SEVENTH FRAMEWORK PROGRAMME
Information & Communication Technologies

Coordination and Support Action

EUINCOOP

Cooperate Collaborate Connect

EU-India Fostering COOPeration in Computing Systems

D2.1: Regional analysis of computing system research activities

Document information

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Executive Summary

This report is prepared as a deliverable for EUINCOOP Project funded by the European commission. It highlights many aspects of National Priorities & Ongoing Activities, India Research Roadmap - in next 5 years and International Collaborations. The nationally funded projects by Department of Information Technology (DIT), Department of Science & Technology (DST), Department of Bio Technology (DBT), and Ministry of Earth Science (MoES) are listed as a separate document (see deliverable D3.1) to demonstrate the national priority areas.

The information culled out and compiled in this report is from published documents from Europe and India, internal sources of partner CDAC, and published government annual reports. The report contains information on European and Indian priorities in computing systems research. This report highlights the similarities and dissimilarities and analyzes the priority areas between the two regions. It is intended to enable the European Commission to invite ICT proposals with Indian cooperation in the near term and to propose joint calls between India and Europe in the future.

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GLOSSARY:

1. IISc- Indian Institute of Science
2. CDAC- Centre for Development of Advanced Computing
3. TOG- The Open Group
4. FORTH- Foundation for Research and Technology Hellas
5. ITSMA- Interactive Technology Software and Media Association
6. KYOS- Keep your Eye Open for security
7. MCIT-Ministry for Communication and Information Technology
8. DIT- Department of Electronics and Information Technology.
9. HiPEAC- High Performance and Embedded Architectures and Compilation
10. ARTEMIS- European Technology Platform for embedded systems
11. Planet HPC- European Technology Platform for High Performance Computing
12. NESSI-Networked European Software and Services Initiative

1 Introduction

1.1 Purpose of this deliverable

This deliverable has been developed by the EUINCOOP Project to analyse the computing system research priorities for government funded research in India and the European Union (EU), and to compare and contrast the research topics that are being addressed in each region, as well as the context and supporting actions that accompany them. The deliverable reports on the various ongoing research initiatives in India, and the roadmaps that are published that set the Computing Systems research agendas and priorities for funding in India and the EU.

The deliverable has a focus towards providing insight into Indian priorities in Computing Systems research, and their relationship to technology roadmaps established in the EU, which are providing guidance towards priorities for the Horizon 2020 Framework Programme. The deliverable is targeted for use by researchers in both academia and industry, as well as those setting policy and coordinating government funded programme in both regions.

The identification and analysis of existing technology roadmaps is one of the early steps in the EU-INCOOP work programme. These planning and vision documents are expected to be the basis for identifying areas of common research, encouraging closer collaboration amongst EU and India funded projects, and creating an opportunity for more coordinated funding of Computing Systems research between India and the EU in technology areas that have shared importance for both regions.

1.2 Structure of this document

This deliverable is structured as follows:

- Section 2 describes the Computing Systems related research priorities and technology roadmap contents from India
- Section 3 summarises the European roadmaps related to Computing Systems technologies
- Section 4 provides an analysis of the EU and Indian research priorities by comparing and contrasting the roadmaps from each region
- Section 5 summarises ongoing projects and programmes for cooperation between India and the EU
- Section 6 describes the actors involved in the next steps that will be carried out following publication of this report

References with website links are provided in the final Section for all of the roadmap and technology priority sources in India and the EU that were utilised in carrying out the analyses in this report.

1.3 Scope

This deliverable has been developed to achieve specific objectives within the EU-INCOOP project under the FP7 ICT Programme, and in particular related to the Computing Systems objective within the European Commission's ICT Work Programme. The time horizon for the information provided is aligned with FP7 (2007-2013). In particular, the roadmaps identified are all recent publications that identify research and development priorities for the 2012-2017 timeframe.

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 technology roadmap information has been collected primarily from public sources, though some and personal insights have been provided by the EU-INCOOP partners, who participate in carrying out the actions described in the Indian government research roadmap documents.

In carrying out the analysis of technology roadmaps research priorities both in India and the EU, the partners have focused on Computing Systems related research and development topics, and have not attempted to analyse the wider range research topics that are funded in both regions.

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 investigated the Indian organisations involved in defining research roadmaps in India including their procedures for establishing roadmaps and supporting documents that provide further details beyond the master five year plan.
- CDAC investigated the published research roadmaps and supporting documents from the Indian region and summarised the focus areas related to Computing Systems.
- ITSMA investigated the industry funded research priorities in India and how these priorities relate to Computing Systems research topics.
- KYOS provided the overall editing of the analysis of the Indian research priorities with a comparative of EU activities in related areas.
- FORTH analysed and summarised the EU roadmaps published from HiPEAC, ARTEMIS, PlanetHPC and NESSI initiatives.
- TOG carried out the analysis of the EU and Indian roadmaps related to Computing Systems to identify commonalities and contrasts between the regions.
- IISc provided the overall coordination of this deliverable, while KYOS carried out reviews and quality control.

As demonstrated by the above contributions, the preparation of this document was a collaborative effort amongst all the project partners.

2 Indian research priorities

The deployment of high-performance computing (HPC) in India is on a steady growth trajectory, opening up exciting opportunities for both industry and R&D organizations to create a significant amount of knowledge-based capital and intellectual property. India is looking for closer cooperation on an international level to realize its dream to create next generation computing systems.

This document lays the groundwork for an EU-India joint roadmap to enhance cooperation for mutual benefits. Road mapping is recognized as a very important strategic planning tool to forecast the direction, and this document identifies a structured way or approach to define critical technology developments and the associated steps required to achieve major milestones in international cooperation in any given area. Based on past successful examples and collecting inputs from specialists, this deliverable identifies and explores commonalities in research for computing systems that could foster greater cooperation between EU and India. An analysis of Indian and European priorities will be one of the bases for the road map.

This document is a prelude to the Research roadmap report; the information gathered for this report would be partly the basis for the final road mapping exercise in the field of computing systems. The report aims to look at the current research activities, the research focus, the key players and the priority of the Indian government and the initiatives it is taking in the important area of embedded computing systems. The information enables the policy makers and the researchers of EU to have an insight into the research scenario in India. This would indeed facilitate both the European experts and Indian experts to assess the direction of the research, to benchmark the activities in comparison to the European research activities and come up with possible areas for EU-India cooperation. The information congregated in this report would act as a precursor to the objective of the project that is to enhance the strategic partnerships between India and EU in computing systems.

The sections below discuss the various initiatives of the Indian government as well as the activities by private industry and the institutes that are involved in computing systems research.

2.1 Government funded research initiatives

The following are research initiatives that are funded by the Indian government and provide a perspective on the priorities that have been established for existing programmes.

- Centre for Development of Advanced Computing (CDAC) is the premier R&D organization of the Department of Information Technology (DIT), Ministry of Communications & Information Technology (MCIT), for carrying out R&D in IT, Electronics and associated areas. CDAC is a national initiative in supercomputing is the chief architect of PARAM, India’s first ever super computer. CDAC regional centres have widespread presence in all major cities in India. CDAC Bangalore’s research focus is mainly into high performance computing, grid computing, multi lingual computing, health informatics and ubiquitous computing.

- A Centre for Supercomputing facility in Bioinformatics and computational biology at IIT Delhi was created and funded by DBT, DST and CSIR. The research focus of the centre is into genome analysis, protein structure prediction, and drug design.
- A centre for computational biology and bioinformatics (CCBB) is set up at Jawaharlal Nehru University, Delhi. This centre is a part of the 12 centres including the Department of Biotechnology which form the Biogrid 12. The research focus of the CCBB is computational genomics, development of tools in bioinformatics such as core algorithms, system biology, distributed computing, drug target ad drug design, micro analysis and data mining, and structure based bioinformatics, and in silico drug discovery.
- The Supercomputer Education and Research Centre (SERC) at IISc provides excellent opportunities for pursuing advanced research and education in various aspects of Computer Systems, Computational Sciences. The centre provides the state-of-the-art computing environment, which compares well with the top Computing Centres anywhere in the world. SERC is engaged in research programs in areas relating to high-performance systems and applications. The research focus of SERC is broadly classified into two areas, namely Computer Systems, Computational Science. The activities of this centre, the projects it has successfully completed, and the ongoing projects are elaborated in deliverable D3.1 under the key players mapping document.
- IIT Kanpur, IIT Delhi, IIT Chennai, IIT Mumbai, and IISc-SERC are the leading technical institutes with HPC as one of their major thrust areas. Apart from these institutes other HPC facilities which made it to the top 500 facilities in the world include: 1) Computational Research Labs, and 2) Indian institute of Tropical Meteorology. With the exception of the Computational Research Labs, which is funded by TATA Sons, all other facilities are funded by Department of Science and Technology and Department of Information technology and the Ministry of Human Resources Development.

India is also rebooting its efforts in supercomputing with an approved plan of investing €800 million (Rupees 5000 crores) to create next generation supercomputers. The money is likely to start flowing in the 12^{th} five year plan period which commences in 2012. This would be the largest ever grant for a single research programme since independence. This initiative is a direct response to the Chinese challenge to keep up with world aiming to achieve peta flop machines and exascale machines thereon. The Indian Institute of Science is identified to spearhead this mammoth initiative. India's defence, atomic energy, aerospace and space labs with the expertise in design and architecture of supercomputers will be involved to coordinate the project.

2.2 Industry funded research initiatives

The following are research initiatives that are funded by industry and provide a perspective on the priorities that have been established for existing programmes.

- INTEL India: The Systems Technology Lab (STL) is one of the four advanced research units in the Intel Corporate Technology Group (CTG). STL works with Intel's product groups to deliver world-class technologies and system architectures for Intel's future silicon products. Its focus is mainly on multicore platform research, platform infrastructure research, trust and security research.

- IBM India: The High Performance Computing (HPC) group at IBM Research - India is engaged in designing and analyzing cutting edge parallel programs and improving the performance of engineering, scientific, and business applications on high performance platforms such as the IBM Blue Gene supercomputer. The group has the following major focus areas:
  - Optimization of performance on multi-core processors, large-scale supercomputers, and clusters
  - Parallel scalable algorithms for supercomputers
- Cloud Computing is a key area helping corporate giants like Patni Computers, Wipro, Infosys, HCL, Oracle and TCS, as well as many small players to create new business models for cost effective computing systems. These companies are willing to substantially invest to realize the benefits of low cost computing. There is a wide spread of conviction that this technology has huge commercial benefits which cannot be ignored by big as well as smaller companies.

Finally, the international market analytics company Gartner reports that according to their surveys and analysis, Indian private industry priorities are the following:

- Cloud Computing
- Multicore architecture
- Virtualization
- Mobile technologies
- IT Management
- Enterprise Applications

The top priorities for Indian industry research are very much focused on Computing Systems technologies.

The Indian research priorities in Computing Systems and related fields are defined through the analysis of three main programmes:

- National priorities and activities during the current 11th 5 Year Plan period
- India Research Roadmap for the next 5 years
- International Collaborations

Details of each of these are provided in the following sections.

2.3 National priorities during the current 11th 5 Year Plan

The areas in which the Indian IT sector is working on have been captured from various sources such as 11th Five Year Plan from the Government of India, thrust areas of the Department of Information Technology, and thrust areas of the Department of Science and Technology. The Eleventh Five Year Plan for Electronics and Information Technology runs from 2007-2012.

In the wake of changing global service landscape, Indian Information Technology (IT) and IT enabled services continue to chart remarkable growth. The outstanding success of IT and IT-enabled services (ITES) has demonstrated what Indian skills and enterprise could do, given the right environment. Encouraged by the IT skills of the country, to become globally competitive in this area, the Government of India has spelt out the following priority areas for Electronics & Information Technology in the 11th Five Year Plan.

1. Electronics manufacturing for domestic consumption, developing infrastructure and testing labs, investing in Fab facilities.
2. Software Export for banking, insurance, manufacturing, pharmaceuticals, travel-hospitality, animation-entertainment.
3. Domestic Software including e-governance initiatives under the National E-Governance Plan (NEGP), digital signature and cyber security, education & skill development, xDSL & Wi-Max technologies for communication spectrum, increase PC & internet penetration, development and deployment of multilingual products, and Free/Open Source Software
4. Human Resource Development for IT Enables Services (ITES)
5. Research & Development in the areas of Next Generation Wireless Networking and High Performance Computing, Open Systems, VLSI Design, Nano-Technology, and RFID

The priorities and initiatives of the government departments responsible for implementing funded research and development programmes that implement these priorities are described in the following sections.

2.3.1 Department of Information Technology

The core areas identified in the 11th 5 year Plan by Department of Information Technology (DIT) are the following:

- e-Government: Providing e-infrastructure for delivery of e-services
- e-Industry: Promotion of electronics hardware manufacturing and IT-ITeS industry
- e-Innovation/R&D: Enabling Innovation/R&D Infrastructure in emerging areas of ICT
- e-Learning: Providing support for development of e-Skills and Knowledge network
- e-Security: Securing India’s cyber space.
- e-Inclusion: Promoting the use of ICT for more inclusive growth

The Department of Information Technology (DIT) has the mandate of e-Development of India as the engine for transition into a developed nation and an empowered society. The following is the list of organizations under DIT fostering research and developmental activities in computing systems:

- Centre for Development of Advanced Computing (CDAC)
- Education & Research in Computer Networking(ERNET)
- Software Technology Parks of India (STPI)
- Electronics and Computer Software Export Promotion Council (ESC)
- Semiconductor Integrated Circuits Layout-Design Registry(SICLDR)
- Indian Computer Emergency Response Team (ICERT)
- Standardisation, Testing and Quality Certification (STQC) Directorate
- National Informatics Centre (NIC)
- Media Lab Asia

Some representative initiatives currently funded by the DIT are as follows:

- Health informatics, geomatics, high performance computing, multi lingual computing and Agri-electronics are declared as high priority areas with a bouquet of projects in these areas running in the North Eastern regions of the country. Cyber security and Cyber forensics are two other areas DIT has declared as high priority areas to combat cyber crimes and increase security.
- Media lab Asia is another initiative of DIT to address societal challenges in ICT by bringing the benefits of ICT to the common man. It started with the functional activity areas such as World Computer (Affordable, ubiquitous computing and access devices), Bits for All (Low Cost, High bandwidth connectivity) and Tomorrow's Tool (Rurally relevant applications). However, it was later changed to application areas such as ICT for Healthcare, Education, Livelihood and Empowerment of Disabled.
- DIT is funding several projects in professional electronics, VLSI and embedded systems which include design of hard-core circuits, hardware, signal processing algorithms, firmware etc. for electronics products and systems. The R&D work focuses on development and validation of various re-usable Intellectual Property modules applying them in various electronics systems. The broad areas of Power Electronics, Advanced Wireless Communications, VLSI, Embedded Systems, Acoustics and Ultrasonics, Control and Automation Systems are covered.
- DIT has funded many projects on health informatics with CDAC's expertise in a range of telemedicine products, for Open Source, Windows-based, Web enabled and point-to-point, Enterprise specific requirements. Many solutions have been installed in various parts of India including the north east.

Projects and initiatives that are specifically in scientific computing currently supported by DIT are the following:

- Coupled Climate Models on Grids at SERC, IISc, Bangalore, is working on building techniques for the efficient executions of different model components of a coupled climate model on different sets of resources in a Grid Environment and compare the various advantages of Grid executions with the execution of all the model components in the resources available in one site.
- Centre for Advanced Computing Research and Education (CARE) at MIT, Anna University, Chennai, : The scope of work includes researches in Grid environment such as Grid Virtualization, Semantic/ knowledge Grid, Grid Scheduling, Grid resource monitoring, Trusted Grid Computing along with addressing the requirement for producing high quality trained R&D manpower. The project is under progress.
- Development of Analytical Tools for Large Scientific Knowledge Bases, CDAC Bangalore: A project is underway for development of Analytical Tools for Large Scientific Knowledge Bases in Grid Computing Environment at CDAC, Knowledge Park in Bangalore. The objectives of the project are to create Web Based Vedic and Sanskrit Knowledgebase, develop Analytical and Search Capabilities and deployment in Garuda Grid environment. The project is currently progressing at fast rate.

DIT has clearly stated in its strategic plan for the next five years to accommodate and develop a framework for incubation of emerging technologies. Cloud Computing, Green Technologies, Virtualization etc. in various e-Governance projects DIT believes that such an initiative will provide the necessary impetus for continuous development of such technologies in future as well as will help government is saving costs and optimizing infrastructure.

As a part of its implementation plan DIT plans to constitute working groups in dynamically changing technology scenarios who would look into the needs and demands of the sectors. The WG's will be from industry, academic institutions, government societies, associations and consultancy groups. In this framework DIT has identified, FOSS (Free and Open Sourced Software), strategic electronics, telemedicine, and broadband technologies as some of the priority technology areas to have the working groups.

A Technology Development Council was established under DIT. The main emphasis of the Council is in the following areas:

- Facilitate proliferation and absorption of emerging technologies in IT by supporting research and development
- Promote the use of Free and Open Source Software
- Develop and apply state-of-art cost effective indigenous solutions for the important industrial sectors
- Technology development in Bio-Informatics
- Technology development in e-Commerce
- Innovation and IPR promotion

In addition, DIT established the IT Research Academy (ITRA) to build a national resource for advancing the quality and quantity of research and development in IT while institutionalizing an academic culture of IT based problem solving and societal development by closely collaborating teams of researchers and institutions having expertise in the different aspects of the chosen research or application problems. The ITRA focuses on strengthening the nation's competitiveness by expanding the R&D base in IT, especially by leveraging the large IT education sector and IT users such as government, industry and other organizations. The Indian Government with a total budget of 148.83 crore (€20 million) has approved the ITRA programme over a period of 5 years in October 2010.

A further initiative of DIT is the National Knowledge Commission, which has the objective of to transform India into a knowledge-based society. It includes access to knowledge, knowledge concepts, and creation of knowledge, knowledge applications and delivery of services. This will have significant impact on health, education and libraries and several other areas.

In summary, DIT funding priority in computing systems can be broadly characterized as having a clear focus on areas such as supercomputing, ubiquitous computing, HPC and grid computing, multi lingual computing for language translation, high speed data communication networking, general purpose computing and software technologies, tools and applications to address challenges in digital divide, e governance and e-learning.

2.3.2 Centre for Development of Advanced Computing

The Centre for Development of Advanced Computing (CDAC) implements several projects of DIT core areas under funding from DIT. CDAC activities are categorised under broad thematic areas of technology:

- High Performance Computing and Grid Computing

- Multilingual and Heritage Computing
- Software Technologies and FOSS
- Professional Electronics VLSI and Embedded Systems
- Cyber Security and Cyber Forensics
- Health Informatics
- Education And Training

Some of these are described in further detail below.

High Performance Computing and Grid Computing

The emphasis is on designing High Performance Computing (HPC) systems using off-the-shelf components such as CPUs and storage along with in-house designed hardware such as high speed networks and accelerators, system software such as light-weight communication protocols, program development environment, and facility management tools; and a range of application software to solve problems which necessitate a massively parallel computing environment. Integration of several HPC systems with a high-bandwidth backbone network to create a national grid infrastructure is also being pursued.

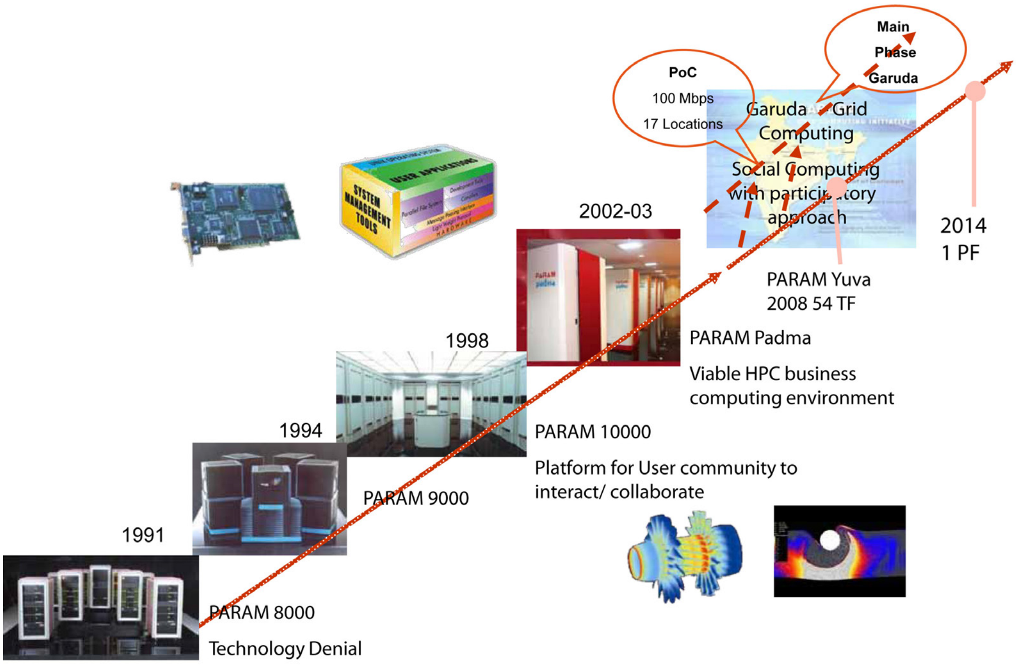

Figure 1: Evolution of HPC @CDAC

GARUDA – India's National Grid of HPC Systems

CDAC has deployed the nation-wide computational grid 'GARUDA' connecting 20 cities Grid GARUDA has evolved from 100 Mbps link to 1 Gbps link with National Knowledge Network. The computing power is 70 Tflops for compute intensive and data-crunching work required in areas such as Bio-Informatics, Disaster Management, etc.

Grid Computing

Service-oriented Grid GARUDA Access Portal (GAP) provide more functionality such as more types of job submission, file management, and integration with GARUDA Storage Resource Manager (GSRM) solution. Essential Services such as login service, job accounting (cpu, memory, etc), compiler service and resource reservation service GARUDA Storage Resource Manager (GSRM) a unified access point for huge capacity distributed GARUDA storage resources, Automatic Grid Service Generator Tool: to convert existing applications or executable files as a Grid Services. PSE for Protein Structure Prediction: Many HPC applications are grid enabled on Garuda, such as Seasonal Forecast Models (SFM) and a Genetic Algorithms (GA) based Problem Solving Environment (PSE) was developed to aid users to work easily with the Protein Structure Prediction (PSP) software.

Biotechnology & Bioinformatics

CDAC is deploying a High End HPC system along with parallel scalable storage and is providing support for porting & parallelization of scientific application software like MPI BLAST, PCAP, SOAP Denovo, GPU-BLAST, bioCLC, ABYS etc. HPC services also comprise computational scientists support at NABI (National Agri Biotechnology Institute (NABI), Mohali). CDAC is establishing a PARAM based HPC System at EIF which will be used for Scientific Research and Parallel programming in the area of Bioinformatics, Computational Fluid Dynamics for Armenia. Anvaya, which literally means ‘logical connectivity’, is a workflow application, capable of executing complex computational genome analysis, by making optimal utilisation of the computing environment. It is a high-throughput genome analysis workflow environment, consisting of bioinformatics tools loosely tied together in a co-ordinated system, along with ‘Rules Engine’ to define logical connectivity. Anvaya is a stand-alone client-server workflow environment that brings frequently used analysis pipelines to user’s desktop. CDAC released a portal named “bioUTILS”. The portal provides an inter-face over BRAF to custom tools and parsers developed in-house.

Open Source Drug Discovery

Open Source Drug Discovery (OSDD) is a CSIR-led global initiative funded by Government of India. The OSDD method tries to collaboratively aggregate the biological and genetic information available to scientists for use to hasten the discovery of drugs for tropical infectious diseases like malaria, tuberculosis, leishmaniasis, etc. GARUDA grid provides an unprecedented e-Infrastructure for OSDD applications. State-of-the-art HPC clusters are provided to run drug discovery problems with NKN connectivity to select OSDD centres.

Green Computing

Power optimization of HPC systems and facilities: The power-aware scheduling algorithm, self-managing system software facilities are being devised at the various centres of the CDAC. Reconfigurable Computing Systems (RCS-IV) card is a small form factor, high performance Reconfigurable Computing based hardware accelerator for speeding-up applications and to save power and space. Cloud services are being developed in order to serve vast computing requirement with optimum number of resources.

Cloud Computing Research

CDAC is working on the 'Pan CDAC Cloud' project with an emphasis to enable applications on the Pan CDAC Cloud, and develop a Scientific Cloud for HPC.

Scientific Cloud for HPC Applications including System Software & Middleware Architecture for Scientific Cloud, Large Data Transactions Handling capability on Cloud, Virtualizations, Licensing Issues, etc. Research is going on for Cloud storage solution, middleware, scientific applications for SaaS on Scientific Cloud.

Private cloud environment is established with open source tools in CDAC and value added components will be developed, customized and integrated in to the cloud. Activity to integrate cloud services is also progressing well.

Multilingual and Heritage Computing

CDAC continuing its efforts towards enhancing the features of already developed tools as well as development of new tools for increased use of IT in Indian languages. These include Comprehensive Indian language support for all computer applications, Machine Aided Translation Systems, Text-to-Speech, Optical Character and Handwriting Recognition, and Indian language software tools to empower the physically challenged.

Software Technologies and FOSS

Development and deployment of software tools, technologies and solutions continued in the areas of e-Governance, Web services, Geomatics, Multimedia computing, Operating Systems, and Digital library. NRC-FOSS related activities aim at establishing and processing viable alternatives to MS-WINDOWS. These include applications, tools, and consolidation of Open Source Software into a single Indian-language enabled CD called BOSS etc.

Professional Electronics, VLSI and Embedded Systems

This area includes design of hard-core circuits, hardware, signal processing algorithms, firmware etc. for electronics products and systems. The R&D work focuses on development and validation of various re-usable Intellectual Property modules applying them in various electronics systems. The broad areas of Power Electronics, Advanced Wireless Communications, VLSI, Embedded Systems, Acoustics and Ultrasonics, Control and Automation Systems are covered.

Cyber Security and Cyber Forensics

To assist in the enforcement of IT Act and to build up expertise in tackling the menace of cyber crimes, CDAC became a major partner of E-Security Division of DIT for research and product development. Major activities are software suite for digital evidence acquisition and analysis by law enforcement authorities, Tools for analyzing network log files, analyzing and reconstructing digital data from sessions of captured network data, Steganography Suite to detect image files with hidden text messages, and Enterprise Forensics and network security assurance products.

Health Informatics

CDAC has a range of telemedicine products, for Open Source, Windows-based, Web enabled and point-to-point, Enterprise specific requirements. Many solutions have been installed in various parts of India including the north east.

Digital Preservation & Green Initiative

A report has been prepared on requirements of Digital Preservation in India by conducting a national level study involving digital preservation experts and other stakeholders. A centre of excellence for Digital Preservation is being set up at CDAC, Pune & CDAC, Noida with an emphasis on developing tools, technologies, standards and best practices for long term digital preservation in India. A project has been initiated at CDAC, Chennai and CDAC, Bangalore to develop ICT technologies for energy efficient and smart buildings with low carbon emissions.

Ubiquitous Computing

The objective of the programme is to create a R&D base in the multi-disciplinary areas of Ubiquitous Computing (UbiComp), resulting in development of core technologies, qualified researchers, development of tools and products to enable realization of Ubiquitous Information Society of India. Under this programme, several projects are being executed by CDAC centres and other institutions. Several UC system components are developed by the implementing agencies in various projects, like - Wireless Sensor Network (WSN), Adaptive Framework for WSN Applications, Sensor nodes, Zigbee based home network and intelligent home artefacts. Applications in agriculture, learning, healthcare and vehicle parking etc., are being tested at lab and fields. Out of the applications developed and deployed, agriculture and vehicle parking were appreciated by various stake holders and further orders for implementing in real applications have been obtained in scaled up configurations. Projects in UC Testbed/ Applications and Real Time Landslide Monitoring have progressed well with useful outcomes.

PARAM system for Weather Forecasting

A project has been successfully completed by CDAC Pune to set up PARAM system at National Centre for Medium Range Weather Forecasting (NCMRWF), Noida and several technological upgradations have been implemented for better storage and operational production data and faster processing in the network environment. A 500 Giga Flop (GF) PARAM- PADMA system with IBM processors, PARAMNet – indigenously developed system area network with 32 nodes, and system software have been installed. At present, several weather forecasting models have been ported on PARAM by NCMRWF with the help of

CDAC. The storage facility of the PARAM system has been successfully and sufficiently implemented.

Free Open Source Software

Free and Open Source Software (FOSS) Initiative Cell has been established with an objective to develop and proliferate FOSS in the country. For example, Bharat Operating System Solutions (BOSS) is a free and open source computer operating system developed by the National Resource Centre for Free/Open Source Software (NRCFOSS) of India. Indian industry/SMEs can benefit from the liberal licensing norms of FOSS which enables software to be freely modified and distributed.

Several milestones have been achieved including indigenized GNU/Linux Operating system BOSS desktop version 4.0 with support for all 22 Indian constitutionally recognised languages and BOSS Advanced Server version 1.0 released for deployment. 27 BOSS Support Centres have been established across the country.

Next Generation Automation Technologies

Under the Automation Systems Technology Centre (ASTeC) Project, development, testing and field trials of Colour Sensing System and Simulation Platform of Modelling have been completed. Other technology modules, developed under this project are offered for field trials. Work on remaining modules, taken up at various participating institutes is completed.

In another collaborative research project entitled "Intelligent Transportation System (ITS) Project" being implemented by CDAC, Thiruvananthapuram as a nodal agency with participation of IIT-Bombay, IIT-Madras and IIM-Kolkata, first National Workshop on ITS project was organized at Pune to create awareness amongst the participants from academic/R&D institutions, industry and user agencies. Development of eight different technology modules undertaken under this project has been progressed. In the newly initiated project entitled "Electronics for Agriculture and Environment (e-AGRIEN)" at CDAC, Kolkata a technology road map has been finalized and projects activities have been started.

Power Electronics

Technology (NaMPET): Through the National Mission on Power Electronics Technology (NaMPET) project, infrastructure required for carrying out research in Power Electronics have been created at 11 leading academic institutes including IITs/IISc and at nodal Centre CDAC, Thiruvananthapuram. As part of collaborative endeavour, twenty projects were jointly taken up for research and technology development by the nodal agency CDAC, Thiruvananthapuram with other academic institutions. NaMPET had supported ten projects. Some of the advanced power electronics technologies developed under NamPET are: Matrix Converter, Full Spectrum Simulator, Universal Front End for Micro Generators using renewable sources, Inverter for Airborne applications, IGBT Gate Drivers, Hall Effect Current Sensor, etc. The NaMPET project has been completed.

Service Oriented Architecture based Standards Compliant e-Learning Framework with Personalized Learning Features - CDAC, Hyderabad:

The objectives of the project are (i) To conceive a service-oriented architecture for standard compliant e-learning framework complemented with web mining and Rich Internet Application technologies (ii) To develop web 3.0 (semantic web) based Personalized learning environment and (iii) To study the interoperable e-learning standard and arrive at possible solution for developing a conversion tool for creating SCORM compliant content. The activity related to Literature survey has been done on the available technologies and their implementation for Personalization. Also the activity related to Exploration of Rich Internet Application (RIA) framework has been completed.

Design & Development Framework for Adaptive Instruction- CDAC Mumbai

The objectives of the project include (i) To develop an open source Framework for Adaptive Instruction (FAI) to deliver instructions in personalized manner (ii) To develop Adaptive Instruction for two sixth standard subjects and two IT courses using the framework and (iii)To set up an adaptive instruction framework server etc. Work is progressing on Design & Prototype implementation of FAI, design of Adaptive Instruction Mark-up language and development of Adaptive Content for one subject of sixth standard.

Video Compression and Decompression for e-Learning - CDAC, Mumbai :- The objective of the project is to improve the performance of video compression and decompression techniques based on H.264 for lower bandwidths (below 128 kbps) and to provide better quality of video and audio at lower bandwidths and lesser latency for E-Learning. Literature Survey has been completed. Work is going on in respect of Experimental set up and exploration of existing H.264 frameworks.

Education and Training

Besides technology development, CDAC is engaged in Human Resources Development in the area of Electronics and Information Technology, with a range of educational programmes. The activities are aimed at enhancing the technical skills of young people at graduate level. Employment-oriented capsule programmes and diplomas in specialized software areas such as Embedded Systems, Geomatics, Cyber security, Enterprise Resource Management, Language Technology and Localisation, .NET, JAVA, JSP, IBM Mainframe, etc. offer value-addition to students and employed professionals to enhance their career prospects. CDAC also offers M.Tech, MCA and MBA Programmes which are recognised by AICTE, and affiliated with reputed Universities. CDAC also offer many short term Diploma Courses viz..: DAC, DSSD, DESD, SCADA, DVLSI.. etc under Advanced Computer Training School (ACTS) [18] programs.

ACTs also conducted many Corporate Training programs for Intelligence Bureau, Police, Defence, Army etc on Computer Awareness programs, information security awareness program. CDAC also involved in organizing many National and International conferences like:

- ADComp
- Think Parallel

- Cloud Computing
- Ubiquitous Computing
- CuDa programming
- Mobile Computing using Android on Intel
- It.Biz
- Indo US joint Collaborations by ERNET

National Informatics Centre

National Informatics Centre (NIC), an attached office of the Department, is a premier S&T organization. It is playing a significant role in using ICT to streamline internal Government functions and facilitating implementation of e-governance. Accordingly, NIC has been engaged in setting up of Internet/ Intranet Infrastructure, preparing IT Plans and developing IT enabled Services including Government 2 Government, Government 2 Business, Government 2 Customer and Government 2 Enterprise portals. A number of major initiatives are undertaken by National Informatics Centre (NIC) for strengthening backend automation and implementation of citizen centric services. E-payment for various Government services, SMS service for sending alerts and updates, e-tendering, e-office, web based counselling for admission into professional courses are some such activities. e-Tendering solution of NIC for various Departments were implemented in a number of States.

Website of National Knowledge Network (www.nkn.in) is launched. 3 Points of Presence (PoPs) have been established with 2.5 Gbps capacity for core Backbone (18 PoPs established so far). A total 38 number of Institutions have been connected to NKN (total 104 Institutions connected so far), and 9 virtual classrooms were setup (a total of 15 virtual classrooms were setup so far). Memorandum of Understanding (MOU) has been signed between (NIC & NICSI) & the service providers namely Bharat Sanchar Nigam Ltd, Railtel, PGCIL & MTNL. Indicative location Map Not to Scale NKN Topology Trans Eurasia Information Network (TEIN3) links is integrated with NKN. Initial set of IP numbers (/16 and /20) and autonomous system numbers from APNIC has been obtained. An MoU has been signed between GLORIAD (The Global Ring Network for Advanced Applications Development), the National Knowledge Network (NKN) and Tata Institute of Fundamental Research (TIFR). Local ring to connect NIPGR, NIPFP, ICGEB, IUAC, NII, and IIMC with JNU has been accomplished. Network Sanitation Lab is being setup at IIT Mumbai, for sanitization of network equipment to be deployed in NKN. The five Model projects recommended by Model Project Evaluation Committee (MPEC) in its first meeting were approved by HLC in its 9th meeting held on 6th August 2010.

2.4 India Research Roadmap – Next 5 Years

The preparation of the 12th Five Year Plan (2013-2018) has progressed following the indicative implementation roadmap to achieve various goals identified by DIT as part of its strategy plan in various topics of IT is as follows:

<table>
<tr><th>Timeline</th><th>Action Items</th></tr>
<tr><td>Year 1</td><td>• Discussion with various stakeholders and constitution of
• different teams to conceptualize in detail the various solutions and policies identified in the IT area
• Taking necessary approvals on various policy initiatives
• from the appropriate authorities</td></tr>
<tr><td>Year 2</td><td rowspan="3">• Program Management of policy initiatives to ensure their
• execution within the stipulated time
• Implementation of policy initiatives in phased manner
• Assessment
• Refinement of policy initiatives</td></tr>
<tr><td>Year 3</td></tr>
<tr><td>Year 4</td></tr>
<tr><td>Year 5</td><td>• Formulation of strategic plan for the next five years</td></tr>
</table>

The Report of the Working Group on the 12th Five Year Plan on Information Technology Sector, which resulted from this 5 year process, provides a roadmap baseline for research related to EU-INCOOP as it has the most details concerning research priorities for Computing Systems technologies.

According to the vision and mission statements about IT sector in the Twelfth Plan will be on:

- e-Development of India through a multi pronged strategy of e-Infrastructure creation to facilitate and fast track e-governance
- promotion of Electronics hardware manufacturing & Information Technology – Information Technology Enabled Services (IT-ITeS) Industry
- providing support for creation of Innovation / Research & Development (R&D), building knowledge network and securing India’s cyber space

The broad areas are:

- e-governance: In the twelfth Five Year Plan, Department of Information Technology proposes to strengthen and extend the existing core infrastructure projects to provide more horizontal connectivity, build redundancy connectivity, undertaken energy audits of State Data Centres (SDCs) etc. Penetration of mobiles will be leveraged
- e-learning: As a part of skill development initiatives, the capacities of National Institute of Electronics and Information Technology, CDAC would be enhanced to generate 10 million skilled manpower by the year 2022 starting from the diploma level right up to doctoral level and in line with the emerging industry/market/society needs.
- e-Security: enhancement of security audit, assessment and certification infrastructure, enhancement of IT product technical security assurance mechanism, etc.
- e-Industry (Electronic Hardware): setting up of a semiconductor fab, providing support to manufacturing across the value chain, providing world class infrastructure through Electronics Manufacturing Clusters, supporting R&D and innovation
- e-Industry (IT-ITeS): sustain IT-ITeS industry’s growth

- **e-Innovation / R&D**: Activities are proposed at all 4 stages of innovation, i.e., idea stage, innovation phase, incubation phase and business acceleration phase. Areas like initiatives on Next Generation Computing Systems/India Microprocessor Development Initiatives, Cloud Computing, a few demonstration projects (like Smart Grid, Solar Village, Indian Satellite Phone) and special initiatives focused for students in the area of VLSI Design.
- e-Inclusion: providing e-accessibility, e-competences, for better access to health, education, and other essential services and programmes of livelihood support to all sections of society.

Complementing the work carried out by the DIT in preparing the roadmap for the next five years is The National Association for Software and Services Companies (NASSCOM) Report entitled "NASSCOM PERSPECTIVE 2020: Transform Business, Transform India", which has identified a set of emerging technology areas which would transform the IT business in India and other markets. These areas include:

- Artificial intelligence
- Cloud computing
- Biometric identification (Security Identification)
- Ubiquitous computing
- Collaborative online interaction
- Pervasive IT security
- Intelligent information gathering and processing
- Flexible IT (Grid Computing)
- Green IT
- Smart Card with PKI protection
- Super Computing application in Fluid dynamics, structural mechanics, bio-informatics, nano-informatics

And finally, the Technology Information, Forecasting and Assessment Council (TIFAC) forecast for Indian Technology Vision 2020 reflects that the following will be the thrust areas in Information Technology for the next few years:

- Networked ATMs for banking and other transactions
- Smart phones for home banking operations
- "Virtual" bank operating from Customer activated terminal (CAT) or a kiosk
- Debit cards
- Smart cards with built-in microchips for electronic cash, pay phones etc.
- Electronic data interchange (EDI) for paperless banking transactions
- Image processing
- Expert systems and neural networks for credit risk appraisal, monitoring/prediction of stock price movement, detection of credit card fraud
- Information security for confidentiality, prevention of data corruption and fraudulent practices
- Multimedia technology & Virtual Reality
- Use of demographic database for age & sex composition, income levels & distribution, regional disparities, fertility & mortality rates, incidence of diseases, life expectancy, etc. would come handy for designing new insurance products & services

These combined sources technology roadmaps and focus areas provide an overview of the research priorities for Indian during 2013-2018.

3 EU Research Roadmaps

3.1 Overview

Europe has a long tradition in developing roadmaps to prioritise and guide the selection of technologies where EU public funding should be allocated. Various processes and mechanisms have been used to develop Computing Systems related roadmaps ranging from European Commission funded support action projects to create roadmaps, to associations that represent public private partnerships (PPP) who establish strategic research agendas, to Networks of Excellence projects providing funding to facilitate the exchange of information amongst experts with a common interest in preparing roadmap documents.

European roadmaps that are relevant to Computing Systems have been developed through each of the following initiatives:

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

The following sections summarises the main elements of the roadmaps that have been developed by each of these European initiatives.

3.2 Research priorities set by European initiatives

3.2.1 HiPEAC

HiPEAC (High Performance and Embedded Architecture and Compilation) is a European Network of Excellence for coordinating research, improving mobility, and enhancing visibility in the computing system field. It covers all computing market segments: embedded systems, general purpose computing systems, data centers and high performance.

HiPEAC is organized in 11 specialized Task Forces:

- Multi-core architecture
- Programming models and operating systems
- Compilation
- Design and Simulation
- Interconnects
- Reconfigurable computing
- Virtualization
- Task force on low power
- Task force on reliability
- Task force on applications
- Task force on education

All activities conducted by HiPEAC, are open to the public. Members of this project are professionals in the domain of embedded systems and high-performance computing.

HiPEAC's open network contains activities such as internships, summer schools, mini-sabbaticals, conferences, workshops and computing systems weeks. Members and HiPEAC partners can affiliate colleagues and PhD-students.

HiPEAC has identified three core computing system challenges which will be important for the future growth of computing capabilities and the societal benefits derived from them:

- **Efficiency:** Efficiency focuses on maximizing the amount of computation we can accomplish per unit of energy and for a minimum cost (both development and production), and is the key for sustaining growth in our computational capabilities.
- **Complexity:** Complexity identifies the need to provide tools and techniques for enabling developers of software and new hardware to leverage increasingly complex systems for increasingly complex applications.
- **Dependability:** Dependability encompasses the reliability and predictability needed for safety-critical systems and the security and privacy demanded for ubiquitous computing.

To achieve these Core Computing Systems Challenges, HiPEAC considers critical to advance the following research areas and topics.

- **Parallelism and Programming Models**
  - **Locality Management:** Scalability and performance require optimizations to keep data local. Locality has been traditionally managed via either shared memory or message passing. The two approaches represent a tradeoff of simplicity to use vs. performance. This gap should be filled by developing new programming models and abstractions which will allow the productivity-oriented programmer to develop correct parallel programs with reasonable effort and at the same time the efficiency-oriented programmer to optimize parallelism and data locality.
  - **Optimizations, programmer hints, tuning:** Despite the research efforts of the past thirty years, automatic parallelization proved very hard to tackle. A promising medium-term solution to unlock significant amounts of parallelism and exploit multiple processing cores is to have programmer provide hints for parallelization opportunities based on their application domain knowledge. However, this approach can cause unexpected side effects between different portions of the code. Further integration is required between the compiler and runtime system to avoid these issues.
  - **Runtime Systems and Adaptivity:** Future runtime systems must address the issue of code portability and optimization across devices with different architectures, such as CPUs and GPUs. These devices require both different binaries and different optimizations. Additionally, the target device may not be known at compile time, or may change at runtime due to load balancing. Runtime systems must be aware of the state of the whole system to prevent oversubscription and conflicts across applications, maintain high performance while controlling the consumed power.

- **Architecture**
  - **Processors, Accelerators, Heterogeneity:** The instruction set architecture (ISA) has changed little in the past decades due to the need to maintain backward compatibility. However, with the move to parallel multicore architectures, the

ISA must be re-evaluated with respect to what additional primitives are needed to assist the development of parallel software and providing support for them at the architecture level.

- **Memory Architectures:** In the near future, core specialization will increase the computation speed relative to memory speed. This suggests that memory latency, as perceived by individual load/store instructions, will remain a problem in the years to come. Moreover, the available memory bandwidth will also be critical in order to fully exploit the potential of future chips with hundreds or thousands of cores. Scaling the memory subsystems in an efficient manner to accommodate the increase in core count is a major challenge.
- **Interconnection Architectures:** Interconnection networks are essential components of computing systems, enabling the communication (a) of processors to their memories, (b) among the levels of the memory hierarchy, (c) processors or compute engines to each other,(d) communication to storage and I/O devices, and (e) intra- and inter-system communication. Although the general principles of switch, router, and network architecture are the same across all levels, technologies and constraints vary widely, resulting in radical differences among networks-on-chip (NoC), chip-to-chip inter-connects, and system, local, or wide area networks.
- **Reconfigurability:** Reconfigurability has the potential to combine software like flexibility with the high-performance ability of hardware. Reconfigurable devices can achieve power/performance ratios which can often be considerably better than a general purpose processor as they adapt to the specific needs of applications. A new generation of efficient architectures, tools, methods, and runtime support are fundamental in order to deploy this technology more successfully in more application domains. These advances will improve ease of programming and reduce the overhead for configurable switching and logic.

- **Compilers**
  - **Automatic Parallelization:** Although multi-core processors have been mainstream for several years, current software development still lags behind, with sequential applications still the dominant program design. The underlying reason for this is that parallel programming is far more difficult than sequential programming. An alternative to manually parallelizing applications is automatic parallelization. However, despite the significant advances in automatic parallelization research, the performance gains from automatic parallelization are disappointing. No automatic techniques exist today that can truly take advantage of the execution power of modern multi-core machines across a wide range of applications.
  - **Adaptive Compilation:** Nowadays programs must run under varying conditions that cannot be known until execution time, such as power constraints and resource contention from other applications, and the end system may span a wide range of systems, including mobile, desktop, and the cloud. In this context, adaptive compilation becomes increasingly important, as applications can be tuned once the final system is known and then re-optimized as runtime conditions change.

- **Intelligent Optimization:** The majority of optimizations in modern compilers have hard-coded parameters and are executed in a fixed order that may not produce the most optimal code for each application or platform. An automatic method is required for learning the best optimizations to run, their order and their parameters for each program on each target system. Recent work has shown how this intelligence can be included in the compiler through the use of machine learning.

- **Systems Software and Tools**
  - **Virtualization:** Proliferation of heterogeneous hardware computing platforms and the need for predictable performance for timing-critical systems is widening the gap between the virtual machine and the physical hardware. This gap creates several challenges for virtualization technology.
  - **Input, Output, Storage, and Networking:** All system input and output interfaces are potential bottlenecks in virtualized environments. In the future, significant improvements are required in their performance to keep up with the increasing number of cores without becoming the bottleneck.
  - **Simulation and Design Automation Tools:** Although many design techniques have been developed over the last decades for the current generation of electronic devices, the soaring complexity of electronic systems will soon require new evolutions in exploration, design and verification processes. To manage the complexity of systems and to reduce the design cycle time, new and more efficient methodologies are needed to create the future generation of electronic devices.
  - **Deterministic Performance Tools:** There is a need to promote the notion of time as a first-class notion across the whole computing stack: programming languages should allow the programmer to express timing constraints, and compilers and virtual machines should enforce these constraints using timing information produced by the hardware. Further, measured statistical timing information should be tied back to these constraints to assist with performance and correctness debugging.

3.2.2 PlanetHPC

PlanetHPC was a two-year FP7 funded Support Action which was launched in 2009. The goal of this initiative was to bring together the major players in European High Performance Computing (HPC) in order to identify the research challenges facing the field and coordinate their activities, strategies and roadmaps.

The key findings of the project are summarized in their 2011 roadmap document titled *"A Strategy for Research and Innovation through High Performance Computing"*. There, they identify the following key industrial and societal applications on which HPC can have a major impact.

- **Design and manufacturing:** This field includes the *Automotive* and *Aerospace* industries, which make heavy use of HPC. HPC could also have an impact on *future manufacturing* of consumer goods and help Europe to be more competitive in this area.

- **Services and utilities:** The *Energy* industry could 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. *Financial services* would also benefit by being able to processing more data streams in real-time. Finally, advances in HPC could create new opportunities in the *Digital Media* industry and establish Europe as a leader in CGI movies production.
- **Quality of life, wellbeing and sustainability:** HPC could have an impact on *Healthcare and Medicine*, as medical science is increasingly turning to computational models to simulate complex experiments in a short time. Additionally, HPC is the key to *Efficient Transport* networks as it can help to both real-time traffic management as well as the planning of expansions to the existing transport network. Similar to transport, HPC can help us make our *buildings safe and efficient* by simulating different scenarios during their design phase, as well as processing real-time sensor data during their lifetime. Finally, it could lead to better *Emergency Response* in case of a disaster, where different strategies need to be rapidly evaluated in order to produce an optimal response to the situation.

Subsequently they outline how they anticipate HPC systems to change in the near future. This introduces additional challenges and restrictions in the research that has to be conducted in the future. The main points they notice are:

- **Scalability:** Applications must be made to scale so that they can use processors in numbers that are several orders of magnitude higher than today. This need becomes more urging by the fact that processor speeds are no longer expected to increase in the way they have in the past, leaving improved parallelism as the main means towards better performance.
- **Availability to business:** HPC must be an easily accessible technology to businesses of all types supporting a huge range of applications.
- **Ease of use:** HPC must become more usable. It should not be necessary to be an expert in HPC to use it in a business context. It must be easy for developers to build and integrate applications based on HPC.
- **Openness:** Developers must not lose the ability to migrate applications to other HPC systems (current and future) with relative ease to avoid vendor lock-in.
- **Power efficiency:** Energy consumption is a major challenge. Continuing to build ever larger machines using today's technology will lead to prohibitive energy requirements.

Finally they outline the topics that have to be researched in order for HPC to be able to have a positive impact in the future on the identified key industrial and societal applications. These topics are mapped in three broad categories as following.

- **Technologies**
  - **Energy efficient computing:** Much work is going on in the embedded systems field to develop low-energy processors, driven by the requirements of the hand-held market. HPC systems must leverage these developments and complement the hardware with energy-aware tools such as compilers and run-time environments.
  - **Multi-core/many-core/heterogeneous computing:** We are rapidly moving towards systems with millions of processing cores. To exploit this massive

parallelism, new programming models, languages and tools are needed. This need is made more imperative by the fact that the available processing cores may be heterogeneous (e.g. general purpose CPU vs GPU).

- **Robust and reliable real-time HPC:** With the ever increasing number of components in HPC systems occasional failures will become more frequent. HPC systems and applications should exhibit much greater degrees of fault tolerance in order to be able to recover from the occasional component failures.
- **Application developer productivity:** Effective development tools have helped developers of enterprise computing applications and embedded systems to dramatically increase their productivity. The HPC community must learn from this, in order to improve its productivity and generate applications rapidly and efficiently.

- **Applications**
  - **New simulation and modelling methods:** Existing simulation and modelling methods have been largely designed with the sequential processing paradigm in mind. Today we are rapidly shifting away from this paradigm. So, in the near future we will need new designs, which will exploit the massive parallelism.
  - **Improved ease of integration:** We need to be able to couple HPC applications together in order to extend their functionality (e.g. simulate multiple phenomena). We also need to devise standards for better integrating HPC applications in existing business workflows.
  - **Data intensive applications:** We are collecting an exponentially increasing volume of data from a multitude of sources: measurements, observations, results of simulations, etc. Because of the sheer volume of the collected data, being able to extract knowledge from them becomes increasingly challenging. Research efforts must be directed towards collecting, storing and curating data and extracting knowledge from them.

- **Accelerating take-up**
  - **HPC & SMEs:** There are plenty of new HPC applications that would benefit SMEs. However, small companies are reluctant in adopting new and unproven technology. New programmes must be initiated to encourage them to exploit HPC infrastructures and applications in order to improve their business.
  - **New HPC access and business models:** HPC community must exploit the opportunities created by the proliferation of cloud computing in order to bring HPC applications to large groups of actors, for whom HPC is currently inaccessible. This will also open new revenue streams towards HPC software owners and service providers.
  - **Migration pathways for legacy applications:** Legacy applications represent a huge investment for many companies. In order to enable such companies to adopt HPC, migration pathways must be provided for legacy applications. This includes either porting the applications to a modern platform or enabling them to run side-by-side with new applications.
  - **Innovation by Independent Software Vendors:** Many ISVs cannot afford to invest in major restructuring or rewriting of their software. They must be encouraged to innovate and participate in co-design with system developers and end-users to ensure knowledge transfer which will lead to systems and

applications which together deliver high-quality results and excellent performance.

- **Awareness raising:** Many end-users are simply unaware of the potential technology disruption that is pending, and believe that it will be business as usual for HPC in the future. Effort must be spent to make them aware of the changing technology landscape so that they are able to timely adapt to it.
- **Break the dependence on dual expertise:** In many domains today there is a reliance on experts with dual expertise (HPC and domain specific) in order to exploit the benefits of HPC. This significantly hinders the adoption of HPC applications. Models of collaboration should be researched that will help us to break free of this dependence.

3.2.3 ARTEMIS

ARTEMIS (*Advanced Research &Technology for Embedded Intelligence and Systems*) is an *European Technology Platform*[1]which started in 2004 and has the mission of creating a Pan-European guideline for the research, technology and innovation in the field of embedded technology. ARTEMIS envisages Embedded Systems playing a major role in responding to the Societal Challenges we face, while responding to the evolution of application markets and the emergence of new technologies. However, instead of striving to address all possible so-called Grand Challenges, ARTEMIS focuses on three specific societal challenges in order to derive the research challenges and prioritize the Embedded Systems research topics addressed in this Strategic Research Agenda. These three societal challenges are:

- **Affordable Healthcare and Wellbeing:** Healthcare is under intensive strain due to demographic and economic challenges - a globally increasing number of patients with chronic diseases - leading to skyrocketing healthcare costs and staffing shortages. This requires novel methods to handle more patients within acceptable healthcare costs while keeping a high quality of care. The healthcare cycle can be made more cost-effective by improving the quality of care and by shortening medical treatment and hospital residence through care at home, early diagnosis and prevention, image guided intervention and personalized treatment supported by validated decision support systems. Application scenarios:
  - Care at home and everywhere
  - Early diagnosis and prevention
  - Image Guided Intervention and Therapy (IGIT)
  - Clinical Decision Support (CDS) systems
- **Green, safe, and supportive transportation:** The world is well aware that transportation, whether automotive, marine, air, heavy-duty road vehicles or rail, is a major contributor to climate change and, in some localities, to the ill health of the local communities. In the ever more interconnected world, there is a global trend

[1]European Technology Platforms (ETP) are industry-led communities with the aim to bring together R&D key players including industry, SMEs, and academics, to identify joint research priorities, and to facilitate the translation of research results into innovations.

towards more mobility, which must be sustainable mobility. The European transportation industry can remain competitive only by leading in green technologies. At the same time, there are increasing expectations for safety. Notwithstanding sustainability concerns, citizens expect more and more mobility at lower and lower cost. Application scenarios:

- Green mobility
- Accident free mobility
- Supportive individual transportation (including elderly people)
- Efficient, clean, safe and seamless mobility

- **Smart buildings and communities of the future:** Both urban and rural communities of the future will heavily rely on large, invisible networks of embedded systems. Embedded Systems networks will combine the individual networks of future homes and offices with the networks of surrounding smart building facilities up to whole cities and regions. The Embedded Systems networks will further collaborate with the information infrastructure of the environment. At the same time, privacy will have to be preserved as far as possible. The city of the future will be spanned by a huge system-of-systems that will enable our society to respond to other societal challenges such as energy management, safe transport, and healthcare. Application scenarios:
    - Mobility for everyone
    - Energy control in the urban and rural environment
    - Security

The developed application scenarios help to break down the complexity of these challenges to manageable pieces and map them to application contexts and technological domains. These application contexts are:

1. **Industrial systems.** This domain contains large and complex systems which embraces automotive, aerospace, manufacturing and biomedical area.
2. **Nomadic environments.** Mobile services and user information access by enabling portable devices and on-body systems.
3. **Private spaces.** Solutions for improved enjoyment, safety and comfort for systems which exist at homes, cars and offices.
4. **Public infrastructure.** Embrace large-scale deployment of systems and services for airports, cities and highways that benefit the citizen.

ARTEMIS aims to overcome the fragmentation created by the bottom-up development and evolution of Embedded Systems by prioritizing research and encouraging coherence, compatibility and synergy of technological developments across these application contexts. The aim is to cut barriers between them, thus yielding multi-domain reusable results and increasing the overall efficiency of technological development. To achieve this, they have prioritized the following research topics in three different areas:

- **Reference designs and architectures**
    - **Composability:** We should be able to compose independently developed components in order to raise the level of abstraction of designing embedded systems. A scalable framework should be developed to support this.

- **Dependability and security:** We need a generic framework that will provide to the designed systems resilience of operation against both accidental component failures and the activity of malicious attackers.
- **Certification:** An independent certification authority and a modular certification mechanism are required for the components that directly interact with the physical world.
- **High-performance embedded computing:** We need to increase by several orders of magnitude the computing power of embedded systems in order to achieve embedded intelligence. Towards this end, scalable multiprocessor computing architectures and systems incorporating heterogeneous, networked and reconfigurable components should be researched.
- **Low power:** The advent of Giga-scale Systems on a Chip will require researching system level techniques for handling the power dissipation of silicon.
- **Interfacing to the environment:** We need to research new ways of interfacing between the embedded systems and the physical environment. The new interfaces should be intuitive for humans to interact with.
- **Interfacing to the Internet:** Communications over the Internet are of limited reliability and timing predictability. We need to research and adopt new communication protocols and control mechanisms in order to adapt Embedded Systems functions to these harsh conditions.

• **Seamless connectivity and interoperability**

- **Certifiable operating systems:** New micro-kernels and hypervisors need to be researched that can be distributed and composed, and support dynamic reconfiguration.
- **Opportunistic flexibility:** Embedded systems should be able to take advantage of their currently accessible opportunities (e.g. network connection to a cloud) in order to dynamically improve the quality of service.
- **Ubiquitous connectivity:** Ubiquitous connectivity schemes need to be researched that support the syntactic and semantic integration of heterogeneous sub-systems, under the constraints of minimum energy usage and limited bandwidth.
- **Self-configuration, self-organisation, self-healing and self-protection:** Computational components of embedded systems should be able to sense their current environment and autonomously cooperate and compose in order to provide services in a particular application context.
- **Perception techniques:** In order to have more intelligent Embedded Systems, their individual components should be able to recognize objects and events. This will also enable distributed monitoring and control of large-scale Embedded Systems.

• **Design methods and tools**

- **Better design tools:** There is a need for novel design tools that can be integrated into the core design process workflow in order to help addressing heterogeneous structures, complex memory hierarchies and improve power efficiency.
- **Certification of mixed criticality systems:** Proposed Embedded Systems designs should be able to be convincingly demonstrated through the development of well structured safety cases.

- **Advanced control algorithms:** For finding the optimal operating points in Embedded Systems that are characterised by non-linear behaviour advanced control algorithms have to be devised.
- **Embedded fault handling:** Embedded Systems should be able to deal with any faults that occur in their operation using model-based fault detection at run-time and associated algorithms for fault tolerance.
- **Design process management:** Designing Embedded Systems may quickly become an unmanageable task. To avoid this we will need models and tools to manage the complexity, product hierarchy, supply chain and information flow during the system design.
- **Open interface standards:** The interface standards for Embedded Systems should be open. Developers of tools that are used to support these standards will only hold intellectual property rights on the specific tools they created.
- **Traceability of component properties:** Attributes of components used in Embedded Systems (e.g. safety and dependability) should be traceable during the development and integration of the system.
- **Product lines of embedded systems:** Embedded Systems should evolve from custom-built creations to product lines of off-the-shelf components that can be picked and adapted for each specific use.

ARTEMIS JU is based in Brussels. It is a public–private partnership between the European Commission, 22 participating ARTEMIS member states and the ARTEMISIA association.

3.2.4 NESSI

NESSI *(Networked European Software and Services Initiative)* is the European Technology Platform dedicated to Software and Services. NESSI was launched in 2005 and aims to achieve impact in the Internet of Services through complementary activities in research, standards, training, education, application and community support. From 2011 onwards, the central element uniting these activities is the *NESSI Open Innovation Environment*, an evolution building on the existing research and strategic results of NESSI and taking into account the context evolution.

The four core objectives of NESSI are:

1. **Achieving interoperability of services:** Services should be easily composed; they should be able to interwork and exchange information via open platforms and standardized interfaces.
2. **Extending and supporting the global accessibility and pervasiveness of services:** Services ought to be accessible everywhere, at any time and on any devices.
3. **Securing software and services and making them trustworthy:** Services must be secure, protect privacy and generate trust and confidence.
4. **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.

In the 2011 update of their Strategic Research Agenda, NESSI highlights the research priorities that will contribute towards achieving these objectives. The priorities are mapped as shown below in five different research areas. It is stressed that these areas should not be considered in isolation since in many cases a multidisciplinary approach is required.

1. **Service usage:** This area is looking at technologies and the ways users can interact with services, and what is needed to improve and to optimize the usage of services. Research priorities:
    - **Personalized, intuitive, and seamless service usage:** Services should adapt to the needs of individual users through automated personalization mechanisms. User Centered Design Human Computer Interaction methodologies should be developed in order to improve services usability in terms of QoS and QoE. At the same time security and privacy concerns should be addressed.
    - **Service usage in a fast changing business world:** The distinction between service producers and service consumers should be blurred by empowering end-users to create services and service-frontends. To achieve this there is a need to provide advanced semantic interoperability in order to enable seamless composition of heterogeneous services.
2. **Service infrastructure:** This area is looking at the infrastructure needed to run services. This includes for example cloud computing as well as technologies helping to reduce resource consumption. Research priorities:
    - **SLA handling in heterogeneous service scenarios:** SLA mechanisms should offer an integrated end-to-end approach across different layers, including services, network infrastructures and devices. They should also be extended to consider other service aspects besides QoS (e.g. security, privacy, interoperability). Finally, high availability and recovery mechanisms should be investigated for complex service infrastructures.
    - **Management for single, hybrid and multi cloud scenarios:** For fully exploiting the potential of the cloud for providing services, its common components should be identified and implemented as standardized building blocks. We should also move towards standardized and open approaches for managing cloud resources, including computing, storage and network resources, in a coherent way and implement monitoring techniques which will allow insights into the cloud, verification the compliance with SLAs and energy-aware cloud management.
3. **Security, privacy and trust:** This area is dedicated to methods and technologies to provide secure and trusted services as well as privacy protection. Research priorities:
    - **Security Usability:** Service security should be easy to use for the users, requiring zero-configuration. Additionally, tools should be provided that allow users to assess services compliance to a particular set of security, privacy and trust criteria. From an administrator's point of view, usable tools should also be provided to enable policy based security management of services and visualization/analysis of monitoring information. Furthermore, the idea of using the cloud to provide Security as a Service should be investigated.
    - **Identity and Trust Management:** There is a need for identity management federation solutions that scale up to Internet size, potentially serving billions of users, devices and ID providers. It is important for such solutions to be open to attract as many stakeholders (e.g. service providers) as possible. In the European

context, the European eID security and privacy policies should be tested and adapted for use by services.

- **Internet cyber security:** New ways should be devised for system-wide security monitoring and analysis at all levels from networking up to services. The potential of the cloud as a facilitator of collaboration among network operators, service providers and governments on security issues (e.g. pro-active defence against DDOS) should be exploited. New security mechanism should be devised for the Internet of Content (e.g. managed data distribution services), Internet of Things (e.g. M2M communication), and the underlying network infrastructure (e.g. mobile networks).
- **Security by Design:** There should be research on security-oriented development environments and their coupling to a broad range of system families (e.g. service-based, internet-based, cloud-based). Additionally, security test environments should be developed, defining widely accepted assurance levels and common guidelines supporting product integrity protection. The security mechanisms should be aware of their context and able to dynamically adapt to it.

4. **Service engineering:** Methods, approaches and technologies needed to design and implement services are covered in this discipline. Research priorities:

   - **Engineering for Future Service platforms:** Future service platforms should be able to exploit context models and provide context-driven adaptation to services. To exploit the cloud potential cloud based development frameworks and platforms for rapid service creation and deployment should be developed. New service frameworks should be flexibility and open to cope with fast business and technology cycles. Service platform should provide data for the long-term usage and the reputation of a service to help both users to choose a service and providers to optimize their service.
   - **Community-based service engineering:** Internet-based development tools should be evolved and extended with new development concepts in order to support a distributed, collaborative style of service development. Frameworks and environments for community-based service provisioning should also be developed.
   - **Engineering complex and adaptive heterogeneous services:** In order to enable service composition between heterogeneous services there should be an automated negotiation mechanism for SLAs and service contracts. There should also be a defined a coherent lifecycle for adaptable and evolvable service compositions with continuous quality assurance after deployment. Approaches should be investigated to provide end-to-end QoS given the QoS levels of constituent services. Finally, adaptation mechanisms should be researched in order to help composed services to proactively avoid critical problems and their incurred repaired costs.

5. **Software engineering:** All technologies which help to develop high-quality, reliable, and maintainable software in a cost-efficient way have to be considered. Research priorities:

   - **Productivity in software engineering:** Design patterns, techniques and tools for specific application domains, together with domain-specific application frameworks and platforms for efficient construction of software and service systems and extensive testing and verification support should be investigated. Modeling and programming languages should be extended to support fault management. Finally, it is important to devise software engineering processes and tools to support the maintenance, evolution and portability of legacy code into new runtime environments such as distributed and virtualized platforms and multicore-based computing systems.

- **New ways to increase software performance and energy-efficiency:** New algorithms and programming paradigms should be investigated to improve performance by exploiting parallel processing capabilities. Languages and tools should also be extended to support parallel modelling and programming in order to enable their widespread use. Methods to engineer energy-aware software to improve power-efficiency of software systems and services should be researched.

4 Analysis of EU and Indian research priorities

4.1 Background

The priorities as well as the current work in Computing Systems stems partially from the strengths of the respective regions as well as the surrounding eco systems that developed during the past 50 years. Also, access to available technologies in both the regions has been very different. India has often been impaired due to unavailability of hardware as well as software to meet the computational requirements of the country.

During the initial years (early 60’s and 70’s) in India due to availability of hardware resources, albeit at a relatively high price, focus was on software and application development. Importantly, most engineering schools brought software development to curricula, which over years, percolated steadily to lower classes. This helped the development of an eco-system in India that was predominantly software oriented. As the hardware technology started developing rapidly in the USA, availability of some of technologies was restricted in India due to a variety of reasons. This then started a plethora of national activities in high performance computing including system design and design of high performance computer hardware. However, development of system elements such as processors, storage devices, and peripheral devices never took a place of importance. System design, software design, and application development were the major focus in India.

In the past decade or so several projects in India have been launched at a national level to address the design of processors, peripherals, and other associated devices mainly for strategic applications. Mainstream computing still depends heavily on components from international sources. System design, verification, software design, security and other applications are at an advanced level and some cutting edge work can be seen in these areas. Services in design of processors, peripheral devices, system-on-chips, their verification and validation, physical design, and tool design are all at a cutting edge level in the commercial sector, with research in these areas being pursued in only a few elite institutions.

In summary, the Indian scene is dominated with research in system, software and application designs with cutting edge services offered in processor and other design areas. It is somewhat less orientated towards research in architecture, processor design, peripheral systems, storage devices, etc.

Creation of HPC infrastructures, e-infrastructures, building exascale supercomputers, are high on the priority list of India. Initiatives in these areas are believed to give an edge in terms of global competitiveness and fuelling economic growth and well being of the nation. HPC in bioinformatics is the next big disruptive research topic India is looking at actively with the establishment Centres of excellence in supercomputing for bio informatics.

In contrast, European research and development has also been extensive in the basic areas of computer engineering as reflected by contribution of major architectures (like ARM), and companies producing silicon such as ST micro systems, Philips and Siemens emerging as major international players. Some smaller companies also did well and have been acquired by some US majors. Also, labs such as IMEC have emerged as power houses of IP development. Initiatives such as DSP valley in Flanders districts of Belgium have contributed significantly to the main stream research and development even in small and medium enterprises. Moreover, major standards such as MP3 emerged from European labs that contributed indirectly to the development of large computing research in application development. While Europe perhaps never reached the commercial scales of production of computing elements like USA, it generated first class and fundamental IPs in areas such as storage, communication and some peripherals. For example the first low power micro and mini motors for magnetic storage emerged from university labs in Europe. Major communication standards such as ISDN, ATM, and GSM that led to computer and communications convergence also emerged from European efforts.

In summary, European efforts in computer engineering have been less skewed than in India, covering all major areas including some fundamental and basic areas. The eco system that has emerged is well rounded and supports almost all areas. However, except for a few examples, these efforts are yet to be scaled to a level that makes it commercially significant providing strong competition towards USA or Japan.

Cloud Computing is the next big thing happening in both India and Europe. In particular, a research study conducted by IDC and commissioned by Microsoft, predicts that Cloud Computing will generate over 2 million jobs in India by 2015. The findings further reveal that Cloud Computing will generate nearly 14 million new jobs worldwide in the same time. More than 50 percent of these jobs are to be generated in the small and medium businesses. Pointing to the strong linkage between Cloud Computing, innovation and entrepreneurship, the study estimates that revenues from cloud innovation could reach US$1.1 trillion per year by 2015. Combined with Cloud Computing efficiencies, this will drive significant organizational reinvestment and job growth.

4.2 Roadmap analysis

4.2.1 Anatomy of a Technology Roadmap

As shown in Sections 2 and 3, both Europe and India have established various technology roadmaps that lay out plans concerning the research and development that should be undertaken within the region over typically the next 4-7 years. These roadmaps have been constructed following different procedures for achieving consensus for their recommendations including committees of government appointed experts, formal government funded collaborative projects that bring together academia and industry, and other variations such as networks of stakeholders focused on shared interests.

In order to analyse and compare the research and development roadmaps produced in each region, it's useful to first understand the components of a typical roadmap to enable a structured approach for analysis and comparison to be utilised.

A research and development roadmap will typically have three main categories of information:

- Motivation
- Technologies
- Actions

The information in each of the categories will have been created using some type of process to obtain inputs from experts and achieve consensus.

These categories may appear in a different order depending on the roadmap, for example "Actions" may appear early on in the roadmap as part of the motivation for the identified technologies to be developed. In general, at least the "Technologies" category and one other category of information appear in every roadmap, while in many roadmaps all three categories of information are present.

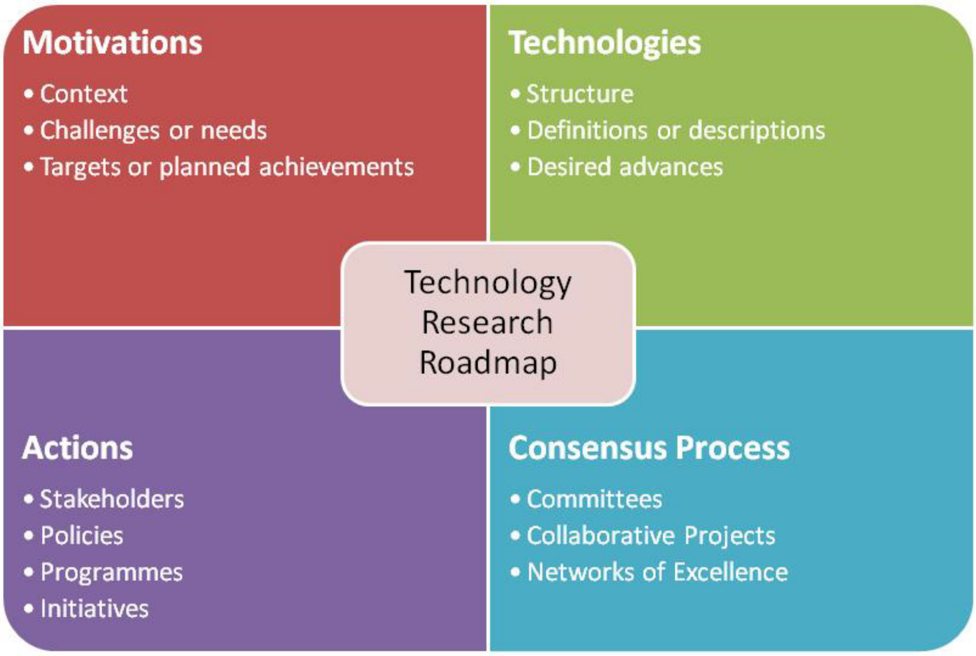

Figure 2: Elements of a typical technology research roadmap

In terms of comparison and analysis of roadmaps within the EU-INCOOP project, the consensus process used to establish the roadmap is not of particular interest, so the focus will be on understanding the Motivation, Technologies and Actions categories as points of comparison and contrast. Details concerning each category of roadmap information are described below.

Motivations

The motivation information includes the elements or factors that explain why a roadmap is needed and what has driven the development of the technology recommendations. It often includes three types of sub elements or details:

- **Context** – refers to items such as the stakeholders, factors or changes that are motivating new technologies, current situations or expected transitions that relate to the technology domain, and societal change and market trends, which merit consideration when planning further research and development or new innovative strategies to be adopted.

- **Challenges or needs** – these will be the specific areas that the new technologies are intended to address. These can be anticipatory reflecting upcoming changes such as population, environment, patterns of usage, etc., or they can be existing shortcomings or needs that new technologies would alleviate.
- **Targets or planned achievements** – these are specific and usually quantified measures, which are associated with the challenges or needs, and used for determining whether the research and development recommendations and any associated actions have addressed the identified challenges or needs.

The degree to which each of these are described will vary depending on the specific roadmap, and also the level of detail provided may be substantially different depending on whether the roadmap is driven from higher level societal challenges, or expected evolution of specific technologies.

Technologies

This is usually the core of the roadmap where the specific research and development recommendations are described. It may not necessarily be the largest part of the roadmap as often the technologies are only listed without details beyond a brief description. As part of the technology content there are typically three types of sub elements of information provided:

- **Structure** – this provides a way of understanding the research and development recommendations and how they relate in some type of grouping that provides focus for the advances to be achieved. Often the structure will follow the architectural elements of the typical system that would be comprised of the various recommended research components. Alternatively, it may be structured by stakeholders such as technologies for software developers, hardware developers, user-facing technologies, networking providers, and so forth.
- **Definitions or descriptions** – these are the specific recommended technologies to be developed during the implementation of the roadmap. They will be grouped according to some structure and are sometimes prioritised, but more often listed without any particular ordering.
- **Desired advances** – the technologies described may in some cases also have specific advances that should be achieved such as increased processing speeds, capacity, energy usage, usability or other measures that indicate the level of advancement or breakthroughs that are expected to be achieved through new research and development initiatives. Desired advances may also be stated in terms of impact the new technologies should have on stakeholders, industries, or regional positioning.

Roadmaps vary widely in terms of the level at which they describe technologies. Some will identify details down to specific technologies to be developed, while others will described the technologies more in terms of capabilities and possibly impact, leaving those involved in research and development to decide the specific technologies to implement that provide the desired capabilities.

Actions

Roadmaps will sometimes identify additional actions that are needed to accompany the research and development of new technologies. These may be directly related to the way the new technology development should be supported or implemented, or may be supporting actions that ensure the new technologies have the desired impact. They may also address non-technical aspects of the challenges or needs described in the motivation part of the roadmap such as support for SME's, or increasing innovation in how new technologies are exploited. Often the section describing the actions will have up to four types of information:

- **Stakeholders** – those impacted or who need to take action in support of achieving the intended impact of the research and development may be identified. Specific actions for different types of stakeholders may be described or more general guidelines indicating the various stakeholders to be considered may be provided.
- **Policies** – actions may take on different forms depending on the roadmap level in terms of context and also the stakeholders that are identified. In general, policies are directed at government actions that need to be put in place in support of the recommended research and development.
- **Programmes** – these are well structured operations that have specific activities and frameworks in which they are intended to operate. Often programmes are described where there are clear actions to be carried out, well defined stakeholders, and a clear ownership of implementation of the programme.
- **Initiatives** – these will often be more exploratory or less formerly defined actions that involve stakeholders in support of achieving the desired impact of the technology research and development recommendations.

Often programmes start off as initiatives, and in many cases new actions are described as initiatives, while continuation of existing actions already underway will be considered programmes.

It's worth noting that some of the sub-elements under Actions are often intermixed with other elements of the roadmaps. For example, actions may accompany the specific technology research and development recommendations, or may be paired with challenges in the Motivation section of the roadmap. Also, some roadmaps don't include any actions as their focus is only to motivate and identify research and development technologies.

Having described the typical elements of technology roadmaps we can use this structure to analyse the different European region roadmaps and contrast these with the roadmap and directions from India.

4.2.2 Comparison: Motivation level

A useful point of comparison for the EU and Indian roadmaps is the motivation behind the establishment of the roadmaps themselves. This provides an indication of the types of issues that the technologies identified in the roadmaps are intended to address, and whether there is common ground from which joint research and development initiatives in Computing Systems might be achievable between the EU and India. By examining the various roadmaps from the EU and India, a scale emerges concerning the level of motivations identified in each document.

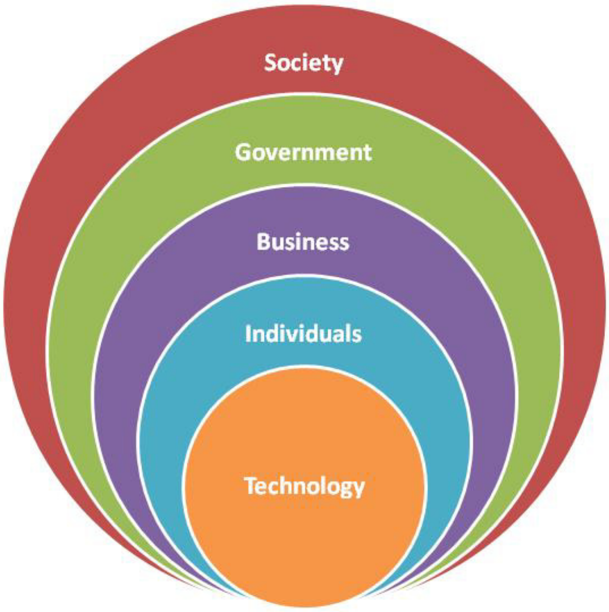

Figure 3: Motivation levels for technology roadmaps

Figure 3 provides a view of the different levels where the roadmap motivations can be positioned. The scale ranges from motivations that have a societal focus to the needs of business and government, to individuals, and at the lowest level, motivations related to specific technologies. In most cases, the motivations of each roadmap relate to expected or desired changes focused mainly at one level, which in turn drives the selection of the Computing Systems research and development priorities identified.

Table 1 shows the motivational statements extracted from each of the EU and India roadmaps. There are significant variations in the level of the motivations that underpin the roadmaps. In particular, none of the motivational levels of the roadmaps are actually the same. ARTEMIS and NESSI are perhaps the closest each having societal needs or challenges as their main motivations.

India	HiPEAC	PlanetHPC	ARTEMIS	NESSI
• Contribute to overall socio-economic growth of the country • Promote R&D for development, commercialisation and manufacturing of products, packages and services • Widen the R&D base in the country, and expand R&D infrastructure	• Complexity arising from multicore • Power efficiency for platforms • Increasing data volumes • Heterogeneous systems	• Scalability to support many-core platforms • Accessibility of HPC technology for business • Usability of HPC for building applications • Migratability of HPC to new platforms	• Affordable Healthcare and Wellbeing • Green, safe, and supportive transportation • Smart buildings and communities of the future	• Sustainable economic and social benefits • Lack of interoperability • Fragmented digital markets • Rising cybercrime and risk of low trust

India	HiPEAC	PlanetHPC	ARTEMIS	NESSI
• Innovation promotion and development of entrepreneurs				

Table 1: Extract of roadmap motivational statements

India's motivations are primarily driven from challenges as perceived from the perspective of government. Motivations relating to improving the country's economic growth, promoting R&D for industry and new products, improving the country infrastructure and encouraging innovation and entrepreneurship, are all objectives that governments typically set for themselves as measures of achievement. The research and development roadmap is therefore driven partly from a motivation of using technologies to achieve the objectives of government, which indirectly is in fulfilment of societal expectations. As the roadmap from India is ultimately prepared by government ministries, it naturally follows that motivations are described in terms of fulfilling government objectives. The Indian roadmap is essentially created based on a top-down approach from policy matters towards implementation.

In contrast, the European roadmaps, ARTEMIS and NESSI, both originate from European Technology Platforms that are supported by the European Commission as initiatives that bring together research and industrial organisations across Europe. The motivation for these roadmaps are mostly societal where ARTEMIS looks at new opportunities for society that technology should enable such as smart buildings or green transport, while NESSI has a mix of societal opportunity and societal issues or challenges that should be addressed.

The HiPEAC and PlanetHPC roadmaps each have technological motivations with HiPEAC motivations being challenges due to the evolution of technologies, and PlanetHPC being more business orientated challenges concerning use of HPC in business settings.

While it's difficult to provide a precise mapping of the roadmap motivation levels as some span more than one level, a representative mapping is shown in Figure 4.

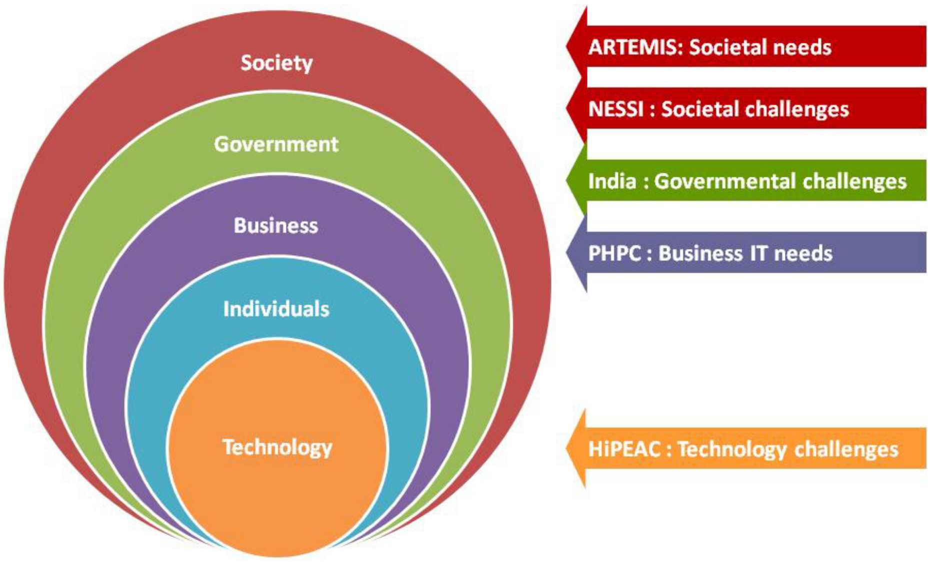

Figure 4: Motivation levels of India and EU roadmaps

Understanding the motivation levels of the existing roadmaps is useful for preparing a joint roadmap between the EU and India for Computing Systems research and development. In particular, establishing a common level between India and the EU will increase the speed at which a consensus can be reached on shared research topics.

4.2.3 Comparison: Context

The context for the roadmaps such as the stakeholders, factors, and issues that are motivating new technologies, and other “setting the scene” statements, provide a useful set of comparisons between EU and India roadmaps. An extract of the contextual references from each of the India and EU roadmaps is shown in Table 2.

India	HiPEAC	PlanetHPC	ARTEMIS	NESSI
• Enlarging the pool of scientific manpower • Strengthening the S&T infrastructure • Attracting and retaining young people in science careers • Flagship Programmes for technological competitiveness of the country • Globally competitive research facilities and centres of excellence • Translate R&D leads into scalable technologies • New models of PPPs in higher education • Catalysing industry-academia collaborations • Linkages with advanced countries	• Energy • Transportation and Mobility • Healthcare • Aging Population • Environment • Productivity • Safety • Security • Education	• Design and manufacturing ○ Automotive ○ Aerospace ○ Factories of the Future • Services and utilities ○ Energy ○ Media ○ Financial • Quality of life, wellbeing and sustainability ○ Healthcare and medicine ○ Efficient transport ○ Safe and efficient buildings ○ Emergency response	• Embedded systems as artefacts of life • Increasing value from embedded intelligence • Dependable and safe operation of embedded systems • Greater public awareness and increasing expectations • Concerns for potential failures and safety, privacy and security	• The connected world – People, devices, sensors, machines, and business get increasingly interconnected in the Future Internet. • Explosion of digital information – The amount of structured and unstructured data is increasing at an annual rate of 57%. • Changing life style – People spend more time online. They not only consume services, but produce increasingly content and even applications. • Fast business and technology cycles – Internet commerce is growing along with falling prices of storage and processing.

Table 2: Extract of roadmap contextual references

In examining the extracts, there is a clear distinction between the India and EU roadmaps in the context that is the basis for preparing the recommended technology research and development priorities. For example, the India roadmap makes direct references to the context for the research and development recommendations being global competitiveness for the region, where such references to global standing are largely missing from the EU roadmaps. It is, however, possible to imply for some of the EU roadmaps context about regional competitiveness from the inclusion of specific industry references where the EU has a strong position in global markets (e.g. automotive, aerospace, etc.).

As was seen with the roadmap motivational levels comparison in Section 4.2.2, context for the India roadmap in many cases relates to targets for government programmes. In contrast, the context for EU roadmaps relate largely to societal or business challenges. It's also interesting to note that HiPEAC and PlanetHPC have quite a few similarities with both referencing specific industries, such as Healthcare, Automotive, Aerospace, and concerns such as security and safety. Likewise, there are similarities between ARTEMIS and NESSI where the contexts for both are stated in terms of trends and societal changes that are either occurring or desired.

From the analysis of the context between India and EU roadmaps, it's clear that one of the first challenges in defining a joint roadmap for India and EU for Computing Systems research will be establishing a common context. At present the only context explicitly stated in the India roadmap that is common with EU roadmaps is "Strengthening the S&T infrastructure". However, the Indian government funded research and development projects and programmes would indicate there is in fact the possibility to establish a wider range of context that is common between the two regions.

4.2.4 Comparison: Targets

The Indian roadmap includes a number of targets to be achieved in implementing the 12th Five Year Plan, and in fact, has too many to list and analyse in this report. The Indian roadmap documents serve not only for setting research priorities, but also in identifying performance measures for government programmes and initiatives in the area of ICT, and other technology fields. In contrast, amongst the EU roadmaps, only ARTEMIS has specific targets stated in terms of quantifiable measures. Table 3 provides a representative extract of the measurable targets that are included in the India and EU roadmaps.

India	HiPEAC	PlanetHPC	ARTEMIS	NESSI
• To provide support to 50 centres for selection of 20 new student innovative ideas by competition per centre. • To provide support to 40 centres each with a grant of Rs 10 crore (1.4 M€) for supporting 20 innovations each. This is aimed towards creation of about 800 IPs. • To provide support to 30-40 centres with a grant of Rs 10 crores (1.5 M€) for grooming 10 IP based ventures at each	No specific targets	No specific targets	• 50% of Embedded Systems deployed throughout the world will be based on ARTEMIS results and will have been developed within the engineering discipline established by ARTEMIS. • Double the number of European SMEs within the aegis of ARTEMIS engaged in the Embedded Systems supply chain, from concept through design and manufacture, delivery and support. • Integrated chain of European-	No specific targets

<table>
<tr><th>India</th><th>HiPEAC</th><th>PlanetHPC</th><th>ARTEMIS</th><th>NESSI</th></tr>
<tr><td>centre. The aim is to have 300-400 IP based ventures.
• To provide support to 10 centres with a grant of Rs 50 crores (8 M€) for grooming 10 IP based ventures. This aims at creation of about 100 global ventures.
• Promotion of Virtual Incubation Centres
• Setting up National/regional facilitation centres for training of Incubates and Incubation Managers
• Setting up innovator Laboratories</td><td></td><td></td><td>sourced tools, based on ARTEMIS results, to support development of Embedded Systems from user requirements, through system design, to system-on-chip production.
• ARTEMIS will generate at least 5 ‘radical innovations’ of a similar paradigm-breaking nature to the microprocessor, digital signal processing and software radio.
• Double the number of relevant patents granted per annum to European companies engaged in ARTEMIS.
• Major educational programmes and technology acquisition programmes will be able to deliver new skills in less than 2 years.
• To close the design productivity gap between potential and capability, ARTEMIS will:
o reduce the cost of system design by 50%.
o achieve 50% reduction in development cycles.
o manage a complexity increase of 100% with 20% effort reduction.
o reduce by 50% the effort and time required for revalidation and re-certification after change
o achieve cross-sectoral reusability of devices for automotive, aerospace, lighting, healthcare and manufacturing</td><td></td></tr>
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Table 3: Extract of roadmap measurable targets

Having specific targets strengthens the justification for undertaking the research and development recommendations identified within the roadmap. While it is not always the case that EU roadmaps have specific targets, the ministries that develop the roadmaps for India are accustomed to including measurable targets and it is recommended that this practice be continued when preparing a joint research roadmap for EU and India.

4.2.5 Comparison: Identified challenges

All of the EU and India roadmaps have identified a set of challenges that new technology research and development are expected to address. These challenges form part of the overall motivational content of each roadmap and often there is a direct mapping between the challenges and the recommended technologies to be developed. Table 4 provides an extract of the main challenges identified in each of the roadmaps.

India	HiPEAC	PlanetHPC	ARTEMIS	NESSI
• Strengthen innovation in product design, development of value added products • Strengthen research Linkages between academics-industry • Capacity Building in research institutes • Infrastructure creation amongst research institutes • Support for Centres of Excellence • Support for Entrepreneurship • Encourage "Made in India" Goods	• **Efficiency:** maximizing the amount of computation per unit of energy. • **Complexity:** enabling developers to leverage increasingly complex systems and applications. • **Dependability:** reliability and predictability for safety-critical systems and security and privacy demanded for ubiquitous computing.	• **Scalability:** Applications must be made to scale so that they can use processors in numbers that are several orders of magnitude higher than today. • **Availability to business:** HPC must be an easily accessible technology to businesses of all types supporting a huge range of applications. • **Ease of use:** HPC must become more usable. It should not be necessary to be an expert in HPC to use it in a business context. It must be easy for developers to build and integrate applications based on HPC. • **Openness:** Developers must not lose the ability to migrate applications to other HPC systems (current and future) with relative ease to avoid vendor lock-in. • **Power efficiency:** Energy consumption is a major challenge.	• Sustainability • Design efficiency • Ease of use • High added value • Time to market • Modularity • Safety/security • Robustness • Competitiveness • Innovation • Cost reduction • Interoperability	• Interoperability of services • Global accessibility and pervasiveness of services • Securing software and services and making them trustworthy • Fast business cycles and increasing productivity by software and services

		Continuing to build ever larger machines using today's technology will lead to prohibitive energy requirements.		

Table 4: Extract of challenges identified in roadmaps

While the choice of wording is different between the regions, and the level at which the challenges are stated also differs, there are some common challenges that appear between roadmaps from the EU and India. For example, the higher level challenges from India in some cases map to the more detailed level challenges identified from the EU. Figure 5 shows one such mapping that can be constructed.

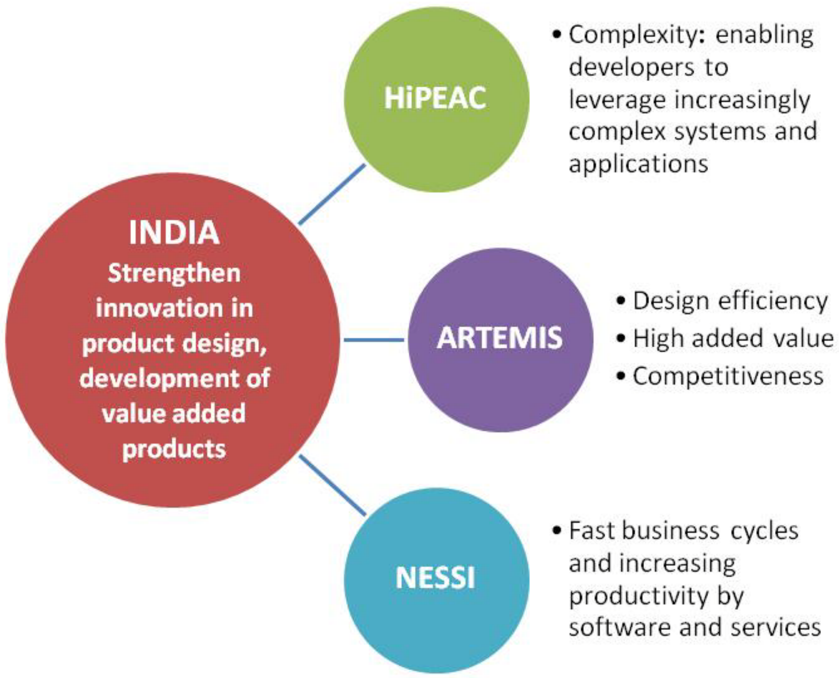

Figure 5: Mapping of India and EU roadmap challenges

The difference in levels between challenges identified in the EU and India leads to a somewhat hierarchical relationship between the EU and India roadmaps in this particular aspect. The higher level objectives are stated in the India roadmap, and a breakdown of the high level challenge into several related sub challenges are identified in the EU roadmaps. Based on this analysis it appears that identifying a common set of challenges for a joint roadmap for Computing Systems research between Indian and the EU would be feasible.

4.2.6 Comparison: Desired advances

There are a substantial number of technology development topics that are common between India and the EU when examining the desired advances specified in the technology sections of each roadmap. Table 5 provides an extract of the main recommendations for new technology research and developments.

India	HiPEAC	PlanetHPC	ARTEMIS	NESSI
• India Microprocessor Initiative ○ Operating system ○ Compiler ○ Platform tools • Operating Systems Initiative ○ Scalability for multicore ○ Dynamic resource management ○ Fault management ○ Large system programming ○ Security • HPC Initiative ○ Petascaling and exascaling of application code ○ High speed networks and accelerators ○ Light-weight communication protocols, ○ Software development environment ○ Facility management tools • System on Chips • Cloud Computing Initiative ○ Multicore HPC ○ Energy efficiency ○ Failure resilience • Ubiquitous Computing Programme • Perception Engineering Programme	• Parallelism • Programming Models • Processors, Accelerators, Heterogeneity • Memory Architectures • Interconnection Architectures • Reconfigurability • Automatic Parallelization • Adaptive Compilation • Intelligent Optimization • Virtualization • Input, Output, Storage, and Networking • Simulation and Design Automation Tools • Deterministic Performance Tools	• Energy efficient computing • Multi-core/many-core/heterogeneous computing • Robust and reliable real-time HPC • Application developer productivity • New simulation and modelling methods • Improved ease of integration • Data handling	• Composability • Dependability and security • High-performance embedded computing • Low power • Interfacing to the environment (machine) • Interfacing to the Internet (human) • Certifiable operating systems • Opportunistic flexibility • Ubiquitous connectivity • Self-configuration, self-healing and self-protection • Perception techniques • Design tools • Certification of mixed criticality systems • Advanced control algorithms • Embedded fault handling • Design process management	• Security Usability • Identity and Trust Management • Internet cyber security • Security by Design • Engineering for Future Service platforms • Community-based service engineering • Engineering complex and adaptive heterogeneous services • Productivity in software engineering • Software performance • Software for energy efficiency

Table 5: Desired technology advances identified in roadmaps

By examining the various initiatives identified in the India roadmap and the related technology research and development topics indicated, it's possible to establish several mappings between Computing Systems research planned for India and similar or related advances identified in roadmaps for the EU. One such initiative is the India Microprocessor Initiative, which involves research and development in operating systems, compiler and platforms tools. Figure 6 shows a potential mapping of topics in India to those addressed in roadmaps from the EU.

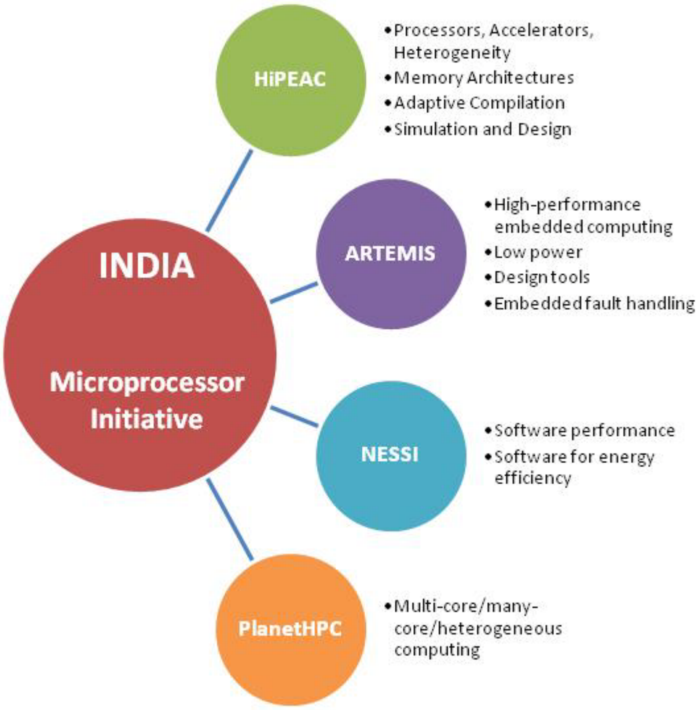

Figure 6: Mapping of India Microprocessor Initiative to EU roadmap topics

A further example is the Operating Systems Initiative in the India roadmap, which includes topics ranging from multicore technologies, to resource management, fault tolerance and security. Figure 7 shows a potential mapping of those topics to those addressed in roadmaps from the EU.

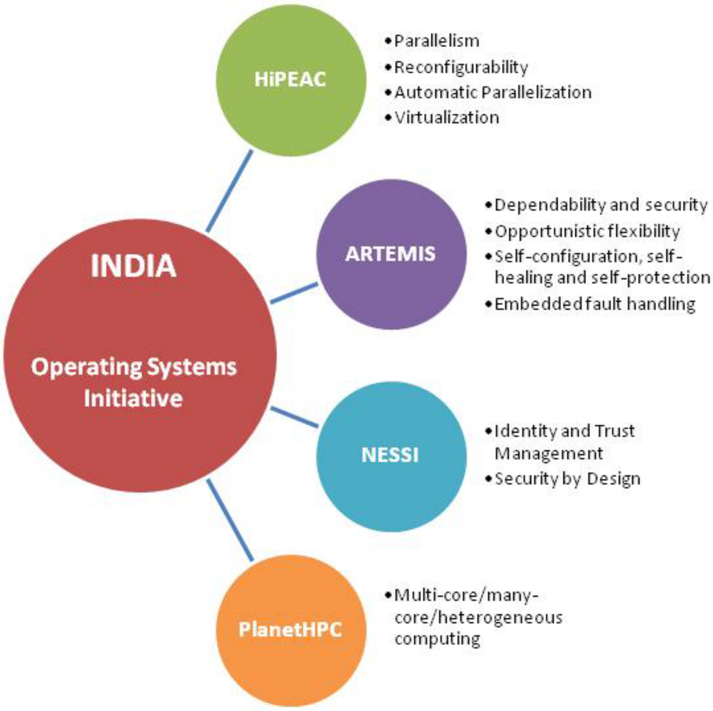

Figure 7: Mapping of India Operating System Initiative to EU roadmap topics

High Performance Computing plays a major role within the India roadmap with subtopics such as petascaling and exascaling of application code, high speed networks and accelerators, light-weight communication protocols, and software development environments. In this case, there are many related topics identified within the EU roadmaps as is shown in Figure 8.

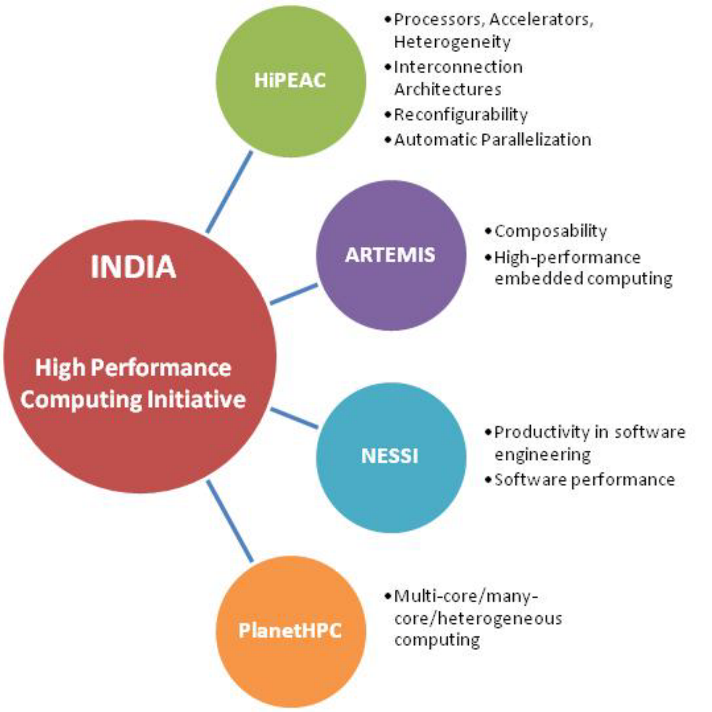

Figure 8: Mapping of India High Performance Computing Initiative to EU roadmap topics

Finally, the Cloud Computing Initiative within the India roadmap includes multicore HPC, energy efficiency, and failure resilience. These have several counterpart topics that are readily identifiable within the EU roadmaps as shown in Figure 9.

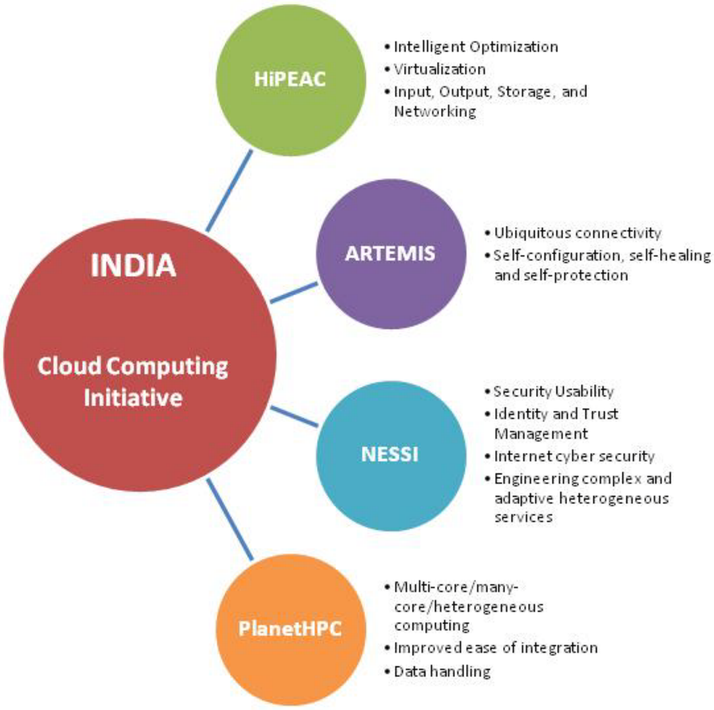

Figure 9: Mapping of India Cloud Computing Initiative to EU roadmap topics

The above examples identified in the India roadmap indicate there are many areas where common Computing Systems research and development topics can be identified between the India and EU roadmaps. The differences is mainly in how the topics are categorised with India tending to focus on initiatives that include a few focused sub topics and EU roadmaps tending to be broader in the number of technical advances that are desired. This may be mostly related to the available funding levels in each of the regions for Computing Systems research.

4.2.7 Comparison: At EU- INDIA Targeted technology level

1. **Building Ecosystems EU and India: Standardization and Interoperability**

India	Standardization for interoperability and data migration is considered an immediate need. Indian research institutes and scientists believe 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. India is actively pursuing the comprehensive standards that will address migration, management, and interoperability among cloud-computing platforms through IEEE Working Groups.
Planet HPC	The roadmap of planet HPC has no reference to standardization and interoperability, the focus of its attention was more towards energy efficiency, new programming models for the next generation computing systems and data intensive applications. Nurturing SME's was considered an important area to build a robust HPC ecosystem.
Artemis	ARTEMIS has identified seamless connectivity and interoperability as very vital challenge for future of Embedded Systems. Its requirements pervade the middleware, operating systems and other functions required to link them to the physical world. The research areas which are of prime importance identified by Artemis are Reference designs and architectures, Seamless connectivity and interoperability and design methods and tools. The technical challenges may be summarized as how to create a consistent architecture for smart environments characterized by three equally important trends: multivendor interoperability, dynamic device configurations and extreme scalability.
Horizon 2020	Standardization is considered very important for interoperability in all ICT and computing systems development. Since standardisation helps marketability of products and solutions, they should be part of any research activities.
SIENA	Standardization and interoperability for e-infrastructure implementation initiative and cloud computing is the single major initiative in Europe closely looking at issues of standardization and interoperability of cloud services with open specifications that deliver customer needs driven competitive markets.

2. Multi core and Heterogeneous computing

India	India is witnessing a clear trend towards multi core heterogeneous computing with an aim to double the number of cores with each processor generation.
Planet HPC	The planet HPC network believes in major investments in new methods for performing simulation and modeling which can exploit parallelism and heterogeneous computing on a massive scale. Programming models, languages and software engineering methodologies must be found to manage and exploit this massive parallelism and heterogeneity.
Horizon 2020	Multi-core technology is understood to be the only way for increased performance and energy efficiency with good architecture model with software for load balancing across multi-core processors.

3. Energy Efficiency and Parallelization

INDIA	Parallelization is believed to be the key enabler of HPC in many applications and one of the most important techniques to achieve energy efficiency of HPC machines is parallelization. Organizations like CDAC, Computational research labs, corporate like IBM, HP and Intel are seriously looking at research in parallelization in pursuit of energy efficiency.
HiPEAC- EU	"Speaking at the conference of The High-Performance and Embedded Architectures and Compilers Network (HIPEAC), Dr Max Lemke, Deputy Head of Unit for Embedded Systems and Control in the Directorate General Information Society and Media of the European Commission, explained that the main goal of the research in computing systems is getting energy efficient and low-cost computing technologies into the full spectrum of devices and systems, from mobile and embedded systems to data centers and supercomputers." This statement corroborated the emphasis HiPEAC has been laying on energy efficiency and low power computing.
IREC	The Catalonia Institute for Energy Research (IREC) is involved in CoolEmAll, a project funded by the European Commission that will attempt to improve energy efficiency in data processing centres. The project aims to deliver better energy efficiency to supercomputers and the infrastructure of data processing centres, which consume enormous amounts of energy and resources. To do so, energy performance will be assessed in the interaction between hardware and heating and air-conditioning systems, as well as the role played by applications in the field of energy efficiency and carbon emissions. CoolEmAll will use two key tools for managing and monitoring energy consumption: monitoring software and a prototype server.
Planet HPC	Energy consumption and limits to processor speeds are major issues that will lead to new computer architectures. A key challenge for the future is to develop low-energy systems and components, and use them effectively within HPC systems. Much work is going on in the embedded systems field to develop low-energy processors, driven by the requirements of the hand-held market. HPC systems must leverage these developments by designing architectures which can use such components. Tools such as energy-aware compilers and run-time environments are envisaged.
PRACE	PRACE is a partnership which has strong interest and commitment towards low cost, energy efficient components for computing.
Horizon 2020	Multi-core processing and software in appropriate architectural models with parallelization can lead to energy efficiency. Hence considered the as the main target and challenge.

4. BIG DATA Challenges

INDIA	India identifies big data or data deluge to be a major challenge in the years to come and the technologies that need to gear up to handle big data are summarized as instrumentation technologies, memory technologies, and visualization technologies to be the key enablers to handle big data.
HiPEAC- EU	HIPEAC identifies challenges that emerge to handle data deluge issues will be of paramount importance. There needs to be major breakthrough in architecture, programming and compilation to handle big data challenges.
Planet HPC	With the volume of data from measurements, observations and the results of simulations rising at an exponential rate, extracting knowledge from data will become an ever more important issue. Research efforts must be directed towards collecting, storing and curating data and extracting knowledge from databases.
Horizon 2020	New business models with Big Data mining to target the products to the target users group is taking shape in a big way. Big Data would be the buzz word in Horizon 2020, and most of the computing business data analysis will be based on Big Data.

5. Cloud computing and Virtualization

INDIA	Cloud Computing is a key area helping corporate giants like Patni computers, Wipro, Infosys, HCL, Oracle and TCS, as well as many small players to create new business models for cost effective computing systems. These companies are willing to substantially invest to realize the benefits of low cost computing. There is a wide spread of conviction that this technology has huge commercial benefits which cannot be ignored by big as well as smaller companies.
HiPEAC- EU	Disruptive technologies such as cloud computing and the convergence of HPC and embedded computing represent opportunities for Europe. The trend towards more distributed environmentally integrated cyber-physical systems could be beneficial to the European semiconductor industry, which has significant expertise in the wide range of required technologies has been recognized as a major opportunity for Europe by HIPEAC.
Planet HPC	Cloud computing is changing the landscape in many commercial and societal applications. The HPC community, in particularly software and service providers must exploit the opportunities this period of change is bringing. This network has cloud computing as one of the technologies that would bring HPC to a wider reach of actors
Horizon 2020	Since cloud computing has big impact on virtual business and social activities, care to be taken in developing computing systems which are trustable, reliable and secure from malicious attacks, to comply with all safety requirements, and to protect privacy. The security issues in cloud computing is one of the main challenge to be addressed.

4.2.8 Comparison: Proposed actions

The roadmap for India and some of the EU roadmaps include a set of supporting actions to accompany the proposed research and development advances. These are generally closely related to the identified motivations and challenges in each roadmap. It's interesting to note that there are similar themes found amongst the EU and India roadmaps with regard to the proposed actions. Table 6 provides an extract of the actions proposed in each roadmap.

India	HiPEAC	PHPC	ARTEMIS	NESSI
• Separate Electronics Development Fund to incentivize R&D where Government and Industry bodies are the stakeholders. • IPR promotion programme covering education, awareness creation, IP exchange, related technology development and support to SMEs & start-ups. • Innovation promotion by providing financial support to start-up companies. • Preferential procurement policy to encourage manufacturing of electronic/IT products with Indian intellectual property. • Holistic approach for funding socially relevant R&D projects in Public Private Partnership (PPP) modes.	None proposed	• SMEs must be encouraged to take up technology. • New access and business models must be explored. • Migration pathways for legacy applications must be found. • Encouraging innovation by Independent Software Vendors. • Raising awareness of the changing technology landscape. • Break the dependence on dual expertise (HPC and domain specific) • HPC pilot networks which stimulate the HPC solutions marketplace. • Research & development activities, which stimulate technology development in the HPC domain, and transfer of technology to the HPC domain from other computing domains and constituencies. • Visioning, roadmapping and constituency-building activities, which prepare a long term strategy for R&D&I initiatives under Horizon 2020.	• Creating new innovation eco-systems • Aligning Research Agendas for Embedded Systems in Europe • ARTEMIS repository • Centres of Innovation Excellence • Standards for Embedded Systems • Tool Platforms • Regulations, safety, security and digital trust certifications • Intellectual Property Management • Open Innovation and Open Source policy • Industry-Academia Collaboration • Research Infrastructure	None proposed

Table 6: Proposed actions from roadmaps

Themes that appear in actions proposed in both EU and India roadmaps are the following:

- Raising awareness
- Societal applications

- Encouraging innovation
- Support for SMEs
- Assistance in intellectual property management

These themes of common interest in supporting actions would indicate that a joint roadmap for Computing Systems research between India and the EU could likely include recommended support actions.

5 India EU Cooperation

Several ongoing projects to promote S&T cooperation between EU and India should be considered when developing a joint roadmap for Computing Systems research for India and the EU. These projects have important inputs and in some cases have identified joint initiatives in other ICT areas and their experiences are likely to prove valuable as the EU-INCOOP project progresses its roadmapping activities. The relevant projects are identified below along with a short summary of the objectives and expected outcomes.

INDIA Gate Program

The main objective of the INDIA GATE project is to increase the S&T cooperation between India and the EU by creating a "one-stop shop" for funding opportunities that are available in India for European organisations. The S&T agreement between India and EU recognizes the mutual benefit of access to respective funding programmes, and while several initiatives exists to support Indian organizations' participation in the Seventh Framework Programme, INDIA GATE aims to play a similar role for European organisations who wants to benefit from RTD funding sources from India. The INDIA GATE project will identify Indian research and innovation funding programmes, the obstacles that inhibit EU researchers and organizations from taking part in the identified opportunities and make the information available in a user-friendly manner to stimulate, encourage and facilitate participation.

The strategic objectives of INDIA GATE are to:

- Map and identify funding opportunities open for European organisations in India with a focus on their reciprocity character, rules of participation and funding rates
- Analyse the obstacles for participation with focus on their reciprocity conditions
- Review the bilateral agreements between EU Member States and India
- Improve the flow of information on programmes and funding opportunities (Initiatives of the Government of India, Bilateral Programmes) designed to support scientific and technological cooperation between the EU and India
- Enhance know how on cultural differences in business conduct and working style via an user friendly e-training
- Identify and demonstrate mutual understanding, interest and benefit in S&T cooperation between the EU and India
- Monitor the participation rate of European organisations in Indian funded programmes
- Develop feedback and recommendations for decision makers and provide expert input to the Joint Committee meetings
- Increase the mutual understanding of respective research systems

List of Partners

- Agency for the Promotion of European Research, APRE, Italy
- Foundation for Research and Technology Hellas, FORTH, Greece
- Council of Scientific & Industrial Research, CSIR, India
- Europa Media, EM, Hungary
- EIRC Consulting Private Limited, EIRC, India

- The Brussels Enterprise Agency, BEA, Belgium
- Indian Institute of Foreign Trade, CITT, India

Contact details of Co-ordinator of "India Gate Program" Name: Mrs Diassia Dimaggio,Phone: +39 06 48 93 99 93 ,Email: dimaggio@APRE.it

Website: http://www.access4.eu/india/

EU-India Grid 2

Europe and India are collaborating to exploit the vast potential of global e-science infrastructures through Grid computing in order to address global challenges such as climate warming and disease.

The goal of grid computing is "to provide a service-oriented infrastructure that leverages standardized protocols and services to enable pervasive access to, and co-ordinated sharing of geographically distributed hardware, software and information resources". The original aim has been pursued over the years and the numerous achievements have led more and more research institutes, governmental organizations and enterprises to adopt grid technologies in their activities.

In this domain Europe has a long term coordinated and shared vision, mission, and strategy road map and funding, driven by EC's FP. Europe has embraced the notion of a 'world wide grid for research' as expressed in the e-infrastructure's reflection group white paper. For Europe, the 'world wide grid' will form the basis of the information and knowledge society by enabling many diverse elements such as:

- Virtual collaborative environments;
- Tools for education and research,
- Planning and simulation,
- Tools for complex problem solving,
- Virtual environments for medical treatment,
- Storage and analysis of high resolution data, pictures and video,
- Providing access to massive scientific databases for disciplines from bio informatics, and bio chemistry to meteorology, physics, and astronomy and non-scientific databases for cultural heritage, museum collections and many more.

Similarly, in India, GARUDA, the National Grid initiative and the NKN plan represent the clear indication for a government strategy addressing the main needs of education, R&D by the use of ICT distributed resources. The EU-India Grid2 project bridges European and Indian e-infrastructure to ensure sustainable scientific, educational and technological collaboration.

EU- India Grid Target results include interaction with 4 user communities: climate change, high energy physics, biology & material science.

6 Next steps

The EU-INCOOP project will be preparing a proposed roadmap identifying research topics to be jointly carried out between India and the EU in the area of Computing Systems. Key to preparing the proposed roadmap is a combination of brokerage events between India and EU academia and industry representatives from both regions, and inputs from a select group of experts who have been invited to form the EU-INCOOP Research Roadmap Advisory Board.

The following table provides the profiles of the expert members of the Advisory Board from India and Europe.

Name, Title, Organization and Country	Expertise to contribute EU-INCOOP
Dr G V Ramaraju - Head nano division, Ministry of information technology- Delhi- India	Dr Ramaraju is the current head of the Nano Technology division at the Department of information technology. He has administered several projects in computing systems and Information technology with leading institutions. He is currently the program committee member of the US - India Network enabled research collaboration. He is the additional charge of the IT Research Academy Division. He has over 20 years of experience in policy formulation and research project administration. His experience and strong connections within the department and with leading institutions of India brings in invaluable benefits to the project EUINCOOP.
Shri Raj Singh- IC Design Group Center for Electronics Engineering Research Institute, Pilani Rajasthan	Shri Raj Singh has over 24 years of experience as a Chief Scientist at the Center for Electronics Engineering Research Institute (CEERI- Pilani) Rajasthan. He is also the nodal officer for Information Technology infrastructure, networking and cyber security. He has held various positions in the industry, he is currently involved in structuring curricula in computer architectures and embedded systems. He has coordinated several of the Department of Electronics and Department of Information technology sponsored projects on reconfigurable micro systems and multi material desktop computing capabilities. Amongst other roles he is also the adjunct faculty at the Birla Institute of Technological Sciences , Pilani. His rich experience and contribution to the IT sector will provide the project EUINCOOP with a strategic vision in identifying topics for EU- India Collaboration and providing guidance to the project.
Professor Sanjeev Agarwal- Department of Computer Science Engineering, IIT Kanpur, Kanpur India	Professor Agarwal has over 25 years of rich experience in teaching, research and coordinating industry oriented projects. His research interests mainly

Name, Title, Organization and Country	Expertise to contribute EU-INCOOP
	include Grid computing, multi core architectures, high performance computing, programming and scheduling Grid/Cloud technologies. His interaction and implementation of projects with major IT industry giants like Intel, Sun micro systems, British Telecom, Wipro and the Government gives a rare advantage of bringing in Industry, academia and government perspectives and priorities in computing systems. He has several publications related to his research interests to his credit. He is one of the architects of implementing the Special Manpower Development programme in VLSI. He has several accolades to his credit. He is member of various committees in computing systems including the HiPC, Distributed and parallel computing, Computer Society of India and IEEE and its computer society.
Professor R Govindrajan- Chairman Supercomputer Education and Research Centre, IISc- Bangalore	Professor Govindrajan is the current Chairman of the Supercomputer Education and Research Centre, Indian Institute of Science. He is widely experienced academician and a known name in computing systems research; his current research interests include High Performance computing using general-purpose architecture, Compiler analysis and Compiler Transformation and Process architecture. He has executed several government and private funded projects and was instrumental in building connections with the Industry and Government. He has over 100 publications to his credit and several years of teaching experience in high performance computing, modelling and simulation and computer architectures.
Acting Global Manager- Technology Entrepreneurship & Head, South and West India, Corporate Affairs - Intel India	Manav Subodh joined Intel Corporation in 2004. He lead Intel's university & innovation programs with an objective to foster academia and government linkages in technology areas of strategic importance to Intel & the industry. His main charter was to a) Expand the R&D capabilities in academia (b) Build skilled pipeline to meet the IT workforce requirements of the industry and (c) Develop the technology ecosystem to support new technology adoption. He represented Intel in various industry & government forums and works closely with them to drive a change in the ecosystem. Manav lead several public private partnerships (PPP) for Intel's university programs. Manav was instrumental in driving significant impact out of the Multi Core university program in engineering schools of India. These initiatives led to 242 engineering schools in India to change curriculum & go Multi Core. He has also led the first of its kind PPP model in India on Innovation, Research & Technology entrepreneurship with Department of Science and Technology (DST), Govt of India & Indo-US Science and

Name, Title, Organization and Country	Expertise to contribute EU-INCOOP
	Technology Forum (IUSSTF). He also drives Intel's Global Technology entrepreneurship programs in emerging countries; create partnership models with local government, US universities and multilateral agencies. Prior to joining Intel, Manav was with Hughes Network Systems. He is an engineering graduate in Electronic and telecommunications and has done a Masters in Business Administration (MBA).
Professor Neeraj Suri-Dependable Embedded Systems & Software Dept. of Computer Science (Informatik) TU Darmstadt Darmstadt, Germany	Professor Neeraj Suri has interacted with Indian universities and R&D institutions for the last two decades. He has held multiple seminars at IIT-Delhi, Mumbai, Kharagpur and government/industry & research centers for advocating joint EC-Asia Embedded Unit activities. He has wide range of contact with Indian academia (IIT-Delhi, Mumbai, Kharagpur), IIIT-Delhi and industry (GM, Yahoo Labs, Motorola, TCS, Robert Bosch etc) and is currently guiding 4 Indian Phd students. He is involved in several EU FP7 funded projects in computing systems such as (NextTTA, DECOS, ReSIST, DBench). By virtue of executing industry sponsored projects, Prof Suri has established longstanding relationships with US and European companies such as Volvo, SAAB, Microsoft, Intel, US Defence and NASA . Prof Suri has several publications and award to his credit. Prof Suri wide experience and contribution in the field will greatly benefit EUINCOOP project to lay out a well defined vision and road map between EU and India.
Professor Luciano Baresi- Politecnico di Milano, Italy	Prof Luciano is an associate professor in the Department of Electronics and Information at Politecnico di Milano, Italy. He was a visiting researcher at University of Oregon at Eugene (USA) and University of Paderborn (Germany). In addition, Luciano is a member of the editorial board of Service Oriented Computing and Applications (published by Springer). He was program co-chair of ICECCS, STEP, and ICWE ICSOC. Luciano has authored some 100 papers in international journals and conferences on Various Aspects of software engineering. Present his Research interests are in dynamic software systems, service-oriented applications, and software architectures. Luciano has a PhD in computer science from Polytechnic of Milan. He is the Chair and member of the IFIP working group on service oriented architectures. He is currently the Program Chair for the SEAMS 2012, symposium and the ICSE 2012 conference in software engineering.
Dr-ING Stefan Wesner- High **Performance Computing Center (HLRS), Stuttgart- Germany**	Dr Stefan wesner is currently the managing director of High performance computing center, Stuttgart-germany, he is alos the Head of the Department of

Name, Title, Organization and Country	Expertise to contribute EU-INCOOP
	Applications and visualizations. In addition to performing these roles, Dr Wesner is the principal investigator of the HLRS centre whihc is a part of the Partnership for Advanced computing in Europe (PRACE). He is the Pi for many large scale distributed computing and Grid projects such as the BRIEn, BEinGRID, IRMOS and CHALLENGERS, TiMACS, and national projects IMEMO. His research interests include grid computing and cloud computing. His experience in establishing centre and realizing the dreams of the PRACE technology platforms is highly valuable for a project like EUincoop to further its objective of defining EU-india research roadmap.
Professor Terrence Fernando -University of Salford, UK	Professor Terrence Fernando (University of Salford) is the Technical Manager of the CoSpaces project and the leader of Cluster 3 (Collaborative Workspace Applications). He is the Director of the Future Workspaces Research Centre at the University of Salford and the Director of the North West Research Centre for Advanced Virtual Prototyping, which is a regional multi-disciplinary research centre involving several research teams from four prominent Universities in UK. He has a broad background in conducting multi-disciplinary research programmes involving large number of research teams in areas such as distributed virtual engineering, virtual building construction, driving simulations, virtual prototyping, urban simulation, and maintenance simulation. He has successfully completed several national and European projects and currently co-ordinating the Future_Workspaces roadmap project. As a part of this roadmap project, Prof. Fernando has brought together over 100 companies and research centres, from areas such as aerospace, automotive, building construction, multi-modal interfaces, system architecture, networking, human factors etc, to define a 10 year European vision for future collaborative engineering workspaces. His multi-disciplinary background, experience in technical management, strong links with industrial partners and the leadership in developing the Future_Workspaces roadmap will be invaluable in providing a strong technical leadership within the EUINCOOP project. He is also playing a key role in the MOSAIC SSA and the INTUITION NoE to develop future research agenda for collaborative work environments.

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  - www.artemis.eu
- ARTEMIS-IA
  - www.artemis-ia.eu
- ARTEMIS-JU

- www.artemis-ju.eu