomenon [2]. As Ridley states in [3], "the way the human history is taught can therefore mislead, because it places far too much emphasis on design, direction, and planning, and far too little on evolution". He further states that, "… to see past the illusion of design, to see the emergent, unplanned, inexorable and beautiful process of change that lies underneath".

One of the earlier recognitions of evolution due to the ingenuity of the human mind, reflected in the successful inventions described in patents and technological knowledge, was discovered and explained by the Theory of Inventive Problem Solving (TRIZ). This resulted in the discovery of laws of evolution of technical systems which became the basis of classical TRIZ. As per Altshuller the purpose of the evolution of technical systems was to achieve the "Ideal system". Technical systems exist or are created to perform a function. The ideal technical system describes the fulfillment of the function with a reduction in a number of the elements to zero of the technical system that actuates the function [4].

The key to "knowing" or creating "new knowledge" should be an evolutionary approach which is of course the natural one. However, using the output of human ingenuity as reflected in the inventions described in Patents, Altshuller was searching and creating *an algorithm for inventing through* design, direction and planning, and above all thinking. The algorithm of achieving ideality was to avoid the costly "trial and error" approaches of evolution – small local changes in multiple copies of the same system which get reflected in the "subsequent generations of the system". TRIZ proposed to leap frog the costly "trial and error" and focused on ideality to jump many avoidable generations of unnecessary random stages. TRIZ and its laws of evolution of technical systems discovered in the era of physical systems – the era of machines – explained the fulfillment of function in an ideal way. TRIZ remains a powerful methodology, philosophy and thinking mode. It however, has to evolve in the new waves of innovation as per the theory of Creative Destruction – given by Schumpeter and explained as waves or cycles of innovation [5].

From the start of the industrial revolution, different technologies have changed the way economic value and means of production of economic value are created. As the figure below indicates each such wave has ranged few decades. However, the duration of each such wave of innovation is reducing. World has seen two world wars during the 3rd wave of innovation which was driven by electricity and steel. The 4th wave of innovation was driven by electronics and aviation.

1st Wave: Cotton, Iron, Water power 1785- 1845 (60 Years)
2nd Wave: Railways, Steam, Mechanization 1845-1900 (55 Years)
3rd Wave: Steel, Heavy Engineering, Electricity 1900-1950 (50 Years)
4th Wave: Petrochemicals, Electronics, Aviation 1950-1990 (40 Years)
5th Wave: Software, Digital Networks, Mobility 1990-2020 (30 Years)

The fifth wave of innovation was driven by software, networks and mobile computing (years 1990-2020) is now giving way to the sixth wave of Innovation. However, we need to *cross the chasm of new creative destruction* – wherein newer technologies will change the modes of economic value creation replacing, transforming, and dismantling the older systems and ways of functioning of society. The destruction will be considerable and so will be the creation in *any creative destruction* period in history. To move on the creative side as quickly as one can is usually the key objective of all organizations. To do so, we first need to describe the sixth wave of innovation.

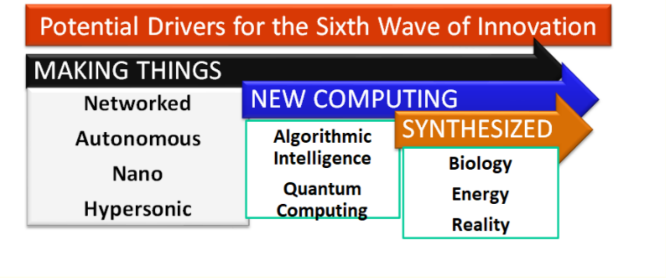
The paper is organized in the following sections. In the next section, we discuss the creative destruction and calibrate the sixth wave of innovation. In Section 3, we propose and define the emergence of Complex Intelligent Strategic Systems (CISS) that are visible in the sixth wave of innovation. Section 4 defines the concept of antifragile criticality (AFC) of systems as robust evolvability. In Section 5 we describe an innovation framework for thinking CISS for antifragile criticality (AFC).

2. The Sixth Wave of Innovation (2020-2045)

In any creative destruction, as per the definition, a new economic system is emerging through the application of new transformational technologies, as the existing economic system is becoming irrelevant or mutating its key tenets and aspects. Rapidly learning the new ways and thinking dimensions for applying new technologies is the only way ahead. The current creative destruction is giving way to what we call the sixth wave of innovation [6].

This sixth wave of innovation, we propose, is being driven by
(a) Things becoming Networked, Autonomous, Nano and Hypersonic,
(b) Algorithmic Intelligence and Quantum Computing, and
(c) Synthesized – Biology, Energy, and Reality.

If algorithms were the building blocks of the fifth wave of innovation - Algorithmic Intelligence (Year 2020- 2045) is the building block of sixth wave of innovation. To this Quantum Computing (Year 2030 - 2045) will start finding transformation level applications to evolve the world economy towards a self-organizing, adaptive infrastructure and multi-dimensional inter-human and human-bot hyper-connectedness. To operate-in and to ride the new wave of Innovation - new thinking and calibrated actions at multiple levels and with multiple perspectives are needed.



2.1 Reality and Synthetic Reality

Significantly, the last three decades gave us a technological substrate that connects one another instantaneously, at a substantially lower cost. This should be the greatest achievement of human ingenuity and thinking. We named this new artificial substrate of our reality - cyberspace. It exists in some form that is distinct from reality in the physical world. Reality, however, defies precise definition, is inherently paradoxical, and is typically driven by dominant social and political beliefs [7]. This substrate also has become a vehicle to "own the reality", by forces who would like to control us for their specific purposes and "cultism" of all kinds. The "synthetic reality" is real [8].

2.2 Biology and Synthetic Biology

There was a crisis of biology after World War II, when physics and to some extent chemistry, were ruling the sciences. Ludwig Von Bertalanffy changed it with his "theoretical biology" that proposed a "system theory of organism". The system (organism) tends to preserve itself and life builds itself in a "hierarchical mode of organization". This expanded to general systems theory. Higher level of organizations is built by lower-level components with new laws relevant to the level being built. These new laws are not deducible from the laws of lower levels. Further, so long as the system ("organic") has not yet reached the maximum organization possible to it, it tends towards it. We have come a long way in biology especially with our ability to go deeper into the basic building blocks of life. The genetics revolution has given us new ways to rebuild "living systems". Non-natural, cell-less synthetic biology is already threatening to transform the way we will live. A small error or deliberate mistake or even a designed synthetic biology attack can not only destroy a nation but can create new pandemics. Lesson from the current Pandemic, even though the evidence of it being a bio-weapon is insufficient, is that a controlled version of such potentially synthetic bio-weapons can be an interesting option for adversaries [9].

2.3 Energy and Synthetic Energy

The Internal Combustion (IC) engine that has given us more than a century of mobility in the form of automobiles is in for replacement. That depends however upon how soon we can synthesize cheaper Electric Vehicles (EV). The expected EV boom, however, hinges on EV batteries. The lithium-ion battery that powers our mobile phones and electric vehicles are the key. 2019, Nobel Prize for Chemistry was given to the inventors of Lithium-Ion batteries, a clear indicator of how much our new world of anytime connectivity is enabled by these. As the world grapples with creating cheaper and durable EV Batteries - see for example recent Tesla Patent [10], we are headed for the EVB boom [11]. Our ability to synthesize ways for cheaper, durable and green energy will impact all dimensions of human existence.

2.4 Things – Networked, Autonomous, Nano, and Hypersonic

If one studies what is called the "inventive energy" [12] of the world, which indicates the current focus of the inventors of the world in specific domains of technology as reflected in the published Patent applications and grant of patents by patent offices, one can see the focus of the world for last decade or so has been to *make things – networked* as reflected in the Internet of Things (IoT), *make things autonomous* – for example many programs and projects across the world to make autonomous cars, make *functional things at the nano level* which is one-millionth of a milli meter and increase the *speed of the objects to hypersonic levels* – which is greater than 5 times the speed of sound. We are inventing to expand the boundaries of human existence and human-interactivity with the matter at extremes that have been unfathomable just about a couple of decades back. The impact of these efforts and inventions across the human living spectrum – across the known or unknown future operations will be transformative.

2.5 The Glue – Algorithmic Intelligence

The key to synthesizing biology, energy, and reality is the ability to embed intelligence or what should appropriately be called algorithmic intelligence into machines there-by making them more and more autonomous [13]. The ability of these algorithms to quickly filter multi-dimensional data from sensors providing rapid streams of data and create quick meaningful, relevant, and decision-enabling picture is well known. What has changed and is changing rapidly is the ability of the technical systems *to act in real time autonomously without the need for any human intervention*. This has its dangers and also its great benefits – just like any other technology. The future system of systems will be glued together through the algorithmic intelligence.

2.6 The Emerging Glue – Quantum Computing

Quantum computing and quantum technologies will be the next level transformational technology of the sixth wave of innovation. "Imagine a 2030 world where nanomaterials are quantum-active with quantum information encoding and manipulating their behavior. The unmanned aircraft, the robots and the factories may be nanomaterials with the ability to hack the sub-atomic information using quantum technology systems" [14].

3. Emergence of Complex Intelligent Strategic Systems (CISS)

A set of elements interacting together and with the environment to perform a function(s) or achieve an objective(s) is defined as a system. Conceptual construct of a system gives us a lens to identify key dimensions of the world for our understanding and action. Disparate systems of the previous era became systems-of-systems through the information technology in last forty years or so which gave us a transformed world of information era where the network was central and systems were hybrids of software and hardware. This was proclaimed as a revolution. This led to a concept of a hybrid world where the boundaries of physical and cyber living rapidly started blurring as information became the glue of the fifth wave of Innovation. Utilization of physical space and cyberspace in a seamless fashion to launch, influence, and disrupt the existing economic system led to a congruence of information and the physical world.

3.1 Classification of Systems

As we move on from physical space to cyberspace and currently, phygital space [15], new thinking and new capabilities are needed to operate, survive and thrive in the amalgamating physical and cyber worlds. It is imperative that we create systems that are seamlessly integrated to operate in physical, cyber, and *phygital* spaces. This itself will need a rapid transformation of existing systems, through what can be called as multi-layered systems fusion. If the *phygital* is a novel need of the modern world, we need to be ready to operate and respond to what we can call an emerging world of quantum-cyberspace ahead. There is a need for a paradigm shift in our thinking as the substrates of our existence has evolved from (a) physical space, cyberspace as separate spaces with links to each other through well-defined interfaces to (b) phygital space where the digital and physical boundaries are seamlessly being blurred, to the emerging (c) quantum cyberspace where a new level and resolution of operations will be needed ahead.

System Engineering Body of Knowledge (SE BOK) [16] identifies four general classes of system contexts – product systems, service systems, enterprise systems,

System Classification Dimensions

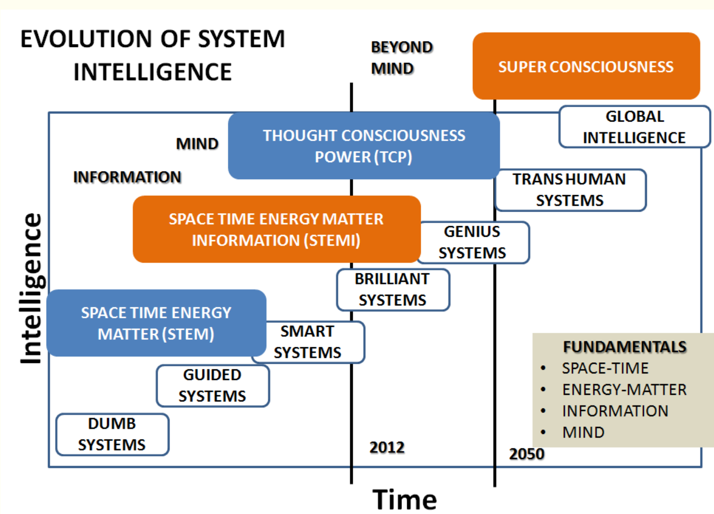
System Dimensions	Specific value of system dimension	POSSIBLE VALUES THE DIMENSION CAN TAKE							
System Type	Complex	Simple	Complicated	*Complex*	Chaotic				
System Function/Process Type	Computing	Transformation	Distribution	Storage	Control	*Computing*	Learning	Market	
Main Operand Type of the System	Information	Matter (Objects)	Energy	*Information*	Value (Money)	Ideas	Emotions	Beliefs	Intentions
Level	Strategic	Tactical	Operational	*Strategic*	Policy				
System Inteliigence	Brilliant	Unguided	Guided	Smart	*Brilliant*	Genius	Transhuman	Global Intelligence	
System Context (SE BOK)	Product System	*Product System*	Service System	Enterprise System	System of Systems				
Nature of system (Checkland's Classification)	Designed Physical System	Natural System	*Designed Physical System*	Designed Abstract System	Human Activity System	Transcedental System			
Hierarchy of Engineered System of Interest (SOI)	Technology SOI	*Technology SOI*	Product SOI	Enabling Service SOI	Service SOI				

and system of systems. There is a classification based on the nature of systems, for example, natural systems, designed physical systems, designed abstract systems, human activity systems, and transcendental systems.

In the engineered systems of interest, SE BOK classifies four systems of interest (SOI) – technology SOI, product SOI, enabling service SOI and service SOI. Systems are also classified as simple, complex, complicated and chaotic. There are system classification schemes based on what type of operand they operate on, for example objects, energy, etc. Systems also are classified based on their functions at the abstract level – transformation, storage, distribution, etc. The Table above provides 8 dimensions of classifying technical systems.

3.2 Increasing Intelligence of Technical Systems

Further we have included a new dimension based on system intelligence and what we proposed in 2012 as *the law of increasing intelligence of technical systems* [17]. As per this law, systems can be classified as dumb or unguided systems, guided systems, smart systems that started emerging in the 4th wave of innovation driven by electronics and proliferated in the 5th wave of innovation paving the way for brilliant systems that have self-learning abilities. We proposed these brilliant systems will be defining the sixth wave of innovation and somewhere at the end of this wave will graduate to genius systems where their ability to have a "mind" of their own will become common place.



Rudimentary "minds" of technical systems are already emerging in the brilliant technical systems that are emerging.

3.3 System Complexity

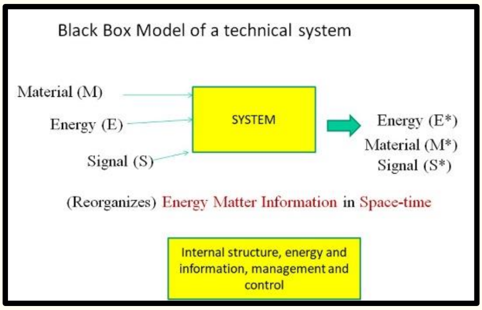
Complex systems have been defined as having many parts and interactions that exhibit properties such as non-linearity, emergence, adaptation, spontaneous order, etc. With many feedback loops, complex systems exhibit emergent functions and capabilities that usually may not be discernable from simple or a linear combination of constituent parts that make these complex systems. The interaction mechanisms and the feedback loops that combine the components of these systems into such complexity many times lead them to unintended consequences as well.

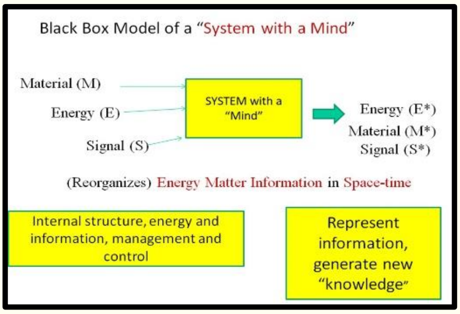
3.4 Strategic Systems

In our system classification dimensions we have included a level dimension based on level of information they process – strategic, tactical, operational and policy levels. Strategic information systems collect, collate, process and enhance information relevant to their operations, processes and contexts that may be needed in future. Using the continuous/frequently evolving/changing information these systems keep on updating their processes and operations to improve, adapt or adopt to the current view(s) of the information they have created, learned or have been supplied with. Every system, potentially, can be transformed or enhanced to have strategic level by – (a) making it collect data and information relevant to its operations, processes and domains; and (b) processing and/or computing relevant actionable information that it can utilize during its future operations.

3.5 CISS – Systems with an Appropriate Mind

We proposed that the systems that are emerging, needed and most prevalent in the Sixth Wave of Innovation (years 2015-2045), will exhibit complexity, intelligence and will have strategic information processing capabilities. To design these systems and operations with these systems, we need a rapid transformation to invent and design systems that are going to evolve to high complexity, display intelligent behavior and will have ability to leverage strategic information a seamless manner. We call these as Complex Intelligent Strategic Systems (CISS)[18] - a new class of systems and products. CISS are technical systems with an appropriate and relevant "mind" of their own.



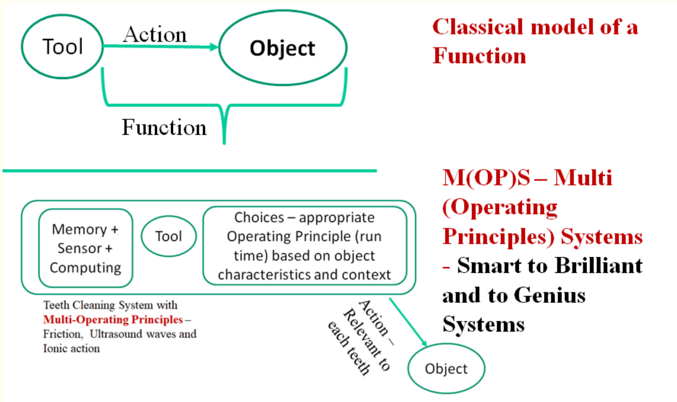


In our traditional definition of a technical system – we have defined a system as a set of elements to reorganize material, energy and signals/information with defined internal structure, energy, information, management and control. The system with a "mind" is also a classical system however, it also has an ability to represent information and generate new relevant or appropriate information or knowledge for action and updating its behavior or structure.

3.6 Function Modeling – TRIZ Evolution for CISS

Classical TRIZ defines the model of a function around which a system is developed. In the classical model of a function in TRIZ, a "Tool" "acts" on an "object" based on a scientific principle – called the "operating principle" to complete a technical "function". For example, a toothbrush (Tool) acts on the teeth (Object) based on the scientific principle of friction (The Operating Principle) to remove the dirt or plague on the gums and teeth. This action through the operating principle achieves the cleaning function. Typically, the 4th and 5th wave systems were built around a single operating principle to achieve a function. If there were multiple systems combined together, each had its own operating principle – for example, a Swiss knife.

In the emerging systems with a "mind", we are already seeing the emergence of multi (operating principles) systems (M(OP)S). We define these as having more than one operating principle or "engine" if one may wish. For example, the hybrid vehicles combine the traditional IC engines with an electric power and transmission system with leads to a system with two operating principles. One can imagine a future toothbrush (rather tooth cleaning system) that will have say friction-based tool and also ultrasound waves to pick and choose a specific sensitive teeth or areas of the mouth that bristles cannot reach. Such a function model will need to have tool that can pick and choose the relevant operating principle in the context and situation that teeth demand and also need to have memory, sensors and appropriate computing or processing capability. More and more of Complex Intelligent Strategic Systems (CISS) will be Multi-Operating Principles – Systems or (M(OP)S).



3.6 Increasing Intelligence– Smart to Brilliant to Genius Systems

Further, the *smart systems* as per law of increasing intelligence of technical systems will move towards what we articulated and defined as *brilliant systems which will pave way for Genius Systems*. Following Altshuller's work and TRIZ discovery of laws of systems evolution, we have also identified the following lines or evolution of technical systems under the law of increasing intelligence. The 7 lines of intelligence comes from the study of functions of mind and also the way we are trying to build more

algorithmic intelligence into technical systems as per sixth wave of innovation. These 7 lines of intelligence are as given in the figure. We are developing our systems towards perfect sensing, wisdom, learning, decision-making, concept creation, and even perfect intuition and collaboration. It is an ideal model what we perceive an ideal human capability should be. *It is interesting that humanity after finding that it can itself achieve the idea human being, is aiming to create machines with perfect or an ideal human intelligence.*

Complex Intelligent Strategic Systems (CISS) developed and operating along these lines of increasing intelligence will be more adaptable and also will be able to operate in much diverse operating conditions and environments.

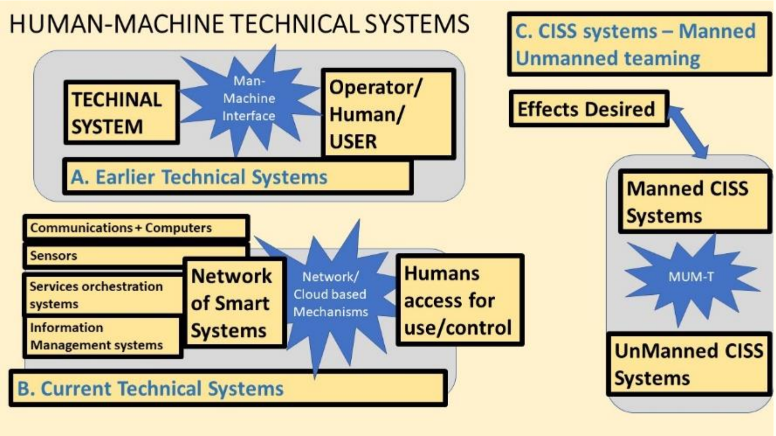
Stages on the Lines of System Intelligence

LINE OF	I	II	III	IV	V	VI	VII	VIII	
Sensing, Detecting and Recognizing (SDR)	Single system parameter	Multiple System Parameters	System Parameters Interactions	System of Systems (SOS) parameters	SOS Parameters Interactions	Age of Perfect Sensing Machines			
Processing, Computing, Knowing	Data	Information	Beliefs	Knowledge	Wisdom	Truth	Age of Spiritual Machines		
Learning	Store	Memory	Assisted	Heuristics (goal oriented)	Supervised	Unsuperwised	Learning New Meaning	Age of Perfect Learning Machine (Guru Machines)	
Choices	Storing Pre-defined Choices	Choice Demarcation	Evaluating Choices	Selecting Choices (Data/Criteria Driven)	Context Adaptive Choice Selection	Context & Emotional State Adaptive Choice	Age of Leader-Machines		
Concept Creation	Clustering	Inductive and Deductive Connections	Discovering Information /Knowledge	Proposing/ Discovering new connections	Ideas/Imagination/ "whatif" propositions	Creating New Knowledge	Creating New Concepts	Inventions	Age of Inventive-Machines
Intuition	Feeling	Emotion	Belief	Intuition	Expected/ Predicted/ Believed Behaviour Adaptive	Age of Intuitive Machines			
Collaboration	Micro-Organisms	Insects	Fishes	Birds	Animals	Humans	Politics	Culture	Age of Cultured Machines

The specific stages on each line as the smart systems become brilliant and then genius systems will emerge as newer solutions, features on these lines of increasing intelligence emerge. The CISS moving on these lines of intelligence will strive to create an age of perfect sensing, perfect learning, wisdom-filled, leadership enabled, inventive, intuitive, and cultured machines as stages on each line of intelligence are progressed in the sixth wave of innovation.

3.7 Manned-Unmanned Teaming (MUM-T)- The holy grail of CISS

As humanity learns and adapts to newer technologies of the sixth wave of innovation, the future complex intelligent strategic systems (CISS) will evolve into two clear classes – *one will be manned and the other unmanned*. These manned and unmanned CISS will be teamed through different algorithmic constructs and linkages to enable them to achieve desired results that the designers or users may need or desire. The *Manned-Unmanned Teaming (MUM-T)* will evolve in multitudes of explorations by utilization of nano, networked, automated, and hypersonic things through algorithmic intelligence and later quantum computing. The earlier technical systems (as shown in Fig part A) transformed to the network-centric or cloud-based systems of today (Fig part B) are already giving way to a raw version of manned-unmanned CISS networks. The emerging systems will comprise elements of cyber, space, electro-magnetic, and all physical domains. The CISS networks will have integrated structures comprising manned and unmanned CISS utilizing appropriate MUM-T which will follow constructs or execute operations to achieve the desired effects. This is as shown in (Fig part C).



The holy grail of achieving CISS lies in collaborative mechanism designs of how the continuously increasing-intelligent technical systems will work with human beings who may have various levels of understanding and comprehensions of the intelligence of technical systems with whom they are interacting, cooperating, collaborating, and networking. These variations of human collaborators with their increasingly intelligent unmanned systems will require a match-making, adjustment and tuning in run-time as behaviors of both humans and bots can-not be designed ab-initio. The MUM-T seems to be the key need of the CISS complexes that are emerging and that need to be figured out ahead.

This brings us to a challenge – how will we ensure the reliability, robustness, safety and even security of CISS. Indeed, the critical systems, if they are going to be CISS, or Manned-Unmanned CISS plexus, will need a new theoretical construct to be built to ensure their robustness and safety.

4. Antifragile Criticality (AFC)

Critical Systems are highly reliable systems that are evolvable yet retain their robustness as they evolve with the least cost. In the environment of large-scale changes, evolution with robustness is the natural design principle. It requires a diversity of components combined together in more or less loose coupling with well-defined operational principles combined with continuous learning and adaptation. A robust system doesn't imply an unchanging system. In fact, robustness implies an ability to change in a manner that *maintains the system function*, sometimes evolve through creation of new functions by changing its components and mode of operation in a flexible manner. *An adaptable structure is the key to responding to such perturbations.* Robustness is a fundamental feature of living systems. Evolution requires robustness; natural systems if they have to evolve need to be robust.

However, robustness is challenged when top-down design of good enough performance or highly optimized structure leads to fragility. To understand robustness, we need to look at the stable states of a system. *The stable state is a state of the system that maintains itself in a range of specific environmental conditions.* The fragility of system components or their chaotic nature may be balanced through higher-level layers of minimum control and adaptation. Further, if the stable state is attacked by random changes that are unknown or unprecedented – the system needs to move to a new stable state without losing its key functionality. It may do so by re-arranging its system components, creating new system components, changing its mode of operation, or doing all of the above. The key is to return to the previous stable state or move to a new stable state without compromising on its key functions.

Robust Evolvability is clearly the key feature of anti-fragile systems that Taleb defines [19]. In a scathing attack on top-down design and policy-driven optimization, Taleb says, *"…letting tinkering work slowly would lead to true efficiency – real efficiency. The role of policy-makers should be to allow the emergence of specialization by preventing what hinders the process*". The anti-fragile systems become more stronger as they are exposed to different stresses and impacts. Taleb states, "… systems make small errors, design makes large ones".

We have a classic case of a contradiction or a conflict between key system parameters, as per TRIZ parlance – the criticality as defined above requires that the systems be highly reliable and robust and should *fail-operational or fail-safe* especially if they are safety-critical, yet they should actually become stronger when conditions that lead to their failure or potential failure emerge or are presented. This leads us to view system development from the perspectives of different goals.

4.1 Optimization goal of system development

The best of a specific system parameter or metric of interest is designed to be achieved within the constraints of other parameters that hinder or reduce the maximization of the metric of interest. Optimization has been the focus in the development of critical systems. The problem with such a goal of course is that systems get optimized for specific *range of operating conditions* for which they are designed for. In fact, under those conditions, the systems work effectively. The problems emerge when either the operating conditions start changing and/or systems are assigned to environments or conditions for which they are not designed for. Under such conditions, which are clearly more pronounced in the so called VUCA world – variability, uncertainty, complexity and ambiguity – optimization goal of system development – makes these systems fragile. The fragility of critical systems of course proves disastrous. Traditionally critical systems have been developed through well-established, known and proven methods and methodologies which usually fall in the class of formal methods. A substantial cost of developing critical systems goes into their verification and validation.

4.2 Robustness goal of system development

The focus is to ward of stress or absorb the stress when these become pronounced- the robustness driven approach leads to development of fail-safe or fail-operational mechanisms. Such systems can absorb shocks and changes in conditions which are out of range of operating conditions. However, they also lead to a design where components themselves and their mechanisms should be built with stronger materials and/or redundant components. This not only increases costs but also in a catch-22 way makes the robust systems optimized for conditions that has changed considerably from the conditions for which these systems were designed.

4.3 Antifragile Criticality – Robust Evolvability goal of system development - We define *antifragile criticality* as *robust evolvability* as described above as the goal system development. We propose that antifragile criticality of systems is enabled by following mechanisms

(a) Runtime configurability of system components (re-configurability)
(b) Autonomous (re -) Configurability based on sensory inputs and assessment
(c) Multi-(OP) Systems
(d) Manned-Unmanned Teaming (MUM-T)

(e) The CISS should be *Scalable* for them to pass the antifragile criticality threshold.

4.4 Achieving Antifragile Criticality of CISS – A Thinking Challenge

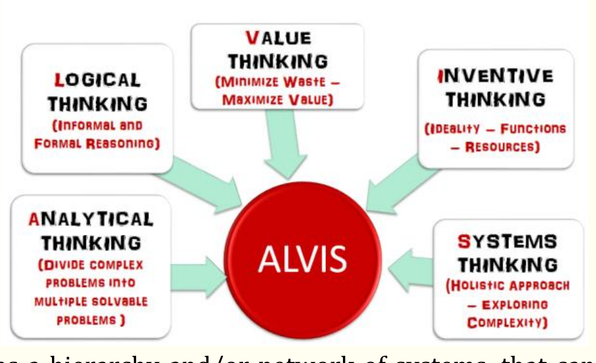
The CISS will be characterized by substantial decentralization, higher embedded and ambient algorithmic intelligence, inherently conflicting, unknowable, and diverse needs and requirements, continuous evolution, learning, with heterogeneous, inconsistent, and changing elements. There is substantial erosion of people-system boundary, regular failures, and new paradigms of regeneration of parts of the system on failures need to be built-in. Key aspects of the CISS lifecycle i.e., value, inventiveness, human interaction, computational emergence, multi-level design, computational engineering, adaptive system infrastructure, adaptable and predictable system quality, and management will need comprehensive multi-dimensional and synergistic thinking.

5. The Framework for CISS for Antifragile Criticality (AFC)

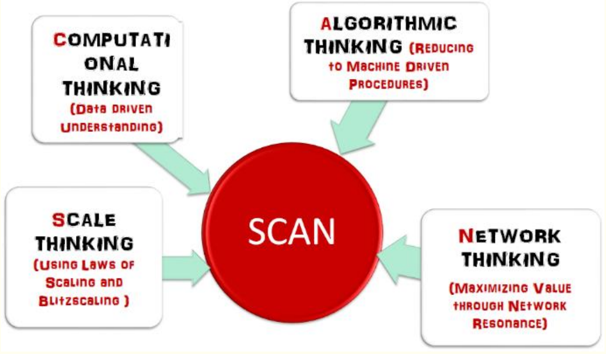
The emerging CISS in the sixth wave of innovation will require new thinking dimensions to be integrated with the existing thinking dimensions that we have developed in the previous waves of innovation. Till the fifth wave of innovation we have developed and utilized analytical, logical, value, inventive and systems thinking dimensions. It is clear that in the fifth and emerging sixth wave of innovation we need to develop and utilize the scale, computational, algorithmic and network thinking dimensions that have emerged already. As we move ahead in the sixth wave of innovation we will need to develop the quantum thinking and nano thinking dimensions as well. Though, we believe their need to be developed will become more pronounced in this decade. The 11 thinking dimensions of ALVIS-SCAN-QN are the basis of our proposed framework.

5.1 ALVIS-SCAN-QN Thinking

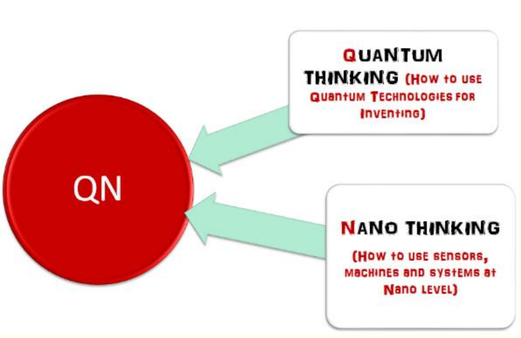
We have identified 11 key dimensions of thinking that have been prevalent, have emerged or we can see will be emerging ahead. The Analytical and Logical thinking developed over many centuries has stood the test of time. Three other relatively dormant dimensions of human thinking have been brought to the forefront and integrated with these established thinking dimensions to respond to new challenges in the fourth and fifth wave of innovation. These are – Inventive Thinking, Value Thinking, and Systems Thinking. It gives us a framework to view the world as a hierarchy and/or network of systems, that can be studied through *Analytical, Logical, Value, Inventive, and of course Systems thinking (ALVIS)*, i.e., five classical dimensions of thinking are explicitly included in our framework.



Scale, Computational, Algorithmic, and Network (SCAN) thinking have emerged in the new wave of innovation. These thinking dimensions need to play a much larger part in an integrated manner than the current mostly analytical and logical thinking that we have been utilizing. *Computational thinking* is concerned with transforming raw data into meaningful form to be useful for solving problems, designing systems, or understanding and assigning meaning. *Algorithmic thinking* utilizes a set of rules or generates new rules that define and describe each step to a solution from an explicit problem statement with precision and exactness so that these procedures can be repeatedly carried out by a computer which ensures reaching the solution deterministically or with high probability. *The Scale thinking* has become more interesting and important in the platform economy that has emerged in the fifth wave of innovation. For platforms catering to N-sided markets, traditional or classical scaling which requires certainty to be established with efficiency before embarking on scaling, has evolved to what is called *blitzscaling* – which thrive in speed despite being in an uncertain environment. Finally, the understanding of network forms or organization and ways networks thrive and evolve as against the traditional hierarchical organizations is relatively new understanding thereby creating a dire need to include *network thinking* in our framework.



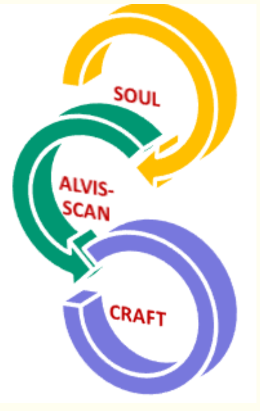
We estimate that by middle of this decade the quantum-cyberspace will start functioning at nano-levels once the 4th Industrial Revolution (4IR) gains greater traction and spreads – especially in-pandemic and post-pandemic world ahead. Two more thinking dimensions that we need ahead, besides the ALVIS-SCAN thinking dimensions i.e., Quantum and Nano Thinking (QN) will become a specialized need. The quantum technologies including quantum computing, quantum cryptography and quantum level manipulation at the atomic level will be pronounced ahead.



5.2 Innovation Crafting – end-to-end ALVIS-SCAN-QN Thinking

We need new or different lenses to understand the world. Our lenses need to evolve to go deeper and go wider in the world around us. We need to explore our world faster and at a scale that we have not accomplished before. Only when we have understood the world – or at least have some semblance of working of the world can we apply our thinking to create the needed change. Therefore, the first phase is really to understand the world around us. Understand the needs of the changing world.

In our innovation crafting framework [20] We name the first phase as **Explore**. We propose 4 key steps to understand the world in Explore phase **- See, Observe, Understand and Live (SOUL)**. Seeing requires focusing the attention to a specific subset of the world around us. This may emerge from our interest, scope of exploration, and focus. Key is to shift our focus on specific as[ects of the world that may impact us and our business. This requires making our model of the world explicit.



This is specifically true for businesses. To make our model explicit we look at a conceptual construct that has stood the test of time and variety in analysis. That is the concept of a system. Everyone and every business exist in the world which undergoes continuous changes in social, technological, economic, ecological, political, human values and legal dimensions. Our model of the world should consider the world as a super system for our business, our city, our country, etc. which may be considered as the key system. How do we understand a world that is impacted by forces and mechanisms we do not have much chance of comprehending?

The second phase is to generate ideas. We name it **Ideate**. This requires application of integrated thinking combining the eleven dimensions with systems to invent, design, create or engineer new concepts/solutions to the new needs. For each of these needs, we may generate many different solutions. To generate solutions a comprehensive integrated application of mind with all the 11 dimensions of **ALVIS-SCAN**-*QN* need to be applied. However, these new ideas and solutions may not propagate much in the world which normally doesn't welcome the new. Ideas need to be given enough shape, form and strength not only to live, but to strive and thrive in the world.

Empower is the third phase. Objective is to empower ideas. Here, we focus on **CRAFT**. *We define crafting as a process of giving shape, form and structure to an abstract concept or idea in such a manner that it performs specific functions or behave in specific ways under a range of environmental conditions and situations.* Also, crafting distinguishing itself from engineering – where a repeated process creates a repeated replica or similar/same product or system. We realize, when *we are crafting, variation/variability is not only* ***not-bad*** *but is essential to create the new or respond to the new*. Further, crafting is essential to propagate the new concepts and solutions rapidly so that they are used and implemented by many. The conceived set of solutions or the new system conceptualized to achieve specific function, need to be **communicated** to existing users and potential users. The new solutions need to be **related** to their context. They should be **allowed to** use these solutions. Their use of new solutions should be studied with a **follow-up**. With these inputs from the experiences of the users, solutions should be adjusted in various contexts to **turn-around** the users to the new solutions. CRAFT is also an acronym for Communicate/ Relate/Allow/Follow-Up/Turn-Around – steps that make the empowered phase of the framework.

6. The 7Ds of CISS System Development – Thinking Dimensions focus

Given the above end-to-end framework for innovation, with its 11-dimensions of thinking, we turn our attention to the life-cycle of CISS in the context of Antifragile Criticality. The challenges of discovering, defining, describing, designing, developing, deploying, and deducing (7Ds) the CISS require a complete relook of their lifecycle. Besides the advent of cyber-physical systems, increasing intelligence of technical systems, the massive scale of these systems coupled with the strategic nature of many of these systems leads to unprecedented challenges.

We have defined 7D phases of lifecycle of any system that humanity has developed. These include Discover, Define, Describe, Design, Develop, Deploy and Deduce. We will describe the 7 stages in brief below and then look at which thinking dimension of the 9 existing thinking dimensions of ALVIS-SCAN thinking is most prominent in the specific phase of the life cycle of the CISS from the three system goals of Optimization, Robustness, and Antifragile Criticality (Robust Evolvability).

The 7Ds of the system lifecycle are:

DISCOVER - Your business, your market, your social network, your customers, or even yourself. In this step – a need for a specific type of system is felt or emerged. This may emerge through imagination, through solving an existing problem, or through technological foresight.

DEFINE - What is your business and what is the key message of your business and for whom? What key problem of the world you will be solving? Defining the new system becomes an important step as it gives a distinctiveness in terms of specific differences with existing situation.

DESCRIBE - Elaborate what you defined by describing in detail the customer value that your business is creating or will be creating. Value here can be in terms of how the new system being proposed will be better and different for specific stakeholders.

DESIGN – This is the most crucial part of the process. Design needs to balance multiple extremes – making your business system such that these extremes merge. Ideal way to design is to include the contrasting requirements such a way that solution eliminates the contrast or what is called in TRIZ parlance a contradiction.

DEVELOP – Once you have designed your business or system you need to develop it. Also, develop the messages/communications for all possible channels - print, TV, online, Email, social networks, micro blog, blog of your company, SMS, and online videos and all possible channels. Also, the business model needs to be developed – by experimenting in real markets.

DEPLOY - Deployment involves the contexts in which the system is going to be operating in real life. You typically will have a deployment strategy on going context by context, city by city, or customer by customer. In the case of a business, the deployment also includes a marketing plan about the system.

DEDUCE – Once deployment of your system is carried out you need to find out how it's happening.

The 7Ds are not in a linear flow in say like a waterfall model. These stages/steps are in different parts happening in multiple contexts and combinations. There may as well be many loops in the design of systems.

6.1 Thinking Dimensions for 7Ds of goal-specific CISS design

The Complex Inventive Strategic Systems (CISS) with an integrated ALVIS-SCAN thinking with the emerging Quantum-Nano (QN) thinking should be the blueprint ahead. ALVIS-SCAN-QN thinking for evolution of CISS in physical, phygital and quantum-cyberspace is needed. In the 7D lifecycle of critical systems the 9 existing thinking dimensions focus will vary as per the key goals of the critical systems – we have identified three key goals of critical systems – (a) Optimization (b) Robustness and (c) Antifragililty or Robust Evolvability. The quantum and nano thinking dimensions will be emerging within this decade. The existing 9 thinking dimensions – Analytical, Logical, Value, Inventive, Systems, Scale, Computational, Algorithmic and Network thinking can be mapped on the 7D lifecycle stages for critical systems lifecycle based on the system development goal. This is shown in the table below.

ANTIFRAGILE CRITICALITY - Thinking Framework				
7D LifeCycle		CRITICAL SYSTEMS DEVELOPMENT - Key Thinking dimension focus		
System Goals ->		Optimization	Robustness	AntiFragile
1	DISCOVER	Systems	Systems	Systems
2	DEFINE	Logical	Inventive	Scale
3	DESCRIBE	Analytical	Computational	Network
4	DESIGN	Inventive	Logical	Computational
5	DEVELOP	Value	Algorithmic	Inventive
6	DEPLOY	Network	Value	Algorithmic
7	DEDUCE	Algorithmic	Network	Value

As can be seen the key thinking dimension during system discovery phase is systems thinking in all the three system goals. However, in other six life cycle stages the predominant thinking dimension should be different based as per overall goal for the critical system development. For antifragile criticality or as we equate it with robust evolvability the thinking dimension focus should change substantially from optimization focus.

6.2 Teeth Cleaning System – An Example

By any stretch of imagination, teeth cleaning system for example a toothbrush is not a critical system. Just to illustrate the CISS evolution and also to give a flavor of what antifragility with M(OP)S system design could lead to we would like to examine the thought process.

Function : Cleaning
Tool: Bristles
Object: Teeth
Action: Brushing
Operating Principle: Friction

Let us consider the common toothbrush. Classical TRIZ suggests focusing on mini-problems first (that is resolving contradictions in the existing system). Then classical TRIZ suggests thinking of new system design with same operating principle or creating new systems with new operating principles. In this case, first make the existing toothbrush design as close to ideal as can be before creating a new system or exploring the other operating principle – say, for example, friction-based cleaning of solid surfaces which human teeth are versus cleaning the solid surfaces with say directed ultrasound waves.

Using classical TRIZ's function modeling and action matrix as shown below we can see the problems in the existing toothbrush system. Problems typically are due to the harmful action of the tool and due to absent or Inadequate useful action of the tool on the object. As one can see this analysis can give us the potential improvement opportunities in the existing teeth cleaning system in terms

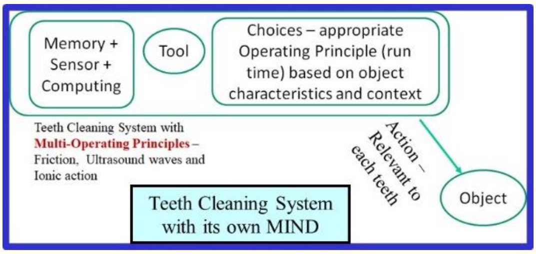
Harmful Action		Useful Action: Absent	Useful Action: Inadequate	Useful Action: Adequate
Harmful Action	Present	Potential loosened bristles in the mouth	(Damaging Gums) as partial brushing potentially brushes gums hard	(Cant Brush every teeth with same reach)
Harmful Action	Absent	Brushing action not there as bristels are worn-out or removed	Partial Brushing	Adequate Brushing - Soft Bristles

Surfacing problems with Function Modeling (Toothbrush) of partial brushing, excessive brushing, also the brushing action can not be at the same level of efficiency at each tooth. Also, perhaps some teeth may need more brushing action and some may need less brushing action. The user and also the toothbrush has no way to adapt its brushing action as per the need of the individual teeth.

Classical TRIZ and its enhanced manifestations of inventing strong [21] gives pointers to solving the inventing problems as technical or physical point contradictions, changing the operating principle of the system (in this case friction) and-or moving along the laws of system evolution to the next stage. Classical TRIZ doesn't allow the following per se -

- Can we have systems that perform the same function but using multiple operating principles (OP) – say friction, ultrasound waves and ionic action for cleaning teeth?
- Can we have systems that will sense which OP is needed when?
- Can we have systems that will adapt itself (its own internal structure) to deliver the function but with the appropriate operating principle at run-time?

To answer the above questions the technical system will need certain capabilities.



The system will need "data and information" and also rules and "computing" to "understand" the context and object that needs appropriate structural elements to be activated. In fact, the tool will need to have a "mind" of its own. A Hidden Resource in brushing system (in all mechanical systems) is the daily interaction data that gets wasted or remains unused. This data can lead to appropriate prediction of health or status for each tooth (potential cavities). Number of root-canal surgeries and costly visits to dentists in your life time can be reduced considerably. Further, this is an anti-fragile system as it can be evolved through continuously capturing data about daily-health of each tooth of yours to send it to a server wirelessly or to your mobile through a wireless connection from the toothbrush – rather – the teeth cleaning system of the sixth wave of innovation.

Agreed, that teeth cleaning system is not a critical system. However, the capability of CISS thinking as we demonstrated above can lead to create make a system that in the long run provides the users much more critical value than a mere 4th or 5th wave of innovation smart or otherwise toothbrush will. One can also say that such a teeth cleaning system will be brilliant.

7. Conclusions

We have defined a thinking framework involving 9+2 dimensions of thinking that are needed in the sixth wave of innovation (2020-2045) that the current creative destruction is giving way to, Further, we explained as per TRIZ 10th law of increasing intelligence of technical systems and the classification of systems – the emerging technical systems are what we call complex intelligent strategic systems (CISS). Further, if such systems are critical then the potential goals of antifragile criticality as distinct from optimization and robustness goals leads us to define the antifragile criticality goal of system development as robust evolvability. In the life cycle phases of such CISS, the key thinking dimensions vary in specific phases as per the goal of optimization, robustness, or antifragile criticality i.e., robust evolvability.

In a further development of this framework, we will be evaluating the relative contribution of each thinking dimension in each phase of system development. This thinking distribution framework can guide any developer or innovator in conceiving and designing the future complex inventive strategic systems in the sixth wave of innovation with antifragile criticality.

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