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Information & Communication Technologies

Coordination and Support Action

EU-India Fostering COOPeration in Computing Systems

D2.2: Preliminary Research Roadmap

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Executive Summary

The Indian government's announcement to invest in petascale and exascale computing is an outcome of its realization of the country's need for high performance computing (HPC) facilities. With the developed and emerging economies investing huge sums of public money into HPC infrastructure, India has taken to the competitive race. With many new markets that exploit HPC, responding to the emerging need is imperative from an Indian perspective. It is now widely understood that the demand for high computing power is coming from almost all major sectors, from government to individuals, from scientific applications to small businesses; from climate modelling to energy exploratory missions, HPC plays a major role in every sphere of our lives. With HPC holding so much promise to all communities, the Indian government's view is the country that adapts the quickest will gain the greatest benefits.

Europe has similar interests in advancing HPC technologies and cloud computing, multi core and many core architectures, and FPGA programming models for these technologies are currently the "hot" topics for both scientists and industrialists in both regions.

This document summarises the EUINCOOP project work to identify needed research programmes that impact a wide spectrum of application areas in India, with an urgent need to nurture new emerging commercial areas that would exploit computing systems, which is critical for India to be globally competitive. The views presented are authorized by the experts from Industry leaders and research institutes with whom the editors of this document consulted.

Also included is an examination of the various research roadmaps of Europe where there are quite a few common interests in terms of research needs and challenges that India and Europe are trying to address. Issues such as energy efficiency, cyber security, interoperability, multi core and heterogeneous computing, big data handling technologies, and utility based computing for newer businesses are examples of priorities shared between the two regions.

High-level action points have been recommended by experts from the Indian HPC community and a long term research strategy well implemented and coupled with research collaboration with Europe and other parts of the world will ensure India is in the leading edge of the curve in the exploitation of high performance computing.

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1 Introduction

1.1 Purpose of this deliverable

The EUINCOOP 'Research Road Map' is intended to communicate and recommend the prioritized strategic requirements of India, aligned with European objectives, to further cooperation in computing systems research covering the many areas of embedded systems, general purpose computing and high performance computing.

This document represents the Indian computing systems community spanning across academia, industry and the government and serves as an information source to further the interests of these groups and the needs of the nation. The purpose of this document is to understand research objectives of India and the application areas India is looking at to solve its societal needs through HPC technologies.

The rationale of preparing this document is to give a prioritized list of topics and areas of research that India is seeking to advance in view of its societal needs and challenges. Hence there is a need to have an insight into what are the needs, trends, challenges and societal applications requiring computing systems capabilities, which are essayed in this document. However, while the array of technologies and challenges are aplenty and impractical to capture in a single document, the most needed and those that form the government priorities and those collected from industry and academia are listed in this document.

This report discusses the various research needs and priorities as identified by the experts from academia and industry that are seen as the future of computing systems research in India, which were elaborately discussed at a two day workshop/round table held at CEDT, IISc Bangalore on 7-8 August 2012.

The report also consolidates the view points of the sub groups identified by the government of India proposed in the working group roadmap report for the 12th Five Year Plan. This report discussed the various challenges and opportunities of HPC in India and how India and Europe can benefit mutually through collaboration. A brokerage event in conjunction with the workshop to disseminate opportunities for collaboration in computing systems was also held, which is elaborated in a separate report and will be submitted as a further project deliverable.

An account of the European priorities and the challenges Europe is actively engaged in is given to have an overall picture of both the regions. The information included in this report is an extract from the previous work done in preparing D2.1 'Regional analysis of the research scenarios of EU and India'.

Future reports from the EUINCOOP project will combine the views and priorities gathered from India with those being collected from eminent experts across Europe. These activities will form a combined view and aggregated 'Research Road Map' that will provide recommendations and guidance in the formation of joint research initiatives between India and the EU in the upcoming deliverable D3.2 'Research Challenges for Europe and India'.

1.2 Structure of this document

This deliverable is structured as follows:

- Section 2 describes India's approach to Computing Systems research and in particular to high performance computing systems
- Section 3 summarises the technology research challenges identified from analysing European roadmaps related to Computing Systems technologies
- Section 4 summarises the technology research challenges for India identified from the available roadmaps and consultations for Indian experts from academia and industry
- Section 5 provides a comparative analysis of the EU and Indian research interests
- Section 6 describes the social and application specific challenges faced in India
- Section 7 summarises the recommendations and actions in support of future EU-India joint cooperation in computing systems research

References with website links are provided in the final Section for the roadmaps and other sources in India and the EU that were utilised in preparing this report.

1.3 Scope

The EU-INCOOP partners note that there are limitations in describing Indian government research priorities when compared to those funded in the EU. The Indian government takes a more macro level approach in identifying its roadmap for computing system research and does not publish details concerning desired technology research at the same level as available from European Commission supported roadmap projects and initiatives. The Indian strategic priorities information has been collected primarily from public sources, though some personal insights have been provided by the EU-INCOOP partners, who participate in carrying out the actions established under Indian government research programmes.

1.4 Contributors

The deliverable was prepared with contributions from all of the EU-INCOOP partners, each playing an important role in preparing the contents:

- IISc was the lead editor for the document and organised the data gathering and hosted the workshop involving leading organisations from Indian industry and academia.
- CDAC collaboratd with other Indian research organisations to establish a common view of HPC needs and technology directions in India.
- ITSMA investigated the industrial priorities for HPC research in India and how these priorities relate to the growing ecosystem HPC systems and related services.
- KYOS contributed to the facilitation of the workshop of Indian experts and towards achieving a consensus view concerning the strategic directions and actions to be recommended.

- FORTH analysed and summarised the EU roadmaps published from HiPEAC, ARTEMIS, PlanetHPC and NESSI initiatives with respect to shared interests and commonalities with India's strategic directions.
- TOG contributed in various sections based on the experience of its members from both India and Europe concerning HPC needs and future directions.

In addition to the partner contributions, the following experts from Indian industry and academia have participated and presented technology visions and collaborative approaches during the workshop/round table discussions that played an important part in developing the content of this deliverable:

- Mr Manav Subodh, Global Higher Education Manager, Intel India
- Professor Chiranjib, Bhattacharya Convenor, Machine Learning Lab- IISc
- Mr Suraj Mukundrajan, Global Head- Infineon Technologies
- Dr Prahlaad Rao, Centre for Development of Advanced Computing
- Dr Bindhu Madhav, Centre for Development of Advanced Computing
- Dr Sham Banerji, CTO- i2i telesolutions- SME
- Professor Govindrajan Ramaswamy, Chaiman Supercomputng Research centre- IISc
- Dr Satya Rao, Kyos Switzerland
- Professor Jamadagni H S, Professor Indian Institute of Science

As demonstrated by the above contributions, the preparation of this document was very much a collaborative effort.

2 India's approach to computing research

India like many developed and emerging economies is taken on the competitive race of high performance computing (HPC). India has announced a €767M grant to create next generation super computers and invest in HPC. The US is a clear leader in the high performance computing (HPC) segment with 253 of the 500 systems, followed by Europe with 107 systems. Dominant countries in Asia are China and Japan with 68 and 34 systems respectively. India has a supercomputer in the top 100 ranking and a few in the top 200 band. While a country's economic success is often not defined by who has the fastest computer, building the required capabilities & ecosystems to use these capabilities, and develop solutions for applications in different domains will nevertheless strengthen its position in any given area. Going by this dictum, India is keen to promote the high impact area of HPC.

2.1 Need for HPC

The need for HPC is more pronounced in the modern day than it was a few decades back. The demand for high computing power is seen in almost all major sectors, from government to individuals, from scientific applications to small businesses; from climate modelling to energy exploratory missions, HPC plays a major role in every sphere of our lives. In India, Government led initiatives such as the universal identification for all the citizens, providing affordable health care to the rural masses through telemedicine are in need of HPC systems. HPC is a widely needed tool to solve many societal challenges. HPC applications to enable efficient transportation systems impact the automotive and the transportation sector. Health care devices for improved health care delivery systems give major breakthroughs to the health care industry. Scientific and life sciences related applications will revolutionize science and technology of the nation, consumer electronics and retail businesses related applications bring in large economic benefits to the society in direct and indirect ways and if there is one common thread to achieve success in these sectors, it is HPC machines that can bring about the much desired success. With HPC holding so much promise to all communities the country that adapts the quickest will gain the greatest benefits.

2.2 Technological limitations

While there is widespread recognition of the benefits and the Indian government is keen on committing resources, it is to be noted that although there has been an increase in performance of computing capabilities, HPC is threatened by technological limitations. These limitations are global and not country specific and hence any country looking for solutions in these areas will be solving a global problem. The major technologically limiting factors are:

- Energy requirement of HPC devices is a major concern for countries like India, wherein 70% of its rural population is energy starved. Energy intensive applications like HPC cannot be well justified. The energy requirements of these devices are at a prohibitively high level.
- True to the Moore's law prediction the processor speeds are moving towards optimal levels. The doubling speeds of the processors slowing down is compelling scientists and engineers to look towards other ways of improving performance.

These technological constraints are giving rise to interests in many new technologies such as cloud computing, multi core and many core architectures, and FPGA programming models for these technologies.

Speaking of cloud computing, the market in India is expected to grow by 70% by the end of 2012 and will maintain the high growth of 50% for the next three years, driven by cost and performance efficiencies, IT research firm IDC predicts[1].

In such a scenario, India with its proven strength in software, can leverage its strengths to become a leader in systems software applications made to scale so that they can use processors in numbers that are several orders of magnitude higher than today.

2.3 India's strengths

India has well-established academic and research centres with a proven capability of designing and assembling supercomputers. Most of these supercomputers serve the scientific community. These centres have great expertise in the provision of HPC services. Key strengths for India in the area of HPC are the following:

- With India's proven expertise in software, it has the potential to pursue global leadership in rewriting software codes required for petascaling and exascaling of HPC applications codes. This is a major business opportunity for the Indian ICT industry.
- India has a vast pool of talented workers; strong research groups working on almost all computing systems aspects spanning from embedded systems, grid computing to cloud computing and large scale distributed computing.
- With developed R&D expertise in future HPC technologies, India can lead in providing HPC training and education. The world will badly need this type of service in near future and this can become a major business opportunity for India.
- Focused development groups like CDAC, C-MMACS and computational research labs who have the capability of developing system software stack and support.
- Groups are very strong in domain expertise of diverse HPC applications.

These strengths are leading to a growing interest and expertise in India on HPC and related applications. India has vast experience in software applications and can build upon these strengths to adapt to newer programming models.

2.4 India as an opportunity

The government of India has announced a €767M grant to accelerate advances in the HPC area. The framework elements that will be supported by the grant are the following:

- Develop tiered HPC centres across India
- Develop research labs focusing on systems software, HPC application and other related areas
- HPC man power training

India offers a huge market opportunity for cloud computing, big data applications and HPC as a whole with organized wholesale and retail markets fast developing. There is also a

[1] Announcement in Indian financial daily 'The Economic Times'

widespread belief that there is a ***need*** to build the HPC ecosystem involving hardware, storage capacity and scalable application software.

It is only prudent for any nation, while investing huge resources, to analyze objectively its limitations such that it can play to its strengths and create opportunities while working on its weaknesses. In this context it is important to examine India's limitations and challenges:

1. One of the major limitations which can be turned into a challenge is India's limited or no manufacturing capability which limits it from addressing R&D and makes it more dependent on strategic partnerships from firms abroad. It can hone its software and programmability strengths by creating ecosystems.
2. Commercialization of HPC technologies is not a strong point of India, usually only the government agencies exploit the applications of CDAC, C-Mmacs etc. There are very few users of these systems which makes it dearer for the nation to invest only for niche applications. Hence commercialization of these technologies to serve enterprises and businesses will make investment in R&D a viable proportion.
3. Culturally, research in India is often done by smaller groups and lacks large visionary projects, multidisciplinary communities along with stake holder communities to drive the HPC research and technology will overcome this challenge.
4. Under preparedness to handle the man power requirements, this is where India needs to invest in nurturing skill sets and talent in these areas to handle the future requirements of computing, else India faces the danger of being out competed. Engineers who can analyze, visualize and address issues relating to big data is a major requirement for India. Big companies like Amazon acknowledge the fact that there is a dearth of data miners, machine learning experts and skilled people who can handle terabytes and petabyte machines for cloud computing. Currently the country's need of such specialized talent is met by a few premier and regional colleges but the demand-supply for such specialized skill set is skewed.
5. Experts from academia and Industry in India believe that India needs to increase its processing power by 10 times to move from its teraflop capability to petaflop capability. This would need 4,000 tonnes of cooling power and close to 5- 10 mega watts of power. With Indian capability at tera level the scale of growth it requires is non-linear at this stage, which represents a major challenge considering the power shortage India faces[2].

These challenges indicate there is a clear need for a concerted effort if India is to exploit the opportunities presented through the research and development of new HPC technologies.

2.5 Importance of HPC

How many people know, for example, that HPC plays an integral part in designing the vehicles they drive and the airplanes they fly in, locating and extracting the fuel that powers these vehicles, developing life-saving new drugs and medical treatments, and producing the

[2] www.livemint.com/Industry/pzuRyUR3vmMT2A9mmf5UWL/India-gives-away-supercomputing-gains.html

weather forecasts they rely on to plan for daily activities and severe weather that can devastate lives and property?

Recent worldwide studies by IDC[3] have consistently shown that HPC has become indispensable for both scientific advancement and economic competiveness. It has proved to be a substantial multiplier of scientific and economic investments, a major productivity tool for researchers, and a critical asset for global competitiveness as it can often produce scientific and industrial solutions faster, less expensively, and with higher quality than traditional theory and experimentation alone. HPC is also valuable because it can help address "grand challenge" societal problems that are impractical or simply impossible (e.g., future climate changes, star form nation) to evaluate with "live" physical experimentation.

HPC can be defined as a collection of powerful computers which use parallel processing to run advanced application programmes efficiently, quickly and accurately. It has varied societal and business applications and carries a lot of economic importance which is a major differentiator for global competitiveness. HPC systems range from desktops with accelerators through groups of servers to high end supercomputers to put it broadly.

HPC spans all aspects of modern life and there are many examples of their use. From telecommunications, scientific computing, consumer electronics, transportation, manufacturing to weather modelling and environment, gaming and entertainment, computing systems touches all spheres of our day to day lives. It is a powerful tool and has the potential to shape societies and overcome many challenges facing present day society. From control systems of huge nuclear power plants, monitoring devices for medical parameters, telephone switches for network, mobile phones, digital cameras, PDA's, home appliances to electronic remote operated car keys computing devices are embedded into the society in a big way. High performance computing is an important tool to improve productivity and handling the problems of our future and an investment in the research and development of these technologies are expected to pay rich dividends to society.

2.6 Current research

The top technical institutes in India such as the IIT- Delhi, IIT-Kanpur, IIT-Mumbai, IIT-Chennai, IIT Kharagpur and IISc Grid Applications Research Labs (GARL), CDAC, C- MMACs focus their computing systems research mainly in the areas of:

- Compilers, computer architecture, computer networks, databases, distributed computing, parallel computing
- Embedded systems, energy-aware computing, graphics and visualization, mobile and wireless systems, operating systems, real-time operating systems, storage area networks, systems security, performance modelling
- Traffic modelling, grid computing, human computer interaction, wireless networks, multi core architectures, web based software systems, intelligent systems and knowledge engineering
- Scientific cloud computing research and solutions to academic and research communities
- Peta Scale Systems Development
- Heterogeneous or hybrid (CPU, GPU, and FPGA) computing systems research

[3] www.hpcuserforum.com/eu/downloads/SR03S10.15.2010.pdf

- "Internet of Things" (IoT), wherein all objects of the world are equipped with miniscule devices/sensors and interact over a network

It is beyond doubt that HPC with its varied applications and importance is a crucial technology and the demand for larger computing power will continue resulting in many innovative solutions. In this report it will be noticed the huge demands certain medical, climatic, biological and automotive applications place on HPC systems[4].

[4] Sources: IISc, IIT's, CRL, GARL. CDAC web information

3 Europe's technology research challenges

In deliverable D2.1 'Regional analysis of the research scenarios of EU and India' the key points of the roadmaps of the following European roadmap initiatives were examined:

- **HiPEAC**[5] – European Commission funded Network of Excellence
- **PlanetHPC**[6] – European Commission funded Support Action project
- **ARTEMIS JU**[7] – Part funded by industry and part funded by the European Commission (i.e. Joint Undertaking) to support the ARTEMIS European Technology Platform
- **NESSI**[8] – European Commission supported European Technology Platform

The initiatives cover a broad spectrum of research topics on Computing Systems, from architecture and compilers (HiPEAC), to super/cloud computing (PlanetHPC), to embedded computing (ARTEMIS), to service-oriented computing (NESSI). Despite starting with different motivations and focusing on different contexts, there is considerable overlap in the research challenges identified. Of course common identified challenges are given different interpretations by different initiatives and ultimately result in variations in the specific research topics addressed.

3.1 Energy efficiency

	HiPEAC	PlanetHPC	ARTEMIS	NESSI
Identified	✔	✔	✔	✔

There is a consensus among all the roadmaps we examined that Europe needs to improve the efficiency of computing. This will help both bringing down the energy requirements of large installation, as well as improve aspects of embedded computing.

More specifically, **HiPEAC** proposes to work towards maximizing the amount of computation per unit of energy. They identify this as the key for sustaining growth in European computational capabilities.

PlanetHPC shares this view and stresses that continuing to build ever-larger machines using today's technology will lead to prohibitive energy requirements. Moreover, they add that developments on low-energy computing should be leveraged across different computing fields. For example, low-energy processor technology developed for the hand-held market should also be exploited in HPC.

ARTEMIS also advocates researching high-performance, low-power computing architectures for us in embedded computing. They see that as a key advance towards achieving embedded intelligence.

[5] Summary from www.hipeac.net/roadmap

[6] Excerpts from http://cordis.europa.eu/fp7/ict/computing/.../planethpc-strategy.pdf

[7] Arguments summarized from Artemis Strategic research Agenda 2011

[8] Extract from www.nessi-europe.com/.../ResearchPapers/NESSI%20SRA_

Finally, **NESSI** proposes developing methods to engineer energy-aware software to improve power-efficiency of software systems.

3.2 Interoperability and composability

	HiPEAC	PlanetHPC	ARTEMIS	NESSI
Identified		✔	✔	✔

A few decades ago locked-down, vertically integrated systems were the norm in computing. This trend has been reversed and today Europeans are moving towards systems composed of software and hardware components independently developed from different vendors.

PlanetHPC focuses this challenge on the ability of HPC users to migrate their applications and data between different systems and vendors. They also identify interoperability via standardization as the means of enabling HPC applications to integrate into existing business workflows.

ARTEMIS identifies interoperability as the key for raising the level of abstraction in the design of embedded systems and transitioning from (the still dominant) vertically designed to composable embedded systems. Additionally they stress the importance of open interface standards, which will allow the developer tools market to grow and flourish. Finally, they identify the need for new micro-kernels and hypervisors to support dynamic composition in embedded systems.

Amongst the four initiatives it is **NESSI** who is the biggest proponent of interoperability, as they have a strong focus on software services. Having non-interoperable services would severely limit their total value. So, NESSI proposes researching open platforms and standardized interfaces, which will allow services to be easily composed. They will also help to blur the distinction between service producers and service consumers as they will make it easier to seamlessly compose existing services to provide a new one.

3.3 Dependability

	HiPEAC	PlanetHPC	ARTEMIS	NESSI
Identified	✔		✔	✔

Dependability in computing systems is a quite broad term that encompasses different loosely related properties. Such properties are reliability, predictability, resilience, privacy, security etc.

Given Europe's increasing reliance on computing systems for safety-critical tasks, **HiPEAC** stresses the importance of making system more reliable and predictable. This task is made more challenging by the proliferation of virtualization technologies, which add another level of abstraction that should be taken into account. In order to introduce the required determinism in the behaviour of computing systems, they propose to research programming

languages that allow the programmer to express timing constraints as well as compilers and virtual machines that enforce these constraints.

Having embedded and ubiquitous computing in mind, **ARTEMIS** highlights the need for a generic framework that will provide to these computing systems resilience of operation against both accidental component failures and the activity of malicious attackers. Moreover, they propose to research and implement model-based fault detection algorithms for fault tolerance.

NESSI identifies the need for identity management federation solutions that scale up to Internet dimensions while conforming to the European security and privacy policies. Additionally, they call for the creation of tools that will allow users to assess the compliance of services with their security, privacy and trust requirements. They also propose embracing security by design and, towards this end, research security-oriented development environments for a broad range of system families (e.g. service-based, internet-based, cloud-based).

3.4 Design and development tools

	HiPEAC	PlanetHPC	ARTEMIS	NESSI
Identified	✔		✔	✔

Designing computing systems has always been a complex task. There is a common view among most of the roadmaps examined that Europe will soon need more advanced tools for managing this complexity.

HiPEAC stresses that the soaring complexity of electronic systems will soon require new evolutions in exploration, design and verification processes for hardware. They also highlight the lack of deterministic performance tools, which will allow programmers to express timing constraints, and compilers and virtual machines to enforce these constraints using timing information produced by the hardware.

Similarly, **ARTEMIS** calls for the development of novel design tools that can be integrated into the core embedded systems design process workflow in order to help address heterogeneous structures, complex memory hierarchies and improve power efficiency. Additionally, they identify that we need tools to manage the design process of embedding systems. These tools should encompass aspects of the process like complexity, product hierarchy, supply chain and information flow.

NESSI focuses on tools and methods that will increase the productivity in software engineering. These include design patterns, techniques and tools for specific application domains and domain-specific application frameworks. Finally, they also identify the importance of devising software engineering processes and tools to support the maintenance, evolution and portability of legacy code into modern runtime environments.

3.5 Reduced energy requirements of other human activities

	HiPEAC	PlanetHPC	ARTEMIS	NESSI
Identified		✔	✔	

Apart from reducing its own environmental impact by improving energy efficiency, computing has also the potential to reduce the European energy requirements of other areas of human activity.

Planet HPC proposes that the energy industry should leverage advances in HPC to tap into new energy sources as well as improve the efficiency of the power grid using real-time input from smart meters. Additionally, they identify HPC as the key to making transport networks more efficient (and thus less energy-hungry and more environment friendly) through real-time traffic management as well as simulating and planning expansions.

Similarly, **ARTEMIS** views embedded computing as an enabler for green transportation networks and sustainable mobility. Their vision also extends to green buildings and energy control in the urban and rural environment.

3.6 Availability to business

	HiPEAC	PlanetHPC	ARTEMIS	NESSI
Identified		✔		✔

In the PlanetHPC and NESSI roadmaps there is a sense that many European business have not tapped into the possibilities offered by HPC and cloud computing.

PlanetHPC stresses that business will not leverage the possibilities offered by HPC unless it is made easily accessible to them. They argue that migration pathways for legacy applications should be provided for business to fully embrace HPC. They also support further advancing cloud computing as a means of bringing HPC applications to large groups of actors, for whom HPC is currently inaccessible. Especially for the case of SMEs, PlanetHPC identifies a lack of awareness of the potential benefits from exploiting HPC infrastructures.

NESSI focuses on supporting fast business cycles and increasing productivity by software and services. This includes making services more adaptable to the context and user needs, more resource efficient and autonomous. Towards this end, they stress the need for SLA mechanisms that offer an integrated end-to-end approach across different layers, including services, network infrastructures and devices. They also propose the standardization of the cloud stack by identifying its building blocks and providing open approaches for combining and managing them.

4 India's technology research challenges

The EUINCOOP organised a two day workshop/round table discussion held at CEDT, IISc Bangalore on 7-8 August 2012 where invited experts from academia and industry identified and discussed the key technology research challenges for computing systems being faced by India. The following sections describe each challenge and the associated technological issues and potential approaches.

4.1 Standardization

Standardization for interoperability and data migration is considered an immediate need. Standards will be critical for the successful adoption and delivery of cloud computing as well as other HPC applications. Standards are also critical to ensure clouds have an interoperable platform so that services provided by different providers can work together, regardless of whether they are provided using public, private, community, or a hybrid delivery model. IEEE Working Groups P2301 and P2302 are developing comprehensive standards that will address migration, management, and interoperability among cloud-computing platforms.

Data migration is a major problem in cloud computing and customers cannot easily extract their data and programs from one site to run on another. Although, cloud computing is revolutionizing how information technology resources and services are used and managed, the revolution comes with new security problems. Existing processes and methods for incident handling are geared towards infrastructures and operational models that will be increasingly outdated by cloud computing. Cloud infrastructure commonly relies on virtualization. While a large amount of research has focused on improving the security of virtualized environments, existing security techniques do not necessarily apply to cloud computing because of the mismatch in security requirements and threat models. The cloud users do not want to trust their essential data to be stored on a machine on which they have no control.[9]

4.2 Big Data Challenges

Handling 'big data' or data deluge is a major challenge requiring prioritized research on varied fronts. With India aiming to be in the supercomputing league and the major technology and research institutes going to be involved in realizing this dream by 2018, scientists and researchers are looking into various aspects of hardware, software, low power, low cost computing requirements.

Big data is emerging from almost all sources spanning from governments, businesses, individuals, entertainers, citizens, healthcare applications apart from scientific areas. Millions of databases have been used in business management, government administration, Scientific and Engineering data management, and many other applications. This explosive growth in data and databases has generated an urgent need for new techniques and tools. In this context, ***machine learning*** is identified as an important arm of computing systems research which is being seriously nurtured to meet the current as well as the upcoming large

[9] Extract from http://planningcommission.nic.in/aboutus/committee/.../cit/wgrep_dit.pdf

data demands of the future. In the years to come machine learning, which has a huge practical impact and is in the beginning of its evolution, is expected to be an important area with the tremendous scope it offers.

Space applications, healthcare applications, business applications, computational biological applications, genome sequencing, and biometric data processing are a few big data generators that require high processing speed to interpret where in machine learning will be the key technology in the future.

"Role of machine learning in the big data analysis, what are the aspects people are looking for in analyzing big data analysis, what is the skill sets required to take on the challenges of big data analysis is what we need to look at, with machine learning as the core tool in resolving the challenges of big data." says professor Chranjib Bhatacharya of IISc.

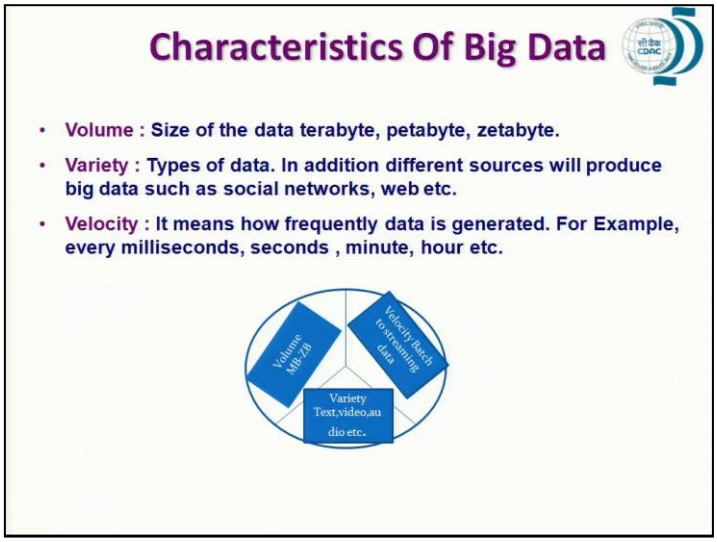


Figure 1: Characteristics of Big Data

The major challenges faced to handle 'big data' or widely known as 'data deluge' are the following:

- Capturing data – quick capturing without information loss poses the need for ***instrumentation technologies***
- Storage issue – requiring ***memory technologies***
- Sharing the data – requiring ***distribution technologies***
- Analysis of the data which is the value addition the data needing ***machine learning technologies***
- Visualization of the big picture needs data ***visualization technologies***
- ***Heterogeneous Computing Technologies***
- ***Cloud and Internet of Things*** [10]

Even as of today, there is a huge amount of data generated due to mobile and ubiquitous devices, which are all set to increase exponentially. Several applications such as governance based on IoT, data analytics, self configuring systems and many others will soon emerge. Hence future HPC research should gear up to address the challenges of Big Data.

[10] Professor Chiranjib Bhattacharya- IISc talk on 'present and future of computing systems with potential for EU and India collaboration'.

4.3 Parallelization

Parallelization is a major challenge where research institutes like C DAC, Computational research labs, corporations like IBM, HP and Intel are seriously devoting energies. With silicon chips reaching its vertical limit in processing speeds and constrained by energy consumption and certain thermodynamic laws, most research institutes realize that it's important that systems such as cloud computing systems, large scale distributed systems, and petascale systems be examined to determine and increase the amount of parallelization amongst the systems. Parallelism is also a key technology to achieve energy efficiency. Issues relating to design of parallel computers with efficient parallel algorithms, programming techniques and languages and portability are being researched to exploit parallelism which is believed to be a key enabler of HPC in many applications[11].

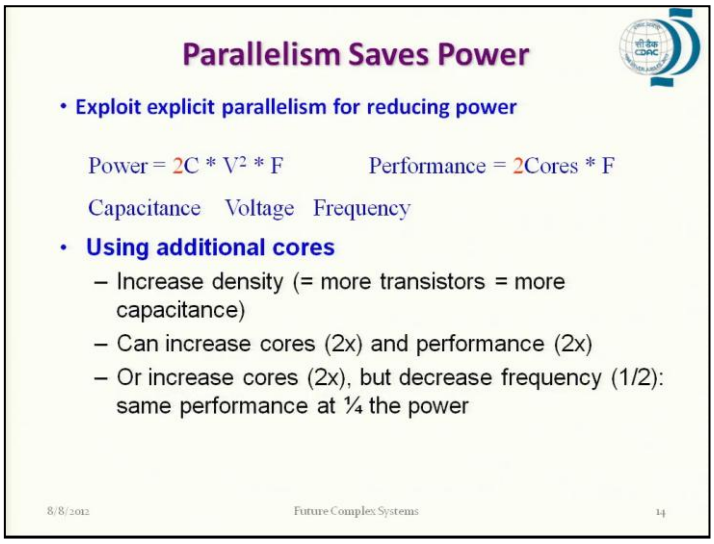


Figure 2: Parallelism and energy consumption

Apart from big data handling techniques, the other major thrust which dominates the scientific applications is **parallelization.**

4.4 Multicore and heterogeneous computing

It was widely agreed by the experts that multi core in itself coupled with heterogeneity of the cores will be a major challenge with the computing industry more and more moving towards these technologies. Previously almost all embedded software could be written with the assumption that a single processor is the execution vehicle, and where multiple processors were involved they were loosely coupled and could be considered separately or were collaborating on parallelized computations.

[11] Excerpts from Dr Dheeraj Bharadwaj's presentation on 'parallel computing the key to performance', available at: www.cse.iitd.ernet.in/~dheerajb/parcomp_2up.pdf

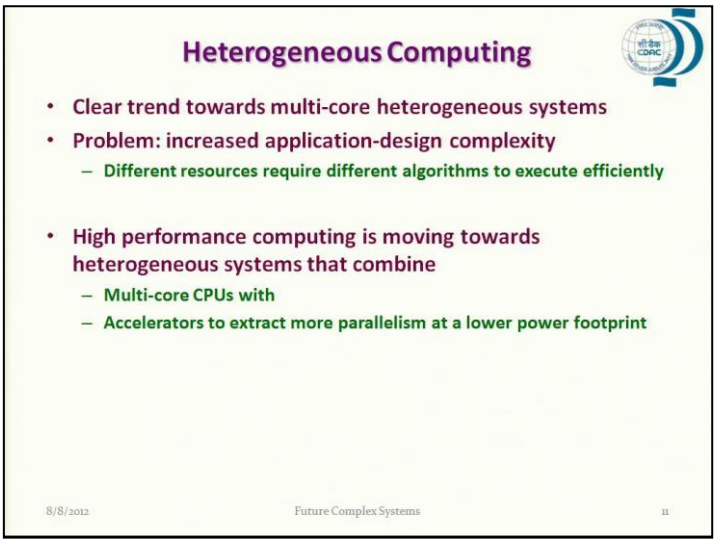


Figure 3: Trends toward heterogeneous systems

With dual and multi core machines, India can expect the number of cores to double with each processor generation. Furthermore, chips of the future can be expected to exhibit high degrees of heterogeneity in terms of cores, interconnect hardware acceleration and memory hierarchies.

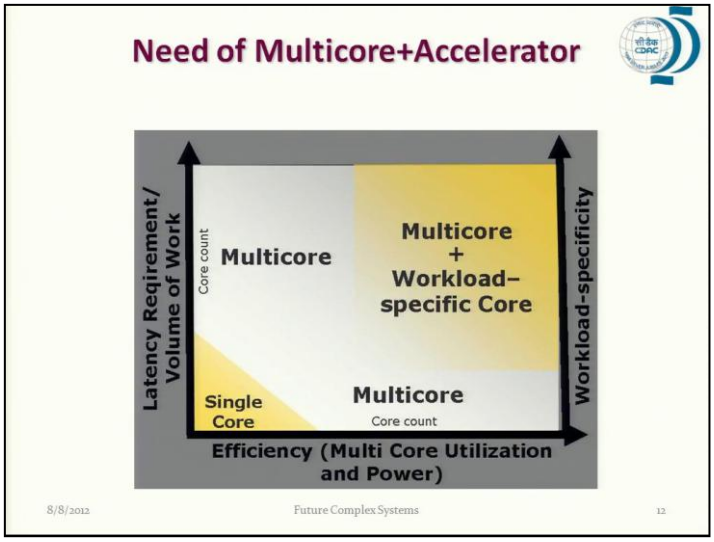


Figure 4: Use of acceleration technologies in multicore platforms

While multiple cores offer potential of parallel processing capability, the complexity of software programming, languages and engineering poses a great challenge in its adaptation, as well as challenged in managing and exploiting massive parallelism and heterogeneity.

With exascale computing power, the targets of many countries and India being one amongst them, there is a clear trend and need to move towards multi core heterogeneous systems. The challenge of this trend is the increased design and application complexity. Multi core CPU with accelerators to extract more parallelism at low power foot print is the aim and goal.

4.5 Power industry Smart Grids

Smart grids attributes in India are part of the HPC challenges where India is looking for collaboration in large storages, security and self healing attributes where in a dynamic revival of systems is needed. Parallel algorithms, advanced sensing, self-aware systems and self-healing grids are areas where India is looking for collaboration.

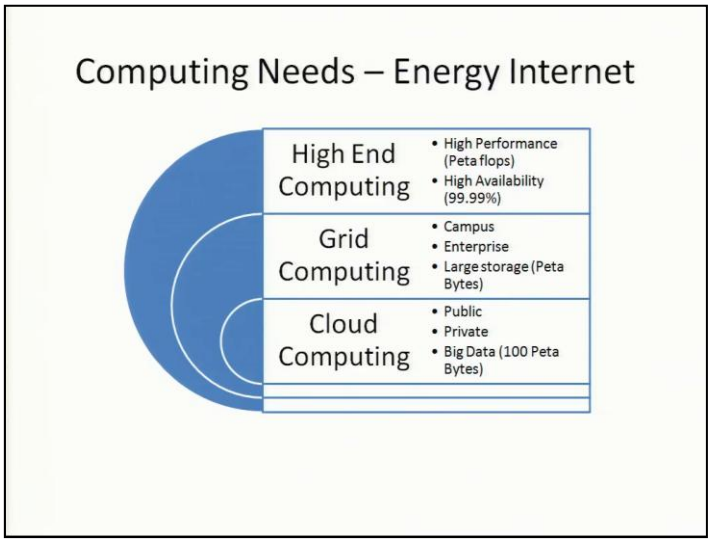


Figure 5: Use of HPC technologies in Energy management

System software challenges for exascale machines are mainly being researched with one of the major challenges being power, power efficiency for devices as well as power saving for cooling, threading software, memory and storage capacity, extremely scalable performance methods and tools, fault tolerance, programming models and cost effectiveness which need sustained effort to overcome these challenges.[12]

4.6 Utility based computing

A clear direction towards utility based computing is on the rise with many service oriented businesses and enterprises demands moving clearly towards utility computing which is placing demands on cloud computing and SAAS technologies. HPC enabled applications are bringing breakthrough advantages to the services and utility businesses.

[12] Dr Bindhu Madhav talk on Energy Internet

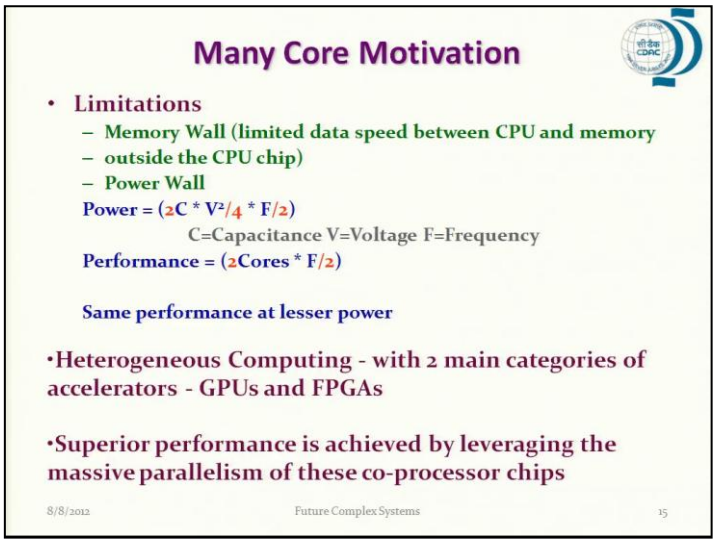


Figure 6: HPC technologies used in utility based computing

Indian enterprises will soon be catching up with the trends and placing demands on dependable technologies to give them real time results.[13]

4.7 Energy efficiency through exploiting parallelism

The unaffordable power consumption of the chips is putting a constraint on the deployment of the technologies. To address this issue adding additional core and exploiting parallelism is to be seriously considered as a technology to reduce power consumption and increase performance. The memory wall or the gap between the CPU processing speed and the memory outside the CPU chip resulting from the limited communication bandwidth across chip boundaries is one important challenge that needs to be addressed.

The major issues or challenges faced by India in realizing its exascale goals is power or energy efficiency in operation of the computation and data transport, followed by the next major challenge of programmability when talking about threading billions of software threads.

4.8 Information extraction from data in healthcare applications

The problem definition for the HPC solution in healthcare relates to critical healthcare data access where the information to be retrieved for each case could be different and hence a correct mixture of technology needs to be arrived at through careful customization of unique decision support systems for informed decisions. In short, extraction of maximum information from the available data is a challenge to be addressed by HPC systems for healthcare and other decision-critical applications.

4.9 Systems applications

Standardization of software architectures to accommodate multiple phenomena say for automotive industry and security applications where there is a need for multiple physics,

[13] Dr Rao, Joint director CDAC – talk on Hybrid systems and their applications

fluid and aero dynamics and other related fields is a necessity where standardization bodies such as AUTOSAR can be brought to India.

Novel methods to make use of parallelism and heterogeneous computing architectures, adaptive techniques to perform simulations, and modelling using novel methods both at numerical and algorithmic level is already a hot research topic where HPC related research is the focus of certain research and academic institutes such as IISc, IIT- Mumbai and IIT Chennai, CDAC and CRL labs.

5 Comparative analysis of EU and Indian research interests

India's and Europe's key research issues are a result of the societal and business challenges faced by both regions and stems partially from the strengths they possess. India, for a variety of reasons focussed on software development and hardware design capabilities, which helped in the development of ecosystems in these areas. In contrast, Europe's concentration was on R&D in the fundamental areas of computer engineering giving rise to contributions to systems architectures and chip manufacturing. Europe may not have the commercial scales of production but has generated fundamental IPs in areas such as storage, communication and some peripherals which in turn led to large R&D computing research in application development. Although there are many differences in the ecosystems of India and Europe there remains a convergence in the technological needs of both regions which are listed below.

Comparison: Technologies level

Technologies	India	HiPEAC	PlanetHPC	ARTEMIS	NESSI
Energy Efficiency and Parallelism	Energy efficiency is a challenge and making use of parallelism is seriously considered as the most viable technology by research institutions in India.	Working towards maximizing amount of computation per unit of energy	Working towards low energy computing across various fields used for devices markets	Advocates researching high-performance, low-power computing architectures for us in embedded computing	Involved in engineering energy-aware software to improve power-efficiency of software systems
Standardization and interoperability	Standardization for interoperability and data migration is considered as the immediate need by Government of India for its cloud computing initiative**.**		Identifies interoperability via standardization as the means of enabling HPC applications to integrate into existing business workflows.	Identifies interoperability as the key for raising the level of abstraction in the design of embedded systems and transitioning from (the still dominant) vertically designed to composable embedded systems.	NESSI is the biggest proponent of interoperability, as they have a strong focus on software services.
Dependability	Dependability and security are two issues the 12th Five Year Plan aims to take care for its cloud computing and ubiquitous	HiPEAC stresses the importance of making computing systems more reliable and predictable and		ARTEMIS highlights the need for a generic framework that will provide to these computing systems resilience of operation	NESSI call for the creation of tools that will allow users to assess the compliance of services with their security, privacy and trust

Technologies	India	HiPEAC	PlanetHPC	ARTEMIS	NESSI
	computing needs[14]	thus advocated dependability as one of its priorities		against both accidental component failures and the activity of malicious attackers.	requirements.
Data intensive HPC	Big data handling through capturing, storage, sharing, and visualization technologies with machine learning a major challenge as seen by India		Big data handling through capturing and curating and extracting information from data is seen as a challenge by Planet HPC		
Multi core and Heterogeneity	Multi core and heterogeneous systems parallelism: and complexity of software programming, languages, engineering poses a great challenge in its adaptation, managing and exploitation of massive parallelism and heterogeneity.		Multi core, many core and heterogeneous systems must be mastered to exploit parallelism		

Table 1: Extract of roadmap statements from European roadmaps and Indian roadmap

As we can observe, that there is widespread consensus in terms of technology challenges as seen by Indian academia, industry and government when compared to European roadmap statements from different HPC technology platforms. The research issues and challenges identified by Indian research and scientific institutions such as IISc and CDAC is a reflection of the scientific community who are also the consultants in drawing up the five year plan requirements for India.

Comparison: Applications level

India	HiPEAC	PlanetHPC	ARTEMIS
E- Governance	Productivity	Design and Manufacturing	Smart buildings

[14] Working group report to DIT for 12th Five Year Plan

India	HiPEAC	PlanetHPC	ARTEMIS
Education	Education	Safe and efficient buildings	Green and safe transportations
Health Care	Health care	Health Care	Healthcare
Automotive	Automotive	Automotive	Industrial systems
Scientific Computing	Aging population	Aerospace	
Bioinformatics	Energy	Energy	
	Environment		

Table 2: Extract of referenced applications from European roadmaps and Indian roadmap

Indian context, in terms of stakeholder engagement, motivation for new technologies and societal needs are majorly government supported and less market driven. Although there has been a good deal of convergence in terms of research issues the application areas for HPC systems are different between EU and India. There are overlaps in the societal needs, but by and large the application areas in India are more related to governance, education, scientific computing as opposed to more economically and socially relevant applications of Europe. The most plausible reason could be that the European markets are more established and the Indian market is emerging.

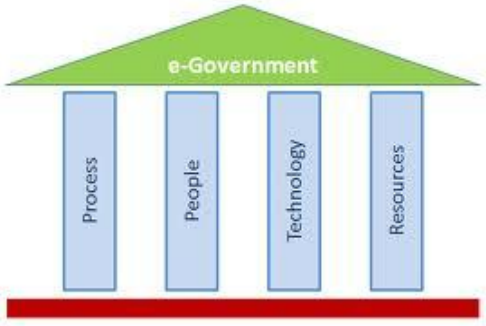
6 Social and application specific challenges

This section deals with the applications where HPC has demonstrated a high degree of impact within India within social, governmental, industrial, entertainment, scientific computing, healthcare, computational biology and financial areas. Interestingly, newer applications with new demands on HPC are emerging. Previously HPC was mostly associated with scientific computing but now many industries, small businesses, and entertainment industrials are relying on HPC machines. HPC undoubtedly is a disruptive technology of the future. It is to be noted most of the demands of the application sectors are data intensive, interconnected, and multidisciplinary in nature.

India is one of the most growing nations in the world. Yet there are several challenges that the country faces; some of them being common with other developing/developed nations. The greatest factor influencing India is its giant population of 1.24 billion. Hence India needs unique ways to handle the common challenges / requirements of a country.

The different areas of concern in India include – Healthcare, Food Security, Education, Economy, Power, Industrialization, Governance, Environment Protection, Housing, Transport, Disaster Management, Security and others. There are several initiatives to provide high quality solutions addressing concerns in each of these areas. ICT is getting seamlessly integrated into the systems. There are several projects using the latest technological advances to address specific needs of each sector. The advances in ICT are being applied to solve the problems in above areas.

6.1 E-Governance



E-Governance is a major challenge considering the huge population of India, and the different segments such as: population census, identity for each citizen, taxation, demographic / societal details, law and order, security, and so on. ICT can help to automate, maintain and manage the huge amounts of information in these sectors. To ensure access to public delivery systems and include the population belonging to the economically lower strata of the society, and for better governance, a unique identification project to map each and every citizen has been devised. Biometric information of every citizen is captured, and stored. These data capturing, storage and retrieval mechanisms are heavily dependent of HPC systems and technologies. Already there are several ongoing projects such as Aadhaar-UIDAI and income tax India forums.

6.2 Education

Education is one of the most powerful instruments for reducing poverty and inequality. As per the data published by the 2011 census India has managed to achieve an effective literacy rate of 74.04 per cent in 2011. However it is important for the country to have highly skilled and educated human resources in the fields of science, technology, engineering, finance, medicine, agriculture, and others.

As per a 2012 summary report on higher education in India released by the University Grants Commission (UGC), the number of universities rose to 634, and affiliated colleges rose to over 33,000. By 2010, gross enrolment in the university system had reached almost 17 million. Engineering enrolment was roughly 2.8 million in 2010 although first year engineering enrolment touched a million in 2012. Approximately 38% of students were enrolled in different branches of science, engineering, medicine and agriculture. The important aspect to be addressed in higher education is efficient e-learning methods including good content management systems where the HPC systems play a pivotal role.

6.3 Agriculture

The country needs to ensure that there is no dearth of food for all its citizens. Proper agriculture technology, education and information should be provided to the farmers to ensure that they get good crop yield, defy adverse climatic conditions and combat crop diseases. It is vital to provide the correct information and warnings to farmers. Attempts are being made to provide the weather forecasts to farmers through mobile phones. The Indian Council of Agricultural Research has setup several Krishi Vigyan Kendras for the benefit of farmers. A lot of ICT and TV programmes are used for educating the farmers. Mobile and ubiquitous devices are being indigenously used for various applications like informing the farmer about the availability of three-phase power for irrigation, help services over mobile phones, etc.

6.4 Disaster management

Accurate natural disaster (flood) prediction should be based on coupled models of Hydraulic Model, Snowmelt, and Atmospheric modelling, which are computationally intensive. In addition, the complete cycle of disaster management involves *Mitigation, Preparedness, Response*, and *Recovery*. Many of these phases require huge compute and data power. It is known that the phases of disaster prediction and assessment are computationally involved (petascale problems) requiring near real time prediction/assessment.

A precursor activity to the mitigation is the *prediction, modelling, simulation* and *evaluation* of hazards. Climatic modelling (based on Atmospheric/Ocean/Earth models) can be used to predict the possibility of a hazard. These models are complex requiring data from distributed observatories and huge compute power. Speed and accuracy of prediction is largely dependent on the computational resources.

Evaluation of hazard impact is done by using *catastrophe modelling tools* and decision support systems that require good computational infrastructure. The *Preparedness* phase includes technology and infrastructure capacity building, and training to improve readiness; this phase is data intensive and thereby computationally challenging. These days, there is lot

data coming from sensors, GIS, social networking etc. playing an important role in the R*esponse phase*, making it data-compute intensive.

6.5 Automotive

Automotive industry worldwide is constantly looking to cost effectively improve their energy efficiency, safety and reducing carbon footprint such that it makes it price competitive and increases attractiveness across all segments. Improved fuel efficiency, reduced carbon footprint, efficient mobility is where the automotive industry would like to invest in innovative solutions[15]

The automotive industry is looking at energy efficiency and safety applications using HPC and multi core technology for improved performance.

The automotive industry typically uses computational fluid dynamics (CFD) and finite element analysis (FEA) to implement high-performance modelling and simulation in a number of areas such as aerodynamics, crash testing, and engine design. It anticipates a need for HPC solutions to address these key challenges. Key technical challenges in designing HPC solutions for the Engine Control Unit and other applications include:

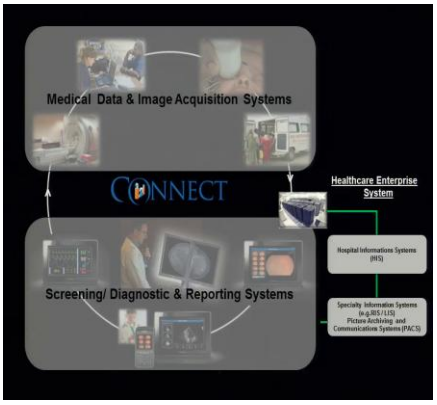
- Software enabled functionality increased microcontroller performance
- Migration of functions from hardware to software, hardware independent software
- Standardization of software architectures to achieve run time environment and accommodate multiple occurrences such as multi- physics, fluid dynamics and aero dynamic simulations
- Improve safety standards in India using dependable computation, dependable power, dependable sensing, dependable actuation and dependable communication and interconnect
- Dual and multi core architectures for decreased power consumption and power saving
- Multi core architecture for safety features such as the lockstep application processor
- Scalability with large number of cores and 'performance and power' load balancing.
- Automatic parallelization

HPC plays an important role in many areas that are important for the automotive industry

[15] Mr Surajmukundrajan's presentation on future of computing for automotive industry

6.6 Healthcare and medicine

Healthcare and medical professionals are turning towards computer scientists and computing applications like never before. Discussions in many conferences are taking place as this is a field which is multi disciplinary in nature. Healthcare information and management systems are currently one of the main interests for healthcare actors. Significant improvement in efficiency and effectiveness in healthcare strategies have been achieved by using information and communication technologies.
In countries like India where the patient to doctor ratio is 1,000 to one and patient to specialist ratio is nearly 10,000 to 1 the dependency of ICT and computing devices to capture and relay data in very short time periods, if not real time, is extremely important in healthcare delivery systems.



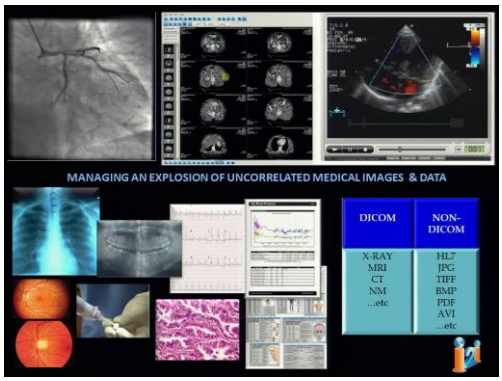
Large scale healthcare applications pose different challenges to computer science such as in distributed data management of medical images, high-performance simulation of organs or biological systems, data mining and warehousing of large healthcare data stores, just to name a few. Similarly, measurements, communication and electronic engineering communities are presenting their results to medical doctors and biologists communities for healthcare and life quality applications. There are research problems in computer science that are addressing critical issues related to healthcare and there are research topics in biomedicine and in healthcare that cannot be addressed without computer science applications.

For instance, high performance computing and communications, (large) data base management techniques, data quality and real time communications poses research problems that find application and validation in healthcare management systems. In other words, the healthcare domain can be considered as a realistic validation platform for many computer science solutions.

Delivering affordable healthcare to India's billion-plus population presents enormous challenges and opportunities for the medical community, insurers and other service providers. The following are some the challenges in healthcare[16]:

- bioinformatics,
- telemedicine
- advanced medical equipment (such as scanners, ECG, imaging),
- hospital information system,
- analysis and diagnosis based on health records,
- automatic robot assisted surgery,
- pathological studies and drug designs,
- Hospital management system, insurance, etc.

[16] Dr Sham Banerji- CTO, i2itelesolutions talk on 'the present and future of computing systems'



Realistic interventions in healthcare using computing systems is a concept where companies work using the business model of collecting valuable medical data of patients who are not closely connected to healthcare services and relaying this information to the doctors and health care professional sitting at a different location for diagnosis and treatment. This service is very valuable owing to the non-availability of care for patients who are physically far away from healthcare services.

The medical data and image acquisition systems connections to screening, diagnostic and reporting systems will give the specialist the needed information to take decisions. These requirements place a demand on the healthcare enterprise systems.

Here the challenges faced are on the following aspects of data handling and analysis with

- Capturing of the data
- Storage
- Sharing or distribution
- Analysis and
- Visualization solutions

The other major challenge in the data generated is that is it is varied in nature, largely uncorrelated and it needs to be stored for huge amounts of time. The magnitude of data growth, the need for fast retrieval systems, 24/7 availability, and improved record management with improved picture archival communication systems are areas where HPC solutions are sought. The data processing is in the order of peta to exascale levels. Apart from the quantum of data and the managing explosion, largely medical data is uncorrelated. The current technologies addressing these issues are in the process of transformation and what the PC and communication industries experienced a few years back the healthcare industry is going through now with miniaturization of devices, and coming up with low cost, low power hand held devices. This is one area where the government, corporates, SME's and research institutes are certain that HPC solutions will revolutionize healthcare and medical science.

6.7 Digital media

India is one of the largest producers of cinema and the world market for Indian cinema has been steadily growing with Bollywood going places like USA, UK, SA, Australia and many other European and western countries. Movies employing *computer generated images* popularly known as computer graphics is a technology enabled by availability of HPC. Although the US has generated successful computer graphics movies, India is well poised to make such movies owing to its market attractiveness. This is yet another area where HPC has immense scope and application in India.

6.8 Financial services

India as a growing economic power is soon going to be in the league of Singapore, Shanghai and Hong Kong where its financial sector, which is fast moving in nature, is going to place highly complex computing demands for risk assessment, valuation of assets and trading. These needs are more real time in nature and require highly reliable robust computing mechanisms where HPC will be undeniably an essential and pivotal technology.

6.9 Corporate perspectives on commercialization of technologies

The following perspectives were provided by representatives of corporations concerning the commercialization of computing technologies:

- Companies such as Intel are aiming to bring together researchers, engineering, technology and innovation onto one umbrella with the belief that such collusion will come up with certain innovative technologies, products or prototypes, which can be commercialized.
- Intel has programmes to bring together the computing systems community from the silicon valley of US to Barcelona, to various parts of Europe and India and other parts of the world's innovation clusters.
- Intel is aiming to get technologies faster (within 6 months) in the high tech and high growth hardware related technologies with low cost low power devices.
- Partnering with universities across the globe with leaders in the semiconductor computing area has resulted in a process for Intel of identifying new technology uses and users, to imagine collectively how the 2020 computing architectures, platform and devices will look, and how can they be employed to solve social problems.

All these efforts are directed towards identifying and fostering teams to create disruptive scalable business that impacts the next generation of users who grew up on computers, mobile devices and internet. Also, it's important to identify teams that have great opportunity to create a scalable business that leverages innovations to handle cloud computing, big data, machine learning, mobile connectivity, augmented reality and advanced sensors. These teams need to create a scalable business with positive financial returns as well as create an impact on social problems of agriculture, education, energy, financial services, health, environment and water.

Intel has brought in many European universities to spearhead this program and it resulted in establishing a 'start-up school' to train on lean start-up modes to churn out technologies within very short time frames.

7 Recommendations for EU-India joint cooperation

A long term research programme needs to be initiated in India to overcome the technological obstacles identified in this report. This report has highlighted the research priorities which would help India in the building of a long term computing systems ecosystem, which is enumerated below:

- Stimulation and support to technologies to handle big data or data intensive HPC such as instrumentation technologies, memory technologies, distribution and visualization technologies, heterogeneous computing technologies, Internet of Things and cloud technologies
- Building capabilities to handle systems software requirements for exascale and petascale computing
- New programming techniques for massive parallelism that can be leveraged as India's strength
- Standardization of software architectures, novel numerical and algorithmic models to be investigated to be applied to heterogeneity
- Creating, identifying and nurturing new markets and new uses for existing HPC technologies to make HPC a viable economic proposition
- Stimulating entrepreneurship and culture of risk taking by private players to build a competitive ecosystem

Concerted efforts with the participation of all stakeholders and exploring PPP models successful in other economies with an aim to create HPC ecosystems and nurture new markets for HPC resources will help solve the societal problems as well as bring economic benefits to the country. [17]

The following high-level recommendations in support of joint actions between India and the EU were identified by the Indian experts resulting from the workshop presentations and extensive discussions.

1. **Establish a computing systems technology platform along the lines of European Technology platforms to build HPC ecosystems**

   India's research motivations are primarily driven from challenges as perceived by the government. Most of the objectives are set by the ministries and it follows a top down approach. Most of the societal needs such as HPC for healthcare are usually undertaken by both large companies and SME's with commercial uptake as their objectives. The result of this approach is the research institutes follow the government objectives, private labs take up research useful to their industry and academia does independent research identifying societal needs by itself.

   Contrast this to the European Model where there are specialized technology platforms within computing systems to further and strengthen the interests of high performance computing (HiPEAC), embedded systems (ARTEMIS), PLANET HPC emphasizes the commercialization and business wing and NESSI to take care of systems software for HPC.

[17] Summary of the discussion and panelists view on 'the future of computing'

India also needs to bring about more coherence within the community, which would lead to building well established ecosystems, with academia aligning the curricula with industry needs, industry identifying end users who form the customer base for HPC resources and the government concentrating on broader societal needs such as scientific computing for climate modelling, oil and gas exploration, etc. under a common technology platform that liaises each other's interests. This only can bring about a holistic development of the HPC area. The Indian technology platforms when engaged in networking with European technology platforms can jointly create synergetic and symbiotic HPC community relationships.

2. Participate in a large visionary project

Currently Indian research projects are usually academic in nature with small funding, there is little industry participation, with a result that the impact it could create is limited. HPC being a strategic technology initiative should lead to large visionary projects, which are currently not present, and in which there is a possibility of technology platforms coming into play. Technology platform models and large consortia based projects are much needed to vision, roadmap and build ecosystems within India. Networking is a very important consequence of creation of an Indian technology platform with European technology platforms that can bring about significant benefits to both the regions in executing research and innovation driven projects.

3. Expand the HPC ecosystem

Owing to the great application value HPC can bring to the table both economically as well as solving many societal problems, a concerted effort by all Indian stakeholders of HPC is needed to drive the country's R&D strategy. Investments in terms of time, sustained efforts in building capabilities such as system software applications, creating and nurturing HPC ecosystems with an eye on commercialization of these applications to make it self-reliant is essential according to the computing systems community. EU-India cooperation can greatly benefit Europe as India offers itself as a robust emerging market, and India in turn can learn the best practices of commercialization of HPC technologies which is one of Europe's strong points.

8 Conclusion

This document emphasizes the need for planned and sustained efforts in support of HPC and general purpose computing which has the potential of churning disruptive technologies to varied social and economic applications which build India's research, technology and economic capabilities. Looking at the arguments for giving thrust to these technologies, it is proposed to forge partnerships and collaborations within India as well as with Europe to exchange best practices and jointly come up with innovative solutions.

The report identifies the similar and dissimilar areas where India and Europe are looking at the synergies they can exploit playing to the strengths of their respective regions. The recommendations listed in the report are an endorsement of by academia, industry and research institutes of the computing systems community of India for the further joint efforts with the Europe in HPC and computing systems research and development.

9 References and sources

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- Mr Surajmukundrajan's presentation on future of computing for automotive industry
- Dr Sham Banerji- CTO, i2itelesolutions talk on Realistic interventions in Health care using computing systems'
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