Understanding the Dynamics of Socio-Technical Transition: A Multi-Level Analysis of Computers Technology Evolution

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Abstract: This article primarily investigates transitions at the level of societal functions especially in terms of technology for communication as computers and as the societal functions are fulfilled by socio-technical systems, which consist of a cluster of aligned elements To understand how transitions from one socio-technical system to another system, which describes a conceptual multi-level perspective working at three levels as technological niches, socio-technical landscape and sociotechnical regime. Here an attempt is made to analyze the evolution of computers technology which is defined in terms of computing as whole and also in Indian context at multi-level as socio-technical transition based on secondary data.

Keywords: Computer Technology. Landscape, Multi-Level perspective, Niches, Socio- Technical Transition and Technological Regime.

I. INTRODUCTION

This paper basically deals at the level of societal functions transitions such as transportation, communication, housing, health care, supply of resources and supply of energy, and for this technology becomes important and because of which it plays an important role in fulfilling of societal functions needs. As Hughes coined the metaphor of a 'seamless web' [2] to indicate how physical artifacts, organizations, natural resources, scientific elements and legislative artifacts are combined in order to achieve functionalities. While working from socio-technical point of view, this article understands societal functions to be fulfilled by socio-technical systems. So, here an attempt is made to understand the evolution of computers as whole and then in Indian context in terms of Socio-technical Transition (STT) as Multi-Level Perspective (MLP).

The whole of the paper is divided in various sections as section I, a brief introduction followed by some history in section II, then multi-level analysis of computer technology evolution based on secondary data in section III, after that section IV deals findings on basis of secondary and also as in one piece and at last there is conclusion as section V.

II. BACKGROUND ANALYSIS

The background analysis is started with the concept of socio-technical system, from which socio-technical transition emerges and followed by its the multi-level perspective.

Socio-technical System: The term socio-technical was introduced by the Tavistock Institute in the 1950's for manufacturing cases where the needs of technology confronted those of local communities, for example, longwall mining in English coalmines. Social and technical were seen as separate side-by-side systems which needed to interact positively, for example, a village near a nuclear plant is a social system (with social needs) besides a technical system (with technical needs). The sociotechnical view later developed into a call for ethical computer use by supporters like Mumford [6], [7], [17], [18]. In the modern holistic view, the sociotechnical system (STS) is the whole system, not as one of two side-by-side systems. And hence Socio-technical systems [said to be] consist of a cluster of elements, including technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and supply networks [3], [5], [7].

The socio-technical system division is shown in figure 1 as physical, information, personal and group and when combined in pair there is socio-technical system which has interaction of hardware to software, then human computer interface. And when all these combined then there is gap created called socio-technical gap [15], [19], [23].

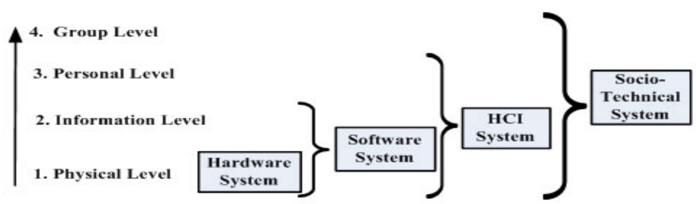

Fig. 1 Socio-technical system levels

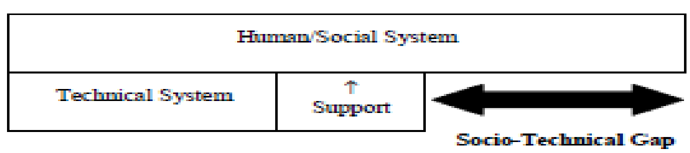

Fig. 2 Socio-technical gap

In Socio-technical Transition (STT), the Technological Transitions (TT) are defined as major technological transformations in the way societal functions such as transportation, communication, housing, feeding, are fulfilled. TT does not only involve technological changes, but also changes in elements such as user practices, regulation, industrial networks, infrastructure, and symbolic meaning. An example is the transition in offices from punched card technology and small office technology to digital computers, 1930–1960 [16], [18], [20].

Multi Level Perspective of socio-technical transition: This briefly outlines the multi-level perspective on transitions, which start with the elucidation of difference between three conceptual levels: niche, socio-technical regime, socio-technical landscape. The basic ontology behind this perspective stems from the sociology of technology, where three interrelated dimensions are important: (i) socio-technical systems, i.e. the tangible elements needed for fulfill societal functions, (ii) social groups who maintain and reproduce the elements and linkages of socio-technical systems, (iii) rules (understood as regimes) that guide and orient activities of actors and social groups. Here rules basically referred to regimes as Nelson and Winter coined the term ‘technological regimes’, which referred to the cognitive routines (e.g. search heuristics) that are shared in a community of engineers and guide engineers in their R&D activities [1], [4], [5], [9].

The socio-technical regime forms the meso-level in the multi-level perspective (MLP). Through providing orientation and coordination to the activities of relevant social groups, socio-technical regimes account for the stability of existing socio-technical systems. It has got seven dimensions as technology, policy, user practices and application, symbolic meaning of technology, industry structure, infrastructure and techno scientific knowledge. Because of the stabilizing mechanisms, it is difficult to create radical innovations within socio-technical systems. So how do radical innovations emerge? Scholars in sociology of technology and evolutionary economics have highlighted the importance of niches as the locus of radical innovations. Because the performance of radical innovations is initially low, they cannot immediately compete on mainstream markets in the regime. **Niches** act as ‘incubation rooms’ for radical innovations, nurturing their early development. This is refer as micro level of MLP.

The macro-level in the MLP is formed by **the socio-technical landscape**, which refers to aspects of the wider exogenous environment that affect sociotechnical development. The metaphor ‘landscape’ is used because of the literal connotation of ‘hardness’ and to include the material aspect of society, e.g. the material and spatial arrangements of cities, highways and electricity infrastructures. These all things can be seen in figure 3 [1], [4], [5].

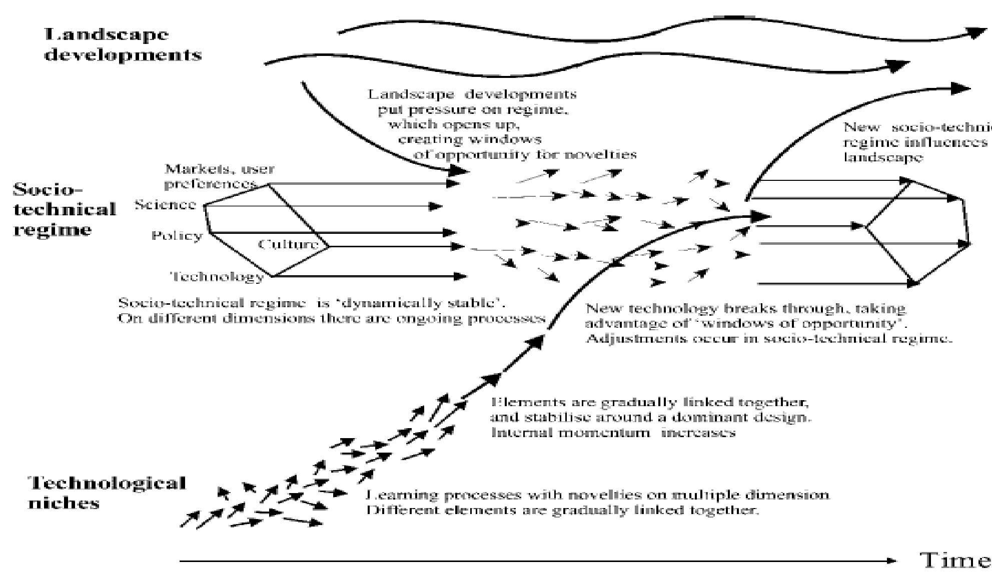

Figure 3. Multi-level perspective (MLP) on socio-technical transitions

Source: Geels (2002)

III. ANALYZING COMPUTER TECHNOLOGY EVOLUTION

This section is divided into two parts, where first part discusses on computer technology evolution as a whole and other section is of how this takes in Indian context which shows how the technological transition is taking place and the term society is mutually correlated with it and fulfilling their needs [11-14].

Computer Technology Evolution: Looking at computer technology evolution at multi-level there are different phases which starts from the Mechanical Era and then six generations each of which was marked by critical conceptual advances.

The Mechanical Era (1623-1945): The idea of using machines to solve mathematical problems can be traced at least as far back as the early 17th century, to mathematicians who designed and implemented calculators that were capable of addition, subtraction, multiplication, and division. Among the earliest of these was Gottfried Wilhelm Leibniz (1646-1716), German philosopher and co-founder (with Newton) of the calculus. Leibniz proposed the idea that mechanical calculators (as opposed to humans doing arithmetic) would function fastest and most accurately using a base-two, that is, binary system. Leibniz actually built a digital calculator and presented it to the scientific authorities in Paris and London in 1673.

Then, the first multi-purpose, i.e. programmable, computing device was probably Charles Babbage's Difference Engine, which was begun in 1823 but never completed. A more ambitious machine was the Analytical Engine. It was designed in 1842, but unfortunately it also was only partially completed by Babbage.

First Generation Electronic Computers (1937--1953): Three machines have been promoted at various times as the first electronic computers. These machines used electronic switches, in the form of vacuum tubes, instead of electromechanical relays. At that time Electronic components had one major benefit, however: they could "open" and "close" about 1,000 times faster than mechanical switches. A second early electronic machine was Colossus, designed by Alan Turing for the British military in 1943.This machine played an important role in breaking codes used by the German army in World War II. Turing's main contribution to the field of computer science was the idea of the "Turing machine," a mathematical formalism, indebted to George Boole, concerning computable functions. And the first general purpose programmable electronic computer was the Electronic Numerical Integrator and Computer (ENIAC), built by J. Presper Eckert and John V. Mauchly at the University of Pennsylvania.

Second Generation (1954--1962): The second generation saw several important developments at all levels of computer system design, from the technology used to build the basic circuits to the programming languages used to write scientific applications. Here the memory technology was based on magnetic cores which could be accessed in random order, as opposed to mercury delay lines, in which data was stored as an acoustic wave that passed sequentially through the medium and could be accessed only when the data moved by the I/O interface. During this second generation many high level programming languages were introduced, including FORTRAN (1956), ALGOL (1958), and COBOL (1959). Important commercial machines of this era include the IBM 704 and its successors, the 709 and 7094. The latter introduced I/O processors for better throughput between I/O devices and main memory.

Third Generation (1963--1972): The third generation brought huge gains in computational power. Innovations in this era include the use of integrated circuits, or ICs (semiconductor devices with several transistors built into one physical component), semiconductor memories starting to be used instead of magnetic cores, microprogramming as a technique for efficiently designing complex processors, the coming of age of pipelining and other forms of 3 parallel processing, and the introduction of operating systems and time-sharing.

Fourth Generation (1972--1984): The next generation of computer systems saw the use of large scale integration (LSI -- 1000 devices per chip) and very large scale integration (VLSI -- 100,000 devices per chip) in the construction of computing elements. At this scale entire processors will fit onto a single chip, and for simple systems the entire computer (processor, main memory, and I/O controllers) can fit on one chip. Gate delays dropped to about 1ns per gate. And the two important events marked: the development of the C programming language and the UNIX operating system, both at Bell Labs. In 1972, Dennis Ritchie, seeking to meet the design goals of CPL and generalize Thompson's B, developed the C language.

Fifth Generation (1984--1990): The development of this generation of computer systems is characterized mainly by the acceptance of parallel processing. The fifth generation saw the introduction of machines with hundreds of processors that could all be working on different parts of a single program. The scale of integration in semiconductors continued at an incredible pace --- by 1990 it was possible to build chips with a million components --- and semiconductor memories became standard on all computers.

Sixth Generation (1990-- Future): Many of the developments in computer systems since 1990 reflect gradual improvements over established systems, and thus it is hard to claim they represent a transition to a new "generation", but other developments will prove to be significant changes. One of the most dramatic changes in the sixth generation will be the explosive growth of wide area networking. Network bandwidth has expanded tremendously in the last few years and will continue to improve for the next several years. And even in forms of high speed robots, glasses and many more which can’t be imagined.

Technological transition, the way it is taking can be seen from figure 4, 5 and 6 respectively which shows technological change from on technical system to another one and the way other parameters such as language used, computer production, management, rules and regulation, followed by the societal group even too is actually getting transformed at each technological transition [11], [21].

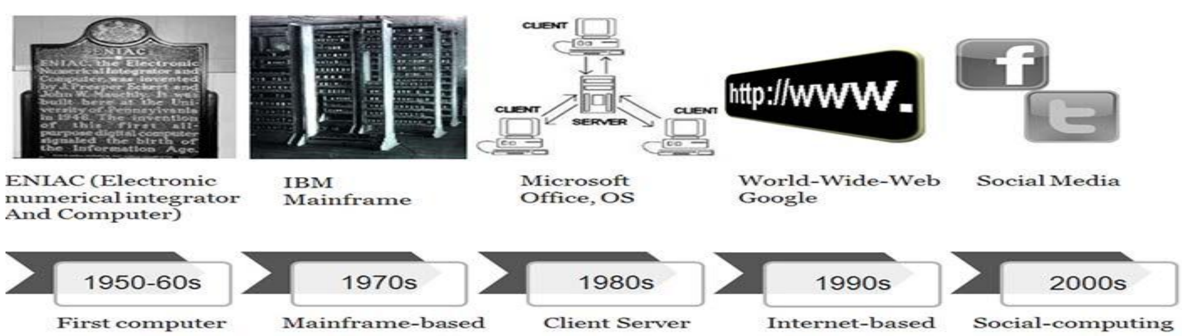

Fig. 4 The computing evolution (in computer technology)

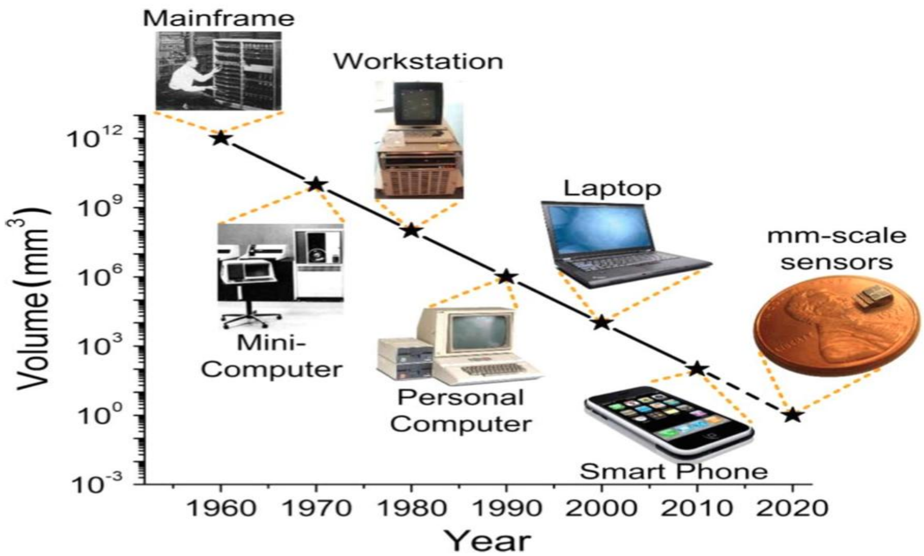

Fig. 5 Generations of Computers technology

Source: http://www.computerhistory.org/atchm/the-worlds-smallest-computer/

As from the computer technology evolution it can be observed that there is technological transition and this transition actually also leads to development of various computers which are defined in terms of generation and each has it own technology, languages and products, this all has been shown in tabular form as showing comparison of various generation and also in figure 6 [22].

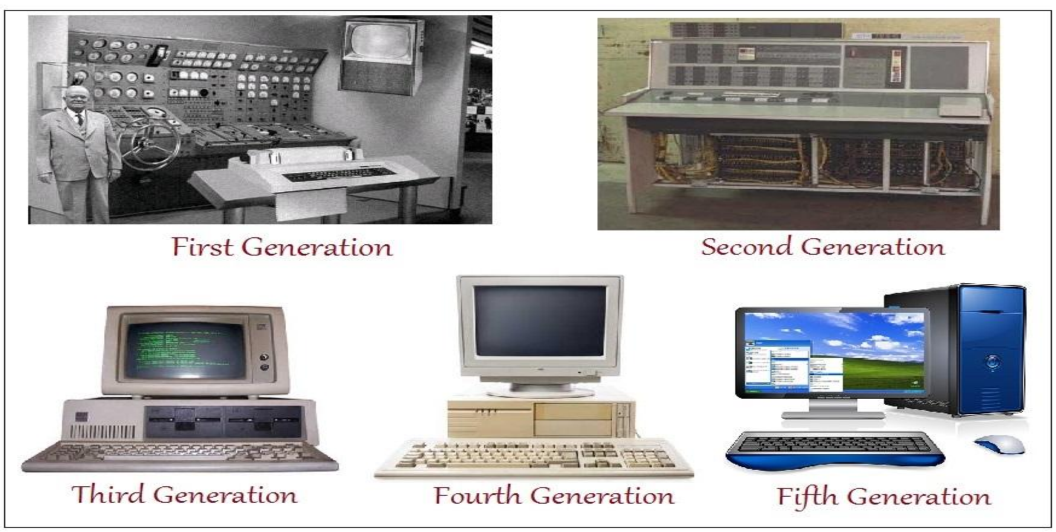

Fig. 6 Generations of Computers

*Source:*https://ibb-bankingdiploma.blogspot.in/2015/06/computer-generation-limitation-and.html

TABLE I
COMPUTER GENERATION COMPARISON

Generation	Year	Main Component	Language Used	Examples
First	1945-1955	Vacuum Tubes	1) Machine Language 2) Assembly Language	1) Electronic Delay Storage Automatic Computer (EDSAC) 2) Electronic Discrete Variable Automatic Computer (EDVAC) 3) Electronic Numerical Integrator And Calculator (ENIAC) 4) Mark-I
Second	1955-1964	Transistors	BASIC, COBOL, ALGOL, FORTRAN etc.	IBM-1401, IBM-1620, IBM-7000, NCR-304 etc.
Third	1965-1975	IC (LSI)	New FORTRAN, New COBOL, PASCAL.	IBM 360, IBM 370, ICL 2900, CDC 1700 etc.
Fourth	1975-1990	IC (VLSI)	C, C++, SQL, Word etc.	DEC-10, IBM-4341, PRP-II , APPLE-II etc.
Fifth	1990- till today	Biochip/ Nano chips	MS Office , Java etc.	Desktop, Laptop, Notebook, Ultra Book, Chrome Book

So here it can be seen that there is focus on high speed, large data manipulation, interfacing of computer and humans, so that society can be benefited from that. This study tries to highlight the ‘inside out’ approach, and the coalition and struggle between social groups (as companies in mechanical era, vacuum tubes companies, IC manufactures, policy makers, local residents, markets representative, and various computer clubs) and even at different computer system levels as shown figure 7[11].

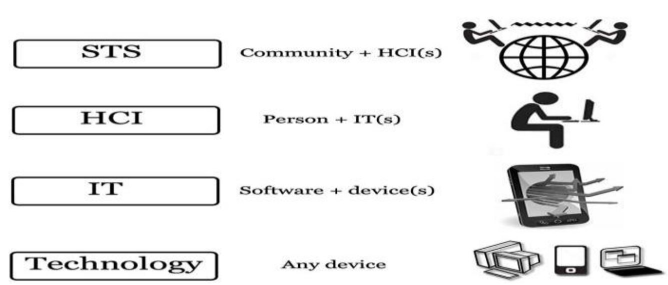

Fig. 7 Computer system levels

This can be seen starting from mechanical era where the idea of using machines was to solve mathematical problems addition, subtraction, multiplication, and division but as time progresses it can be seen from (1935- till today), how the computers evolve with the help of vacuum tubes to the robots computer, followed by mmsenors today, the language related to that too got develop and changes as per user requirement with the skill of various researchers and now we have various R&D centers all over the world.

Computer in India: The age of computer was began in 1955 with the installation of HEC-2M (a computer designed by A.D.Booth in England) at the Indian Statistical Institute (ISI) at Calcutta (now Kolkata) in India. And at that time only a few dozen scientists and engineers knew about computers, while in 2010 over 2.4 million people employed in computer related jobs and over 60 million Personal Computers were in use and today this number has increased tremendously. Even Information Technology which depends on computers has its contribution to GDP of India and IT services became the fastest growing segment among export industries and today it expands three times more and become one of the biggest outsourcing industry of the world [10].

There are some periods in India too where it can be seen how the transition has take taken place and based on that various reform and developments takes place; as the period 1955 to 1970 saw the beginning of the use of computers in India, then period 1970 to 1978 saw a slow controlled growth of computing in India. During this period the political class had genuine doubts whether computer technology was relevant for a poor developing country. The period 1978 to 1990 saw the emergence of a local computer manufacturing industry in the private sector and the gradual loosening of government control over the computer industry. The period 1991 to 1997 saw "economic liberalization" in India which abolished tight government controls in a number of areas that encouraged the private IT entrepreneurs to innovate [10]. And today is the Digital Transformation age.

If taking about activities there were various activities as in 1970 DoE (Department of Electronics) formed which established which take initiates as established the National Centre for Software Development and Computing Techniques (NCSDCT) at TIFR, Mumbai in 1972, followed by in 1975 the DoE set up the National Informatics Centre (NIC) whose main purpose was to assist in e-governance initiatives of the central and state governments. And in 1974, recognizing the potential of software export DoE allowed import of computers exclusively meant for software export. Then there was the establishment of Regional Computer Centres (RCCs) with main Frames, followed by Establishing the Computer Maintenance Corporation (CMC).

What we see today a different scenario, the computers are deeply rooted in India, almost every sector as they are used in educational institutes, in government offices, even banking system has also upgraded. So it can be said that that tech ology transition in India can also be seen at all levels, that means if MLP analysis is done the India computers, at technological niche take example of PARAM computer, a radical innovation in India and has been exported to many parts of the world, and may other development as lot of R&D is going on, many innovators and inventors are working on it. At socio-technical regime all the seven dimensions (technology, policy, user practices and application, symbolic meaning of technology, infrastructure, industry structure and techno scientific knowledge) hast got changed and developed according to time and development. And at socio-technical landscape, it can be seen how this technology is deeply rooted and even shapes, or modify according to use.

IV. FNDINGS

While doing analysis it was found that during the whole the computer technology evolution (even as whole and/or in context to India) basically follows de-alignment and re-alignment of transition pathway, where it can be observed that the elements in the socio-technical regime de-align early, because of internal tensions and pressure from the landscape level, followed by the sense that, the instability of the regime which creates space for the emergence and development of different niches and innovations. When these promise solutions to the regime and Socio-technical elements are re-aligned around this option, leading to a new socio-technical regime [4].

The other thing also found that there is not only technological transition but this lead to creation of different disciplines as shown in figure 8 and later on in today's scenario this can be seen as flower, which has different cross leaflets and this lead to cross disciplinary nature of computer technology which has found its application in various subjects as shown in figure 9 [11].

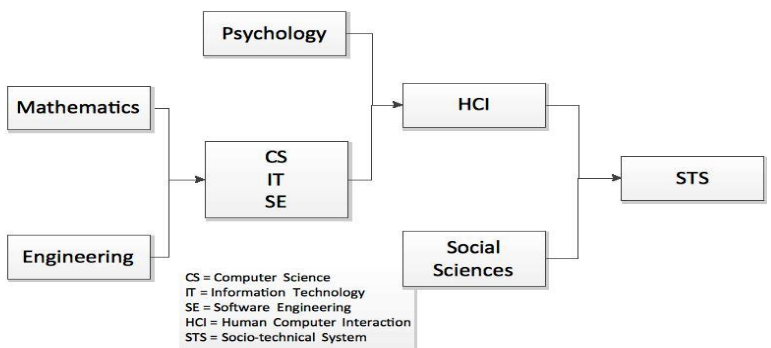

Fig. 8 Different Computing disciplines

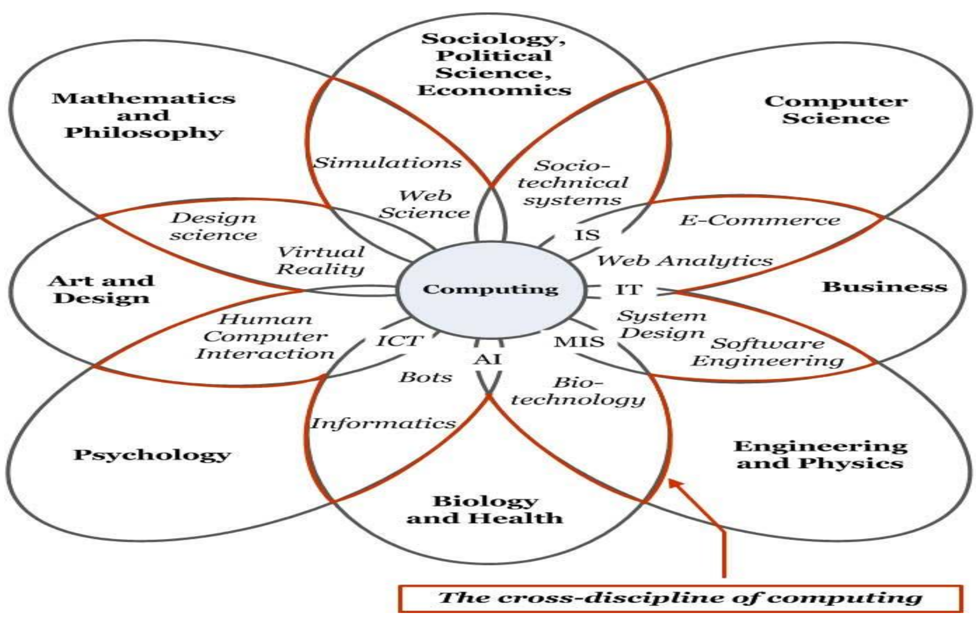

Fig. 9 The flower of computing

Another thing also found that in technological transition there are various levels which create their requirements as shown in figure 10, where it can be seen how the higher level and lover levels are interacted and interdependent as there is an direct impact of higher level on lower level for improving performance based on groups, society, consumers and other parameters [11]. Also interesting thing to be note here is the social level is open ended, as social groups form higher social groups (as physical society (means families; tribes; city; state; nations; and nations of nations, each with more social structures complexity).

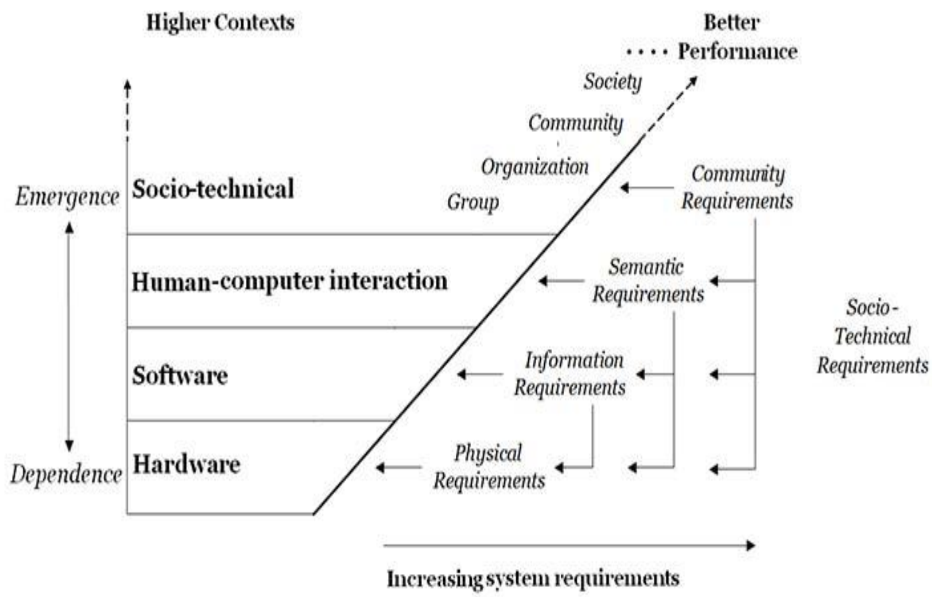

Fig.10 Computing requirements cumulate

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Overall finding of socio-technical transition at multi-level can be seen in figure 11, defined in terms of industries HCL, SAMSUNG, APPLE, ACER and many more, followed by their repair centers, production units in all parts of world; Rules and regulations as Intellectual Property Rights, Software Policy 2016 and so on, then on market and user preference it could also be seen where it can be seen that; followed by Cultural and symbolic meaning it could be seen as student, businessman, corporate etc. with their meanings; then Regime, which is very important in terms of understanding the whole of the computer evolution phase by phase and because of which a stable regime is achieved as technological landscape has also pressure on it and the niches, which can be recognize in terms of radical innovation (that is happening more frequently as it got some opportunity is gets life and develops on its specifications); then technological niches, it could be comprehend in terms of invention of vacuums tubes as radical innovation, use of magnetic cores as memory elements, then ICs, followed by semiconductors, then nanotechnology and in future no one can imagine. And same transition can be seen from one phase to another while with the existing technologies, and while talking of landscape it can seen use of computers as part of it as in schools, universities, companies, governments, even in wars, and daily life etc. that is how various actors and social groups are in use of this technology.

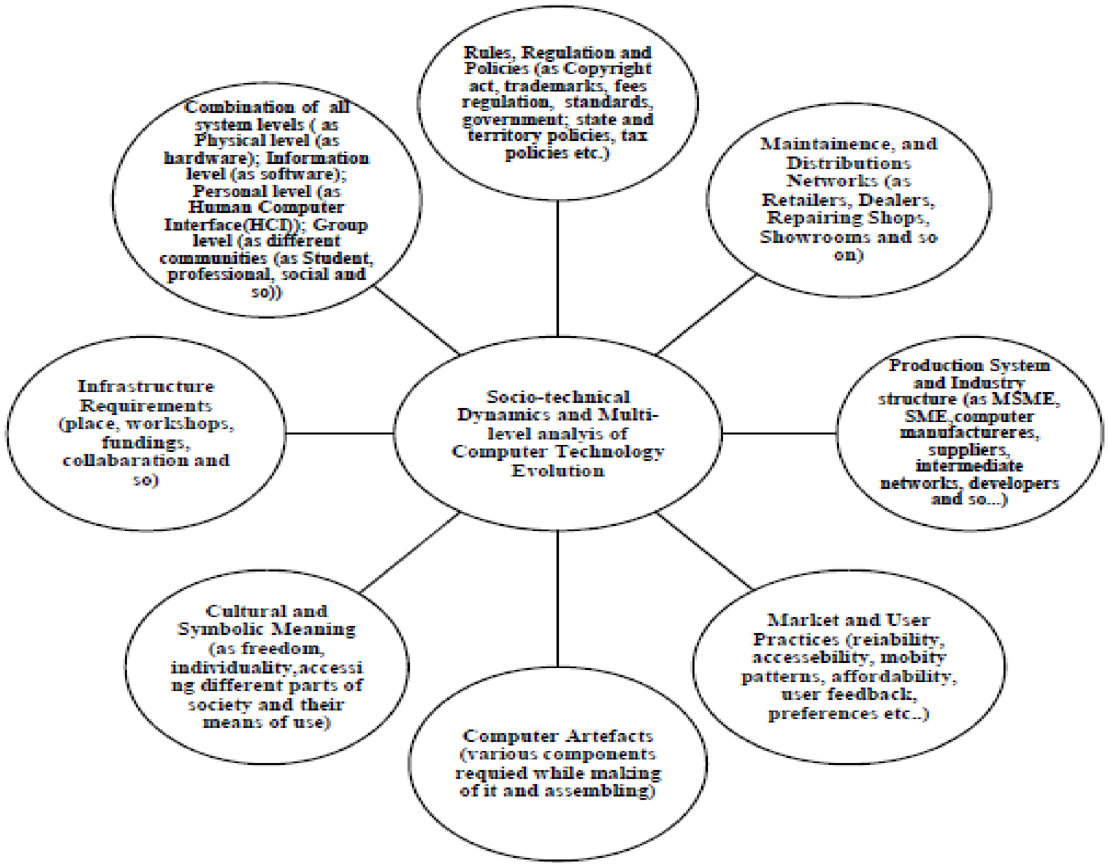

Fig. 11 Socio-Technical Regime for Computer Technology evolution (from Basic to Modern system)

V. Conclusion

Socio-technical transition in multi-level aspects offers a nuanced multi-dimensional framework, which helps in understanding that during transitions in computer technology evolution, innovation transition is also taking place that is not just in one by one that is sequentially but it is taking place in parallel way also in terms of interaction of various technologies. Here parallel interaction refers to positive feedback between various existing technologies while serial interaction refers to relationships between technologies which follow each other over period of time. As there are more transition pathways than head-on economic competition (substitution). And also the alignment in terms of the concept of re-alignment and de-alignment leads to new regime and such pathways provides some ways for future to understand various other technologies. The most important point here is that there is good scope for further investigation in terms of interactions between technology, markets, politics, culture, and infrastructure; so that this can benefit the society in terms societal functional need and also technological needs as both of them has to complement each other and sustainable development can take place.

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