Unconventional Proving Techniques in Cyber – Physical Systems

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Abstract

Cyber - Physical Systems [CPS] are "Engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components". CPS have the potential to provide much richer functionality - including efficiency, flexibility, autonomy, and reliability – than systems that are loosely coupled, discrete, or manually operated. CPS also can create vulnerability related to protection, security and reliability. This can result in a chaotic collapse around the many new complex and powerful technological systems we rely on. The very complexity and interconnectedness of such CPS warrants unconventional proofing to unravel. Moreover, CPS is diffused across the social fabric. The sociology of mathematics is quite elusive for the construction of formal proofing in CPS.

The gap between rigorous argument and formal proof in the sense of mathematical logic is one that will close in CPS.

The generic characteristics of CPS are:

- Self-organization
- Interdependence
- Feedback
- Far from equilibrium
- Exploration of the space of possibilities
- History and path dependence
- Creation of new order

Cyber risk is an increasing concern in the complex, connected world of CPS.The complexity of the ecosystem, the connectivity of devices and the criticality of devices and services all increase risk, and the necessary formal proofs are elusive to take an effective action. 'Fake People" is the Case Study presented in this paper to illustrate unconventional proofing in Humane Security Engineering of CPS. Adapting the Cynefin Framework with the inclusion of Neurotheology, Complexity Science and Indic Studies in Consciousness enables the construction of unconventional proofing systems that transcend the software design limits of CPS.

1. Introduction

"a mathematician's work is mostly a tangle of guesswork, analogy, wishful thinking and frustration, and proof …….. is more often than not a way of making sure that our minds are not playing tricks."**- Gian-Carlo Rota, Introduction to the Book "The Mathematical Experience" by Philip Davis and Reuben Hersh, Mariner Books [Reprint], 1999.**

Aristotle observed that within the universe there are three natural languages which perfectly describe the supreme science - music, color, and numbers. Ancient cultures had no conception of computing beyond simple arithmetic. Modeling the Human Brain in the form of Computers began with Numbers. However, the human brain in itself is an enigma.

1.1 Basics of the Human Brain

Human brain is a collection of large networks of nerve cells. A nerve cell or neuron is the basic unit of neural networks, which can be said to perform computation. Natural neural networks are complex arrangements and connections of a usually large number of nerve cells. Natural Neural Networks are also loosely referred to as Biological Neural Networks.

The nervous system in human beings is classified into
1. Central Nervous System, and
2. Peripheral Nervous System

The central nervous system is further divided into two parts namely
1. The Brain
2. The Spinal Cord

In the average adult human, the brain weighs 1.3 to 1.4kg (about 3 pounds). The brain contains about 100 billion nerve cells and trillions of "support cells" called glia. There are over 1011 neurons. There are over 1014 connections.

Human Brain is organised into regions and the various regions are organised as layers. Cortex and cerebellum are good examples of layered parts. There are more than 100 different types of neurons as well as associated glial (neuroglial) cells. There are a number of different transmitter substances. The cerebral hemispheres are split in right and left and only joined by the corpus callosum.

The spinal cord is about 43 cm long in adult women and 45 cm long in adult men and weighs about 35-40 gm. The vertebral column, the collection of bones (back bone) that houses the spinal cord, is about 70 cm long. So the spinal cord is much shorter than the vertebral column. The various divisions are shown in Figure 1.

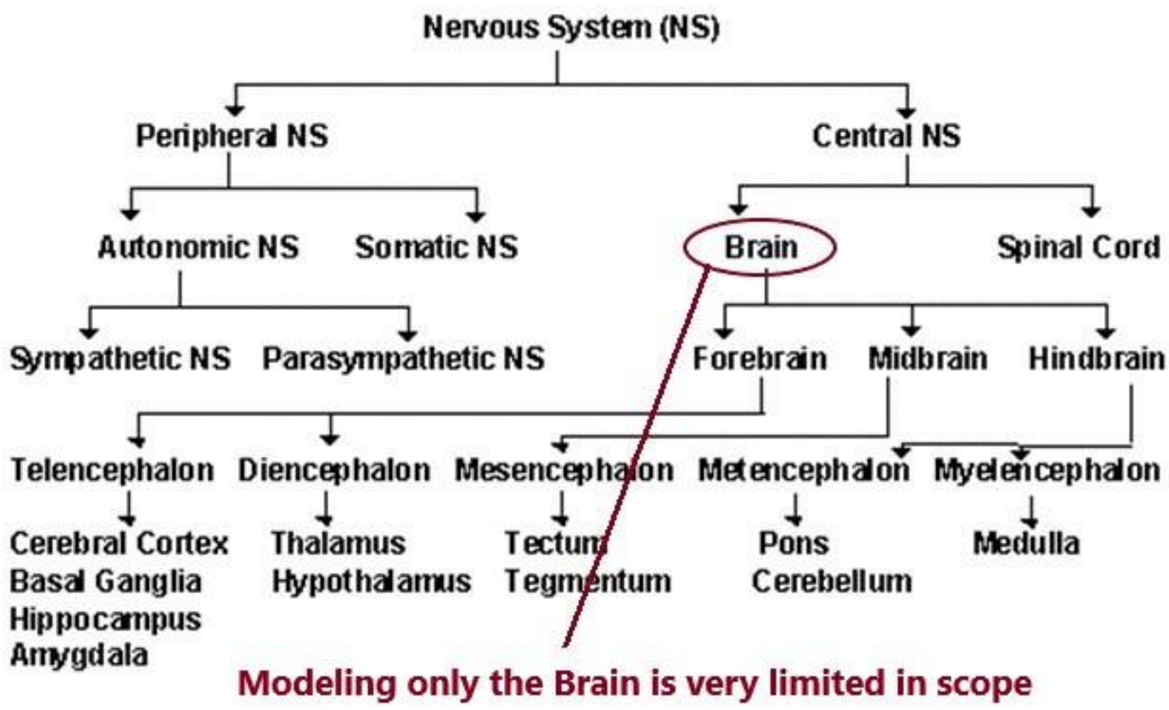

Figure 1: Divisions of Human Nervous System

The human body is made up of billions of cells. The central nervous system [CNS] is composed entirely of two kinds of specialized cells: neurons and glia. Neurons, are specialized to carry "messages" through an electrochemical process. The human brain has about 100 billion neurons. Neurons (nerve cells) come in many different shapes and sizes. Some of the smallest neurons have cell bodies that are only 4 microns wide, while some of the biggest neurons have cell bodies that are 100 microns wide.Glia (or glial cells) are the cells that provide support to the neurons. There are as many as 50 times more glia than neurons in the CNS. Alan Turing accentuated the Neurons and all Computational Models functionally based on the Neurons with support systems necessary for information processing structures.

Neurons are similar to other cells in the body in some ways such as:

- Neurons are surrounded by a cell membrane.
- Neurons have a nucleus that contains genes.
- Neurons carry out basic cellular processes like protein synthesis and energy production.

Neurons differ from the other body cells in some ways such as:

- Neurons have specialized extensions called dendrites and axons. Dendrites bring information to the cell body and axons take information away from the cell body.
- Neurons communicate with each other through an electrochemical process.
- Neurons contain some specialized structures (for example, synapses) and chemicals (for example, neurotransmitters).

A neuron typically has many dendrites and one axon. The dendrites branch and terminate in the vicinity of the cell body. In contrast, axons can extend to distant targets, more than a meter away in some instances. Dendrites are rarely more than about a millimeter long and often much shorter. Neurons communicate through specialized junctions called ‘synapses’. There are as many as 10,000 specific types of neurons in the human brain.The most widely used types of neurons based on their structure are shown in Figure 2.

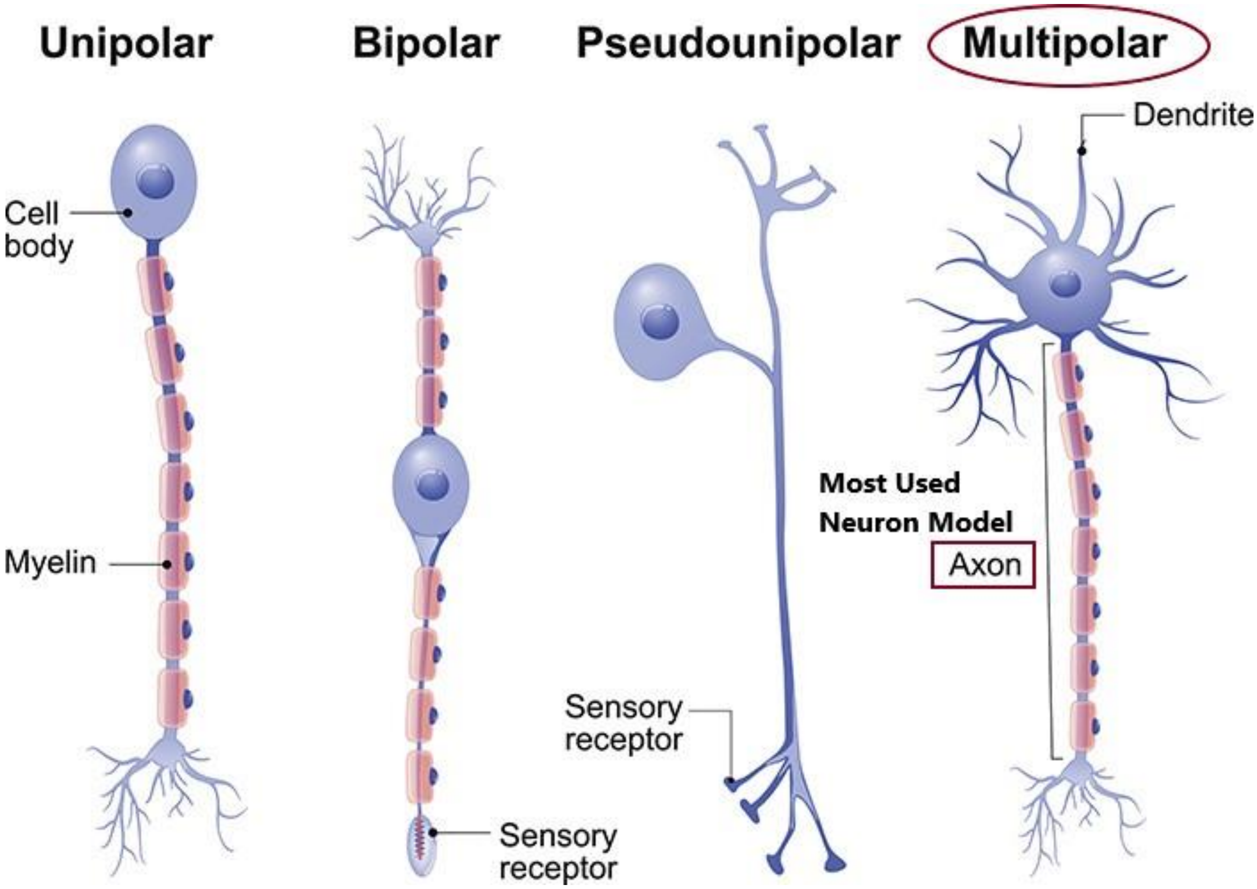

Figure 2: Most Used Types of Neurons based on Structure that is amenable to Mathematical Modeling

Neuron model represents a mathematical structure that incorporates its biophysical and geometrical characteristics. There are a few typical types of Neurons based on the functionality such as Motor, Sensory and those that connect these types called Interneurons.

Human Brain is an electro-, chemical- and biological- organ. Hardly 1% of brain and its functioning are understood by neuroscientists. New research suggests that genius can be nurtured as well. Expertise in calculation is not due to increased activity of processes that exist in non-experts, but they are due to the usage of different brain areas. Musical training at an early age may lead to the increased growth of certain brain regions. These results have made modeling the Human Brain even more difficult.

Alan Turing showed that under certain conditions, random heterogeneities in chemically interacting diffusible substances could generate patterns without a pre-existing organization. In other words self-organization happens. These ideas were very difficult for the biologists.

The notion of Intelligence which is associated with the Human Brain began to appear more attractive than modeling the Human Brain.

"A computer would deserve to be called intelligent if it could deceive a human into believing that it was human" – Alan M Turing

Turing devised a test, which he called "the imitation game," to herald the advent of computers that were indistinguishable from human minds.

"I believe that in about 50 years' time it will be possible to program computers … so well that an average interrogator will not have more than a 70% chance of making the right identification after five minutes of questioning." - Alan M Turing

1.2 The Turing Brain

"Some of the feats that will be able to be performed by Britain's new electronic brain, which is being developed at the N.P.L., Teddington, were described to the SURREY COMET yesterday by Dr. A. M. Turing, 34-year-old mathematics expert, who is the pioneer of the scheme in this country.The machine is to be an improvement on the American ENIAC, and it was in the brain of Dr Turing that the more efficient model was developed.... " - Surrey Comet, 9 November 1946

Turing gives two examples of artificial unorganized machines, which he claims are about the simplest possible models of the nervous system.

The first type are A-type machines – these are randomly connected networks of NAND gates (where every node has two states representing 0 or 1, two inputs and any number of outputs).

The second type Turing calls B-type machines – these are derived from any A-type network by intersecting every inter-node connection with a construction of three further A-type nodes which form a connection modifier. B-type networks with their propensity to form loops of various lengths may be well suited to model the kind of massive, widespread feedback and interacting waves of activity.

Turing also proposed P-type unorganised machines, which are **not neuron-like** and have only two interfering inputs, one for **"pleasure" or "reward"** ... and the other for **"pain" or "punishment".** Turing studied P-types in the hope of discovering training procedures "analogous to the kind of process by which a child would really be taught'".Since this type is non neuron-like and is a modified Turing Machine. The Turing Machine model for computing has enabled the progress of computation as seen in the Figure 3.

Artificial Neuron is a barely functional model for the biological neuron. However, the Artificial Neural Networks have been found applicable in modeling learning. It is another puzzle that the P-type i.e non-neuron like unorganized machines proposed by Turing gave an application domain for the use of Artificial Neural Networks in their present form. Please see the Figure 4.

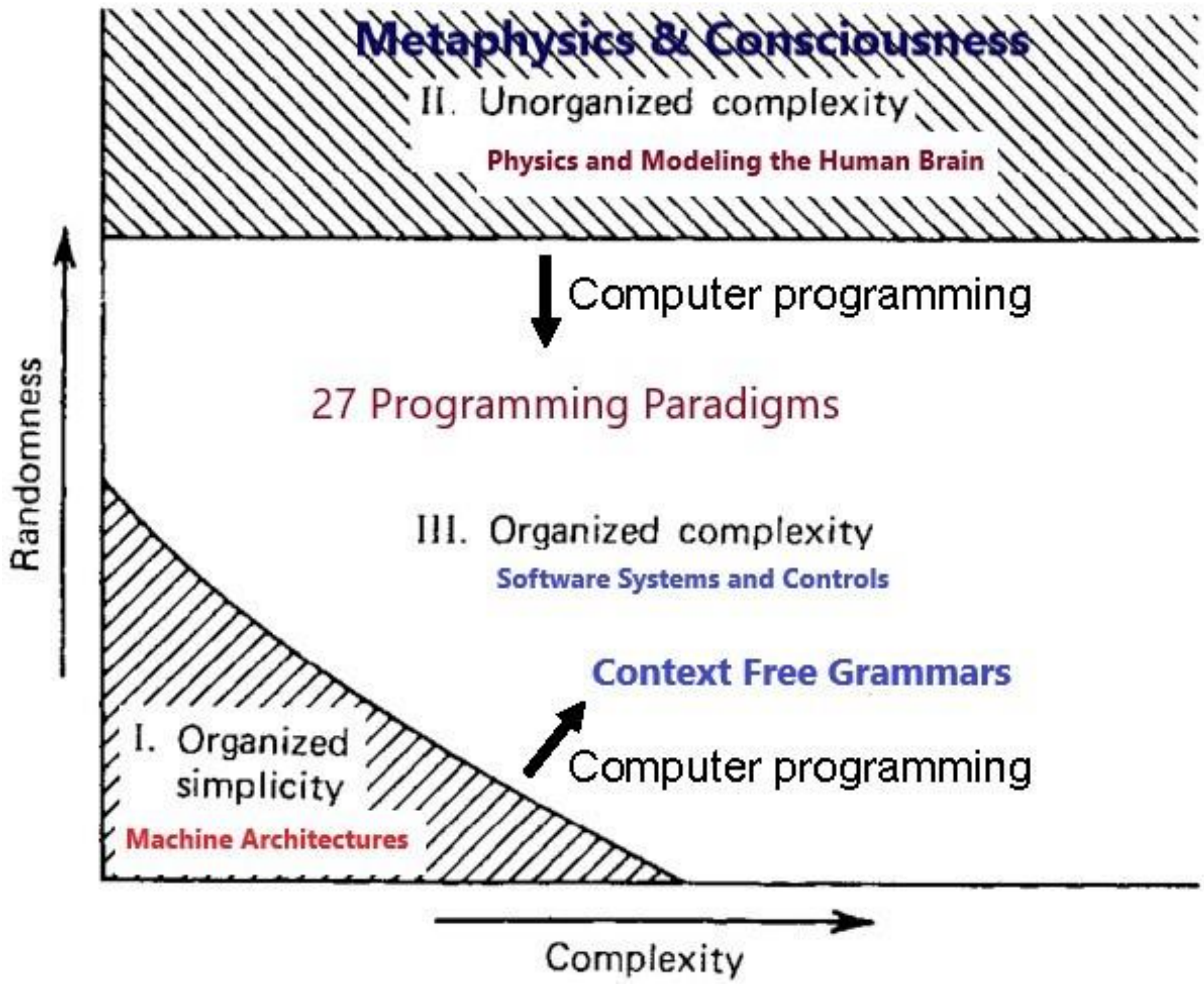

Figure 3: Progress in Computation with the Turing Machine Model

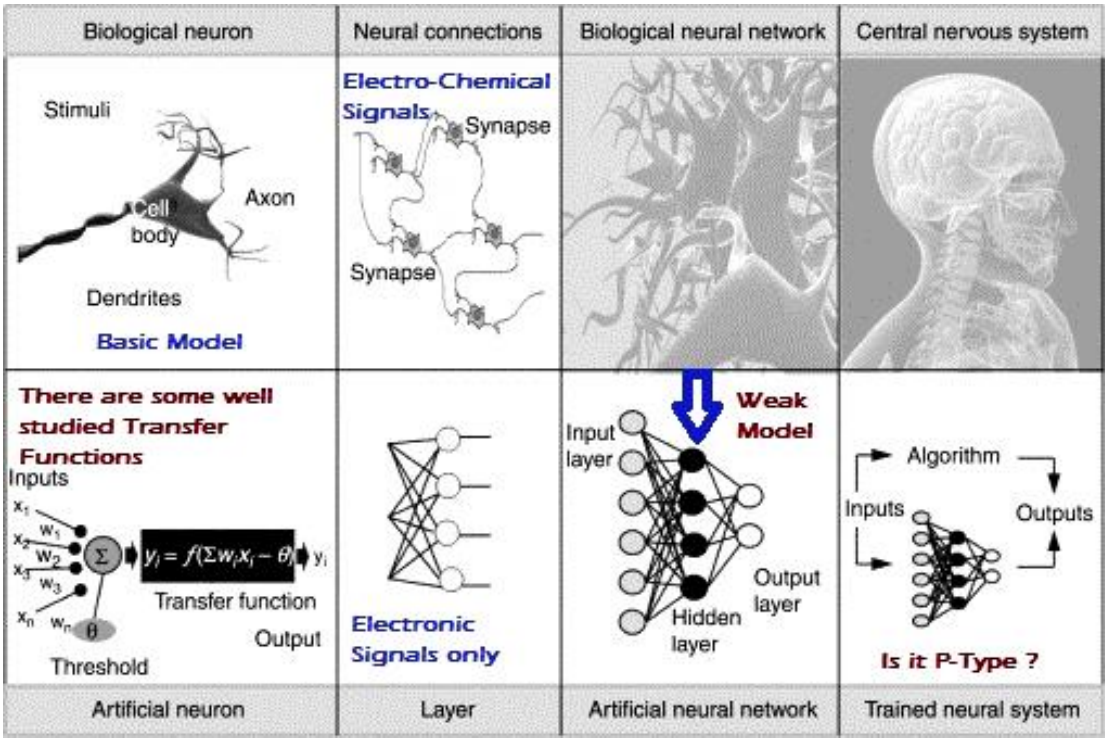

Figure 4: The puzzle of P-Type Unorganized Machine proposed by Alan Turing

"Restrained by our organic constitution and by our different emotions in the lower sphere of our daily occupations, we also feel ourselves urged on by the appeal of the ideal, by more or less precise aspiration towards spiritual values, and from those sentiments even the worst amongst us do not entirely escape." - Louis deBroglie, 'Physics and Microphysics', Pantheon 1955 Quantum Questions, Mystical Writings of the World's Great Physicists [Ken Wilber, Editor]

Turing was way ahead of Artificial Neural Networks. Turing described his idea as a "Universal Computing Machine".In October 1945, Turing joined the National Physical Laboratory [NPL] where he worked on developing the ACE (Automatic Computing Engine). By 1946 he had a finished proposal for the computer, but unfortunately NPL did not have the resources to turn it into reality.

The author opines that Type A is the Reality Layer and Type B is the Spiritual Layer. This is the foundation for the Unconventional computing model for constructing the unconventional proof.

To develop Turing’s idea of building a brain-like B-type machine we need to mirror the brain’s own development. The proliferation of neurones during the brain’s formation involves a substantial random element and only later is this growth fine-tuned by killing off the cells that have grown in the wrong places. This process of weeding out is called programmed cell death, is essential to the development of intelligence, and means that we start off with many more brain cells than we actually need to function as a normal adult.

A B-type cortex would begin with a very large number of nodes and follow a developmental path with the same delicate mix of the random and determined as a living brain. At a magnification where individual nodes and connections could be seen, the resulting very large B-type network would typically look much like a bowl of spaghetti. Such a disorderly structure is prone to forming feedback loops of varying lengths which take varying times to traverse, thus forming possible delay or memory circuits.

In a large network these loops can lead to greatly varying patterns of activity, regardless of input, since activity can be perpetually recycled in a complex manner. The activity in many conventional neural networks stops when the output layer settles into a stable pattern; the equivalent of a Turing Machine halting, its computation over. But just as the brain does not halt, large B-type networks will tend not to either.

The Universal Turing Machine is an excellent mathematical model to establish computations as an activity of the human brain. It is an essential element for explaining how the mind works. However, mind is not so obvious in the present understanding of the work proposed by Alan Turing. This is the premise for the "Spiritual Layer" which fosters Mystic Visions.

In the new field of "Neurotheology," scientists seek the biological basis of spirituality. Is God all in our heads?

The American Psychological Association published "Varieties of Anomalous Experience," covering enigmas from near-death experiences to mystical ones. Some of the early results in from the field of Neurotheology include:

- **Attention:** Linked to concentration, the frontal lobe lights up during meditation.
- **Religious Emotions:** The middle temporal lobe is linked to emotional aspects of religious experience, such as joy and awe.
- **Sacred Images:** The lower temporal lobe is involved in the process by which images, such as candles or crosses, facilitate prayer and meditation.
- **Response to Religious Words:** At the juncture of three lobes, this region governs response to language.
- **Cosmic Unity:** When the parietal lobes quiet down, a person can feel at one with the universe.

"It is certain that thought may be transmitted from one individual to another, even if they are separated by long distance. These facts, which belong to the new science of metaphysics, must be accepted just as they are"…."They express a rare and almost unknown aspect of ourselves"…"What extraordinary penetration would result from the union of disciplined intelligence and of the telepathic aptitude"… - Dr. Alexis Carrel, Man the Unknown

"The catalogue of our ignorance must also include the understanding of the human brain, which is incomplete in one conspicuous way: nobody understands how decisions are made or how imagination is set free. What consciousness consists of (or how it should be defined) is equally a puzzle. Despite the marvelous successes of neuroscience in the past century (not to mention the disputed relevance of artificial intelligence), we seem as far from understanding cognitive process as we were a century ago." - Sir John Maddox, "Consciousness – The Unexpected Science to Come", Former Editor-in-Chief, Nature

2. Conventional Computing and Constructing Proofs

Describing the human brain in mathematical terms is coveted ambition of neuroscience research. The challenges remain considerable. It was Alan Turing who first demonstrated how time-consuming such an undertaking would be. Through the analogy of computer program, Turing argued that a complete mathematical description of the mind would take well over a thousand years.

Computing is essentially a combination of theoretical, scientific, and engineering traditions. Programming is a process of mapping the computing problem into a form that can be executed on an automaton. The resulting software implementations are representations (models) of real-world conceptual systems. The engineering processes move a concept from the Realm of Actions (concepts) to the Realm of Representations (technology). Modeling the application in terms of "well-defined structures and algorithms" is the most important step towards evolving a solution. It is becoming increasingly difficult to decide on a correct solution while building complex evolving software.

The Turing Machine [TM] was invented by Alan Turing in 1936 and it is used to accept Recursive Enumerable Languages [generated by Type-0 Grammar].

A turing machine consists of a tape of infinite length on which read and writes operation can be performed. The tape consists of infinite cells on which each cell either contains input symbol or a special symbol called blank. It also consists of a head pointer which points to cell currently being read and it can move in both directions. A TM is expressed as a 7-tuple **(Q, T, B, ∑, δ, q0, F)** where:

- **Q** is a finite set of states
- **T** is the tape alphabet (symbols which can be written on Tape)
- **B** is blank symbol (every cell is filled with B except input alphabet initially)
- ∑ is the input alphabet (symbols which are part of input alphabet)
- **δ** is a transition function which maps $Q \times T \rightarrow Q \times T \times \{L,R\}$. Depending on its present state and present tape alphabet (pointed by head pointer), it will move to new state, change the tape symbol (may or may not) and move head pointer to either left or right.
- **q0** is the initial state
- **F** is the set of final states. If any state of F is reached, input string is accepted.

Formal proof of correctness is tedious, time-consuming, and outlandishly expensive. Also, it is not necessarily effective. People commit errors when attempting a formal proof. There is no way of determining if a proof is correct. "Clean Room Approach" with informal techniques of proving programs correct is in vogue. The code is never run by the programmers in this approach. It is typically not formal proof of correctness. It is acceptable as a pragmatic practice.

The computational complexity of a problem is the amount of resources, such as time or space, required by a turing machine that solves the problem. The descriptive complexity of problems is the complexity of describing problems in some logical formalism over finite structures. One of the exciting developments in complexity theory is the discovery of a very intimate connection between computational and descriptive complexity.

Computational complexity theory classifies the computational problems according to their inherent difficulty, and relates these classes to each other. A computational problem is a task solved by a computer. It is solvable by mechanical application of mathematical steps, such as an algorithm. The following classes of problems and their inter-relations are well studied.

- EXPSPACE Solvable with exponential space
- EXPTIME Solvable in exponential time
- IP Solvable in polynomial time by an interactive proof system
- NP "YES" answers checkable in polynomial time
- co-NP "NO" answers checkable in polynomial time by a non-deterministic machine
- RP Solvable in polynomial time by randomized algorithms (NO answer is probably right, YES is certainly right)
- ZPP Solvable by randomized algorithms (answer is always right, average running time is polynomial)
- P Solvable in polynomial time
- NL "YES" answers checkable with logarithmic space
- L Solvable with logarithmic (small) space
- BPP Solvable in polynomial time by randomized algorithms (answer is probably right)

The relations among these complexity classes open research problems. There are some standard and startling results based on the Turing Machine Model. A Turing Machine is essentially a neural framework for mental programs.

Proof must begin from axioms that are not themselves proved. To prove a proposition, one starts from some first principles, derive some results from those axioms, then, using those axioms and results, push on to prove other results. This is to avoid mistaken "theorems", based on fallible intuitions, of which many instances have occurred in the history of the subject Axioms in traditional thought were "self-evident truths", but that conception is problematic. At a formal level, an axiom is just a string of symbols, which has an intrinsic meaning only in the context of all derivable formulas of an axiomatic system.

Computational proof offers only the probability - not the certainty - of truth, a statement.The complexity of the Turing machine is limited to serve this purpose. The success of the Turing machine model broke the ideal of axiomatization of mathematics. It paved way for a theoretical computational machine for scoping the capabilities and limitations of an algorithm. Variants of the Turing Machine such as **“Multiple Track Turing Machine”** and **“Two-way Infinite Tape Turing Machine” are well studied.**

The odd symbols and scattered numerals look like a strange language, and yet to read them, neurologists tell us, we would have to use parts of our brains that have nothing to do with what we normally think of as reading and writing. Mathematics and physics researchers are the interpreters of this unconventional language. The subject matter confounds even mathematicians and physicists, as they use mathematics to calculate the inconceivable, undetectable, nonexistent and impossible.Our brains have the ability to compute the abstract mathematics they created to construct theories about reality, and yet they may never be smart enough to comprehend those theories, let alone explain them.

Cyber – Physical Systems need the interplay between software, control and social systems.The existing interplay as shown in the Figure 4 isfar from comprehensive. Neither the Control theories nor the social systems seldom play a major role in the quality assurance of software analysis and design. The core of software engineering and that of control theory / engineering have been developed independently of each other.

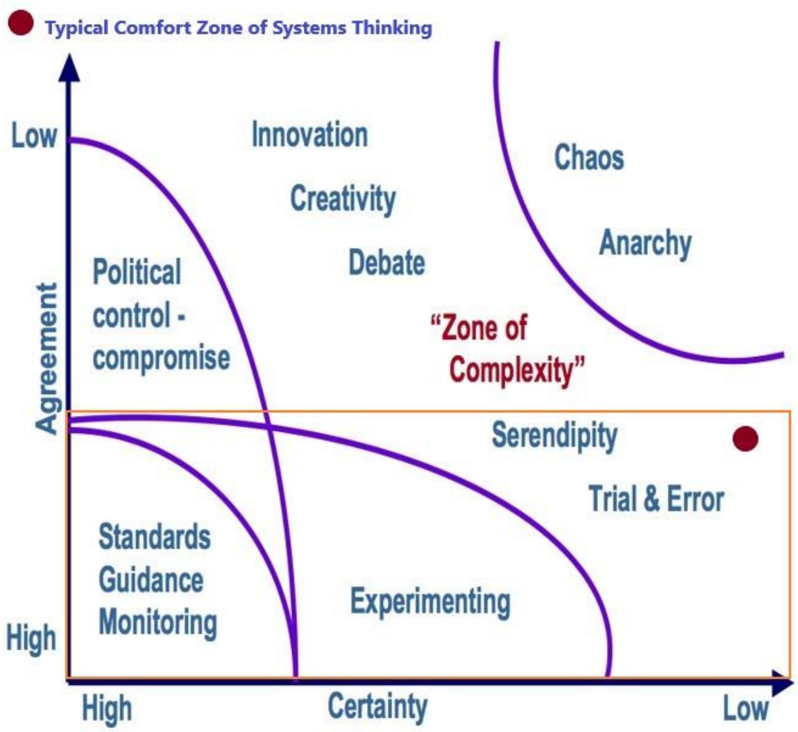

Figure 5: Zone of Complexity and the Present Comfort Zone

The quest for unconventional models of computation and proving techniques for CPS is an important area of research. It is a challenge to attempt the "Zone of Complexity" as shown in Figure 5 and factor as much of the zone not labeled the Comfort Zone.

3. Unconventional Computing

The methods of developing software for the CPS have severe limits such as:

- The Laws of Physics
- The Principles and Concepts of Software Engineering
- The Challenge of Algorithms and Expressing the Solutions for the Machine to Execute
- The Difficulty of Distribution, Decentralization, Centralization, Localization

- The Lack of Design Rules for Software
- The Difficulty of Factoring the Organization – Structure and Behavior
- The Economics of Development i.e Cost and Time
- The Influence of Politics
- The Limits of Human Imagination to work with Incomplete Information and Unstable Requirements

The crux of the proposed Unconventional proofing is to bring back the mind in the Turing machine model. There have been Physical, Chemical, Biochemical, Biological and Mathematical approaches to specify the Unconventional Computing Model with severe constraints. The generic model for Unconventional computing is elusive. The Cynefin Framework, is an interpretative model of the different levels of the systems complexity, ranging from order to disorder. The author uses this model to support the unconventional proofing as shown in the Figure 6.

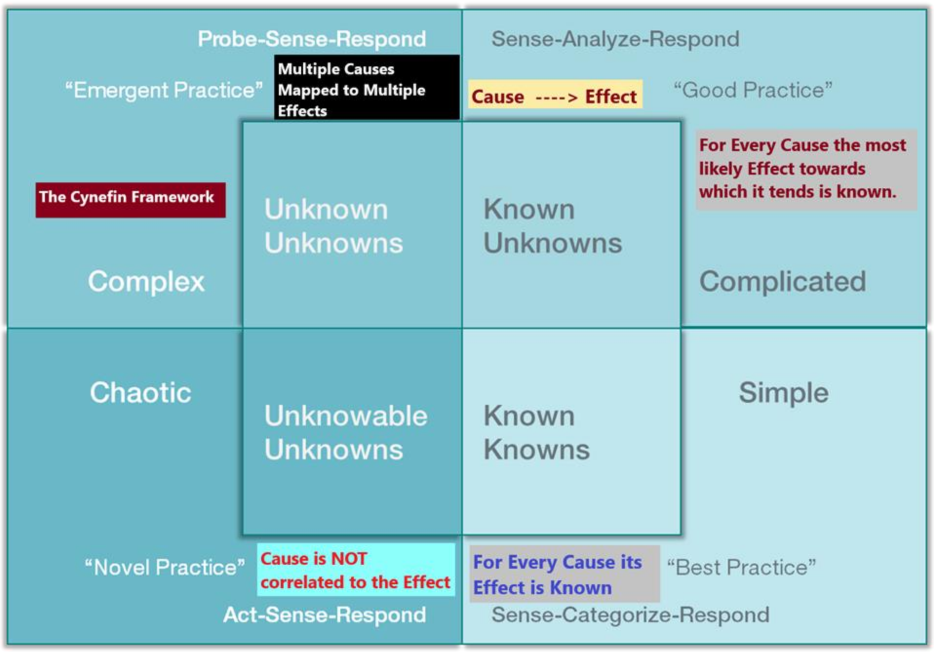

Figure 6: The Cynefin Framework for Unconventional Proofing

The framework is independent of the specifics of the technology to Sense, Choose, Categorize, Probe, Respond and Act that works with this.

3.1 The Need for Unconventional Proofs

The Latin phrase "quod erat demonstrandum [Q.E.D / QED]" placed at the end of a mathematical proof or a philosophical argument indicates that the proof or the argument is complete. In a Cyber – Physical System, the following three standards of proof are necessary in the increasing level of standardization. Please see the Figure 7.

1. Preponderance of the Evidence [50% Proven]
2. Clear and Convincing Evidence [> 70% Proven]

3. Proof Beyond a Reasonable Doubt [> 95% Proven]

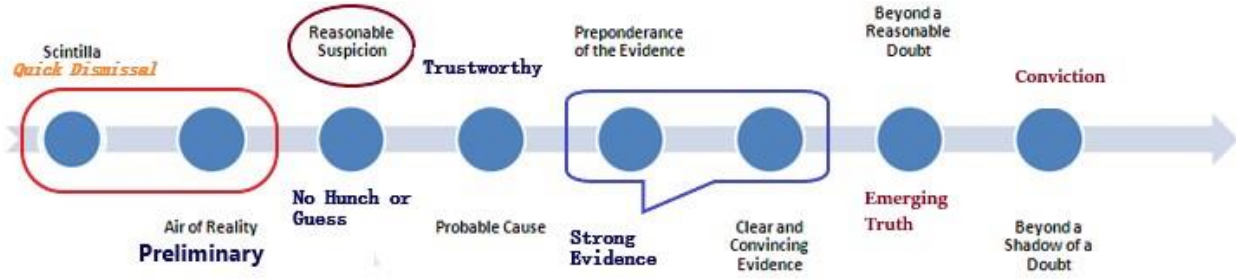

Figure 7: Levels of Standards of Proof

It is a fact that the term "point" is often left undefined in geometrytexts. It is easy for us to conceptualize a point, but it is quitedifficult to define exactly."The Chemical Basis of Morphogenesis" by Alan Turing describes the way in which natural patterns such as stripes, spots and spirals may arise out of a homogeneous, uniform state. Turing' theory that can be called a reaction–diffusion theory of morphogenesis, has served as a basic model in theoretical biology. Please see the Figure 8. Principles of Natural Selection or Artificial Selection govern the inclusion and a given CPS can evolve very slowly in this manner.

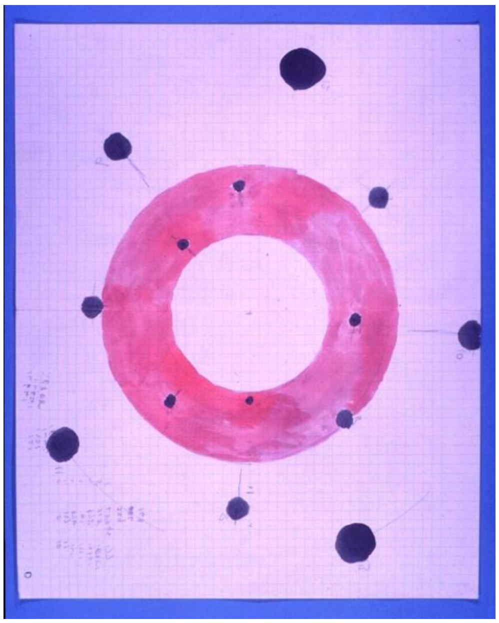

Figure 8: Turing's hand-drawn, hand-colored Chemical Basis of Morphogenesis Diagram

In a CPS, it is important to understand that a point is not a thing, but a place or a computational node. If a set of points all lie in a straight line, they are called 'collinear'. If a set of points all lie on the same plane, they are called 'coplanar'. For coplanar points, we need mythical rules of inclusion. Please see the Figure 9. These rules of inclusion can also be based on the theory of neural systems or fuzzy systems. The interactions among the points is a challenging computational problem. Please see Figure 10 for potential models of Virtual Organizations made from interactions.

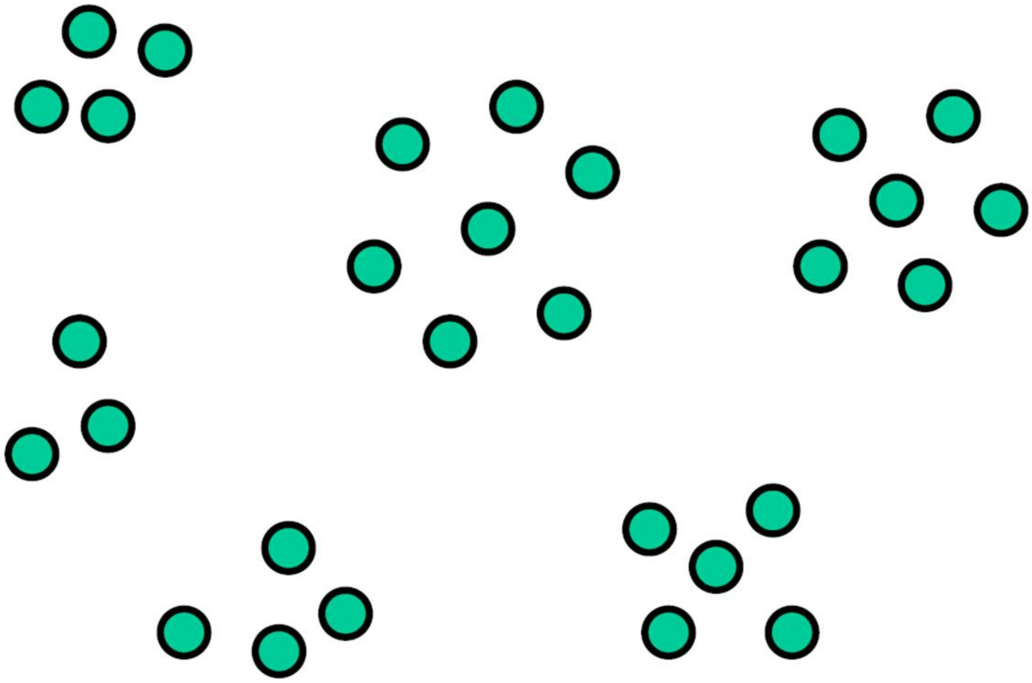

Figure 9: Mythical Rules of Inclusion

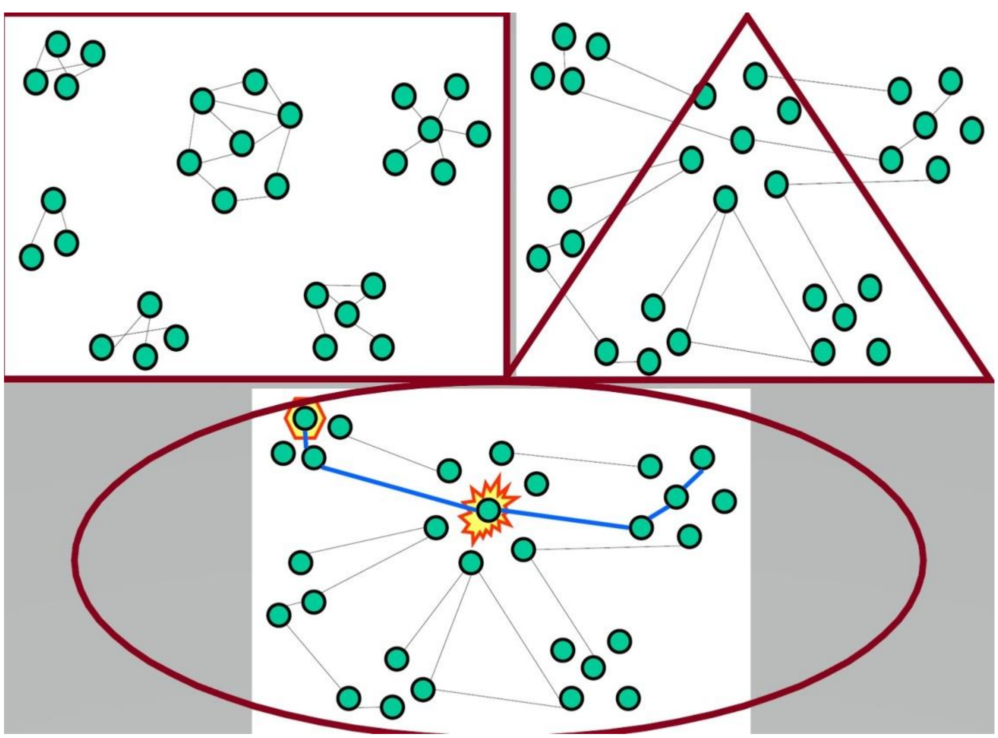

Figure 10: Finding the Optimal Interactions is Computationally Challenging

Bringing the context into the design of CPS is vital as seen in the Figure 11.

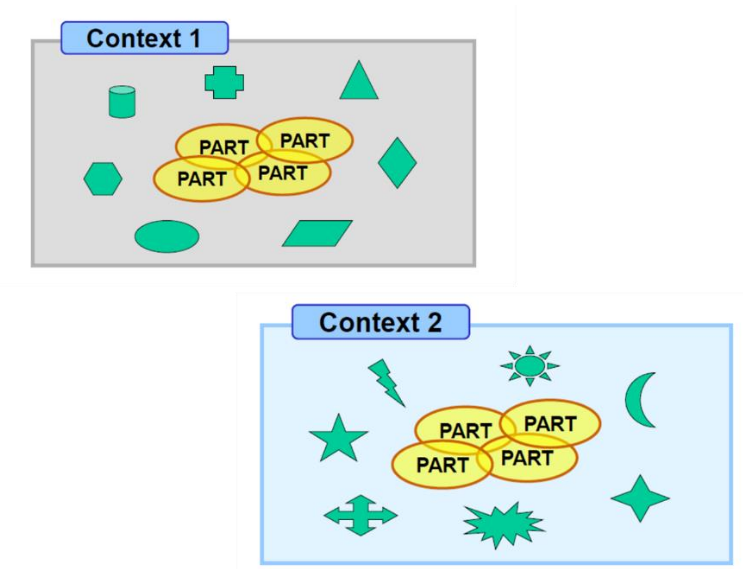

Figure 11: Bringing the Context into Design

Theoretically multiple – realities are possible, A model of CPS for geometric processing emerges with various standards of proof indicated in Figure 7 becoming apparent.

4. Physics and Metaphysics of CPS

The mathematical model of computation has always been challenged. The turing machine provided the algorithmic method of computation that can be formally verified and validated within the scope of the Universal Turing Machine. Problems can be classified based on the complexity classes. As Software Engineering progressed, the Conceptual Metaphor Theory was found useful to prepare the requirements and analyze them. Metaphors and more shallow concepts called “Similes” were soon found to be limited in scope for the purpose of design and development of Software. It is the Natural Language basis of Metaphors and Similies that was promising when a majority of the stakeholders providing the requirements were not from the Computing domain of specialization. The success rate for the software projects was not high.

These models are seldom conclusive when we are not Bayesian. The concept of “Rational Agent” is the cornerstone of classical decision theory. Completeness and Transitivity of Choice are difficult to establish. Desirability of a choice is the same as Utility. A study of Cause – Effect relationships shown in Figure 6 provides the basis for Physics into the proofing. A preliminary mathematical representation of the software development process is shown in Figure 12. Such a representation provide a very limited scope for using the Laws of Motion in the context of evolving complex software systems in CPS..

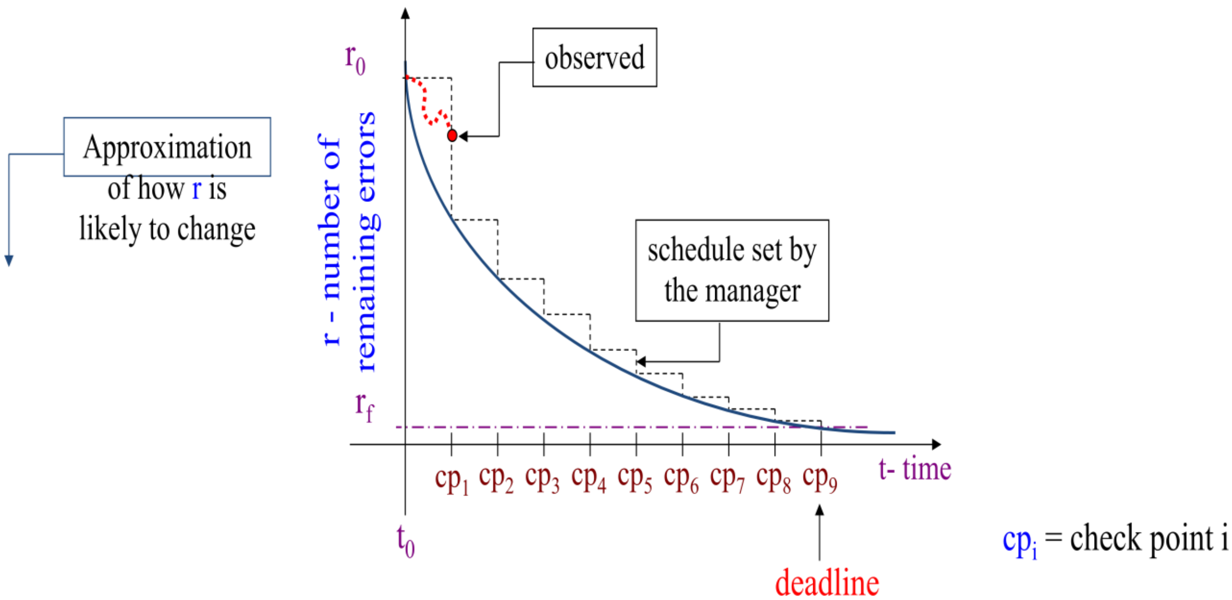

Figure 12: A simple mathematical representation of the Software Development process

Many mathematical objects, such as sets of numbers and functions, exhibit internal structure. The structural properties of these objects are investigated in the study of groups, rings, fields and other abstract systems, which are themselves such objects. This is the field of abstract algebra. Differential Geometry, Representation Theory, Algebraic Topology, and Algebraic Geometry are some computationally effective models for the virtual organizations and contexts of CPS indicated in Figure 10 and Figure 11. This is an unconventional proofing proposed by the author to mark the various standards of proof indicated in Figure 7.

Hempel's dilemma is the classical exploration of naturalism and physicalism. Physicalism avers that everything is physical. "Once every physical aspect of the world is settled or modeled, every other aspect will follow" forms the basis of proofing in Physics. This is far from being a satisfactory metaphysical conception of Physicalism. Even today, certain natural events that involve immaterial entities such as gods, angels and magical creatures in general are perceived to occur.

The mind-body problem is often described as the problem of explaining how the mind fits into the physical world. More generally, it is the problem of explaining the relationship between physical properties and mental properties. Is the "State" in the "Universal Turing Machine" the same as "State of Mind"? Is the computational model same for both? The answers to these questions have to resolve the Hempel's dilemma on the current physics will be discarded in the future, and the not yet known nature of the future physics. The present notion of State in a the Turing machine very limited in scope. It does not factor the human mind that can routinely solve the Towers of Hanoi problem while the mathematical answer is that it takes several times more the age of the universe to solve. The strange geometry of thought is the crux. The author opines that the model in Figure 13 is more suited for the purpose. The concept of geophilosophy, or to be more precise geo-metaphysics, is an enduring bond between the philosophical thought and its terrestial support for contextualization.

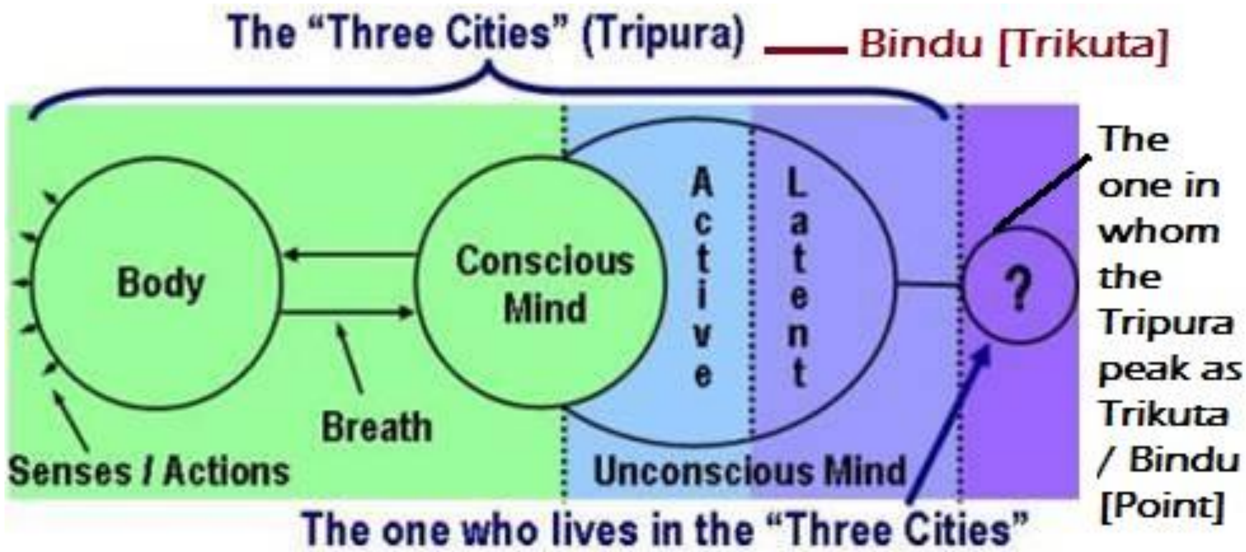

Figure 13: The Model for the Mind – Body

A Voronoi diagram is a partition of a plane into regions close to each of a given set of objects. In the simplest case, these objects are just finitely many points in the plane. For each seed there is a corresponding region consisting of all points of the plane closer to that seed than to any other. A point of view or a thought can be a **"Voronoi Tessellation".** A point in the CPS can be depicted as shown in Figure 14. In theory this can be the Bindu or Trikuta shown in Figure 13. It needs a simulator to study the resulting complex mathematical model for the CPS.

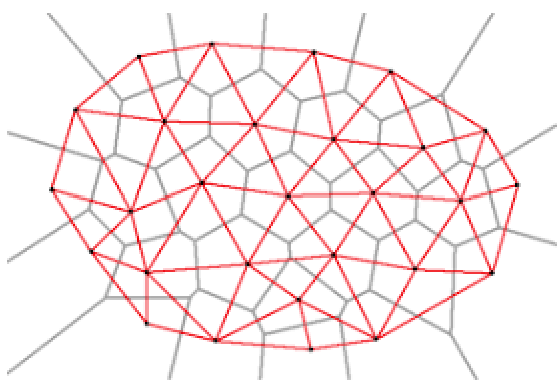

Figure 14: Voronoi Tessallation for a Point in CPS

5. Conclusions

There have been several attempts at specifying unconventional computing such as Reservoir Computing, Tangible Computing, Spintronics , Atomtronics, Fluidics and Chaos Computing. None of these have been a generic model for computation. In the context of CPS they even more restrictive. In this paper, the author proposes unconventional proofing in a CPS using

Neurotheology, Geometry, Physics and Metaphysics based of Indic studies in Consciousness. If the metaphysical dominates, the proof tends to be more experiential than expressive. These are the difficult questions related to Consciousness and modeling to thought and its seamless transmission to other receptive brains.

6. Acknowledgements

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