The control systems engineering foundation of traditional Indian medicine: The Rosetta Stone for Siddha and Ayurveda

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Abstract: This paper uncovers the scientific foundation of traditional systems of Indian medicine: Siddha and Ayurveda, from core principles shared in modern control systems engineering. Grand challenges of modern healthcare are motivating a paradigm shift towards systems of systems (SoS) approaches. The recent emergence of modern systems biology and the concomitant growth of evidence-based research in ancient systems of holistic medicine such as Siddha and Ayurveda, practiced in India for over 5,000 years, exemplify this shift. This paper reveals a *Rosetta Stone*, inscribed from principles of control systems engineering, to comprehend the scientific foundations of the ancient *lingua franca* of Siddha and Ayurveda. This discovery provides a much-needed integrative framework, across east and west, ancient and modern, to develop a systems medicine that overcomes the reductionism of modern healthcare.

Keywords: traditional medicine; siddha; ayurveda; complementary and alternative medicine; CAM; systems biology; systems theory; whole cell modelling; Dosha; Prakriti; multi-scale modelling; healthcare system; control systems engineering; systems of systems engineering; SoSE.

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Biographical notes: V.A. Shiva Ayyadurai holds four degrees from Massachusetts Institute of Technology (MIT) in Engineering, Media and Biology. His training in yoga, meditation and Siddha began, as a child, in India. After attending NYU, in 1978, as a 14-year-old, he was recruited as a research scholar by the University of Medicine and Dentistry of New Jersey, where he invented email, the first full-scale electronic emulation of the interoffice mail system (inbox, outbox, memo, etc.). Following his doctorate from MIT's Department of Biological Engineering, he was awarded a Fulbright to explore linkages across Siddha/Ayurveda and Systems Biology, resulting in Systems Health®. While being the Director of Systems Biology Group at the

International Center of Integrative Systems and a Research Affiliate at MIT's Sociotechnical Research Center, research herein was conducted. His recent invention, CytoSolve®, enables dynamic computational integration of complex molecular pathway models, providing a new paradigm for development of multi-combination therapeutics.

This paper is a revised and expanded version of a paper entitled 'Siddha: the first systems biology' presented at the Fulbright Conference, New Delhi, India, April 2009.

1 Introduction

This paper uncovers the scientific foundation of Siddha and Ayurveda, two of India's oldest systems of traditional medicine, by discovering an ontological link, a *Rosetta Stone* (Downs, 2008), between the terminology of the core principles of control systems engineering and the lingua franca of the core principles of Siddha and Ayurveda. This Rosetta Stone provides a much-needed bridge to comprehend the scientific principles that underlie traditional Indian medical systems, particularly at a time when problems of the current healthcare system are motivating a pervasive and fundamental rethinking: a paradigm shift away from reductionism to systems of systems engineering (SoSE) approaches.

The explosive growth in the use of alternative therapies and concomitant rise in evidence-based research of traditional systems of medicine, such as Siddha and Ayurveda, exemplifies this shift (Miles, 2009). These traditional systems conceive the human body as a holistic system. This shift parallels the emergence of the field of modern systems biology, a result of the post-genomic era (Weston and Hood, 2004). Systems biology aims to develop an integrated and holistic model of the human system across multiple temporal and spatial scales, from molecules to molecular pathways to cells to tissue to organs to whole organism.

Recent developments in systems biology have recognised the importance of multi-layered systems of systems (SoS) architectures (Hunter and Borg, 2003) in its objective to model the whole human system. The core principles of modern control systems engineering (Ogata, 1997) such as:

1. open loop systems, based on general systems theoretic concepts of energy transport, conversion and storage
2. closed looped systems containing control elements such as goal, controller, sensors, feedback and disturbance,

have become central to systems biology's implementation of such architectures (Bosl, 2007). For over a century, control systems engineering principles have enabled major technological advancements from the thermostat to the aircraft. Systems biologists acknowledge that the modelling of the human body, far more complex than any aircraft or man-made engineering system, also requires these same principles (Dhurjati and Mahadevan, 2008; Mandel et al., 2004; Decraene et al., 2007).

The systems architectures of Siddha and Ayurveda, developed over 5,000 years ago (Mukherjee and Wahile, 2006; Fritts et al., 2008; Patwardhan et al., 2005) in the Indian subcontinent, reveal an integrative and multilayered framework that modern systems biology aims to replicate and understand (Patwardhan et al., 2008). Siddha and Ayurveda are themselves a systems biology, and likely, the world's first systems biology (Patwardhan et al., 2008). Though systems of Indian medicine have their origins in basic principles of systems and complexity theory (Hankey, 2005; Rioux, 2012), their ancient *lingua franca* has obfuscated the complete exposition of their foundations in modern control systems engineering. This obfuscation and the inability of modern practitioners to clearly convey those scientific principles have constrained their acceptance by modern science.

This paper demonstrates the commonality and invariance of the use of control systems engineering principles, across east and west, ancient and modern, by showing an ontological link. Such an exposition provides a gateway for modern science to confidently explore systems such as Siddha and Ayurveda, as well as remove any askance that exists on whether such systems have a scientific foundation. Though the representation and communication of observations, made by the originators of Siddha and Ayurveda, occurred within a different historical and cultural context, leading to a lingua franca, foreign to modern science, the underlying framework is scientific and universal.

The pathway to this exposition is done in a step-by-step manner. In the next section, we begin by reviewing the reductionist thinking that pervades the modern healthcare system. In Section 3, the emergence of systems biology as an alternative to this reductionism, its central features, and aims are discussed. Section 4 reviews the core principles of control systems engineering that are the foundations of current efforts in systems biology to model the human system.

In Section 5, with this background on the reductionism of the modern healthcare system, a review of systems biology, and an itemisation of the fundamentals of control systems engineering, the core principles of Siddha and Ayurveda, in their native lingua franca, are introduced. In Section 6, these core principles of Siddha and Ayurveda are juxtaposed with the core principles of modern control systems engineering to reveal a *Rosetta Stone* that interprets the lingua franca of Siddha and Ayurveda. This juxtaposition demonstrates that the principles of control systems engineering are the same as that of Siddha and Ayurveda.

This exposition serves to provide a comprehensible understanding of the scientific foundation of Siddha and Ayurveda. This comprehension is particularly critical at a time when there is a growing recognition that SoS approaches, ancient and modern, must be fully explored and exploited to overcome the reductionism, prevalent in the modern healthcare system. Overcoming such reductionism will advance a systems medicine that can deliver on the real promise of healthcare: timely and cost effective solutions for the cure and prevention of disease.

2 Background

The modern healthcare system faces incredible challenges: high costs, low quality of care, and a drug development process that is in peril. The origins of these challenges can be traced to a system that was designed to handle crises, needing immediate and reactive solutions. Those needs led to a particular systems design philosophy: reductionism. Reductionism fostered a healthcare system that was able to respond and react to such crises; however, this philosophy may no longer be effective to meet the growing demand for a healthcare system that delivers prevention, focused on health and well being, and is considerate of the long-term effects of particular therapeutics, protocols and procedures.

2.1 The modern healthcare system

The modern healthcare system was borne during the industrial era, and was structured to manage the calamities of war (Ehrenreich, 1978). Those conditions compelled a reductionist thinking. Wartime situations required a healthcare system that rewarded specialisation and 'magic bullet' solutions, which triaged to a single drug, the right specialist, or the right procedure to address immediate and catastrophic events (Glynn and Scully, 2010). Reductionism was effective for these situations, delivering life-saving solutions: steroids, antibiotics, specialists and surgical techniques to solve problems, *after* the onset of disease or catastrophe.

Reductionism now pervades all aspects of the modern healthcare system, including basic research, patient treatment and drug development (Miles, 2009). The systems requirements for wartime healthcare are different from the systems requirements for a healthcare that enables prevention of disease and delivery of solutions, which are aligned to the long-term benefit of the whole human. The failure of modern healthcare system can be traced to this mismatch of systems requirements.

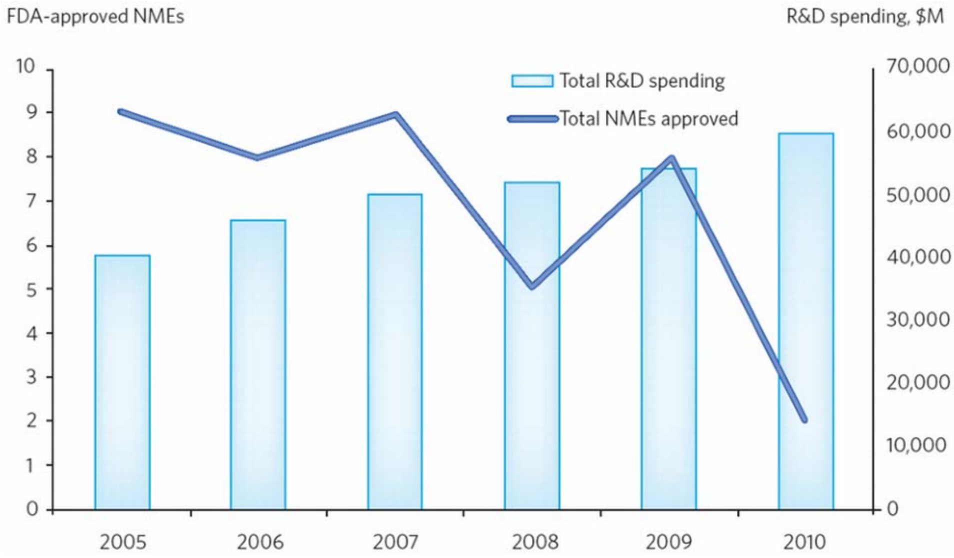
The skyrocketing costs of healthcare are a direct result of such failure. As of 2013, the percentage of US GDP for healthcare was approximately 5% and exceeded defence spending by only 1% (defence spending was at approximately 4% of US GDP as of 2013) (Hartman et al., 2013). By 2050, however, healthcare costs are projected to double to 10% of GDP, while defence spending will remain unchanged at 4%. These rising costs, however, are not delivering a concomitant quality of care.

In the UK, for example, one in five patients suffer harm, caused *after* admission into some National Health Services (NHS) hospitals (Symons et al., 2013). In the USA, the statistics are even more staggering. One in three hospital patients experience adverse events and about 7% of these patients are harmed permanently or die as a result, according to a study that detected patient safety problems (Classen et al., 2011), at a far higher rate than early studies which had concluded one in four Medicare beneficiaries suffer some form of harm during their stay (Levinson and General, 2010; Landrigan et al., 2010). If the US transportation system delivered such equivalent results, meaning one in four drivers got into some type of accident when they took to the roads, it is likely many would look for alternative modes of transport (Binder, 2013). These facts are driving a growing number of citizens to explore alternatives and to conduct their lives, in a way where prevention of disease (Tindle et al., 2004) and staying out of the hospital is the priority.

The high cost of pharmaceuticals is another example of the current system's failure. Upwards of $5 billion are needed to produce a single drug that takes nearly 15 years to develop (Willmann et al., 2008; Harper, 2013). The drug development process is an *open loop system*, with minimal feedback. This ineffective system produces drugs that are only efficacious for a small segment of the target population since they are not personalised, while posing significant risks and side effects to a majority (Woodcock, 2007). The attempt to address this problem by simply increasing spending on research and development (R&D) is not working.

As Figure 1 illustrates, year-over-year increases in R&D are actually resulting in year-over-year decreases in new drug approvals by the US Food and Drug Administration (FDA) (Bunnage, 2011). Rising costs, low quality of care and an ineffective drug development process suggest that the root cause of the healthcare systems' failure have yet to be addressed.

Figure 1 R&D spending versus new FDA approvals (see online version for colours)



Source: Bunnage (2011)

2.2 Reductionism

The reductionism of modern healthcare compels increasing specialisation, where a problem is divided into to many smaller problems. Each of these smaller problems are then assigned to individuals with even greater specialisation (Welsby, 1999). This has resulted in a system that has increasing number parts, where the parts of the system are disconnected from each other and so are the solutions (Williams, 1997). Such a reductionist process has inspired new drugs, protocols, technologies and methodologies for enabling control over smaller and more specialised processes. For clinical problems such as Alzheimer's, diabetes, cancer, etc., this paradigm of research isolates a small piece of the problem, and studies it out of context, that ultimately provides solutions that are not effective to the whole (Castellani et al., 2009; Ahn et al., 2006; Peterson, 2008).

The over-specialisation of disciplines that results from this reductionism makes it challenging for any one practitioner or researcher to pull together enough fundamental knowledge to innovate viable diagnostics or interventions (Mulej, 2007). Moreover, funding and investments in basic science and research do not promote or inspire interdisciplinary or transdisciplinary cooperation needed to create significant clinical discoveries and applications (Kessel and Rosenfeld, 2008). There are also many unintended systems consequences of such reductionism.

In reductionism, causality moves one way from low order phenomenon to higher order phenomenon, and ignores the possibility of complex higher order systems exerting a causal influence on more basic lower order systems (Sawyer, 2005; Schlundt, 2011). Biogenetic determinism, for example, moves explanation of social and behavioural problems to just the genes, where the individual alone, rather than social conditions or economic inequities, are made responsible (Schlundt, 2011). This results in individuals developing a sense of helplessness where they are taught to believe that their genes are the only reason for their particular ailment, e.g., diabetes, obesity, etc. This reductionist approach steers a system that prescribes and develops drugs as the sole method to 'solve' problems (Schlundt, 2011) be they social, interpersonal, emotional, etc.

The alternative to reductionism is a different type of thinking: a systems thinking. Systems thinking is based on a holistic, systems-based approach, that recognises that systems cannot be understood by taking them apart, that there is no single 'magic bullet' since emergent properties manifest as the parts of the system interact together (Ideker et al., 2001). From these interactions, new properties of the systems 'emerge', properties, which cannot be predicted from the properties of any individual part.

3 Systems biology

The field of biology is ultimately the source of knowledge and insight to develop new treatments and therapeutics for healthcare. Significant changes to the healthcare system, therefore, cannot take place without changes to how biology is practiced. Today, biology, unlike physics or engineering, is a field based on experiments, not first principles, *ab initio* (Zhulin, 2009). Biologists do many experiments to understand genes, proteins, protein-protein interactions. An example of perhaps the largest experiment in biology is the Human Genome Project (HGP) begun in 1990 and completed in 2005.

The HGP, when it began, was predicated on the hypothesis that what made humans different than a nematode, a worm, was the number of genes. Originally, it was estimated that a human had approximately 100,000 genes (Schuler et al., 1996). The HGP concluded that humans have only 20,000 to 25,000 genes, far less than what was originally theorised (Pennisi, 2003), and near the same number of genes as the nematode *Caenorhabditis elegans*, of approximately 19,000 genes (Hodgkin, 2001). The genome of the starlet sea anemone – *Nematostella vectensis*, a delicate, few-inch-long animal in the form of a transparent, multi-tentacled tube has approximately 18,000 genes (Putnam et al., 2007).

The HGP revealed that whether, human or a nematode (or sea anemone) they all have a similar number of genes, but a great difference in complexity of function as whole organisms. This contradiction led biologists to conclude that perhaps the number of genes in the genome is not connected with the complexity of the organism, and that much of an organism's complexity can be ascribed to regulation of existing genes by other substances (such as proteins) rather than to novel genes (Putnam et al., 2007). The kinds of molecular interactions across the nucleus, cytoplasm and organelles, beyond the number of genes in the nucleus, may be the critical element in determining the difference between human and nematode, for example.

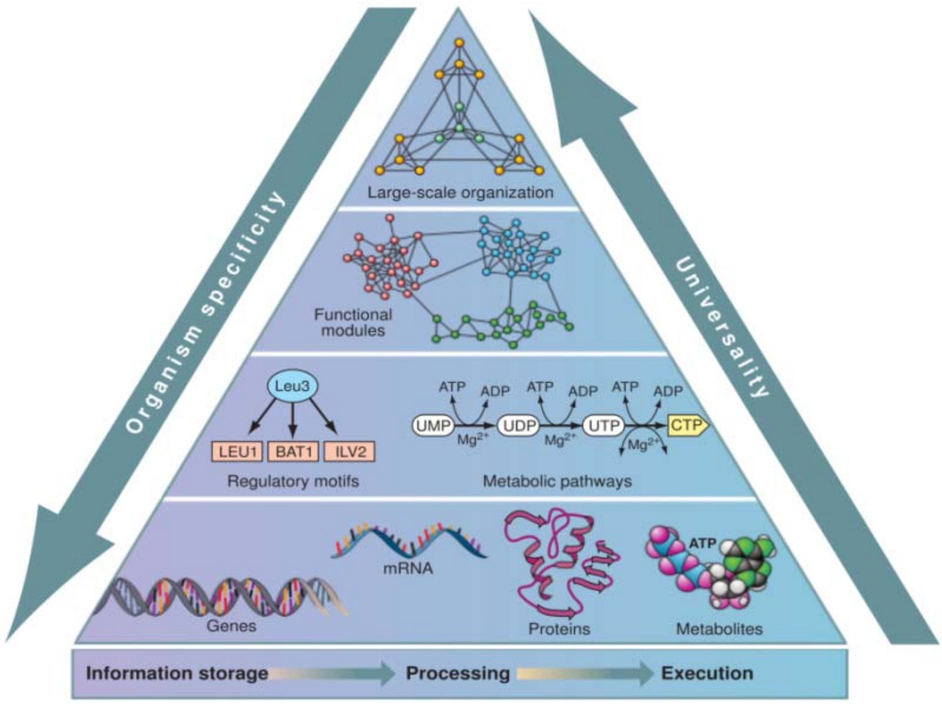
This reasoning has led to an even greater activity to understand the structure of proteins (e.g. the product of genes) and protein–protein interactions.

3.1 A systems approach to the study of life

Systems biology emerges from where the HGP ends. Reductionist thinking and the central dogma theory of Watson and Crick (1953) had emphasised that genes alone are what make us who we are (Schaffner, 1969). Systems biology rose in response to this reductionism, and focuses attention, not on just on one part, such as the genome, but on the complex interaction of SoS across genes, proteins, and complex molecular pathways, which are all influenced by an epigenetic layer (Hood et al., 2004) affected by both endogenous and exogenous systems including nutrition, environment, and perhaps, even thoughts.

This system of system approach aims to create a holistic model of the whole organism by integrating the complexity of SoS from molecule to molecular pathways to large-scale organisation, as illustrated in the multi-layered hierarchy of Figure 2.

Figure 2 Life's complexity pyramid (see online version for colours)



Source: Oltvai and Barabasi (2002)

While systems biology, as a field, is only a decade old, building systems-level understanding of biology is not a new phenomenon. Over 5,000 years ago, many traditional systems of medicine including Siddha, Unani, Ayurveda and traditional Chinese medicine (TCM) proposed systems approaches to describing the whole human physiome (Patwardhan et al., 2005; Subbarayappa, 1997). During modern times, starting in 1930s, with the concept of homeostasis (Cannon, 1933) and biological cybernetics (Wiener, 1948) attempts were made to understand biology from a systems level using the modern language of physics and control systems engineering.

Systems biology is now developing a system-level understanding by connecting knowledge at the molecular level to higher-level biological functions (Kitano, 2000). Previous attempts at system-level approaches to biology were primarily focused on the description and analysis of biological systems, limited to the physiological level. Since these approaches had little to no knowledge of how molecular interactions were linked to biological functions – a systems-based biology of connecting molecular interactions to biological functions was not previously possible. Modern systems biology, as a new field of biology, offers the opportunity, as never before, to link the behaviours of molecules to the characteristics of biological systems. This new field will enable us to eventually describe the SoS of cells, tissues, organs and human beings within a consistent framework governed by the basic principles of physics (Kitano, 2001).

3.2 Modelling life at the cellular level

One important development in systems biology is to model the whole cell by considering molecular pathways as being the elemental modules of complex cellular functions. Biological systems are thought to have large number of parts almost all of which are related in complex ways (Keller, 2007). Functionality emerges as the result of interactions between many proteins relating to each other in multiple cascades and in interaction with the cellular environment. By computing these interactions, it can be used to determine the logic of healthy and diseased states (Noble, 2006). One way to model the whole cell is through a bottom up reconstruction. Such bottom up reconstruction, for example, of the human metabolic network, was done primarily through a manual process of integrating databases and pathway models (Duarte et al., 2007).

It is possible, for example, to regard signalling networks as systems that decode complex inputs in time, space and chemistry into combinatorial output patterns of signalling activity (Bhalla, 2003). By treating molecular pathways as modules, our minds can still deal with the complexity (Ayyadurai, 2011). In this way, accurate experimentation and detailed modelling of network behaviour in terms of molecular properties can reinforce each other (Hornberg et al., 2006). The goal then becomes that of linking kinetic models on small parts to build larger models to form detailed kinetic models of larger chunks of molecular pathways, such as metabolism, for example, and ultimately of the entire living cell (Snoep et al., 2006).

The value of integrating systems of molecular pathways is to demonstrate that integrated network show emergent properties that the individual pathways do not possess, like extended signal duration, activation of feedback loops, thresholds for biological effects, or a multitude of signal outputs (Klipp and Liebermeister, 2006). In this sense, a cell can be seen as an adaptive autonomous agent or as a society of such agents, where each can exhibit a particular behaviour depending on its cognitive capabilities.

Unique mathematical frameworks will be needed to obtain an integrated perspective on these complex systems, which operate over wide length and time scales. These may involve a multi-layered, hierarchical approach, wherein the overall signalling network, at one layer, is modelled in terms of effective 'circuit' or 'algorithm' modules (Ayyadurai and Dewey, 2011), and then at other layers, each module is correspondingly modelled with more detailed incorporation of its actual underlying biochemical/biophysical molecular interactions (Asthagiri and Lauffenburger, 2000). The mammalian cell may be considered as a central signalling network connected to various cellular machines that are responsible for phenotypic functions. Cellular machines such as transcriptional, translational, motility, and secretory machinery can be represented as sets of interacting components that form functional local networks (Ma'ayan et al., 2005).

As biology begins to move into the post-genomic era, a key emerging question is how to approach the understanding of how complex molecular pathways function as dynamical systems. Prominent examples include multi-molecular protein 'machines', intracellular signal transduction cascades, and cell-cell communication mechanisms. As the proportion of identified systems involved in any of these molecular pathways continues to increase, in certain instances already asymptotically, the daunting challenge of developing useful models – both mathematical as well as conceptual – for how they work, is drawing increased interest (Lauffenburger, 2000).

3.3 Multi-scale modelling

Multi-scale modelling is essential to integrating knowledge of human physiology starting from genomics, molecular biology, and the environment through the levels of cells, tissues, and organs all the way to integrated systems behaviour. The lowest levels concern biophysical and biochemical events. The higher levels of organisation in tissues, organs, and organism are complex, representing the dynamically varying behaviour of billions of cells interacting together (Bassingthwaighte et al., 2005). Biological pathways can be seen to share structural principles with engineered networks, along with three of the most important shared principles: modularity, robustness to component tolerances, and use of recurring circuit elements (Alon, 2003).

An important attribute of the complexity pyramid is the gradual transition from the particular (at the bottom level) to the universal (at the apex) (Kitney and Dollery, 2007; Oltvai and Barabasi, 2002). Others have recognised that one can build cellular-like structures from a bottom up approach (Seeman and Belcher, 2002). Integrated models would represent the most compact, unambiguous and unified form of biological hypotheses, and as such they could be used to quantitatively explore interrelationships at both the molecular and cellular levels (Morgan et al., 2004). At this time, for instance, the computational function of many of the signalling networks is poorly understood. However, it is clear that it is possible to construct a huge variety of control and computational circuits, both analogue and digital from combinations of the cascade cycle (Sauro and Kholodenko, 2004).

The need for multi-scale computational modelling is demanding a foundational set of principles that governs the modelling of system components within a multi-layered system of systems. *Control systems engineering* provides those foundational set of principles. Every manmade system of systems, simple or complex, has been designed and developed based on control systems engineering principles. Given the human body is also a complex system of systems, systems biologists are adopting these principles in their effort to design and model the complex inter- and intra-system interactions across multiple temporal and spatial scales of the human system.

4 Control systems engineering

Systems biology is transforming the field of biology from a purely experimental field into an engineering discipline. The engineering discipline uses foundational principles of physics to understand and control matter, energy, and information in order to create products that benefit humankind. Systems biology now aims to adopt an engineering systems approach to understand and model the human system. Control system engineering provides the framework to support such understanding and modelling.

The principles of control systems engineering have produced incredible innovations and systems that enhance the day-to-day existence of nearly every human being. The thermostat in home heating systems, cruise control in automobiles, and the autopilot in aircrafts, are some examples of such innovations. Through a process of iterative understanding and modelling, such systems are created and refined. The human system itself is a product of the principles of control systems engineering, where Nature, as the engineer, has refined and evolved the human system over billions of years.

Identification of the core principles of control systems engineering, as well as itemisation of the terminology used to describe those principles, are the central thesis of this paper. These core principles of control systems engineering are derived from:

1 the notion of a *system*, formalised from general systems theory (GST) (von Bertalanffy, 1968)

2 concepts of *open loop systems* and *closed loop systems* based on feedback theory and linear system analysis that integrate concepts of network theory and communication theory.

4.1 Definition of a system

The modern definition of a 'system' emerges from GST, which arose out of several disciplines, including biology, mathematics, philosophy, and the social sciences (Boulding, 1953). GST came into prominence in the 1950s (Boulding, 1956). von Bertalanffy began thinking of GST in the 1930s; however, his ideas, which were not popular at the time, did not receive widespread attention until much later (von Bertalanffy, 1968). The aim of GST was to be a "…unifying theoretical construct for all of the sciences" (von Bertalanffy, 1968).

The systems approach of GST arose in contrast to the reductionism of the Newtonian method. In the Newtonian method, a system or object was broken down into individual parts. To understand the system, the behaviour of each part was studied individually, without considering the interactions among the set of parts (von Bertalanffy, 1968). One broad definition of GST is, "… a set of related definitions, assumptions, and propositions which deal with reality as an integrated hierarchy of organizations of matter and energy" (Miller, 1978). Another definition is, "… a collection of general concepts, principles, tools, problems, methods, and techniques associated with systems" (Klir, 1972). From the context of GST, a generalised definition of a system emerges as:

> "An arrangement of certain components so interrelated as to form a whole."
> (Klir, 1972)

Given this broad definition, on may ask: Do all systems possess fundamental elements that are common?

This question can be answered by recognising that there are two classes of systems:

1 open loop systems

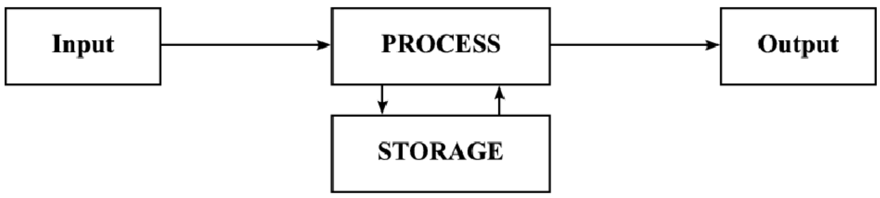
2 closed loop systems.

Every system in the universe either behaves as an open loop system or as a closed loop system. Open loop systems are a subset of closed loop systems. Every system possesses the five basic elements of an open loop system. Some systems, referred to as 'intelligent' or closed loop systems, possess not only these five basic elements, but also an additional four elements.

4.2 Open loop systems

Figure 3 illustrates the elements of an open loop system. In traditional control systems engineering texts, the elements are referred to as input and output, process, and storage as shown in Figure 3.

Figure 3 Input/output, process and storage of open loop system

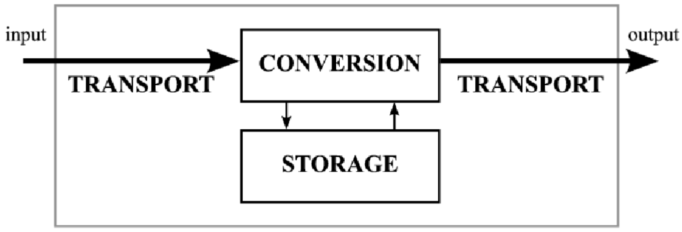


Recent work in classifying engineering systems (Magee and de Weck, 2004) has referred to functional types (van Wyk, 1984) as a method for engineering systems classification. The terminology of functional types refers to the 'functions' of transporter, processor and store. In this discussion, a variation of the functional types terminology is used to identify the five elements of an open loop system:

- input
- output
- transport
- conversion
- storage.

These five elements are illustrated in Figure 4. The *input* element is a set of state variables that denote what goes into the system. The *output* element is a set of state variables that denote what comes out of the system. The *transport* element represents the forces of movement or flow of matter, information or energy within the system. The *conversion* element represents forces of transduction or 'conversion' that transform the input, be they forms of matter, energy or information into an output, that are also forms of matter, energy or information. The *storage* element is used to 'store' or contain forms of matter, energy or information within the system.

Figure 4 Open loop system



The quantifiable levels of transport, conversion and storage determine the state of the system, denoted by the large rectangle in Figure 4.

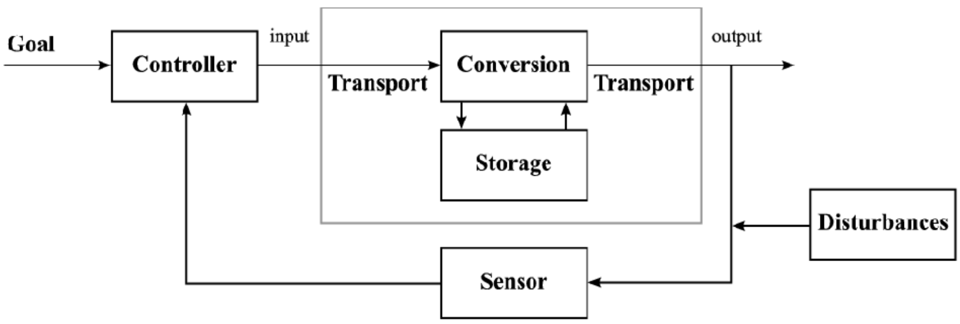
4.3 An example of open loop system: electric heater

One example of an open loop system is an electric heater. Turning on the heater, sends the input of a certain amount of Amperes of current into the heater. The output of the heater is a certain amount of Joules of heat. The transport element moves or transports the electrical and heat energy within the system. The conversion element, represented by the heating coils, converts the electrical energy into heat. The storage element is the structure, which holds or contains the entire system. This system is 'open loop' meaning that the once the heater is turned on, it will simply continue sending out as much heat as possible, without any modulation with respect to temperature. If it gets too hot, someone will have to turn it off.

4.4 Closed loop systems

Closed loop systems, unlike open loop systems, enable the intelligent adjustment of the input to achieve a desired *goal*, in spite of *disturbances* to the system, through the use of a *controller* and *sensor*. The classic closed loop system is illustrated in Figure 5.

Figure 5 Closed loop system



The closed loop system achieves its goal by 'closing the loop' on an open loop system by looping the output through a sensor, which measures the output, and sends the measured output to a controller. The controller is the intelligence of closed loop systems. The controller measures the difference between the desired goal and the measured output.

Based on the difference, the controller calculates a new input into the open loop system, which has the effect of modulating the transport, conversion and storage elements within the system, to produce a new output.

This process of measuring the output, and adjusting the input to ensure that the goal is achieved, given disturbances to the system, is a continual process. This iterative process of adjustment and refinement is what makes closed loop systems, 'intelligent' systems. In summary, a closed loop system has the following four additional components:

- goal
- controller
- sensor
- disturbances

4.5 An example of closed loop system: electric heater with thermostat

An electric heater with thermostat is a classic example of a closed loop system. Unlike the electric heater, which can just be turned on or off, an electric heater with a thermostat allows one to set a goal, a desired temperature. The controller, which is the thermostat, receives the output, the room temperature, from a sensor, the built-in thermometer, and then determines the difference between the goal and this output. This difference is used by the controller to calculate a new input, the electricity into the heater. If there are disturbances (a cold draft, for example), the controller will automatically adjust the input as needed. The process iterates around the closed loop to keep the difference between the goal and the output zero.

4.6 Summary of the terminology of control systems engineering

In summary, there are nine important elements, which reflect the core principles of modern control systems engineering. These nine elements are summarised in Table 1.

Table 1 The nine elements of control systems engineering

Element
Input
Output
Transport
Conversion
Storage
Goal
Controller
Sensor
Disturbances

5 Siddha and Ayurveda

Siddha and Ayurveda are ancient systems of Indian medicine that have been practiced for over 5,000 years. Siddha is from the Tamil word meaning ‘perfection’; Ayurveda means ‘knowledge of life’ from the words Ayus which means life, and Veda, which means knowledge (Mukherjee, 2001). Siddha is predominantly practiced in South India, while Ayurveda is mainly practiced in North India. Siddha and Ayurveda have particular differences, such as emphasis on particular modalities and minor variations in terminology; however, their foundational elements are the same (Vogel, 1991).

5.1 The foundational elements of Siddha and Ayurveda

The foundational elements of Siddha and Ayurveda are conveyed in a native systems architecture that organises the nature of existence from the subtle to the gross. The architecture also reveals core principles that provide a model for regulating one’s life towards optimal health. This architecture is presented in a multi-layered fashion with a particular lingua franca that describes the elements at each layer. This lingua franca, to those unfamiliar with Siddha and Ayurveda, may likely seem foreign or perhaps even ‘mystical’; nonetheless, the focus of this part of the discussion is to expose the reader to this lingua franca, layer by layer.

The *first* layer is known as *Purusha*. The notion of Purusha is best described as consciousness, which expresses itself as will, desire, or motivation (Saraswati and Nikolić, 1984). Purusha is said to give rise to *Prakriti*, the *second* layer. Prakriti represents material existence (Menon and Prince, 2005) that is manifested from Purusha. A goal or an idea, for example, is representative of Purusha. The manifestation of that idea in the material form, in some state, is known as Prakriti. In Indian metaphysics, the entire universe was formed from an idea/thought/will/desire (Purusha) that gave rise to the material existence (Prakriti) that one experiences as matter, energy and information. Prakriti manifests itself in three forms or aspects of energy.

The *third* layer is used to present the three aspects of Prakriti. These three aspects are known as the *Gunas*. The three Gunas are: *Sattvic*, *Rajasic*, and *Tamasic* (Scharfe, 1999). These Gunas are ‘flavours’ of Prakriti, each having particular subtle qualities. These Gunas cannot be seen, touched, tasted, heard or smelt, but are qualities of subtle energy. At the next layer of this architecture, the Gunas manifest in material forms that can be seen, touched, tasted, heard and smelt.

The *fourth* layer is the gross materialisation of the Gunas. When the Gunas materialise, they are known as the *Panchabuthas* or the ‘five elements’ (Rastogi and Chiappelli, 2010). Unlike modern physics, the term ‘elements’ does not mean elements from the Periodic Table but is closer to the term ‘states of matter’. The five elements, in the Siddha and Ayurveda terminology, along with their English translation, are provided in Table 2.

In the Siddha and Ayurveda system, practitioners use the interaction of these five elements to understand the dynamics of nature. The Panchabuthas mix with each other, in different proportions in the body, to form other physiological substances such as tissues as well as to define the whole organism. They are important in Indian medicine because they give rise to one’s individual constitution or body type.

Table 2 The Panchabuthas of Siddha and Ayurveda

Siddha	*Ayurveda*	*English*
Akayam	Akasha	Space
Vayu	Vayu	Air
Thee	Agni	Fire
Neer	Jala	Water
Mann	Prithvi	Earth

The notion of body constitution is presented in the *fifth* layer by what is known as the *tri-Doshas*, or 'three' Doshas. Our bodies are filled with 'space'; they are gaseous, filled with 'air; they have 'fire', heat or temperature; they are solid, made of 'earth'; and, they are liquid, made of 'water'. The body is composed of combinations of these elements, and this combination is central to Siddha and Ayurveda's conception of health and well-being. A particular individual's constitution or body type is expressed as combinations of these elements through the tri-Doshas known as: *Vata*, *Pitta* and *Kapha* (Sharma et al., 2007). How the five elements or Panchabuthas come together to create Vata, Pitta, and Kapha, is shown in Table 3.

Table 3 Relationship of tri-Doshas and Panchabuthas

Tri-Doshas	*Panchabuthas*
Vata	Space + Air
Pitta	Fire
Kapha	Water + Earth

Vata is composed of combinations of space and air; Pitta is composed of fire; and, Kapha is composed of water and earth. In Siddha and Ayurveda, an individual is made up of varying amounts of Vata (V), Pitta (P), and Kapha (K). These particular amounts are present at birth, and determine the body type of the individual, known formally as the individual's *Prakriti* (Bhushan et al., 2005).

The *sixth* layer is composed of the seven Dhatus. The Vata, Pitta, Kapha constituents of an individual control the nature of the particular Dhatus, which are closely related to tissues in human physiology. The Dhatus, in the Siddha and Ayurveda (Yadav, 2014) terminology, along with their English translation, are provided in Table 4.

Table 4 The Dhatus of Siddha and Ayurveda

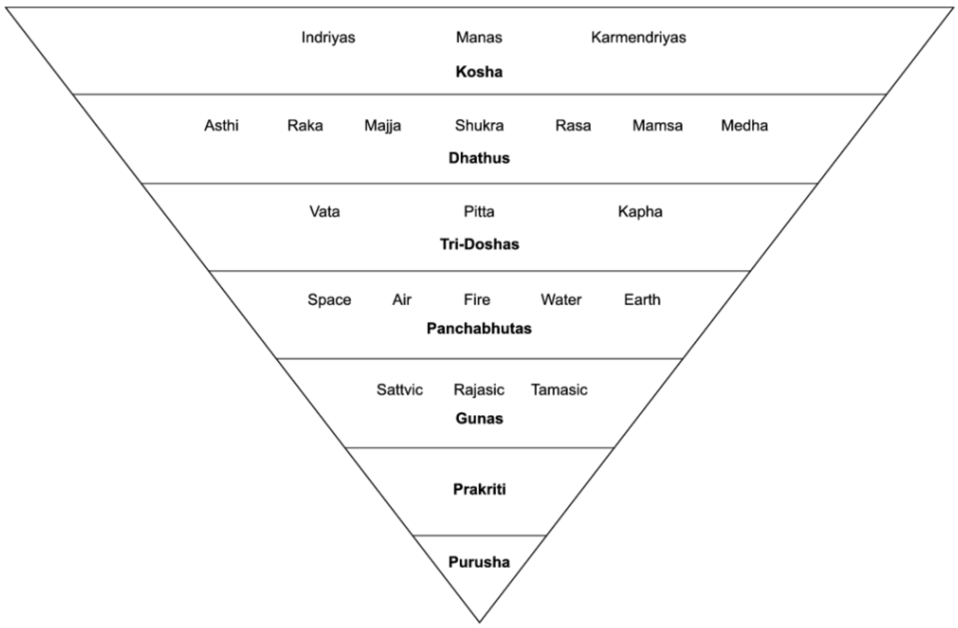
Siddha	*Ayurveda*	*English*
Enbu	Asthi	Bone
Cheneer	Rakta	Blood
Moolai	Majja	Marrow
Sukila/Sronitha	Shukra	Reproductive tissues
Saram	Rasa	Plasma
Oon	Mamsa	Muscle
Kozhuppu	Meddha	Fat

The *seventh* layer is the *Kosha*, which is the whole body of the organism, containing *Indriyas*, which are the fives senses of the body; the *Manas*, which represent the mind; and, the *Karmendriyas*, which represent the physical organs.

5.2 Siddha and Ayurveda: the first systems biology

Figure 6 illustrates the systems biology of Siddha and Ayurveda by referencing the foundational elements discussed in the previous discussion. Siddha and Ayurveda are a systems biology, and likely the first systems biology, as they provide a multi-layered system to understand life. While their terms may be foreign, the organisation of Siddha and Ayurveda provides a holistic model of describing the spectrum of existence from the immaterial to the living organism.

Figure 6 The system biology of Siddha and Ayurveda



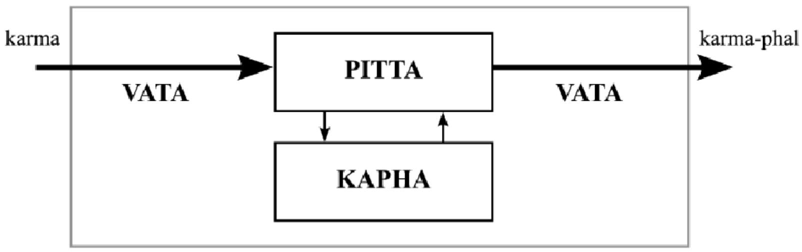
5.3 The core principles of Siddha and Ayurveda

In the lingua franca of Siddha and Ayurveda, the three forces of Vata, Pitta and Kapha, in varying levels, define the state of the Dhatus and the Kosha. Vata is made up of space and air, that control the forces of movement, such as the motion of the body, the process of eating to egestion, or the information flow of receiving and outputting information, e.g., hearing and then speaking. Pitta controls the forces of transformation such as digestion (eating and converting food to nutrition), converting an idea to an action; the process of addition (taking two numbers and adding them to give a result). Kapha controls the forces that provide storage and structure or containment, such as the skeleton of the body, storing fat, or memory and remembering things. The unique combination of Vata, Pitta and Kapha denotes a particular individual's Prakriti.

When Siddha medical practitioners look at an individual, they always start with a basic question: 'What is this person's nature or Prakriti?' They use a personalised approach to perform diagnostics to get a sense of someone's constitutional makeup or Prakriti.

Figure 7 illustrates the Kosha (or the body), within the large rectangle, that is defined by the interaction of Vata, Pitta and Kapha elements. Siddha and Ayurveda recognise that *Karma* (action), upon the body leads to *Karma-Phal*, the effects of Karma or 'fruits of Karma'. The Karma affects one's Prakriti. For example, certain Karma of eating the wrong food and not sleeping enough will lead to certain Karma-Phal, such as poor skin and being overweight. The Karma-Phal is a symptom of the displacement of the individual's Prakriti, caused by the particular Karma. This displaced Prakriti is called *Vikriti*.

Figure 7 Karma affects Vata, Pitta and Kapha to yield Karma-Phal



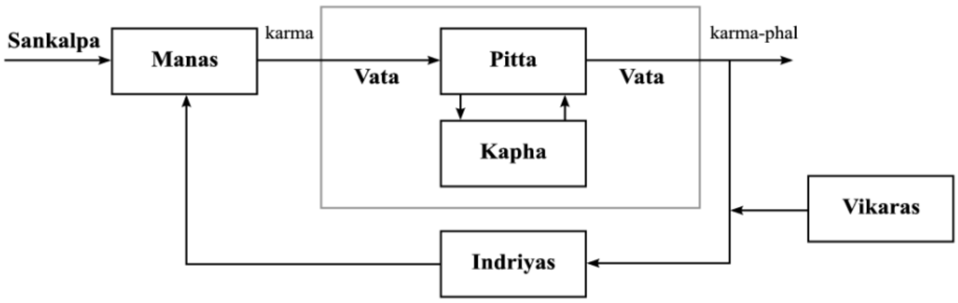
For example, an individual's Prakriti may be 30% Vata (V), 20% Pitta (P) and 50% Kapha (K). But due to certain Karma (inappropriate inputs), their Vikriti may become 30% Vata (V), 50% Pitta (P) and 20% Kapha (K). This means that their Karma displaced their Pitta and Kapha, relative to their Prakriti, by increasing their Pitta by 30%, lowering their Kapha by 30%.

Health, in Siddha and Ayurveda, involves an individual's capacity to maintain their body's particular constitution, Prakriti, in the midst of exogenous and endogenous stresses and disturbances, through a constant regulatory and feedback process (Patil et al., 2014).

5.4 The regulatory cycle of Siddha and Ayurveda for health

In Siddha and Ayurveda, this regulatory process is illustrated in Figure 8. This process begins with one making a *Sankalpa*, a resolution, setting a goal for optimal health. Optimal health means ensuring that the Kosha (the body) maintains its unique Prakriti, in the midst of *Vikaras* (or disturbances) to the Kosha, which may be beyond the control of the individual. Such Vikaras can be weather changes, moving to a new geography, mental stresses, etc. In Siddha and Ayurveda, there is an extensive classification of the different types of Vikaras.

Figure 8 Regulatory cycle of Siddha and Ayurveda



In this cycle, the Manas, the mind, is critical in making the intelligent decisions to select the right Karma, actions, into the Kosha, denoted by the large rectangle, containing the constitutive elements of the body: Vata, Pitta and Kapha. Based on the Karma, sent into the Kosha, the Vata, Pitta and Kapha elements are adjusted to output Karam-Phal. The Manas is critical to modulating Karma to achieve the desired Sankalpa.

In this cycle, the Manas require the *Indriyas* (or senses) of smell, taste, hearing, seeing and touch, to be aware of the current Karma-Phal and the Vikaras. Based on the difference between Sankalpa and the Karma-Phal, the Manas make changes to their Karma to adjust the Kosha, to move it away from a state of Vikriti back to its Prakriti, which are reflected in the Karma-Phal. The Manas send certain Karma into the Kosha such as varying the intake of certain food, going for a jog, meditating, etc. to affect the Vata, Pitta, Kapha elements of the Kosha, which result in different Karma-Phal. This process is a constant feedback process, where the Indriyas continually monitor the Karma-Phal and the Vikaras to make adjustments to their Karma, to achieve their Sankalpa.

5.5 Summary of the lingua franca of Siddha and Ayurveda

In summary, there are nine important elements, which reflect the core principles of Siddha and Ayurveda. These nine elements are summarised in Table 5.

Table 5 The nine elements of Siddha and Ayurveda

Element
Karma
Karma-Phal
Vata
Pitta
Kapha
Sankalpa
Manas
Indriyas
Vikaras

6 The Rosetta Stone

Standard histories place the origin of the use of control systems engineering concepts to Greece in the period 300 to 1 B.C. Such histories substantiate this origin by referring to the development of the water clock of Ktesibios, which used a float regulator that employed control systems engineering principles. Such histories are likely unaware of the development of Siddha and Ayurveda, which were founded on the principles of control systems engineering. This fact becomes self-evident when we juxtapose the terminology of modern control systems engineering, from Figure 5, with the lingua franca of Siddha and Ayurveda, from Figure 8.

This juxtaposition reveals a ‘Rosetta Stone’, as shown in Table 6, which demonstrates that the foundations of the systems biology of Siddha and Ayurveda are the same as the principles of control systems engineering. The Rosetta Stone in Table 6 interprets, for example, the terms Karma and Karma-Phal to input and output of an open loop system, respectively. Vata, Pitta and Kapha are the same as transport, conversion and storage, respectively, which are the critical elements of the system to be controlled. Sankalpa is the goal that one seeks to achieve. The Manas is the controller that receives feedback from the Indriyas, which are the sensor, to assess the current state of the system. Finally, the Vikaras are the disturbances that are always present, which test the efficacy of a closed loop system to regulate its input (or Karma) to achieve its particular goal (or Sankalpa).

Table 6 The Rosetta Stone of Siddha and Ayurveda

Control systems engineering	*Siddha and Ayurveda*
Input	Karma
Output	Karma-Phal
Transport	Vata
Conversion	Pitta
Storage	Kapha
Goal	Sankalpa
Controller	Manas
Sensor	Indriyas
Disturbances	Vikaras

7 Discussion

The systems biology of Siddha and Ayurveda provides two important features that today’s modern systems biology seeks to replicate:

1 holism

2 personalisation, within a framework of control systems engineering.

Siddha and Ayurveda developed a holistic understanding of existence from the immaterial to the whole human form, as expressed in its multi-layered systems architecture, illustrated in Figure 6. This holism provided a unified model of the whole, progressing from non-existence (Purusha) to material existence (Prakriti), leading to the materialisation of subtle energies (Gunas), which then transformed to more grosser forms of matter (the Panchabuthas), that gave rise to a constitutive model called the tri-Doshas. The tri-Doshas, made of Vata, Pitta and Kapha, were central to defining the constitution of the body (Kosha), an individual's Prakriti, which affected the tissues (Dhatus) as well as the Kosha's organs, senses and mind.

The systems biology of Siddha and Ayurveda recognised fundamentally that health and well-being had to be personalised, and that there was no 'magic bullet' solution, no one-size fits all. The concept of the individual Prakriti provides a mechanism to *personalise* care to find the right therapies that enable the individual to find an optimal state of health that may be very different for another individual. Moreover, there was a clear recognition that health was an on going and iterative process, where the individual needed to continually make refinements to their actions, based on sensory feedback from their environment and an intelligent assessment of the results of their actions.

As the Rosetta Stone reveals, the originators of Siddha and Ayurveda created an integrative framework that interconnected its nine concepts: Karma, Karma-Phal, Vata, Pitta, Kapha, Sankalpa, Manas, Indriyas, and Vikaras into a cohesive systems-based regulatory process, that enabled an individual or practitioner to use fundamental principles to manage health. Today, the western world refers to this same process as control systems engineering, conveyed simply in a different language: input, output, transport, conversion, storage, goal, controller, sensor and disturbances.

8 Conclusions

The Rosetta Stone revealed in this paper aims to foster integrative research and dialog among western researchers in systems biology, complementary and alternative medical professionals, and eastern practitioners of Siddha and Ayurveda, as well as Yoga, a branch of these two systems.

Today, in the West, systems biology is leading a paradigm shift to address the reductionism of the ailing modern healthcare system. In this effort, systems biology has recognised the need to create multi-layered systems of systems architecture that incorporates control systems engineering principles towards building a holistic, systems-based model of life that is personalised to the individual. Over 5,000 years ago, the developers of Siddha and Ayurveda, as the Rosetta Stone demonstrates, had already created a systems biology, which was multi-layered, holistic and personalised, and incorporated core principles from what we now refer to as principles of controls systems engineering. Modern systems biology has an opportunity to accelerate its development by embracing the systems of Siddha and Ayurveda, and use this Rosetta Stone as a bridge, to understand the rich knowledge of therapeutics, protocols and procedures, which exist in these systems of medicine, for not only cure, but also for prevention and well being.

For thousands of years in the East, and now growing in the West, practitioners of Siddha and Ayurveda as well as Yoga, are trained in the eastern tradition with the lingua franca of the words: 'Karma', 'Karma-Phal', 'Vata', 'Pitta', 'Kapha', 'Sankalpa', 'Manas', 'Indriyas' and 'Vikaras'. Many of the concepts behind these words are communicated in either a perfunctory, dilettante, or ironically reductionist manner or with little scientific understanding. This lack of understanding has created a barrier in communication of these concepts to the West's evidence-based research methodology, which rightly demands a logical scientific framework from which to comprehend these concepts. Eastern practitioners, themselves, can find value in this Rosetta Stone to comprehend and communicate the scientific foundations of Siddha and Ayurveda – an understanding, which has been lost over the ages.

The United States Fulbright Association funded the field research leading to the key breakthroughs in this paper. The interactions with medical doctors, engineers, scientists and holistic practitioners, who provided feedback to the systems health curriculum, taught at the Massachusetts Institute of Technology, the Chopra Center for Well Being, and online, were invaluable to the development of this paper.

To the best of the author's knowledge, this is the first exposition that presents the core principles of Siddha and Ayurveda in a cohesive manner and their direct relationship to the nine concepts of controls systems engineering. At a time when society is recognising the need for alternatives to the current healthcare system, this Rosetta Stone provides a much-needed gateway across east and west, ancient and modern, science and tradition, to illuminate the modern world to the scientific foundation of Siddha and Ayurveda.

Dedication

To Chinnathai, my grandmother, a farmer and healer, who inspired in me a love of medicine and a compelling desire to create a just world; and, to Paramahamsa Satyananda Saraswati, who taught me that life without principles means nothing.

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