Engineering the Human Mind and the External World

V. V. S. Sarma

विश्वं दर्पणदृश्यमाननगरीतुल्यं निजान्तर्गतं
पश्यन्नात्मनि मायया बहिरिवोद्भूतं यथा निद्रया ।
यः साक्षात्कुरुते प्रबोधसमये स्वात्मानमेवाद्वयं
तस्मै श्रीगुरुमूर्तये नम इदं श्रीदक्षिणामूर्तये ।।

The universe is like the reflection of a city seen in the mirror of one's own inner being. This witnessing of the external world is happening within the Atman through the power of maya (माया) as of a dream in sleep. This is experienced directly at the moment of spiritual awakening within the non-dual realization of one's own Atman. Salutations to Him, the inner Guru, who causes this illumination of awareness, who is personified as Dakshinamurti

Adi Sankaracarya

Cogito ergo sum (I think, therefore I am)   René Descartes

तत्त्वमसि (tat tvam asi, That you are)   Chandogya Upanishad

Context

It is more than three years since Dr. Baldev Raj invited me to write an article for the INAE e-Newsletter. His premise was that the experiences of people who spent their productive lives in the engineering profession or as educators might inspire today's young engineers and students to take the challenges of their chosen profession of creating smarter systems, organizations, structures, processes and artefacts in a complex, dynamic, uncertain and even hostile world. Dr. Purnendu Ghosh reminded me of this invitation some time back. His mention of the title of the forth coming INAE book series, THE MIND OF AN ENGINEER incorporating these essays intrigued me. Is the mind of an engineer different from the mind of any other human being? Does a decade of training spanning the period of one's BE, ME and PhD programs affect the way a person thinks and acts? What does his experience teach him? I felt that introspection is certainly going to be instructive. It is said *"mana eva manushyanam karanam bandha mokshayoh"* (मन एव मनुष्याणां कारणं बन्धमोक्षयोः). The

ultimate source of all human endeavours is the mind and the purpose of engineering education is to train one to play the role of the designer of artefacts supposed to achieve specified goals or to serve some contingent purpose in a particular environment, say home, market place, factory or battle field. My interest in Artificial intelligence, an endeavour to build systems displaying human-like intelligence, makes the quotes in the beginning become part and parcel of my ideas on engineering. Where does the mind begin and end? What is its capability and limitation? What is its relation to intellect, consciousness, knowledge, psyche, self and soul on one hand and brain on the other? These have been questions continuing to bother humans since ancient times and still await complete understanding of the people working in diverse fields such as neuroscience, computer science, psychology, philosophy and religion. Brain is a physical material entity described with terms such as the grey and white matter. What is the ontological status of mind? The Sanskrit terms "*padam*" (पदं = word) and "*padartha*, (पदार्थ = meaning, denotation, category, matter etc.)" summarize the issue.

Beginning of the journey

Earth has made more than 20000 revolutions since I joined the BE program in Electrical Technology in the EE section of the Power Engineering Department at the Indian Institute of Science (IISc) after my BSc from Andhra University (AU). I heard of two famous names connected with the IISc, before joining there; of legendary CV Raman and his protégé and the Institute's then director, S. Bhagavantham, who was to become the first SA to RM (GoI). Both of them were earlier associated with Visakhapatnam and AU. I had to choose between the M. Sc. (Nuclear Physics) program at AU or the BE at IISc. My cousin PR Rao who did his M.Sc. (Physics) at AU then working in Bangalore recommended IISc to me. I also preferred Bangalore to Visakhapatnam, though I had no clear idea about the scope of engineering and its relation with science, mathematics and the human. I realized much later that this confusion was universal and I strongly disagreed with one erudite director of the IISc, who declared in an editorial in a science journal that science and engineering were the two sides of the same coin. Engineering, like any other creative activity, is just a virtual reality (VR) (e1, refer to end notes) world view of our inner being, just like science, philosophy or literature. This article is my journey down the memory lane in the world of engineering education.

Engineering – An ancient art

The words engine, engineer and engineering are related to a qualifying adjective "ingenious", its Latin root being *ingenerare*, which means "to create." God, the Creator, is obviously the first, the eternal and the best engineer creating and recreating the worlds (*lokas*) and the evolving beings inhabiting these worlds. Sri Krishna succinctly defined activities such as engineering as Yoga in his Bhagavad Gita (BG 2.50) as "*yogah karmasu kausalam*" (योग: कर्मसु कौशलम्). Action performed with skill and dedication is Yoga. The appropriate mind-set for action can also be achieved through Yoga. No wonder, the IIT at Kharagpur adopted this as its

motto.   Yoga practice may be termed "control engineering" of human mind and consciousness and the very first sutra of Patanjali Yoga Sutras, says that Yoga stills the fluctuations of the conscious mind (*yogah cittavrtti nirodha*, योगश्चित्तवृत्तिनिरोधः) through techniques such as breath control. The relationship between body, breath, mind, knowledge and bliss is a well- discussed problem of Indian philosophy. According to Taittiriya Upanishad the soul is visualized within the body in the form of a miniature inch-man (अंगुष्ठमात्र पुरुषः) representing a soul (जीव) covered with five sheaths (कोशः) made of – food (अन्नं), breath (प्राणः), mind (मनस्), knowledge (विज्ञानं) and bliss (आनंदः) [e2].

God as creator is a transformation of an idea of creation (*samkalpa*, संकल्पः) arising of the attribute-less (*nirguna*, निर्गुण) Brahman dividing itself into Siva and Sakti or Purusha and Prakriti. This mutation is the starting point of creation. Theories of creation of *Darsana* literature involve a beginning, a transformation and an evolution, aptly described by Sanskrit terms such *Arambhavada* (आरंभवादः), *Parinamavada* (परिणामवादः) and *Vivartavada* (विवर्तवादः). God specifically as an engineer is represented in the Puranas by the divinity for architecture, Viswakarma (विश्वकर्मन्) and his Asura counterpart, Maya (मय:), the architect/engineer of the well-known palace Maya-Sabha in the Pandava Capital city, Indraprastha, identified with the modern city of Delhi in the Mahabharata. Asura Maya was also credited with the ancient Hindu Astronomy text "Surya Siddhanta" of Vedic Cosmology. Viswakarma was credited with many structures. He built the city of Lanka and the Pushpaka Vimana of Ravana in the Ramayana. Ancient civilizations (4000-1800 BCE) also boast of many civil engineering achievements. The Saraswati-Sindhu civilization, also known as the Harappan or the Indus valley civilization discovered in archaeological excavations is characterized by advanced town planning and water resources management applications. The sites such as Harappa (Punjab), Mohenjo-Daro (Sindh), Dholavira (Gujarat), Lothal (Gujarat) and Kalibangan (Rajasthan) are widespread in North West India up to Gandhara (modern Afghanistan) [1]. A recent (2007) paper in the Elsevier journal "Building and Environment" brings out elegantly the relationship between Hindu cosmology and the *vastu-purusha-mandala* (वास्तुपुरुषमंडल) in the 11th century Kandariya Mahadeva temple at Khajuraho, and explains the fractal geometry involved in the architectural design of the temple (Fig. 1) [2].

Fig 1 – Kandariya Mahadeva Temple, Khajuraho

The word "engine" in early English meant "to contrive". While military engineers worried about engines of war, the same principles are used by civil engineers (the term includes their mechanical, chemical, electrical, communication and aerospace counterparts) to design and operate the engineered artefacts in the service of the society. My own journey of half a century in engineering education was well within in the philosophical boundaries of civil and military engineering rather than in the development of a specific technology and its application in a single problem domain. In the Institute, my *alma mater* also, my own career as a teacher which commenced from the EE department (1967-73), went through ECE (1973-77) and settled in the School of Automation (now CSA) (1977-2012) and my 18 PhD students and 6 MSc (by research) students from time to time were drawn from CSA, ECE, Aerospace, Mathematics and Metallurgy departments and engineers from organizations such as IAF, NAL, ISRO, DRDO, BHEL under the external registration program. My working together with them closely was on defining, modelling, representing and solving problems arising in a specific context in a satisficing (meaning satisfy and suffice) manner. Teaching or research in my view is constant learning for the teacher even more than for the student.

From good, old fashioned Electrical Engineering to Cybernetics and Man-Machine Systems

After a colourful B Sc program, which gave us under the then new regulations, a strong dose of English literature, general education consisting of economics, history and politics along with science subjects, MP and C, the BE course appeared rather a dull, colourless, tasteless and out-dated affair. Among seemingly disconnected and assorted subjects such as applied

mathematics, applied mechanics, hydraulics, building construction, surveying, and machine tools in the first year, Electrical Circuit Theory was the only subject connected with the supposed main stream of study. While the Physics course of Electricity and Magnetism in BSc followed the historical route of electric charges, magnetometers, gold leaf electroscope, cells, solenoids and induction coils, Maxwell and Faraday, the EE course started with Ohm's and Kirchoff's laws, R, L, C circuits, voltage and current, both AC and DC. While the other courses generally followed British books, the lecturer of electrical engineering (who had an MS from Wisconsin) followed an American book, which had a better pedagogical approach. The lady, C. Lakshmibai, soon after earned the first Ph.D. awarded by the EE department of IISc. Even in our final year (1963-64) mostly vintage subjects such as electric traction, illumination, utilization, machines, wood pole and tower design and aspects of T&D of electric power were taught. Atkinson's Telephony and Gray's Electronics represented the electronics and communications part of the course. But changes were in the offing in the BE and ME programs of IISc by mid-sixties. The faculty of the department was much more research oriented than what the out dated BE program we went through, represented. The first head of EE, Alfred Hay's bridge circuit named after him and Yoganandam's method of current transformer testing (J of IEE, 1930) found their way into Golding's classic book on Electrical measurements in their time. From 1949 to late 1960s, the EE department's prized possession was an AC network analyser produced by GE. Before 1950, 30 such machines were in operation, 29 in USA and one at the IISc. All electricity boards in India simulated their power networks using it but this machine was out of bounds for students. The machine was a special-purpose analogue computer, used for power system analysis, power flow studies, short circuit calculations, and system stability studies till such machines were ultimately replaced by numerical solutions running on digital computers by 1980s. In 1958 IRE Transactions on Electronic computers published a paper on "A Novel Type of Isograph (Algebraic Equation Solver)" designed and built in the EE dept by P Venkata Rao and his student G Krishna, a special purpose analogue computer for accurate computation of roots of polynomials useful in analysing servomechanisms. Our own computing tool was a German made Aristo Studio slide rule.

By the time I joined ME (Power Systems) course in 1964, many visible changes have come into effect in the curriculum. Deekshatulu's PhD thesis in nonlinear control with many publications in Transactions AIEE (constituent of later IEEE) established that high quality research could be done in India itself. Srinath, a PhD from University of Illinois, taught us control theory. His use of Lee's book on Statistical Theory of Communication for the course on Advanced Control brought out the relation between Control and Communication. In ECE department Rideout and Rajaraman built a differential analyser and Ramakrishna studied relative efficiencies of Indian languages for Morse code. His mention of Panini's name made me curious. Names such as Wiener, Shannon, Bellman, Kalman, Nyquist, Pontryagin and Lyapunov became the new *Sapta Rishis* (Ursa Major, the Great Bear) on the control sky.

Components to Systems

From components such as motors, generators, transformers, towers and transmission lines we encountered in BE, the study of power system was a different ball game. A huge system of hundreds of generators spread over a vast geographical area and considerations such as load flow, load frequency control, stability and operational economics come into picture. The control and management problems get entangled. The problem of power system ever since had become major techno-management problem implying a fundamental reengineering of electric utility and service industry aimed at achieving a smart grid today. A smart grid is an evolving system which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, energy efficiency resources, electronic power conditioning, e-commerce and control of the production and distribution of electricity with high quality of service and dependability.

I realized that general systems, be they transmission, transportation, water resources or communication systems, they were all being studied using a single methodology. I joined as a PhD student working in control theory in 1966 under the supervision of Deekshatulu as a continuation of my ME project on power system control.

Deekshatulu asked me to work on Optimal Control Theory. Tou's book on Modern Control theory appeared just then with a chapter each on Calculus of Variations, Pontryagin's Maximum principle and Bellman's Dynamic Programming. They were like three formidable hills to be climbed and the literature looked like an intimidating forest. My guide had the stamina of a Bhagiratha to do exhaustive search on nonlinear control to come up with solvable problems with novel solutions to specific equations for his thesis but he himself was not much deeply involved in my topic. Luckily a text book on optimal control by Michael Athans from MIT appeared which evolved from his teaching of a course there. It contained many worked examples of optimal control and an exposition of the LQG (linear quadratic Gaussian) problem, showing that a linear control law derived from solving a Matrix Riccati equation as optimal with respect to energy-optimal quadratic criterion. With this work I was able to formulate some performance evaluation and sensitivity problems of optimal control. When the states are not measurable a state observer can be used to estimate the states from the input and output of the system. I was finding it difficult to conceive of some new problems. Thomas Kailath of Stanford was then spending his sabbatical year at the ECE dept of IISc. I attended his lectures on Wiener and Kalman filtering and on his advice I started work on stochastic optimal control and differential game problems and completed my thesis entitled "Some studies in optimal control with quadratic performance criteria". I did not like the title myself and I insisted my students that they should use titles that stress the main contribution of the thesis. Soon I had to find a problem and an approach for solving it for a research student who joined with me. I was awarded PhD degree in March 1971 and Mansoor Alam joined with me in Aug 1971 and I decided that I would give a well-defined problem to him for research rather than suggesting an area of work as in our time.

We had a nice system then working at the IISc library. All the new journals received in the week were displayed in a hall on Friday evening. It has become a habit to me, learnt from my guide, which continued for a long time, of spending few hours in the library at that hour browsing through the new journals. Till my PhD was over I was mostly referring to journals in Control theory such as IEEE Trans Automatic Control, International Journal of Control, Proc. IEE, J of Basic Engineering (ASME) and Automatica. After getting the degree, I was curious about the content of Management Science, Operations Research and other engineering and economics subjects. The terms control, manage and govern sounded similar to my ears. I located some papers dealing with machine maintenance, formulated and solved as optimal control problems, written by two American Professors from management schools at Carnegie Mellon and North-Western. The models were simple and the deterministic control theory they used was elementary. I was better equipped to use advanced control theory. I showed these papers to my student and told him that we can develop a unified theory, also taking into account the uncertainty in the system. We could formulate and solve the problem in a very short time. We wrote a paper and submitted the same to Management Science. The reply was prompt saying that our style of presentation was nearer to engineering than to management science and we were advised to submit the paper to an engineering journal. We sent it to the new IEEE Transactions on Systems, Man and Cybernetics. It was accepted as full paper in the first review. The model was generalized considerably soon using Markov and semi-Markov decision models and papers in IEEE transactions on SMC, Reliability, Automatic Control, International general of Systems Science followed. Alam submitted his thesis in July 1974 with more than 8 excellent publications. The work got him post-doctoral fellowships in UK and Canada in sequence and he is now a Professor and Chair of EECS in University of Toledo, OH, USA. In 1974 AK Rao of aerospace department saw the reports on this thesis in Senate proceedings and inquired me if our methods can be used to study the maintenance problems of aircraft. An air force engineer who completed his ME in Aeronautical Engineering would be able to register for PhD and we could bid for a DRDO (ARDB) project to support the work.

After hours of discussions with the student Ramchand (I should call them domain knowledge elicitation sessions now) on maintenance problems of IAF aircraft and after visits to the flying stations and repair depots, I had an emerging mental picture of the issues at hand. The availability of a small fleet of aircraft in a flying-base, repair-depot combination was modelled and studied. A cyclic queue model showed the effect of the principal uncertainties in operation and repair and the consequent decrease in the availability of aircraft at the flying-base. This was published in IEEE Reliability. Queuing models were not unfamiliar to me. We encountered them in design of automatic telephone exchanges and they were developed by a Danish telephone engineer Erlang much earlier. We had seen some applications of cyclic queues in a Civil Engineering journal in an application concerned with earth moving. We adopted that model for our study. The perennial problem of resource allocation for fleet and facility build up that faces planners was modelled and solved as an optimal control problem.

These models contain two "policy" variables representing investments in aircraft and maintenance/repair facilities. Interactions of major activities involved in air fleet operations, maintenance, and logistics were investigated in the framework of closed queuing networks with finite number of customers. An interesting by-product of this work is the use of spectrometric oil analysis program (SOAP) data from the Rolls Royce Gnome Engines of Westland Sea King helicopters of Indian Navy. I was told that Navy was sending SOAP data samples to London for engine maintenance decisions. We developed a decision theoretic model for health monitoring which was published in the AIAA Journal of Aircraft. Several papers in IEEE Transactions of SMC, Reliability and Simulation journals resulted from these studies. The reviewer of the thesis, Andrew Sage of Southern Methodist University (who was also the chief editor of the IEEE Trans SMC) wrote "the thesis was the best I had seen in recent years". The IAF officer later rose to be the Director of a DRDO laboratory, CABS (Centre for Air Borne Systems) and Mani, the project assistant subsequently became a Professor in Aerospace Engineering at IISc. My ideas on Systems Engineering as distinct from device technologies thus found their initial successes. Pedar from Electronics division of NAL joined for PhD and his lab director, SR Valluri, wanted him to work on aerospace electronics. We discovered that the trend was fly-by-wire (FBW) aircraft. FBW system replaces the conventional manual flight controls of an aircraft with an electronic interface. The movements of flight controls are converted to electronic signals transmitted by wires and flight control computers determine how to move the actuators at each control surface to provide the desired response. The FBW system also allows signals sent by the aircraft's computers to automatically perform control functions without the pilot's input, as in systems that automatically help stabilize the aircraft, or prevent unsafe operation of the aircraft outside of its performance envelope.

The aircraft computer is to be an ultra-reliability system and design of such Fault- tolerant systems was a special area in Computers on which IEEE transactions on computers was publishing special issues regularly. Pedar's work brought out the concept of phased mission analysis of aircraft flight and the architecture optimization of aerospace computer systems. The first paper from the study was published in IEEE Trans on Reliability and the second one was in IEEE Transactions on Computers. The later paper was republished by IEEE as a benchmark paper in the area of hard real-time systems. Pedar later spent some time in NASA labs as a guest scientist. Ramana from ISRO used queuing models for slotted ALOHA satellite channels. He then moved to INMARSAT (maritime satellite organization), London. His results appeared in Proc. IEE (London) and IEEE Trans AC. Ramanjaneyulu (Ram Chakka), who worked for his M.Sc (by research) with me, proposed a model for server unreliability in closed queuing networks. Breakdowns and repairs of servers, assumed to be time-dependent, are modelled using virtual customers and virtual servers in the system. The problem is thus converted into a closed queue with all reliable servers and pre-emptive resume priority centres. The results were published in IEEE reliability 1989. He later completed his Ph D in University of New Castle

UK and continued his excellent work in the same area and is a Professor of Computer Science, and Director of Research at MIET, Meerut now.

With my friends Viswanadham (IISc) and MG Singh of UMIST (UK) we completed a research monograph on "Reliability of Computer and Control Systems" published by North Holland in 1987. Viswanadham distinguished himself later as professor researching in Logistics and Manufacturing at ISB, Hyderabad and NUS, Singapore after voluntary retirement from IISc. Kanchana of CABS (DRDO) in the year 2000 did work on Software quality and dependability issues for the airborne surveillance platform. She used Taguchi methods of experiment design for software quality enhancement.

Move towards PR and AI

Deekshatulu, after his sabbatical at IBM Watson Centre and the Environmental Research Lab (formerly, Willow Run Lab) at the university of Michigan, brought back ideas on subjects such as pattern recognition (PR), picture processing and remote sensing and started courses on such subjects. Around 1976 Deekshatulu left IISc to become director of NRSA Hyderabad where he played a key role in the popularization of remote sensing technology in India.

In the meantime my association with ECE department opened new horizons and also introduced constraints. The mind-set in ECE was a frequency based division of the universe. I had begun to look at signals along with systems that communicate them. Audio, Radio and TV and Microwave along with Tube electronics and transistor electronics were the faculty groupings. Colleague and friend, Yegnanarayana's effort led to the development of an acoustics lab with anechoic and reverberation chambers. He is presently among our top-notch speech scientists now associated with BITS, Hyderabad after superannuation from IIT Madras and later at IIIT, Hyderabad. Speech signal processing and speech recognition were then being talked about. Atal, an alumnus of ECE, working in Bell Labs came out with the linear predicting coding of speech. Atal's LPC scheme was, in fact, the discrete form of Wiener filtering.

In ECE, I used to teach Statistical theory of communication and Detection, Estimation and Modulation. I was also the first to teach a digital signal processing (DSP) course in IISc. With my control background and familiarity with Z-transform in sampled data control systems, DST posed no problems. Speech signal interested me. Languages developed as speech and writing was a much later affair. The phoneme set (varnamala, वर्णमाला) of Sanskrit perfectly matches with the speech production system of a human being (the vocal tract). Speech can be used for a variety of PR problems. Henry Dante worked with me on Speaker recognition. With the limited facility of digitization of speech available on a HP Fourier analyser we demonstrated accurate speaker identification for a set of hundred speakers. The 1979 papers on "Automatic speaker identification for a large population" were published in Acustica and IEEE Trans on Acoustics, Speech and Signal Processing. A paper entitled "A pattern recognition model of

voice-based personal verification systems for forensic applications" appeared in IEEE SMC in 1980. I now see that ICICI bank and SBI are introducing "voice-banking" in India.

"Divide and conquer" was an age old problem solving paradigm, and it is considered a "weak" or "narrow" AI method. In stochastic control it takes the form of separation theorem. The estimation (or filtering) problem and the feedback control problem are solved separately. In PR the separation is between feature extraction and classification. In statistical PR with two classes, the classification problem is the binary hypothesis testing problem of statistics or the detection problem of communication. In medical diagnosis features or test results have associated costs and risks. My student Dattatreya looked at the problem of medical diagnosis as a hierarchical PR problem .and his work with deterministic costs was published in IEEE Trans on Pattern Analysis and Machine Intelligence. He extended it to stochastic costs in a Trans SMC paper. Dattatreya was a professor at University of Texas at Dallas for two decades and is now a principal scientist in MITRE Corporation, an exclusive Systems Engineering and IT consultant firm for the US government.   Bharathi Devi worked on Fuzzy pattern recognition and our IEEE Transactions SMC paper on "Fuzzy Clustering" was republished in a later benchmark paper volume

In 1983 I visited my Guru Maha Mahopadhyaya Dr. K. Sivananda Murty at Warangal, a well-known Vedic scholar and Yogi. His interpretation of Kathopanishad in the light of Yoga Sastra is my reference text for Hindu philosophical issues touched in this essay. He suggested that I should look at Artificial Intelligence (AI) as an area for my further research work. In 1984 I went on sabbatical leave to the Centre for Advanced Computer Studies, University of South-western Louisiana (USL, now University of Louisiana at Lafayette). I started to teach AI at USL. AI was also called MI (machine intelligence) and the term artificial (meaning made in imitation) seemed to convey a negative connotation. Designing machines exhibiting human-like intelligence and smartness was the goal here. We encounter the philosophical questions of the mind-body problem, human rationality, logic, information and knowledge and consciousness issues and AI has strong interfaces with philosophy and psychology. In psychology computers provided an analogy for the mind-brain system I realized that AI books talk only of Aristotle and Greek Logic. The much deeper Indian contributions to logic, language and human mind find inadequate mention in the Computer Science literature. Very few have heard of Akshapada Gautama of yore or more recent (12 -18 century CE) contributions of logicians of Mithila and Navadvipa such as Gangesa Upadhyaya and Raghunatha Tarka Siromani. While the Western logicians were still in the Aristotelian frame of mind, in Navadvipa (Nadia Dist, WB), the Navya Nyaya School of logic reached its peak. In modern times BK Matilal (Kolkata and Oxford), NS Ramanuja Tathachar (Tirupati) and P Sriramachandrudu (Hyderabad) excelled in Darsanas. At least I had the good fortune of meeting the latter two of them. While my thoughts were on the philosophy of AI, my students were working on engineering aspects of AI and incorporation of AI ideas in Systems design.

Computer scientists have already recognized the contributions of Sanskrit grammarians such as Panini, Patanjali and Bhartrhari to the study of generative grammars of languages. In computer science, BNF (Backus Normal Form or Backus–Naur Form) is one of the two main notation techniques for context-free grammars, often used to describe the syntax of languages used in computing, such as programming languages and drew inspiration from Sutras of Panini. Noam Chomsky undoubtedly derived inspiration from Panini. In fact there was some discussion in IEEE to name BNF as Panini-Backus form. This created in me an interest in Indian logic (nyaya, न्यायः and associated tarka, तर्कः) and its possible use in IT. My first encounter with India Logic was in an Encyclopaedia of Logic I saw it in the USL library and my first expository paper entitled "A survey of Indian Logic from the point of view of Computer Science" was in Sadhana (1994). A more recent one which touches Navya-Nyaya relations is in JNU's annual manual on Sanskrit Studies [4].

Computers and the Sciences of the Artificial

Cybernetics, which was defined as the science of control and communication in the animal and the machine by Norbert Wiener way back in 1948, later was defined by many variously as experimental epistemology concerned with the communication within an observer and between the observer and his environment (McCulloch) and science of effective organization (Stafford Beer) focussing on form, pattern, and metaphors of behaviours rather than on specific things. In the twentieth century the human being has become an integral part of the engineering system design. Human-Machine systems have become the order of the day. Design of an aircraft with a human pilot in the cockpit assisted by smart "phantom" flight crew makes the human being a subsystem rather than an external operator or the designer of the system. Mind, intellect and consciousness, the internal instruments (अन्तःकरण) of a human, in some form have to become a part of the engineered system as neuro-system models. Neuroscientists study how different neural circuits analyse sensory information, form perceptions of the external world, make decisions, and execute movements.

Over the last several decades, Cybernetics has evolved as a trans-disciplinary approach for studying self-organizing and regulatory systems. Today Cyber-Physical Systems consisting of collaborating computational elements controlling physical entities and systems are contemplated in areas as diverse as aerospace, automotive, chemical processes, civil infrastructure, energy, healthcare, manufacturing, transportation, entertainment, and consumer appliances. Social engineering and Political Engineering are meaningful terms for an engineer today. Easley and Kleinberg talk of reasoning methods in a highly connected society in their book "Networks, Crowds and Markets". Black money flows, money laundering, correlation of real estate business and general elections with cement factory production can all be modelled and studied using this basis. I wrote some introductory articles on these network topics in newspapers and magazines.

The term "artificial intelligence" was the brainchild of the Noble laureate (in Economics), Herbert Simon. In his classic work "The Sciences of the Artificial" [3] he observes "The world we live in today is much more human-made, or artificial, world than it is a natural world. Almost every element in our environment shows evidence of human artifice." He adds that a computer as part of a system makes it smart. This immediately raises the questions "Can machines think? Are they capable of rational behaviour? Do they display consciousness, sentience and conscience of some form?" The observation is that both the brain-mind system and the digital computer are information processing systems. At the first level, Simon introduces heuristic search, where brute force search is replaced by "search and reason" approach as a first thinking task solvable by computers in imitation of human intelligence. Simon observes that the most characteristic cognitive skill of human beings is the use of language. The key observation of Simon is "While the computer is embodied in hardware, its soul is a program." The similarity is that both work on symbol strings. A computer can provide a model for brain-mind system (an aspect of the mind-body problem) in specific intelligent tasks, such as playing games and solving puzzles. How far can "the emperor's new mind"(e3) go, or is it similar to "the emperor's new clothes"?

Our AI based work

I asked my student Sunil Noronha to look at project management problems from the point of view of AI. The project evaluation and review technique (PERT) is well known. Normally such planning work is done before the project and date of initiation and PDC are given. But if there are delays as usual in the completion of activities and costs, The PERT chart does not help in on-line monitoring. There are lot of uncertainties in the information and knowledge available when the project is initially planned. Noronha developed an intelligent decision support system using imprecise information and knowledge structures called project influence graphs combining the power of PERT networks, influence diagrams and Petri nets. Our 1991 survey paper in a special issue on AI in management with some new material in IEEE Transactions on Knowledge and Data Engineering entitled "Knowledge-based approaches for scheduling problems: A survey" was widely cited. Our joy knew no bounds when we saw the paper entitled "Artificial intelligence: where has it been, and where is it going?" by Herbert Simon, father of AI, in the same issue, preceding our paper. With an Iranian student, Mohsen Moshkenani, I did some interesting work on a less studied problem in expert systems. In his thesis "Knowledge teaching: An alternative strategy for knowledge-base (KB) development" we looked at the knowledge acquisition bottleneck in expert systems. In traditional systems a domain expert is constrained by the structures imposed by the knowledge engineer. In our scheme the computer is modelled as a student and the domain expert as a teacher with or without the intermediary of a knowledge engineer. All that can be expressed in a language by the teacher should find a place in the KB. We looked at dimensions of knowledge, knowledge types, whether knowledge is fully expressible in language, gaps and inconsistencies in knowledge, truth and its degrees and designed an interactive system for knowledge teaching where the domain expert is a teacher and the program a student. In retrospect, today I would

apply Indian logic for testing the veridicality (degree of truth) of proposition. AI can handle only belief systems. Truth is only tentative and is a matter of degree. Language is always ambiguous. Knowledge coexists with ignorance in any human being. Knowledge, which is a created product of the mind, is always specified in relation with awareness of human beings. A proposition in Plato's dialogues views "knowledge as justified true belief". If we consider the proposition "Sun rises in the East", it is true for an observer on the Earth. For a traveller in space it has no meaning. A proposition justified true on the basis of sensory perception also need not be absolutely true. Thus means of arriving at correct knowledge (प्रमाण), thing to be studied (प्रमेय) and doubt or uncertainty (संशयः) are the first three categories of Indian logic according to the first aphorism of Gautama. Thesis of N Srinivas (1996) dealt with uncertainty handling in KBS (Knowledge-Based Systems) and Mohanvelu proposed expert systems for frequency management in ISRO. Another student Suresh Babu from BHEL worked on PROLOG technology for temporal reasoning in relational databases

Vijay Rao from DRDO worked on quantitative software lifecycle modelling. An evolutionary process taking place in engineering systems is the shift from hardware to software and the role of software engineering is becoming more central. This shift represents a trend from a piece-meal vision of software development to a holistic, system-wide vision. The term "software crisis" of 1960's and 1970's was the observation that most software development projects end up with massive cost overruns and schedule delays. The growing complexity of software projects led to Waterfall, Spiral and other qualitative models to depict the software development lifecycle. We developed a generic, unified lifecycle model (ULM) integrating the product, process and project view of software development based on re-entrant lines, which are multi-class queueing networks. The techniques also included fuzzy and rough set concepts. Some of this work was recently published in 2014 Springer monograph on "Innovations in Intelligent Machines – 5 (Computational Intelligence in Control Systems Engineering (Ed: Valentina Balas)).

R Ravi's 2005 thesis is entitled "Intelligent Knowledge Based System for Hot Forging Process Design". Ravi worked with me and a physical metallurgist Y Prasad for his Ph D in CSA department on expert systems for metallurgy. In any bulk metal working process, designing the process for forging is strongly dependent on human expertise, intuition, and creativity, and is an iterative procedure involving extensive and time consuming experimental work. A logical choice for realizing such a complex system is a hybrid intelligent system, consisting of an intelligent knowledge-based expert system and artificial neural network models. Ravi's thesis implements such a system resulting in considerable lead time and cost reduction. Ravi is a Principal Research Scientist in Material Engineering at IISc now.

The last student who got PhD under my supervision in 2012 was Indra from ISTRAC/ISRO. Her thesis dealt with the architecture design of next generation smart satellites. Presently, most spacecraft are controlled from ground, which involves activities such as up-linking the daily operations schedule and monitoring the health parameters. Advanced space exploration

systems demand intelligent autonomous spacecraft, which exhibit goal-directed and adaptive behaviour. An autonomy framework is defined with a six level structure comprising of the following capabilities - reflex, awareness, self-regulation, self-healing, self-adaptation and self-evolution. The last mentioned three theses were really engineering applications of AI.

Post-Superannuation (2006 – 2016)

IISc and INAE supported me during 2006-2012 as honorary professor and distinguished professor respectively. I was able to study my favourite subject of interface between intelligent systems in engineering and Indian Philosophy. I have now greater appreciation of the four Darsanas: Samkhya, Yoga, Nyaya, Vaiseshika and some familiarity with Mimamsa and Vedanta. For exploring the limits of AI and smart systems on the one hand and for exploring the function of human mind in terms of thinking, memory, discrimination (viveka, विवेकः) , knowledge, ignorance (अविद्या), consciousness, self, Atman and Brahman (as defined by *satyam jnanam anantam brahma*, सत्यं ज्ञानं अनन्तं ब्रह्म). Indian philosophy has the potential of clarifying the scope of AI and its boundaries. One of hobbies in this period is writing articles for general public in Telugu and English on topics of Indian philosophy, history, and society for some magazines and newspapers. Smart technology today has tremendous influence on the society. The impact of social networks such as Twitter and Facebook is one such example.

Studies by engineers can influence subjects such as history. Evidence combination methods of AI can check and question the credibility of historical narratives, particularly in the context of Indian history, where evidence from multiple sources is to be combined to get credible narratives. A less credible alternative is presented as a historical fact, such as the so called Aryan Invasion of India. Arun Shourie, an economist by training, could rightly question Indian historiography as the title of his book indicates (e7).

Ethics for AI systems

Ethics involves systematizing and recommending concepts of right and wrong conduct of humans living in a civilized society. In earlier days when it was called moral philosophy, religion and culture used to provide guidelines for acceptable social behaviour for humans by prescribing do's and don'ts. As societies become industrialized and as high technology becomes part of human life, many new ethical problems arise which need to be addressed by system designers and regulatory authorities. In the modern world, humans are constrained to coexist with artificial entities created by law such as organizations, companies and regulators on one hand and technological entities such as robots, driver-less autonomous vehicles, drones and even ubiquitous entities such as smart phone and i-pads interlinked to an Internet of Things (IoT). Laws, Regulations and Ethics are not keeping pace with the rapidly emerging new technologies such as AI.

Few examples where AI appears are sufficient to note its spread and widespread usage: ubiquitous computing, smart phones, mobile apps, mobile internet, Big data, social networks, autonomous vehicles (AV) and near AV, drones, internet of things, clouds, cyber physical systems (robotics) and smart cities. The ethics of artificial intelligence is the part of the ethics of technology specific to robots and other artificially intelligent agents and beings. Each domain listed above raises its own ethical concerns. While all the areas listed above have in the background AI programs, Intelligent Agents, Knowledge Bases, smart materials and subsystems, the regulatory policy and ethics have to be considered domain- wise. For example, what happens when a self-driving car has a software failure and hits a pedestrian, or a drone's camera happens to capture images of persons in a private swimming pool or an autonomous robot injures or kills a human? Contemporary ethical concerns about social networking services are privacy, the ethics of identity and community, friendship and values, democracy, freedom of speech and cybercrime. Recent discussions with members of a study group of ITU=ATP forum are summarized in this report [5].

Inner hierarchical structure of mind

Human mind is defined in Western literature as the set of cognitive faculties that enable sentience, consciousness, perception, thinking, judgement, and memory. All these faculties constitute human intelligence. An intelligent engineering system on similar lines will have a perceptual system (sensors), a memory system, a processing system, a motor system (actuators), and so on. There is a need to consider knowledge and its representation. Is this knowledge trustworthy? There is a distinction between knowledge and belief and knowledge is the set of certified true beliefs. In view of the acceptability or otherwise of the certification process we may assume that AI deals with only belief systems. This is the view of Allen Newell in his paper "The Knowledge Level" (e4). There is a school which believes in brain-mind identity. Consciousness levels – Wake Up, Dream, Sleep, Anaesthesia and Coma consciousness are described with the body. Freud talked of id, conscious and subconscious levels. Jung distinguished between psyche and self. By psyche, he meant the totality of all psychic processes, conscious as well as unconscious. He defined self as a clearly demarcated functional complex that can best be described as a "personality".

Indian philosophy proposes a distinct inner hierarchical structure in the mind. At the lowest level mind (manas, मनस्) is felt only when there is thought. Mind manifests as thought. Thoughts arise when the sense organs make contact with the sense-objects. This contact is reported to the intellect (buddhi, बुद्धिः). Intellect consists in the use of discretion or discrimination taking place on the basis of past experiences known as memory (smriti, स्मृतिः). Memory spans everything in the past extending from the previous instant to remote past extending even to previous lives. Intellect projects its judgment or decision on to the consciousness (citta, चित्त) which is an impersonal non-discriminating reflector like a mirror. It is citta that propels the person (in fact, the core inner actor characterizing him) to action, right

or wrong (karma, कर्मन्). It is this action (karma) which binds the actor or the doer to its chain of consequences. It is the actor that is called ego (ahamkara, अहङ्कार) or self (jiva, जीव). If citta through spiritual practice stops reflecting the intellect and is turned towards the ego, jiva becomes free of the separating consciousness and the jivatva is lost and the identifying tendency with respect to the body is lost. This is self-realization or being God (tat tvam asi). In the quote "I think, therefore I am" the first I is manas and buddhi and the second I is ego. In short, in the terminology of intelligent agents "the mind (manas) is the servant, buddhi is the reporter, citta is the observer and the ahamkara is the actor or owner. Indian logic is the logic of relations and the location-located relation is an important one. In this terminology, consciousness is the location of ego, which is what "I am conscious that I exist" means. This explanation clarifies the notion of mind considerably (e5). Stephen Phillips presented a paper on "The Mind-Body Problem in Three Indian Philosophies, Sankara's Advaita Vedanta, Gangesa's Navya Nyaya, and Aurobindo's Theistic Monism" at IIT Khargapur in 2002 and there is need for exploring this by AI researchers in India (e6).

Concluding Remark

It is true that the smartness of machines is increasing at a high rate. Can a machine be ever made to reach the intelligence level of "the man who knew infinity"? Can quantum computers model brain functions or mental activities? Can "strong AI" (a machine with consciousness, sentience and mind) or "artificial general intelligence" (a machine with the ability to apply intelligence to any problem, rather than just one specific problem) realized in the near future. Probably the new generation researchers think about such things. A mental picture or thought is the specification of a future artefact. As it happens engineering always falls short of perfection and science always false short of truth.

References

[1] R P Kulkarni – Development of Engineering and Technology in India from 1000 BC to 1000 AD as revealed in Raja Tarangini –Indian Journal of History of Science, 22 (4), pp 316-327 (1987)

[2] Iasef Md Rian, Jin-Ho Park, Hyung Uk Ahn, of the Department of Architecture, Inha University, South Korea and Dongkuk Chang of Department of Architecture, Chosun University, South Korea, "Fractal geometry as the synthesis of Hindu cosmology in Kandariya Mahadev temple, Khajuraho", Building and Environment (Elsevier) 42 (2007) 4093–4107

[3] Herbert A. Simon, The Sciences of the Artificial, Third edition, The MIT Press, 1996

[4] V. V. S. Sarma and Kalyani Gopal, Indian Logic (Nyaya) in Modern Information Technology, in Kapil Kapur, ed, Sanskrit Studies, Vol. 1, Samvat 2061-62 (ce 2004-2005), Special Centre for Sanskrit Studies, JNU, New Delhi and D K. Print World, New Delhi

[5] V V. S. Sarma , Policy and Ethical Issues related to Smart Systems in diverse domains, (Lecture Notes, Indian Institute of Science, 2016)

End notes

(e1) Virtual Reality (VR), is multimedia experience of computer-simulated life projecting an environment that simulates physical presence in places in the real world or imagined worlds and lets the user interact in that world. Virtual reality artificially creates sensory experiences, which can include sight, hearing, touch, smell, and taste. Acarya Sankara says that the so called the ephemeral real world is also such an illusory vision of human consciousness.

(e2) Sivananda Murty, in his classic work "Katha Yoga", (Aditya Prakashan, New Delhi, 2009) gives an interpretation of Kathopanishad from the point of view of yoga. He explains the 5 sheaths of the inner man (the self) of anna, prana, manas, vijnana and ananda .

(e3) The Emperor's New Mind: Concerning Computers, Minds and The Laws of Physics is a 1990 book by mathematical physicist Sir Roger Penrose. Penrose argues that human consciousness is non-algorithmic, and thus is not capable of being modelled by a conventional Turing machine-type of digital computer. Penrose hypothesizes that quantum mechanics plays an essential role in the understanding of human consciousness. This makes it closer to the Jaina logic of syadvada.

(e4) Allen Newell was among the pioneers of AI at CMU along with Herb Simon. This is from discussion in "Philosophical frameworks for understanding Information systems", 2007, IGI Publishing, Hershey, New York, (Ed) Andrew Basten, on Allen Newell's paper on The Knowledge Level.

(e5) From unpublished lecture notes of MM K. Sivananda Murty

(e6) Infinity Foundation of Rajeev Malhotra was one of the sponsors of the International Multi-disciplinary Conference on Mind and Consciousness during January 9-11, 2002, IIT Kharagpur and on his initiative Stephen Philips, professor of philosophy at U Texas, Austin presented this paper. Philips studied Navya Nyaya with Ramanuja Tatacharya of Rashtriya Sanskrita Vidya Peeth, Tirupati.

(e7) Arun Shourie, 1998, Eminent Historians: Their Techniques, Their Line, Their Fraud