SEVENTH FRAMEWORK PROGRAMME
Information & Communication Technologies

Coordination and Support Action

EU-India Fostering COOPeration in Computing Systems

D5.3: Research Roadmap

Document information

Delivery Date	06/12/2013
Confidentiality	Public
Editor	Indian Institute of Science
Contributors	All partners
Quality Assurance	FORTH

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The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement № 287820.

Contents

Executive Summary

It is widely accepted by Europe, India and globally that there has been a quantum leap in computer performance in the last few decades, many aspects of the society have been impacted and computing systems itself can be recognized as fundamental field which laid a strategic foundation for many powerful and versatile tools for development. Almost all major aspects of the society from bioinformatics, drug discovery and diagnosis, climate modelling, financial analysis, oil gas and energy explorations to social media, computing systems has been the promising answer that support new innovations and significantly impact development on the whole.

Europe realizes the need for computing systems as the key to the development of new domains and revolutionary technologies, such as personalized medicine, online social interaction, and immersive entertainment experiences. Indeed, computing systems are so valuable that people demand constant access and have an insatiable appetite for new devices and capabilities.

India is fast moving from an emerging market status to a global player status in computing systems with software technologies being its core strength. The demand for computing technologies is spelt out more clearly with the demand for these technologies being placed by governments, businesses, scientific communities and individuals alike.

Having said this, scientists and researchers from different regions of the world are incessantly trying to overcome the challenges of computing systems that are limiting innovations and newer discoveries. The challenges can mainly be classified as ***Technology*** related challenges and ***Requirement/Need based*** challenges applicable to the key strategic areas that are joint priority to both EU and India.

Technology related challenges

System Complexity

Modern age computing tasks involve large data sets and complex coordination techniques between many processors to meet the demands of large number of users and data sets. This is a very cost intensive area needing large investments in designing, verification and production or procurement of the chips to ensure correctness of operation. Efficacy of programmability of the many core and multi core processors is the key challenge that addresses the system complexity challenges while enabling low energy requirements making them cost effective. As the technical challenges of energy efficiency and programmability remains still broadly unanswered the solution to these challenges remain to be addressed.

Big Data is often a repeated buzz word in the computer industry, governments and scientific communities. With PC's and laptops rapidly being replaced by mobile devices such as smart phones and other embedded devices the focus is swiftly shifting towards convergence of these embedded systems, mobile devices and data centres especially in Europe and USA. The data gathered from various global applications and processed in large data centres is made available to the users as customized information. Ensuring smooth interfaces between data generation to processing to information delivery is critical and poses many challenges in developing robust next generation systems.

Currently India perceives Big Data as the next revolutionizing phenomenon with various application domains such as climate modelling, bioinformatics, biology, social media and e-governance being the major generators and users of Big Data technologies. Energy efficient data centres, capturing, storage, and retrieval mechanisms, and software technologies for Big Data are the priorities that India is serious considering the demand from the application domains to be quite imminent.

Energy Efficiency

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. **Planet HPC** 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 use in embedded computing. They see that as a key advance towards achieving embedded intelligence.

Likewise in India the unaffordable power consumption of the chips is putting a constraint on the deployment of the technologies. To address this issue adding more cores and exploiting parallelism is considered to be one of the solutions to reduce power consumption and increase performance. 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. Research in these areas is considered to be a key enabler in addressing top priority societal challenges.

Security challenges

Indian businesses are focusing their efforts on mitigating business risks posed by cloud, mobile and social computing, along with targeted attacks, which are making security more difficult. In fact, in a state security survey report over half the respondents revealed that cyber security is more important today than it was a few years ago. Today, critical information assets are dispersed across the cloud, smart devices and social media, bringing new challenges in security. It is fast becoming a buzzword in the government and business corridors as Indian organizations realize the importance of a holistic strategy in minimizing the business impact of cyber security issues, which positions them to protect themselves against security-related revenue, data, and brand losses.

Detection of malicious software, building trustworthy systems requires fundamentally reliable software and hardware tools and mechanisms to ensure a security in computing services.

These common technology challenges between India and Europe are the binding factors that bring together the researchers from both the regions to join hands in addressing these issues bringing together their joint expertise.

KEY STRATEGIC AREAS

HIGH PERFORMANCE COMPUTING

High performance computing most generally refers to the practice of aggregating computing power in a way that delivers much higher performance than one could get out of a typical desktop computer or workstation in order to solve large problems in science, engineering, or business. It turns out that defining HPC is kind of like defining the word 'car'. You probably know what a car is but to write a concise simple definition is a different matter.

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. Consumer electronics and retail businesses related applications bring in large economic benefits to the society in direct and indirect ways and HPC machines 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.

DATA CENTER COMPUTING

Data centres are a large group of networked computer servers that are typically used by organizations for the remote storage, processing, or distribution of large amounts of data generated by mobile, embedded computing and HPC clusters devices that include online transactions and massive data driven scientific simulations. The role of the data centres is to handle massive amounts of data, (for analyzing and interpreting data as in scientific computing, real time data processing and forecasting), recording, storing and retrieving data when needed and provide ubiquitous access and scalability with maximum reliability.

DEPENDABILITY, SECURITY & SOCIAL COMPUTING

Dependability is a measure of a system's availability, reliability, and its maintainability. This may also encompass mechanisms designed to increase and maintain the dependability of a system. More on this topic is discussed in the Technology Challenges section below. **Security** is the ability of a system to protect information and system resources with respect to confidentiality and integrity.

Commonly **social computing** refers as the computing mechanism which supports any type of social cognitive behavior with the help of computing or computational systems or intelligence. It is actually application of intelligent systems and computing devices for societal interaction and more clearly utilization. The recent tools and names here that raise social computing phenomenon are: E-mail, Instant Message, Social Networking sites (Orkut, Facebook, Twitter, LinkedIn, and Forums), Internet, Community informatics, wikis.

Addressing Joint needs of India and Europe

HPC Technology Platform: During the course of the EU-INCOOP project several workshops and seminars were held to investigate the common challenges between India and Europe.

The project findings clearly showed that both the regions had HPC as a major research interest and are faced by similar challenges such as:

- Threat to the exponential growth of computational power
- Energy efficiency a major challenge and a threat to cost effectiveness.
- Demand for petascale and exascale computing on rise from various sectors.

Both India and Europe are dreaming big to realize the supercomputing dream and are poised to investing heavily in this area. But the major challenge which is a road block to realizing the dream is the lack of trained manpower and the lack of trained faculty to train next generation computing engineers.

Researchers from India and Europe felt the need to establish a common HPC technology platform on the lines of the ETP's (European Technology Platforms) of Europe. It is widely believed, by experts, that a focused network of stakeholders comprising of researchers, academics and people from industry will bring an impactful creation of a planned ecosystem.

Europe is a guiding example with 32 technology platforms striving to address the various requirements and needs of specific technology areas. It is believed India and Europe can benefit by jointly establishing a HPC technology platform and address its many needs for a planned future in computing systems.

Social Computing and Security: With governments, businesses, professionals, health forums etc heavily relying on social media such as blogs, emails, instant messaging etc, social media has gained tremendous importance in expression of opinions, creating public awareness, garnering public support etc. This particular social tool has great social as well as economic value and hence was considered as a topic for research priority owing to its social importance.

The current document derives its research priorities from the academic and industrial expertise of both India and Europe and further identifies the direction of research and innovation. From the above investigations three main research topics in the field of computing systems has been identified for joint cooperation based on the government interest, scientific interest and business interest. *Software for Big Data, HPC technology platform and Software for social computing have been identified as key strategic areas* for research cooperation between India and Europe.

After a thorough examination of both Indian and European roadmaps the timeline for the above topics is considered to the next five years as both 12th five year plan of India, and Horizon 2020 of Europe consider these areas as high priority and will need research attention in the coming 5-7 years timeframe.

1 Introduction

The deliverables D2.2 (Preliminary Research Roadmap) and D3.2 (Research Challenges for Europe and India) provided the detailed activities of both Europe and India in computing systems research and identified some of key challenges for cooperative research activities in the future. These results were presented in multiple workshops and conferences, as well as through questionnaires and discussion forums (e.g. LinkedIn) to get feedback from the stakeholders. The deliverables were also reviewed by the advisory committee, so that the project can project the well justified key challenges for the Euro-India Cooperation. The results were presented to the Euro-India high level group in Sept. 2013 to get a policy level feedback. Both parties have agreed on the broad aspects of computing systems research and have committed their support of possible joint research call possibilities.

This deliverable of the EUINCOOP project on 'Research Roadmap' 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. The project has considered the 12th Five year plan of India which has motive of 'Decade of Innovation' with high priorities in Computing Systems to improve the quality of life for its citizens and 'Horizon 2020' programme themes of Europe in identifying the common interesting research challenges to promote the Euro-India cooperation in the framework of Horizon 2020 framework.

ACKNOWLEDGEMENTS

This document is based on the valuable inputs from the computing systems fraternity of India and Europe. Much though has gone into setting up of the priorities considering each nation's needs and requirements based on their societal, governmental and scientific priorities. The editorial board composed of Prof H S Jamadagni (IISc), Dr Sotiris Ionnidis (FORTH), Dr Scott Hansen (TOG- UK), Dr Sathya Rao (KYOS- Switzerland) and Dr Prahlaada Rao (CDAC).

Professor Balakrishnan (IISc), Professor Neeraj Suri (TU- DARMSTADT), Professor Avi mendelson (Technion, Israel), Professor Khincha(IISc), Mr Manav Subodh (Intel), Mr Suraj Mukundrajan (Infineon) Dr Chranjib Bhatacharya (IISc), Dr Bindu (CDAC), Dr Das (IIIT- Bangalore), Professor Govindrajan (IISc), Dr G V Ramaraju (DIETY- Government of India) have graciously taken part in the project activities and imparted their knowledge, views and vision that would drive the computing systems research scenario jointly with Europe. All of the above mentioned people are highly respected in their fields and are closely connected with the current trends and happenings of the research area.

2 SNAPSHOT OF THE RESEARCH CHALLENGES IDENTIFIED

The most distinguishing factors between India and Europe in terms of motivation for funding can be highlighted as:

- India's research focus is more towards applied research in comparison to fundamental basic research where new technologies are often developed to address specific scientific, societal, or economic problems.
- Europe is inclined towards both applied research and exploratory research which carry high risks and reward of greater impact in Europe and international markets. India has carved a place in software technologies and programming techniques. The visible gap is the lack of investment in hardware and platform technologies.
- In short, European research climate has created an ecosystem for exploratory and applied research with its focused research networking activities in specific fields. India has an evolving research climate with more applied research and focusing more on its software developing strengths. A joint funding by India and Europe will have to bring in the ingredients which are missing to complement each other to foster cooperation. Identifying research topics that offers societal and or economic applicability for India while being sufficiently futuristic for Europe would be a desirable combination that EU-INCOOP tried to elicit through its activities in the project.

  Considering above strong positions of Europe and India, 7 priority areas were identified for consideration of joint activities as reported in the deliverable D3.2.

2.1 Software for emerging platforms

Both India and Europe and quite likely the rest of the world are facing software complexity challenges such as addressing high levels of parallelism, Data transactions, storage and connectivity configurations which are leading to increased complexity. New technologies that seek to find a balance between ease of programmability, portability and exploiting performance of new multi- and many core platforms are research challenges that would benefit both European and Indian industries that rely heavily on software systems, associated with Software programming to keep pace with advances in hardware platforms.

Joint research direction that India and Europe can explore

- Automated parallelization with use of abstraction.
- New transformation technologies to automate exploitation of parallelization at deployment combined with model-based engineering technologies.
- Increased run-time intelligence to dynamically adapt the software to better exploit parallelism of the platform.
- New languages that aid in the expression of parallelism and that provide better mapping or automation of algorithm design.

- Emphasis on portability and scalability to optimize investments.
- Partition of HW and SW architecture for optimized use of energy to achieve the high performance against with energy efficiency.
- Research in human aspects to have an understanding into how people should program for ease of use.
- Adaptive curricula to garner the necessary skills to address greater levels of parallelism.

2.2 Software for Internet based systems

Mobile and Internet telecommunications have had a mega impact globally. These networks are largely software systems based across wide geographic areas and are highly complex due to their dynamic nature of services they support. New technologies are needed to address challenges related to security, quality of service, resilience and resource optimization across service platforms based on telecommunications and the Internet.

Joint research track that India and Europe can explore

- Large scale distributed software systems modeling, mechanisms to reduce costs of verification to ensure run time behavior.
- Dynamic resource allocation while providing appropriate guarantees on performance and energy efficiency in many core embedded and high performance systems.
- Cloud-like resource management infrastructures aiming to harmonize the approaches to dynamic allocation across the complete spectrum with soft performance guarantees.
- Resource allocation techniques that are sufficiently lightweight to be applied during runtime and that are able to take into account performance guarantees for timing and energy use.
- Scalable resource allocation techniques that are capable of supporting different kinds of cloud-like infrastructures including embedded clouds, micro clouds and high-performance clouds.
- Extensions to existing system software (OS, virtual machines, middleware) to support predictable runtime migration of tasks with monitoring and back-propagation for dynamic optimization.
- A collaborative approach to addressing large scale distributed systems that support new Internet based services would greatly benefit markets in both India and Europe.

2.3 Software for Big Data

Like the rest of the world, India and Europe are experiencing explosive data generated from almost all sectors (enterprise, ment, businesses, society, entertainment, science, and technology) and the need to extract value from this data is felt across all those sectors. The information extraction from the data, data mining, data storage, and handling these large volumes of data is placing a

high demand for newer technologies.
New technologies that are required to handle big data should address the challenge from various perspectives such as

- Diversity of information to be analyzed as data comes in structured, semi-structured and unstructured forms.
- Large distributed data across large number of devices which are mobile vary in formats, models, and ontologies.
- Quality issues with imprecise data, inconsistencies, and incompleteness
- Identifying and adapting to external trends and changes amongst data providers that might affect the precision or reliability of data mining and analysis

Joint research track that India and Europe can explore

- Data centric system software exploiting many core parallel computing platforms
- Moving the computing where the data is, instead of moving the data.
- Asynchronous computing and distributed data focused run-time environments
- Scalability of open data management platforms and support for new approaches to analysis and visualization
- Optimization through balancing or delegating work using techniques such as moving algorithms to local data stores
- Improving interoperability of data, techniques, and methods across tasks and scenarios
- Scalability as the volumes of data stores is expected to increase.

2.4 Software for Enterprise

Enterprise software is a key enabler of innovation in India and Europe's business environments. Innovations in new system software technologies for enterprise also hold great promise both in India and Europe for enabling small companies to access and participate in regional and global markets. A vision for both India and Europe is that enterprise software systems can be created through the simple composition of standard solutions from multiple providers. This would reduce the costs of maintaining enterprise systems and reduce the investments required to establish new service based systems.

As of today, there are no suitable software engineering methodologies in place or any appropriate standards.

Joint research track that India and Europe can explore to cooperate in

- Automating interoperability of systems between enterprises.
- Automating adaptation of systems including techniques to recognize when adaptation is required.
- Distributed systems technology addressing the complexities of interfacing, managing and exploiting data from products with embedded intelligence that may have been sold around the world.

- system software supporting real-time data analytics and new enterprise database technologies and related programming and design tools to support rapid adoption
- many core programming methods and models that transform service oriented architectures to better exploit dynamic service composition, virtualization and main memory techniques for enterprise software

2.5 Networked Embedded Systems and interoperability

Europe and India have different visions as to how embedded devices will enable important societal changes. The differences are not technological and result from each region facing different societal challenges and having different targets for global competitiveness. Some of the areas where cooperation is possible are given below:

Possible threads of research that could be explored jointly between Europe and India include:

- Distribution and composability of operating systems and virtual environments able to support dynamic reconfiguration
- Resource augmentation enabling devices to identify resources accessible across a network such as cloud computing, HPC, and/or to exploit these to dynamically improve quality of service and energy usage.
- connectivity schemes that support ubiquitous syntactic and semantic integration of heterogeneous sub-systems, under the constraints of minimum energy usage and limited bandwidth
- self-configuration, self-organization, self-healing and self-protection of computational components to establish connectivity and services, using knowledge acquired from the environment
- monitoring techniques for object and event recognition making possible new control tasks in large-scale systems

2.6 Software for Social Computing

"Social Computing" refers to systems that support the gathering, representation, processing, use, and dissemination of information that is distributed across teams, communities, organizations, and markets.

Both Europe and India have to reconsider the notion of data, information, and knowledge in this social context where the bulk of raw data and information comes from users. New software technologies will be needed to address the cascade of information that will be created because of the volume of data and the associated processing tasks. The major challenge for both Europe and India will be to find tools and interfaces to support the interaction between the volumes of data. Research in these tools and models will help sieve information from the large variety of data which will be generated.

Joint research track that India and Europe can explore are the following:

- Data intensive distributed computing system software and middleware
- Semantic-based data integration and standardization
- Software optimizations and acceleration for reasoning in a huge-scale distributed environment
- Technologies for discovery, surveillance and managing dynamic and mobile data
- Scalability of new technologies will be another area that can tap the collaborative potential.

2.7 HPC platform

One of the largest areas of commonality between India and Europe in computing systems research interests is High Performance Computing (HPC). Each region has substantial programmes for developing new HPC technologies and each region faces common challenges affecting both industry and research organizations:

- The exponential growth of computational power in future is threatened.
- Commitment of large budgets in developing the super-computing to address scientific challenges and computing.
- Future HPC systems will need energy efficient technologies for sustainable cost effectiveness.
- Applications that are critical for biotechnology, mitigation of natural disasters and other societal supporting sciences are already difficult to scale and will need substantial re-engineering for exascale systems.

With these common challenges India and Europe can explore to collaborate on the following research fronts:

- Programming models, languages and methodologies for many core HPC architectures and tools to automate applications and improve developer productivity
- Technologies for energy-aware application and system modeling, compilation and runtime environments for building energy efficient HPC systems.
- Modeling and simulation techniques that scale to expected levels of parallelism in many core based HPC platforms
- Exploiting technologies from other computing domains for mobile, embedded, cloud, telecommunications and sensors to address HPC.
- Definition of a common access framework for the HPC infrastructures.

Establishment of Technology Platform is a well suited option to face the challenges that surround HPC and is expected to:

- Address problems that require multidisciplinary science and engineering inputs where knowledge from different disciplines is applied in new and innovative ways
- Garner contributions from a range of different types of stakeholders in defining the solutions from research institutes to industry

- Share vision and leadership that will provide substantial economic benefits in terms of the resources needed for research and development
- Many real world applications for HPC appear diverse, but the underlying computing systems challenges are shared amongst large classes of applications making it feasible to develop HPC technologies that are applicable to a wide range of industrial and societal applications

Though all these 7 challenges are considered of high priorities, the project tried to filter them further to prioritize these challenges and to provide the lead for joint research activities call. Hence, the objective of the next section is to address top 3 challenges of immediate interest, based on the experts feedback received, through multiple interactive sessions as described in the deliverable D3.2.

3 TOP THREE JOINT PRIORITY RECOMMENDATIONS

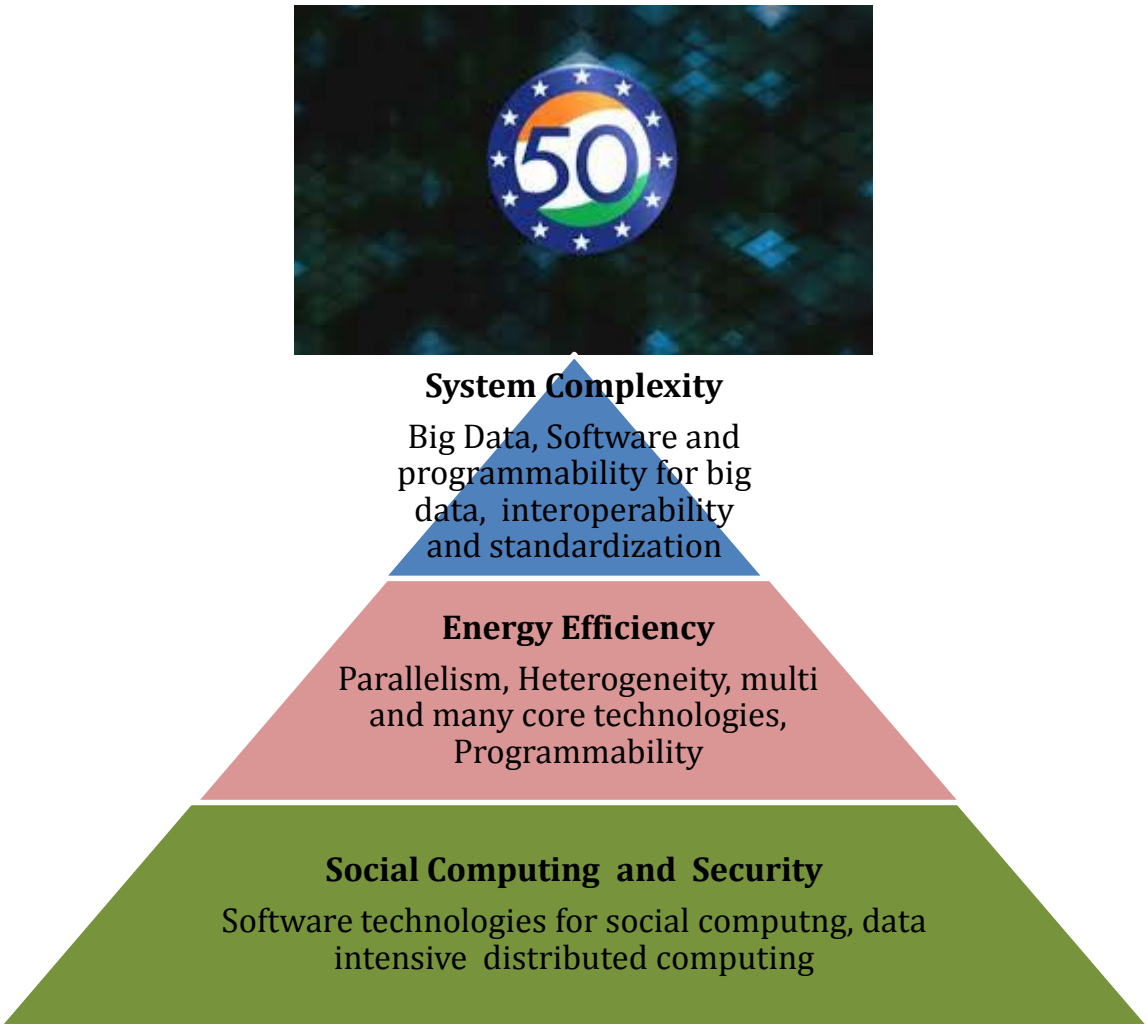

Figure 1: Shows the common technology challenges between India and Europe that can be pursued during the next 5-7 year time frame.

3.1 Strategic Area 1: High Performance Computing

'High performance computing most generally refers to the practice of aggregating computing power in a way that delivers much higher performance than one could get out of a typical desktop computer or workstation in order to solve large problems in science, engineering, or business. It turns out that defining HPC is kind of like defining the word 'car'. You probably know what a car is but to write a concise simple definition is a different matter'.

The need for HPC is more pronounced in the modern days 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. Consumer electronics and retail businesses related applications bring in large economic benefits to the society in direct and indirect ways and HPC machines can bring about the much desired success. With HPC holding so much promise to a wide spectrum, the country that adapts the quickest will gain the greatest benefits.

HPC is the backbone of all the future technological revolutions such as cloud computing, supercomputing, internet of things and cyber physical systems.

3.1.1 Programming Complexity

Currently, power requirements seems one of the most important issues related to high performance systems. Moreover these systems will need an integration of at least 3 distinct computer architectures built into one system. These architectures include *instruction set architectures, system level architecture and machine language architectures.* This would require 3 different programs in order to make the system run and that is an incredible challenge to write three programs to pass data between each of those in stages to push data over to the vector processors and then back again out to the main memory of the system.

To integrate multiple functions requires a high level design compatibility and programming prowess that is very skill oriented and also expensive. Programming talent needs to be nurtured that would provide enough opportunity to understand the complexity and design programs on these many core platforms.

3.1.2 Multi-core and heterogeneous systems and parallelism

India and Europe concede the importance of multi-core parallelism as it is believed to aid the energy efficiency and power consumption pattern of the devices and hence addressing programming complexities and exploitation of parallelism is considered an important area that demand research attention.

It was widely agreed by the experts that multi core being coupled with heterogeneity of the cores will be more and more a major challenge with the computing industry 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 just collaborating on parallelized computations.

3.1.3 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 should 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

3.1.4 Technologies

Technologies that need to be addressed or continued for HPC platforms are nascent as described above. Some of the present efforts and future technologies that need to be addressed at the platform level are:

- Design on these platforms: As mentioned already there are some efforts by agencies like CDAC and Tata Consulting Services designing and testing HPC platforms using standard computing elements. Typically, terascale computing has been routinely designed. Petascale machines and their extensions are on some drawing boards. The main barrier hose seems to be a viable market. However, with the new road map up to 2020 for HPC in India, there is good scope for such platforms'

- Software platforms: Software platforms for HPC are receiving much more attention than the hardware platform. Computing clusters and their operation is extremely common. Moreover, some of the multinational companies are investing on HPC software platform design and application in important areas such as climate change, climate modelling, genome research etc. In fact Computational Science for applications in chemistry, biology, nano sciences, brain research, fluid mechanics, etc., are now receiving appropriate attention from the government and researchers. These areas are likely to grow and drive the platform research.

- System design: Designing complex computer systems as platforms for various applications, and their realisation as building blocks with silicon or board level systems is also a priority area as envisaged by various government agencies and universities.

3.1.5 Related technology: The cloud

As in the HPC area, cloud is also a major player in platforms. At the moment cloud platforms users in India are typically available from outside vendors. Given major issues of privacy there is a growing need for this infrastructure to be locally created, owned and possibly designed to suite local conditions. Only recently cloud infrastructure is gaining momentum in India. This will be a high growth area and needs attention in future. Firstly, establishing the cloud infrastructure is important. This is to be followed by research work in the area, specifically to address privacy, security and any other topic of importance.

3.1.6 Non technical challenges

Creating a market awareness of need of HPC platform is the biggest challenge. Introducing HPC in major areas such as government (for instance for census data processing or highly localised and accurate weather prediction) is very important in this context. While the agencies in these domain have access to and working with HPC, the areas are not common in university laboratories or training institutes. There is a need to bring use of HPC and the associated HPC platforms to mainstream for gaining further benefits from application of HPC.

The challenge being faced both in India and Europe is that advances in high performance platforms are outpacing advances in software development technologies for effective exploitation. A large number of programmers are needed to enable the existing software to new architectures; large number of scientists and application domain experts are required to design superior parallel algorithms for next generation architectures. Skill needs to be augmented in developing Internet applications, mobile applications, cloud computing, Internet of Things, Big Data issues, augmented reality

3.2 Strategic Area 2: Data Centre Challenges

Data centres are a large group of networked computer servers that are typically used by organizations for the remote storage, processing, or distribution of large amounts of data generated by mobile, embedded computing and HPC clusters devices that include online transactions and massive data driven scientific simulations. The role of the data centres is to handle massive amounts of data, (for analyzing and interpreting data as in scientific computing, real time data processing and forecasting, recording, storing and retrieving data when needed), and provide ubiquitous access and scalability with maximum reliability.

3.2.1 Energy Efficiency

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 use in embedded computing. They see that as a key advance towards achieving embedded intelligence.

Likewise in India the unaffordable power consumption of the chips is putting a constraint on the deployment of the technologies. To address this issue adding more cores and exploiting

parallelism is a serious technology challenge in order to reduce power consumption and increase performance. 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. Research to improve energy efficiency is considered to be a key enabler in addressing first priority societal challenges.

3.2.2 Big Data Technologies

Big Data handling technologies through capturing, storage, sharing and visualization technologies is seen as a major challenge in India as is also one of the priority areas identified by the European ETP's such as the HiPEAC, PlanetHPC, Artemis, and NESSI, the technologies that are seen by Europe as the future in handling Big Data are capturing, curating, and information extraction from data.

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 and, low cost computing requirements.

Big Data is emerging from almost all sources spanning from governments, businesses, individuals, entertainers, citizens, healthcare applications many scientific fields. 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 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.

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***

3.2.3 Research Initiatives/Trends

In scientific fields, enormous amount of data is being generated every day in different domains such as biology, astrophysics, weather prediction, high-energy physics etc. The European Bioinformatics Institute (EBI) in Hinxton, UK, part of the European Molecular Biology Laboratory and one of the world's largest biology-data repositories, currently stores 20 petabytes of data about genes, proteins and small molecules. Genomic data account for 2 PBs of that, a number that more than doubles every year. Use of a proper data analytics platform can help in yielding proper research answers. But actually mapping out an analytics plan is complicated.

Current data trend indicates that Big Data applications will eventually need petascale and exascale computing resources. HPC has the capability. Cloud Computing cannot handle complex problems having regular communication between neighbouring components due to lack of high performance networks between components. HPC Tools & Platforms can be a solution as users can re-deploy tools and technologies to tackle the Big Data problems. The HPC technologies and tools are highly scalable as well.

Several mobile devices are having multi-core processors. Researchers and enterprise are trying to develop superior applications on these devices to solve important socio-economic challenges. Internet programming and Cloud model of delivery is slowly getting accepted as standard in IT sector.

C-DAC is primarily engaged in HPC and Grid Computing technologies for scientific advancement in India and has recently launched a half petaflop system (ranking 69 in June 2013 list of top500 supercomputers). CSIR Fourth Paradigm Institute is working on HPC and big data analytics; has a 300TF HPC cluster ranking 95 (of 500); Vikram Sarabhai Space Centre has 188TF system ranking 174 of 500; The best Indian HPC system this year is from Indian Institute of Tropical Meteorology with 719TF ranking 36 in top 500 supercomputer June 2013 list. There are a total of eleven HPC systems of India announced in top500 June 2013 approximating to about 2687TF.

The Government of India has initiated ‘GI Cloud’ to enable government (both Centre and States) to leverage cloud computing for effective delivery of e-services. In its 12^{th} five year plan the government of India, has included several initiatives for faster more inclusive and sustainable growth. Establishing top ranked supercomputing facility, Nano mission, e-Governance, Clean Energy initiatives, etc provides the necessary thrust to Cloud initiatives.

The European Commission, in its communication titled “Unleashing the Potential of Cloud Computing in Europe,” recently announced a new strategy for cloud computing in the EU. According to the statement released by the EC, the strategy is designed to accelerate and increase the use of cloud computing across EU businesses and the public sectors.

3.2.4 Related Technology: The cloud

Most of these technologies identified above are closely associated with the cloud. Most cloud vendors are already offering hosted Hadoop clusters that can be scaled on demand according to their users’ needs. Also, many of the products and platforms mentioned are

either entirely cloud-based or have cloud versions themselves. Big Data and cloud computing go hand-in-hand.

Programming of Emerging HPC, Cloud & Embedded Architectures: Multi-core Programming, Parallel Programming, Mobile and Internet Computing

- This domain is witnessing confluence of technologies in embedded computing, HPC and Cloud computing. Multi-core and many-core processors are becoming very popular due to their superior performance: power ratio.
- Cloud technology's on-demand anytime – anywhere model is very attractive to enterprises; added with mobile technology benefits is leading to highly ubiquitous and large user – large data applications.
- Multi-core designs have been used in processors for some time. Less restricted by traditional architectural designs, graphics processing units (GPUs), and the Cell Broadband Engine (Cell BE) processor by Sony, Toshiba, and IBM, have demonstrated tremendous performance improvements employing massively parallel approaches to processor architecture. These processors provide opportunities for high-performance applications. But the multi-core revolution isn't limited to these processors. With multi-core designs being adopted by CPU vendors such as AMD and Intel, parallel programming is a necessity for all developers.
- Cloud computing is a model for on-demand access to a shared pool of configurable resources (e.g. networks, servers, storage, applications, services, and software) that can be easily provisioned as Infrastructure (IaaS), software and applications (SaaS) . Cloud based platforms help to connect to the things (IaaS) around us so that we can access anything at any time and any place in a user friendly manner using customized portals and built-in applications (SaaS). Hence, cloud acts as a front end to access Internet of Things. Applications that interact with devices like sensors have special requirements of massive storage to store Big Data, huge computation power to enable the real time processing of the data, and high speed network to stream audio or video. Sensing as a Service on cloud leads to few good applications like Augmented Reality, Agriculture and Environment monitoring.
- New technologies that seek to find a balance between ease of programmability, portability and exploiting performance of multi / many-core platforms are research topics that would benefit both Indian and European industries that rely heavily on software systems.

3.2.5 Non Technical Challenges

Developers have to be familiar with parallel programming models like Open MP, MPI when they are dealing with multi-core architectures, Open ACC, CUDA, Open CL with GPU programming, VHDL programming and FPGA programming. Too few universities teach parallel programming at an undergraduate level and new paradigms are needed to help software programmers better understand and conceptualize parallelisation. Few undergraduate engineering disciplines have started offering courses in Mobile Application Development.

The challenge being faced both in India and Europe is that advances in high performance platforms are outpacing advances in software development technologies for effective exploitation. A large number of programmers are needed to enable the existing software to new architectures; large number of scientists and application domain experts are required to design superior parallel algorithms for next generation architectures. Skill needs to be augmented in developing Internet applications, mobile applications, cloud computing, Internet of Things, Big Data issues, augmented reality etc.

3.3 Strategic Area 3: Dependability, Security and Social Computing

Dependability is a measure of a system's availability, reliability, and its maintainability. This may also encompass mechanisms designed to increase and maintain the dependability of a system. More on this topic is discussed in the Technology Challenges section below. **Security** is the ability of a system to protect information and system resources with respect to confidentiality and integrity.

Commonly **social computing** refers as the computing mechanism which supports any type of social cognitive behavior with the help of computing or computational systems or intelligence. It is actually application of intelligent systems and computing devices for societal interaction and more clearly utilization. The recent tools and names here that raise social computing phenomenon are: E-mail, Instant Message, Social Networking sites (Orkut, Facebook, Twitter, LinkedIn, and Forums), Internet, Community informatics, wikis.

3.3.1 Context for Social Computing

Currently, social computing has moved from a teenage fad to a mainstream communication and collaboration mechanism. It is rapidly redefining the way people and businesses communicate. Today, social media is an integral part of any organization's communication strategy. The focus is on two fronts: internal; where organizations leverage social media such as wikis, blogs, and corporate social networks to encourage and improve employee interaction. Within an organization, social computing can drive innovation and creativity. The other is external, where organizations harness the power of social computing to foster visibility. The power of social computing comes with several inherent risks, and it is vital that an organization adopts a cohesive and well thought out social computing strategy.

Today's corporate websites feature integrated social media capabilities, such as blogs, wikis, discussion forums along with sharing and bookmarking shortcuts. As a result, companies are able to obtain real time feedback from their customers and partners, as well as integrate and adopt them in their processes.

A greater cross section of employees is now open to the public via these fora, as compared to the occasional press releases from CEO. This is driving a bottom up innovation, as compared to a traditional top down innovation. Social media helps customers to promote an organization’s products as in viral marketing, and this has been proved over and over again as one of the most effective referral mechanisms.

Public media is extensively using social media tools such as tweets, blogs, online surveys etc. to influence government decisions and policies as was witnessed recently in the anti-corruption movement in India and the group appeals for the change in justice systems in the infamous Delhi rape victim’s case.

Political parties are increasingly using social media for launching political campaigns and increasing their publicity. With governments, public, corporate, pressure groups widely using social media and the list of stakeholders probably increased exponentially in the next few years. Social computing will be the technology that steers societal change, government thought processes and market trends. With such wide reach and impactful social tool social computing merits a planned strategic research and development to be adopted.
Very interesting products based on social computing and crowd sensing are emerging in such diverse areas like healthcare, crowd sourced funding of research and development, education and entertainment etc. The number of products in this space is galloping up every day and their benefits are so significant that some disaster recovery and advisory systems more or less now are routinely built using these technologies.

3.3.2 Challenges and Needs

Social media can be defined as the backbone of the social computing tools and technology. Hence understanding social media is an important step in identifying the requirements and challenges of social computing. Social media brings a host of opportunities as well as presents some unique challenges. Social media is being harnessed innovatively in business, education, healthcare, government, law enforcement and more. The next generation of social media will be more sophisticated with rich features and innovative interfaces and will enable collaboration and interoperability. We yet don't know the full potential of social media and how we can exploit its untapped potential. We also need new models of computing, called social computing approaches and methodologies to process vast array of information scattered in social media and to satisfactorily address some of the growing concerns on social media applications. Further, effective mining, analyzing, aggregating, and exploiting information sourced from social media is an open and exciting challenge. To better exploit the power of social media, several technical, organizational, societal issues, and challenges needs to be better understood and addressed.

An important and often ignored area that calls attention is the integration of the classical sciences areas such as humanities, sociology, ethnography, crowd psychology, behavioral economics, etc., in the new areas of social computing. While some efforts are being made in this direction, enormous efforts are needed to bring these disciplines into the main stream computation during the next few years.

3.3.3 Research trends/Initiatives

As noted in the above section research in this area is nascent and often haphazard in many countries. There are some excellent groups in MIT media lab and universities like CMU that are working on some of the major issues in this area. For example, use of references on social sites and news sites are now regularly used for prediction of occurrence of epidemics, or trends in militancy in a given area. Many disaster monitoring and recovery are based on very ingenious social science research using the social databases. There are claims from some researchers that main events such as Arab Spring were predicted using these research studies. However, researching in these areas and bringing them to main stream useful applications is still a major challenge.

Main initiatives in this area are by non-profit organizations and NGOs that use social computing to address disaster and aid issues. Examples such as Ushahihi (Kenya) and nuclear

radiation monitoring in Japan are big success stories in the recent past. Many forest conservation efforts using social computing are under way in IISc for example.

3.3.4 Technologies

- Analytics of all kinds (image, speech, etc) is perhaps the most crucial area for social computing. Also, social linguistics and linguistic analysis is a major area that has been used successfully, and will continue to be exploited extensively in future.
- Versatile, sensitive and sophisticated software technology needed for better social computing
- Social computing is also greatly dependent on improved networking technology for better interaction between the social computing users and the service providers for better resource and technology sharing.
- Data base technology is required for to sieve necessary data without messing up the data, for storage and retrieval purposes.
- Communication Technology [CT] powered by satellite and VSAT Technology to reach the rural communities in India, is also important for a healthy sophisticated Information Network. Ultimately CT is essential for better communication between the stakeholders of social computing.
- Data intensive distributed computing system software and middleware
- Semantic-based data integration and standardization
- Software optimizations and acceleration for reasoning in a huge-scale distributed environment
- Technologies for discovery, surveillance and managing dynamic and mobile data
- Scalability of new technologies will be another area that can tap the collaborative potential.

3.3.5 Related technologies

The most important allied technology for social computing is wireless communications with high security. Lessons learnt during the past few years (for example the theme of the Congress on Privacy and Surveillance, conducted in September 2013 at EPFL) highlighted many dangling issues in this area. Particularly monitoring of communication systems and doing so in real time, their legal implications, etc., are going to play a major role.

3.3.6 Non Technical Challenges

Legal frameworks and their integration in understanding many social issues are crucial (again highlighted in the Congress on Privacy and Surveillance, conducted in September 2013 at EPFL as this framework is highly region dependent and what is legal and normal social aspect in one region may be completely different from other regions. Many issues on use of social computing are clearly not understood in the national context. Some of the case studies presented in the past on violations of privacy, respecting (or not) of sovereignty of states, personal data gathering and their use are barely understood. Research as well as well documented case studies is important in this context to build social computing in a solid foundation.

4 TECHNOLOGY CHALLENGES 1: SYSTEM COMPLEXITY

Most countries including India and Europe are grappling with challenges of integration of large distributed systems involving numerous embedded devices, mobile devices and data centre devices. Optimal and efficient tools and designs will be needed to enable future hardware and software developers to ensure correctness and dependability, high performance, low energy consumption and security.

High Performance Computing	Data Centre Computing	Security and Social Computing
Scalability for large multi user databases. Integrating heterogeneous frameworks into an end-to-end workflow	Creating an integrated data source. Working in a hybrid technological environment Capture & Store massive data Understanding the unstructured data, filter and compress the data	Controlled Data Sharing, Privacy and security management
Programmability issues concerning many-core and multi core processors. Issues of interconnects and effective resource utilization.	Curation through Data Management, Metadata management, data accuracy and right of use	Developing quantifiable models of fault-tolerant and vulnerability-tolerant architectures – Quantifying the benefits of implementation diversity – Understanding the scaling of attacker and defender effort in fault-tolerant systems.
Multi core and heterogeneous computing issues. Reliable and green components to reduce carbon foot print and make it cost effective.		Using programming models and network/computer architectures that are inherently more secure.

In scientific fields, enormous amount of data is being generated every day in different domains such as biology, astrophysics, weather prediction, high-energy physics etc. Use of a proper data analytics platform can help in yielding proper research answers. These data analytics is widely used in all strategic areas of embedded computing, mobile computing and data center computing.

Data issues have been essentially two-fold: find cost effective ways to store ever increasing amounts of data and information, and find ways to mine this information to extract meaningful business Intelligence and scientific solutions. In the future, these applications will re-

quire large scale integration across large distributed systems comprising of thousands of devices. Enabling future programmers and system designers to work effectively and efficiently will require developing of software and hardware tools able to efficiently optimize performance and energy, ensure trust worthiness, security and privacy and dependability.

These challenges are the current inspiration for much of the innovation in modern analytics information systems, giving birth to relatively new machine analysis concepts such as complex event processing, and other new ideas. It also indicates the need of data scientists with deep analytical training in data discovery, predictive modelling, open source statistical solutions, visualization skills and business acumen to be able to frame and interpret analyses.

5 TECHNOLOGY CHALLENGES 2: ENERGY EFFICIENCY

High Performance Computing	Data Centre Computing	Security and Social Computing
Challenges of tightly coupled hardware and software - designs. Overcoming limiting factors such as feedback loop on systems design.	Data Centers and supercomputers are extremely power hungry. Energy aware devices, low power devices and cooling techniques requiring minimum energy with energy efficient solutions.	
Reduction of waste in computing including wasted transistors, wasted computation, wasted bandwidth and chip designs optimized for serial performance increasing the complexity and power consumption.	Software-defined networking for Energy aware computing is the approach that is being considered and developed for cost effective energy efficient and environmentally sustainable solutions.	
Creating ultra scale parallel applications for compatibility with new systems architectures.		

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. Co designing of hardware and software are the new emerging techniques in addition to parallelization to achieve energy efficiency. US is actively working on these techniques, the Green Flash project is intended to dramatically accelerate the development cycle for exascale systems while decreasing the power requirements.
Although multi core clearly provides potential for high performance, software needs to explicitly take advantage of the multiple cores to fulfil this potential. Sadly, no compiler turns serial algorithms into perfectly parallelized programs that scale to an arbitrary number of cores. Traditional approaches such as multithreading forces one to spend time worrying about thread management, instead of designing scalable parallel algorithms. With the number of threads growing as the number of cores does, dealing with bugs caused by deadlocks and race conditions hampers developer productivity significantly. At four or more cores, the complexity of threading becomes a serious problem.

The popularity of Graphics Processing Units (GPUs) has been fuelled by software frameworks, such as NVIDIA's Compute Unified Device Architecture (CUDA) and Khronos Group's OpenCL that make GPUs available for general purpose computing. Nowadays CPUs, GPUs and FPGAs are combining into hybrid systems to achieve more performance.

Newer methodologies and tools are sought to allow the specification of the system at a higher level and relieve the developers of the need to manage communication, storage and distribution of computation. Techniques to enable development and deployment of both software and hardware solutions globally will address cost effective debugging, testing, verification and profiling at once. This is a complex challenge requiring coordinated efforts and partnerships between countries in order to make it work.

6 TECHNOLOGY CHALLENGES 3: DEPENDABILITY & SECURITY

High Performance Computing	Data Centre Computing	Security and Social Computing
Data security is an issue when applying parallelism.	Search and Query huge unstructured data , indexing helps improve latencies in data transactions with use of appropriate mechanisms. Seamlessly and efficiently handling of queries across vastly different time granularities, e.g from over the past 30 seconds to over the last month.	Trust in data sensing, collection, transport, analysis and process Trust of Internet of Things Trust in online, mobile and instant social networking Human-computer interaction trust Device-to-device and machine-to-machine communication and collaboration trust Identity & data trust, as well as data storage trust Privacy preservation (especially personalized privacy enhancement and concern)
Encryption challenges without losing flexibility and speed.	Fault tolerance, redundant components	Power reliability, reliability of physical elements Embedded system & software trust System trust against intrusions and attacks Social trust and social communication trust Trust in cloud and mobile cloud computing and services

With more and more data being stored in global data centres, issues of privacy, security, trustworthiness need greater attention on the reliability and dependability of systems. A tiny error can have a global impact entailing huge losses. With increased demand for reliability

and dependability and decrease in the functional level of the components the balancing act becomes more and more challenging. While talking of global connectivity and dependability hardware and software development should be such that they store public, private, sensitive and critical data in trustworthy data centres. The need for legally compliant technologies cannot be more emphasized in the global scenario.

HPC and data centre computing faces reliability issues emerging from fault tolerance caused by long delays in recovery of sub systems. It is almost mandatory to develop hardware and software resiliency strategies that are very important storage accesses, and developing hardware and software strategies are very challenging.

7 OBJECTIVES AND EXPECTED OUTCOMES OF THE CALL FOR PROPOSALS

The section is developed to give an example of text for joint call between India and Europe.

Expected outcome: To promote international cooperation in complementary topics in computing systems of each region's strengths. The aim is to enable innovative solutions that address high performance computing and embedded computing domains. Proposals to develop visionary solutions in addressing Big Data challenges in handling Velocity, Variety, Volume and Veracity with a robust testing verification and debugging programming abilities will be encouraged. Proposals should encourage and support involvement of wider section of players such as participation from SME's, industry and research institutions from both regions. Proposals towards coordination and support action of computing systems from both India and Europe to form into a specific task force to exchange best practices such as the Emerging Technology platforms (ETP) will be encouraged.

Topics on HPC and embedded computing:

Projects will aim at developing innovative solutions in

- Programming models, languages and methodologies for many-core HPC architectures and tools to automate applications and improve developer productivity.
- Technologies for energy-aware application and system modelling, compilation and run-time environments for building energy efficient HPC systems.
- Modelling and simulation techniques that scale to expected levels of parallelism in many-core based HPC platforms.
- Exploiting technologies from other computing domains for mobile, embedded, cloud, telecommunications and sensors to address HPC.
- Definition of a common access framework for the HPC.
- Interoperable and open Cloud infrastructure for HPC projects.
- Applications which deal with constant operation and monitoring of infrastructure such as electricity generation and distribution, transport control, logistics and industrial processes and decision support in crisis situations will have new requirements for robustness, real-time and reliability to be addressed by HPC technologies.

Up to one proposal in each area will be funded by the EC and Indian Government for the corresponding regional partners.

8 CONCLUSION

India and Europe share a common vision of creating a position in computing systems and is evident with the fact that they are on the verge of investing several billions of euros on supercomputing. However with the moore's law hitting the wall and the free trip of automatic exponential performance increase is over, many unanswered and unsolved mysteries in computing systems research poses many interesting challenges in chasing this huge dream.

EU-INCOOP project was instrumental in bringing together the research fraternities from EU and India to discuss and weigh various options and possibilities where both the regions can come together to cooperate on the research front, to find ideal solutions to the challenges, and establish their respective positions in the globally competitive scenario.

The roadmap therefore considered the main opportunities and challenges that are governing the field with specific reference to EU and India's status on these issues. Coming to a common agreement on the ***three strategic areas identified as HPC, Data Centre challenges and Security, and social computing challenges and the three technology challenges identified as System complexity, Energy Efficiency and Dependability and Security,*** the visionary group proposed these topics as joint priority recommendations to be pursued for joint research cooperation. Besides a ***joint technology platform for HPC related issues driving the research scenario in India is also proposed on the lines of the European Technology Platforms.***

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