

## **H2020-FETHPC-2014**

### **Coordination of the HPC strategy**



#### **EXDCI**

#### **European eXtreme Data and Computing Initiative**

**Grant Agreement Number: FETHPC-671558**

#### **D6.2**

#### **Analysis of international collaboration opportunities for the European projects**

***Final***

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## List of Acronyms and Abbreviations

BDEC	Big Data and Extreme-scale Computing
BDV	Big Data Value
BDVA	Big Data Value Association cPPP
BOF	Birds-of-a-Feather Session
CoE	Centres of Excellence for Computing Applications
cPPP	contractual Public-Private Partnership
D	Deliverable
DoW	Description of Work
EC	European Commission
EPCC	Edinburgh Parallel Computing Centre
EsD	Extreme-Scale Demonstrators
ETP4HPC	European HPC Technology Platform
EU	European Union
FET	Future and Emerging Technologies
FP7	Framework Programme 7
H2020	Horizon 2020 – The EC Research and Innovation Programme in Europe
HPC	High Performance Computing
ICT	Innovate, Connect, Transform
ISC	International Supercomputing Conference
M	Month
MoU	Memorandum of Understanding
MPI	Message Passing Interface
NWP	Numerical Weather Prediction
PMO	Project Management Office
PRACE	Partnership for Advanced Computing in Europe,
Q	Quarter
R&D	Research and Development
RIKEN AICS	Advanced Institute for Computational Science, Japan
ROI	Return On Investment
SC	Supercomputing Conference
SKA	The Square Kilometre Array project.
SRA	Strategic Research Agenda
TRL	Technology Readiness Level
US	United States
WG	Working Group
WP	Work Package



## Executive Summary

During the first year of its operation, Task 6.2 of EXDCI (*Facilitate International Collaboration Opportunities*) has achieved its principal objective according to the Description of Work (DoW): to increase the international collaborations that will be set up between the European projects and actions occurring outside Europe, i.e. it has **established an effective process** for the further development of the international collaborations of the Technology Pillar of the European HPC Ecosystem.

This document reports on the progress of developing international collaborations for the European HPC Technology Projects<sup>1</sup> and analyses the future potential of developing these collaborations, rather than identifying all the existing opportunities in this area. This is because during the period covered by this Deliverable, the Projects were in their early stages. The next Deliverable (D6.3 Final international identification report) is due in Month 30 when the Projects will be mature and will have produced tangible results. It will, therefore, present a complete analysis of this topic.

This work is being carried out by ETP4HPC, the European High-Performance Computing Technology Platform, in the context of the EXDCI project. ETP4HPC represents the European HPC Technology Value Chain and issues a Strategic Research Agenda (SRA), a multi-annual roadmap for HPC technology development in Europe, the guidelines of which are used to define the contents of the European Commission's HPC Technology R&D Work Programmes. The current European research programme, Horizon 2020, comprises of projects aiming to develop cutting-edge HPC technology. These projects, together with projects funded by previous programmes, present a number of opportunities for international collaboration with similar or complementary initiatives in other regions.

**As a result of Task 6.2 to date, there is an established and recognised presence** of all the European HPC technology projects at the world's largest HPC-related conference (Supercomputing Conference, SC). In particular, we are pleased with the success of the first Birds-of-a-Feather (BOF) session organised at SC'15, which attracted over 120 attendees. We have also produced a **European HPC Technology Handbook**, which includes up-to-date information on all the Projects – an up-to-date version of this document and other related material is available on a web page dedicated to this task <http://www.etp4hpc.eu/euexascale.html>. We have approached the most prominent regions in HPC technology development in order to obtain updates on the work taking place in those countries. These actions will help the Projects develop their international collaborations as they mature and produce tangible results. International<sup>2</sup> partners can also access the ETP4HPC networking tool at <http://www.etp4hpc.eu/en/networking.html> in order to contact the members of the association.

The key conclusions of our assessment of the international collaboration opportunities for the European HPC projects are as follows:

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<sup>1</sup> The term 'European HPC Technology Projects' (hereafter referred to as 'Projects') includes all EC-funded European research and development projects producing HPC technology, regardless of the EC programme used as their funding instrument.

<sup>2</sup> The term 'international' in this document is used to refer to 'non-European' (i.e. foreign or overseas) projects from outside of Europe.

## **D6.2 Analysis of international collaboration opportunities for the European projects**

- The Projects are open to international collaboration opportunities and willing to engage in activities in order to facilitate this process. Likewise, the international community has demonstrated high level of interest in the results of the European projects.
- There are a number of areas where cooperation seems possible, and the Projects are able to identify these areas and pinpoint potential partners in both academia and industry. Some projects have already started work involving international partners.
- The European HPC Ecosystem should further facilitate this process by identifying areas of priority where European and overseas projects could jointly contribute to the goals of the international HPC community and organise e.g. common workshops in selected areas and research visits ((in particular in the area of Programming Tools), leading to joint calls and other funding mechanisms. Also, a clear dissemination plan is needed in order to help the Projects reach the appropriate partners.

**The following web page is constantly being updated and it contains up-to-date** information on this initiative and related developments: <http://www.etp4hpc.eu/euexascale.html>.

# 1 Introduction

The objective of Task 6.2 is to Facilitate the International Collaboration Opportunities of the European HPC Technology projects. This particular document reports on the work done from the start of the EXDCI project until Month 11 (Aug 2016), and aims to deliver an ‘Analysis of international collaboration opportunities for the European projects’ as of the end of this period. This work is being carried out by ETP4HPC on behalf of EXDCI and in some of its parts it is a continuation of previous activities of ETP4HPC.

The work carried out within this task aims to support the international collaborations that could be set up between the European projects and actions occurring outside Europe. It aims to:

- Help the European HPC Technology Projects connect with other similar or complementary initiatives around the world;
- Present the Projects, with a view to facilitating the initiation of international collaborations;
- Determine what mechanisms could facilitate collaboration between these projects and potential overseas counterparts.

This task **federates** the efforts of European HPC in this area by ensuring a single interface for all the projects.



**Figure 1 - During proceedings at our SC'15 BOF - the main tool used to date to promote the European HPC technology projects beyond Europe<sup>3</sup>.**

In this document, we first describe the **Background** of the work carried out in this task: the European HPC Ecosystem, the role of ETP4HPC in it, and the Future and Emerging Technologies – HPC research programme. Next, we explain the **Process** selected to deliver the objectives of this task. The following two Chapters outline the **Implementation and Results** of the work and the **Future Actions** planned. The last Chapter contains the **Conclusions** of this task.

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<sup>3</sup> See also Chapter 4.1.1

## 2 Background

### 2.1 The European HPC Ecosystem and its strategy

The current European HPC Strategy was first defined by the European Commission in a publication titled: 'High Performance Computing: Europe's place in a Global Race' [1] issued in 2012 and adopted by the European Union as an official strategy document in 2013 [2].



**Figure 2 - This 2012 document first defined the European HPC Strategy; HPC Technology is one of the three pillars of the entire Ecosystem.**

This document recognises the value of HPC for the European economy and society. The European HPC Ecosystem aims to develop world-class HPC technologies, platforms and applications, leading to the eventual production of Exascale systems, and promoting their use for advanced research. This will create jobs, enable scientific discoveries, and allow companies to become more efficient. All of this in turn will contribute to the economic competitiveness of the European economy as a whole, and also, to the well-being of the European citizen by equipping our scientists, economists, sociologists, agriculturalists, politicians and engineers to address the Grand Societal Challenges that the continent faces.

The strategy stipulates the need for the balanced development of the European HPC Ecosystem based on three pillars.

- **HPC Infrastructure** (represented by Partnership for Advanced Computing in Europe, PRACE) [3]
- **HPC Technology** (represented by ETP4HPC, the European HPC Technology Platform) [4]
- **Application Expertise** (represented by the Centres of Excellence of Computing Applications) [5]

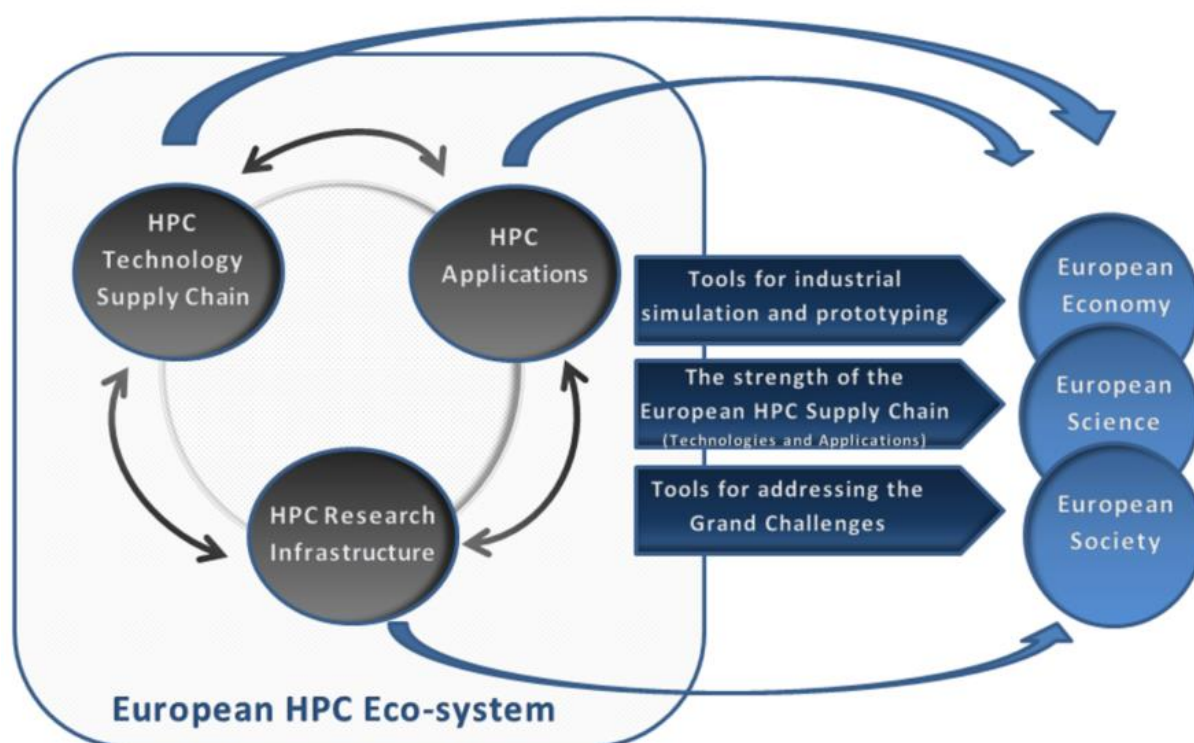


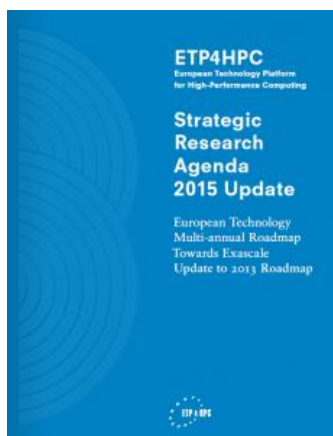
Figure 3 - The interactions between the three pillars of the European HPC Ecosystem and the European economy, science and society.

## 2.2 The European HPC Technology Platform – ETP4HPC



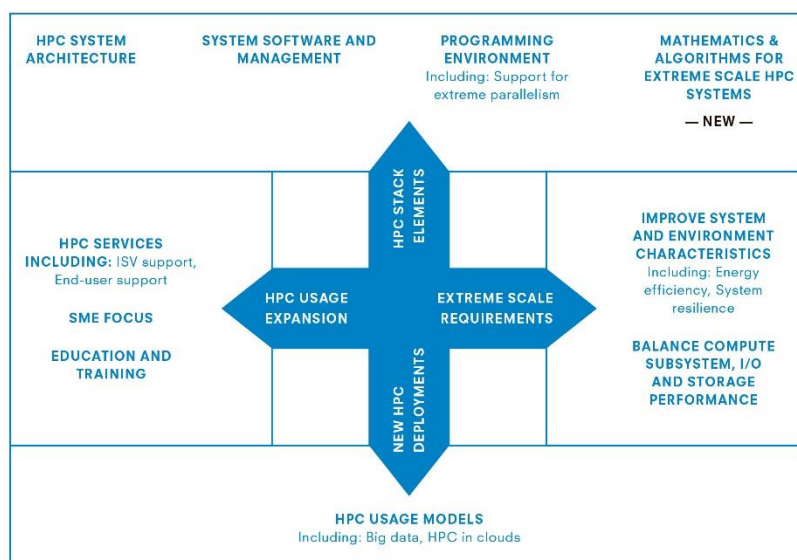
ETP4HPC (European HPC Technology Platform, [www.etp4hpc.eu](http://www.etp4hpc.eu)) is an industry-led organisation – an association of companies and research centres involved in HPC technology research in Europe. It aims to build a world-class HPC Supply Chain and increase the global market share of European HPC vendors. It issues a **Strategic Research Agenda** (SRA, [www.etp4hpc.eu/sra](http://www.etp4hpc.eu/sra)) to define the EU HPC research priorities in the area of the HPC Technology pillar, and sets out the guidelines which are used by the EU to define its HPC Technology research programme with the Horizon2020 framework.

## D6.2 Analysis of international collaboration opportunities for the European projects



**Figure 4 - The Strategic Research Agenda of ETP4HPC, i.e. the European HPC Technology roadmap that serves as the basis of the EU HPC Technology Calls.**

The SRA uses a four-dimensional HPC development model – each of the ‘dimensions’ represents a building block of HPC technology and has a dedicated chapter within the SRA.



**Figure 5 - The SRA four-dimensional HPC development model, with each area being a separate SRA chapter.**

ETP4HPC is managed by a Steering Board of fifteen organisations (European HPC Technology vendors, SMEs, international companies and European research centres) elected by its General Assembly, i.e. all active members who are able to demonstrate research activities in Europe. Any organisation with an interest in the development of HPC technology can become an Associated Member.

ETP4HPC is also one of the two partners in the EXDCI (European Extreme Data and Computing Initiative) project led by PRACE. The objective of EXDCI is to coordinate the European HPC strategy. In this project, ETP4HPC leads the delivery of the SRA, the development of international collaboration opportunities for the European HPC Technology Projects and a work package on the measurement of the European HPC ecosystem.

**The majority of the participants of the European HPC technology projects are also ETP4HPC members [6].** As one of its objectives, ETP4HPC represents the HPC technology

## **D6.2 Analysis of international collaboration opportunities for the European projects**

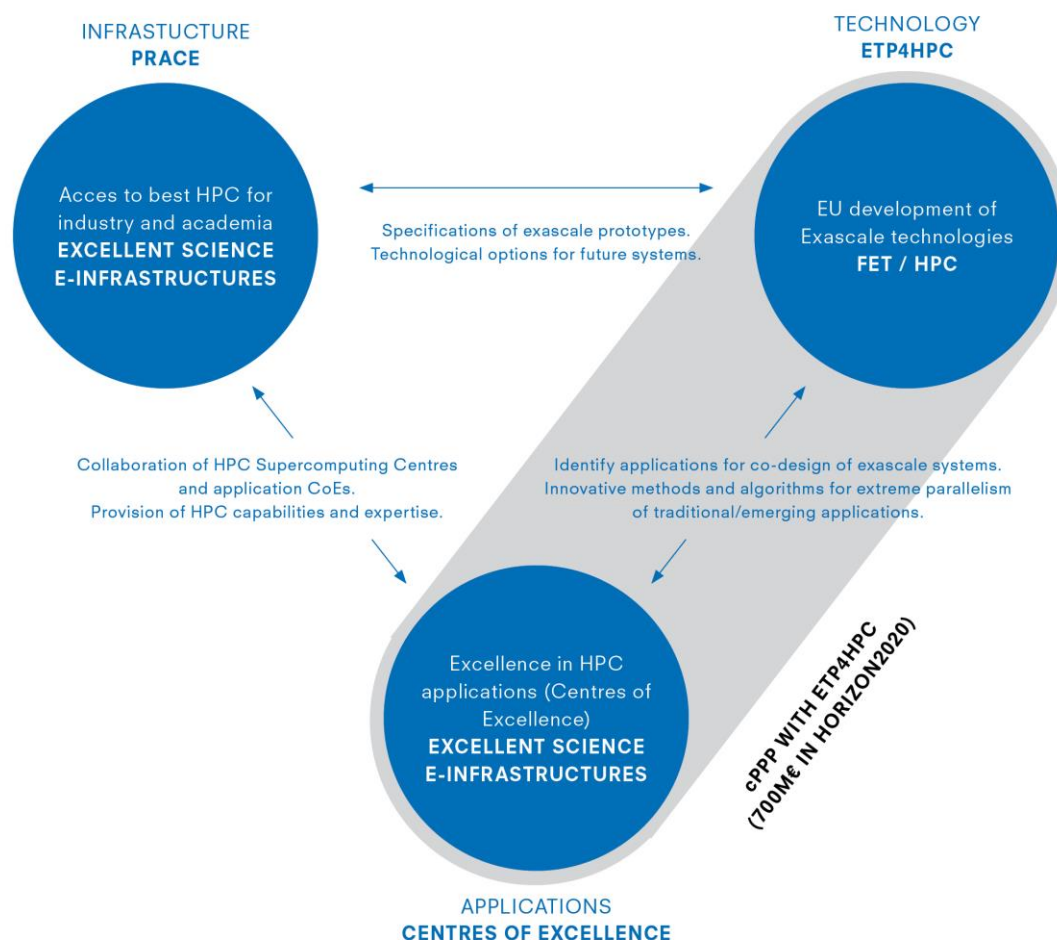
Ecosystem in dealings with e.g. the European Commission, the European member states and the international HPC community. ETP4HPC acts as a single point of contact for European HPC technology, and had already represented European HPC technology prior to the EXDCI project through e.g. participation in events, organising information sessions and direct contact with overseas companies, government bodies and vendors.

ETP4HPC has also developed working relationships with other major European programmes, initiatives and projects such as Big Data Value Association (BDVA, [7]) and the Square Kilometre Array (SKA, [8]) project.

### **2.3 The Contractual Public-Private Partnership for HPC in Europe and other initiatives**

ETP4HPC is also the EC's partner in the HPC contractual Public-Private Partnership, one of eight of such partnerships in Europe, established on 1<sup>st</sup> January 2014 [9]. Its scope covers Technology Provision and Application Expertise. Its aim is to develop HPC technology and applications, leading to the production of the first Exascale systems, and stimulating the advanced and pervasive use of these. In turn this will foster the creation of new jobs, products and companies, as well as enabling scientific discoveries. This will not only contribute to the economic competitiveness of Europe, but also to the well-being of the European citizen by addressing the Grand Societal Challenges. The HPC cPPP has now reached a stable configuration with the inclusion of Centres of Excellence and increased interaction with industry and research. In order to reach all aspects of the HPC value chain and all three pillars of the European HPC strategy, the HPC cPPP cooperates with PRACE.





**Figure 6 - The three pillars of the European HPC Ecosystem and the interactions between them.**

The HPC cPPP covers the areas of technology provision and application excellence. The FETHPC programme of the EC supports the development of European HPC technology.

## 2.4 The European Cloud Initiative

In April 2016, the initial 2012 EC Communication describing the EU strategy in HPC [1] was updated by new communications within the broader context of the EC's package of measures for Digitising European Industry [10]. The "European Cloud Initiative – Building a competitive data and knowledge economy in Europe" [11,12] aims to strengthen Europe's position in data-driven innovation, improve its competitiveness and cohesion, and help create a Digital Single Market [13] in Europe. This initiative will provide European science, industry and public authorities with:

- a world-class data infrastructure to store and manage data;
- high-speed connectivity to transport data; and
- **ever more powerful High Performance Computers to process data.**

This initiative sets ambitious goals for European HPC and complements the efforts included in the cPPP and other related areas.



**2.5 European HPC Technology: The Current Landscape**

The current European HPC Technology Projects originate from two EC funding programmes: 1/ the Horizon 2020 Future and Emerging Technologies HPC Projects – FETHPC, and 2/ the previous Seventh Framework Programme (FP7). Future and Emerging Technologies HPC Projects - FETHPC

The European Commission’s current Horizon 2020 [14] research programme includes public calls for the development of HPC technology in its ‘FET Proactive HPC’ (Future and Emerging Technologies – HPC) section, and calls for the implementation of research infrastructures and application expertise in its ‘Infrastructures’ section. This programme is based on the Strategic Research Agenda roadmap prepared by ETP4HPC - the projects submitted to the FETHPC programme are required to address the guidelines of the SRA developed by ETP4HPC. Many ETP4HPC members [6] participate in the FETHPC Technology projects.

The following table summarises the details of the past and current HPC-related calls:

**Table 1 - The details of the past and future HPC-related EC calls.**

Call Name	Topic	Funding (Euro)	Closing Date
H2020-FETHPC-2014 [15]	FETHPC-1-2014:HPC Core Technologies, Programming Environments and Algorithms for Extreme Parallelism and Extreme Data Applications	97,400,000	25 November 2014
	FETHPC-2-2014:HPC Ecosystem Development	(funding of 4,000,000 included in the figure above)	
H2020-FETHPC-2016-2017 [16]	FETHPC-01-2016:Co-design of HPC systems and applications	41,000,000	27 September 2016
	FETHPC-02-2017:Transition to Exascale Computing	40,000,000	26 September 2017
	FETHPC-03-2017:Exascale HPC ecosystem development	4,000,000	

The first FETHPC research projects [17] – with a total value of almost 97,4M Euros – are now in operation. The implementation of these technology projects will lead to the development of innovative and globally competitive HPC technology solutions in Europe. It will increase the global market share of European HPC vendors and help Europe achieve independent Exascale system capabilities. These projects represent the first part of a 700M Euros investment package committed by the European Commission within the Horizon 2020 Research and Development Programme. There will be three more HPC technology calls, with an emphasis on system prototypes, meeting the needs of academic and industrial end-users, and ensuring market viability. The 19 HPC technology projects involving European HPC industry and research centres address the topics of:

- HPC core technologies and architectures,
- Programming methodologies, environments, languages and tools,
- APIs and system software for future extreme scale systems, and
- New mathematical and algorithmic approaches.

These projects are [18]:

## D6.2 Analysis of international collaboration opportunities for the European projects

**Table 2 - The FETHPC-1-2014 Projects - the currently running European HPC technology projects.**

Acronym	Title
ALLScale	An Exascale Programming, Multi-objective Optimisation and Resilience Management Environment Based on Nested Recursive Parallelism – <a href="http://www.allscale.eu">http://www.allscale.eu</a>
ANTAREX	AutoTuning and Adaptivity appRoach for Energy efficient eXascale HPC systems – <a href="http://www.antarex-project.eu/">http://www.antarex-project.eu/</a>
ComPat	Computing Patterns for High Performance Multiscale Computing – <a href="http://www.compat-project.eu/">http://www.compat-project.eu/</a>
ECOSCALE	Energy-efficient Heterogeneous COmputing at exaSCALE – <a href="http://www.ecoscale.eu/">http://www.ecoscale.eu/</a>
ESCAPE	Energy-efficient SCalable Algorithms for weather Prediction at Exascale – <a href="http://www.ecmwf.int/en/research/projects/escape">http://www.ecmwf.int/en/research/projects/escape</a>
ExaFLOW	Enabling Exascale Fluid Dynamics Simulations – <a href="http://exaflow-project.eu/">http://exaflow-project.eu/</a>
ExaHyPE	An Exascale Hyperbolic PDE Engine – <a href="http://exahype.eu/">http://exahype.eu/</a>
ExaNeSt	European Exascale System Interconnect and Storage – <a href="http://www.exanest.eu/">http://www.exanest.eu/</a>
ExaNoDe	European Exascale Processor Memory Node Design – <a href="http://exanode.eu/">http://exanode.eu/</a>
ExCAPE	Exascale Compound Activity Prediction Engine – <a href="http://www.ecmwf.int/en/research/projects/escape">http://www.ecmwf.int/en/research/projects/escape</a>
EXTRA	Exploiting eXascale Technology with Reconfigurable Architectures – <a href="https://www.extrahpc.eu/">https://www.extrahpc.eu/</a>
greenFLASH	Green Flash, energy efficient high performance computing for real-time science (no website available)
INTERTWINE	Programming Model INTERoperability ToWards Exascale (INTERTWInE) – <a href="http://www.intertwine-project.eu/partners">http://www.intertwine-project.eu/partners</a>
MANGO	MANGO: exploring Manycore Architectures for Next-GeneratiOn HPC systems – <a href="http://www.mango-project.eu/">http://www.mango-project.eu/</a>
Mont-Blanc 3	Mont-Blanc 3, European scalable and power efficient HPC platformbased on low-power embedded technology – <a href="https://www.montblanc-project.eu/montblanc-3">https://www.montblanc-project.eu/montblanc-3</a>
NEXTGenIO	Next Generation I/O for Exascale – <a href="http://www.nextgenio.eu/">http://www.nextgenio.eu/</a>

## D6.2 Analysis of international collaboration opportunities for the European projects

NLAFET	Parallel Numerical Linear Algebra for Future Extreme-Scale Systems – <a href="http://www.nlafet.eu/">http://www.nlafet.eu/</a>
READEX	Runtime Exploitation of Application Dynamism for Energy-efficient eXascale computing – <a href="http://www.readex.eu/">http://www.readex.eu/</a>
SAGE	Percipient StorAGE for Exascale Data Centric Computing – <a href="http://www.sagestorage.eu/">http://www.sagestorage.eu/</a>

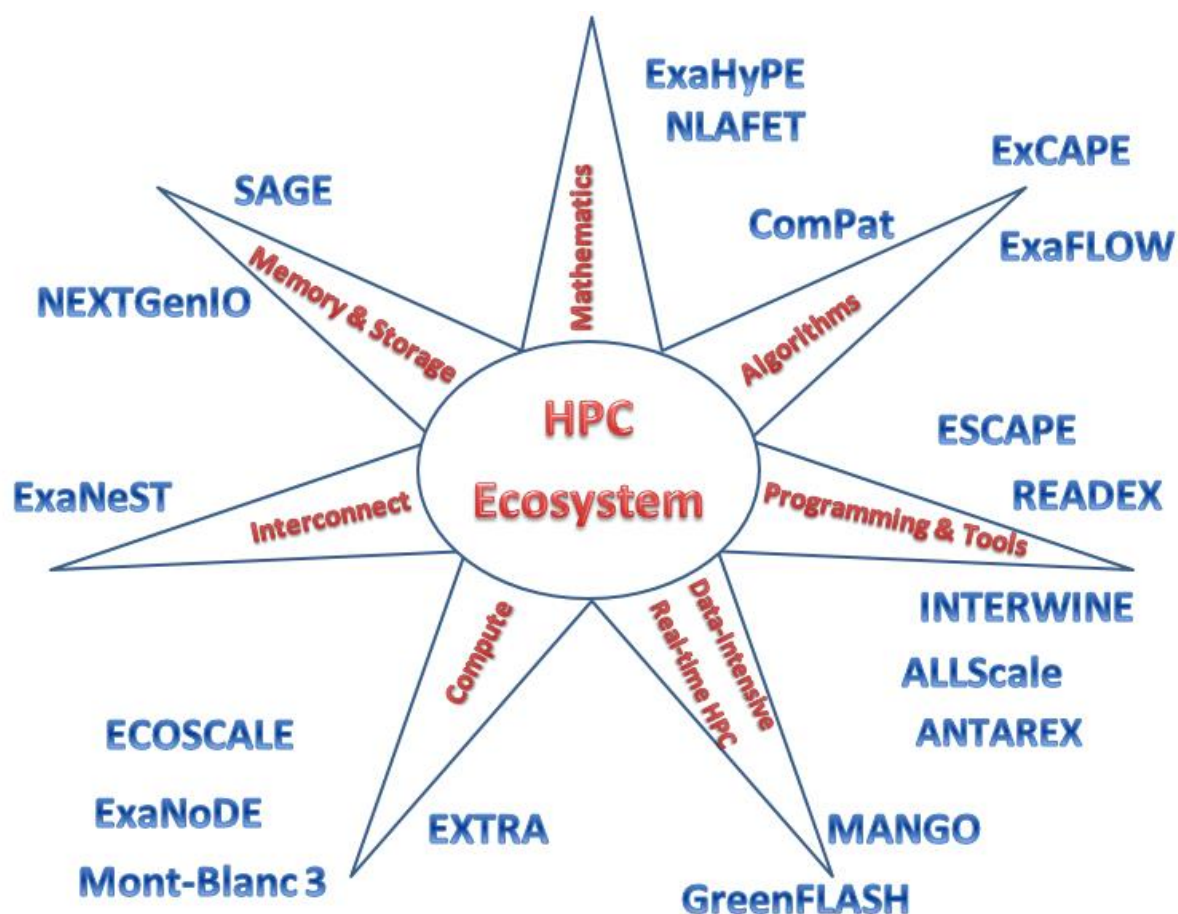


Figure 7 - The FETHPC-2014-1 Projects mapped onto areas of HPC Technology (courtesy of the European Commission)

Table 3 - The logos of all the FETHPC-2014-1 Projects.



### 2.5.1 Framework Programme 7 (FP7)

The EC's previous programme - Framework Programme 7 (FP7) – also funded a number of exascale projects. They are [19]:

**Table 4 – Exascale projects funded under the EC's previous programme - Framework Programme 7 (FP7).**

CRESTA	Collaborative Research Into Exascale Systemware, Tools and Applications – <a href="https://www.cresta-project.eu/">https://www.cresta-project.eu/</a>
DEEP & DEEP-ER	Dynamical Exascale Entry Platform – and its Extended Reach – <a href="http://www.deep-project.eu">www.deep-project.eu</a> , <a href="http://www.deep-er.eu">www.deep-er.eu</a>
Mont-Blanc	European Approach Towards Energy Efficient HPC – <a href="https://www.montblanc-project.eu/">https://www.montblanc-project.eu/</a>
EPiGRAM	Exascale ProGRAMming Models – <a href="http://www.epigram-project.eu/">http://www.epigram-project.eu/</a>
EXA2CT	Exascale Algorithms and Advanced Computational Techniques – <a href="http://www.exa2ct.eu/">http://www.exa2ct.eu/</a>



## D6.2 Analysis of international collaboration opportunities for the European projects

Numexas	NUMerical Methods and Tools for Key Exascale – <a href="http://numexas.eu/">http://numexas.eu/</a>
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Table 5 - The logos of the FP7 HPC Technology projects.



### 2.5.2 The entire spectrum of European HPC Technology Projects

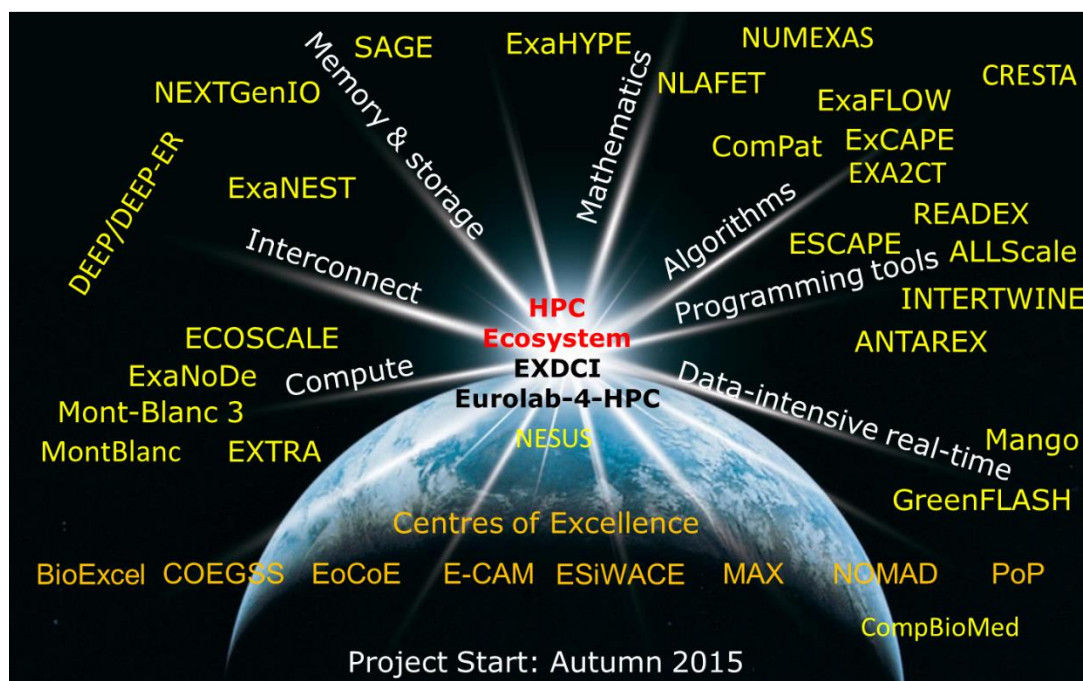


Figure 8 - The entire spectrum of the European HPC Technology projects divided into areas of technology<sup>4</sup>.

The entire spectrum of the European HPC Projects includes the H2020 and FP7 projects in various areas of HPC Technology accompanied by:

- The Centres of Excellence for Computing Applications [20]:

<sup>4</sup> As used at the SC'15 BOF – see Chapter 4.1.1

## D6.2 Analysis of international collaboration opportunities for the European projects

**Table 6 - The European Centres of Excellence in Computing Applications.**

EoCoE	Energy oriented Centre of Excellence for computer applications
BioExcel	Centre of Excellence for Biomolecular Research
NoMaD	The Novel Materials Discovery Laboratory
MaX	Materials design at the eXascale
ESiWACE	Excellence in SIMulation of Weather and Climate in Europe
E CAM	An e-infrastructure for software, training and consultancy in simulation and modelling
POP	Performance Optimisation and Productivity
COEGSS	Center of Excellence for Global Systems Science
CompBioMed	A Centre of Excellence in Computational Biomedicine

- The EXDCI strategy coordination project and the Eurolab-4-HPC coordination project (aiming to build the foundation for a European Research Center of Excellence in High-Performance Computing (HPC) Systems [21])
- The NESUS cost action [22] - focusing on a cross-community approach of exploring system software and applications for enabling a sustainable development of future high-scale computing platforms.

### 2.6 EXDCI's Position on International Collaboration

In 2015, prior to the start of the EXDCI project, ETP4HPC defined its position on international collaboration [23]. To achieve HPC leadership, Europe must engage in international cooperation. This cooperation should target two objectives:

- Develop synergies with the most active areas in HPC technologies research and their optimal usage. Priority should be given to developing links with Japan and the US, which demonstrate the longest experience in HPC and the most structured and mature related programmes;
- Collaborate with some of the countries which are in the early stages of developing their HPC strategies (e.g. Australia, South Africa, Brazil), in order to encourage them to utilise the expertise and capabilities of the European HPC ecosystem. This cooperation should not only focus on HPC technologies but also on policies to develop wider use of HPC within the scientific and industrial communities.

PRACE has undertaken similar activities by signing MoU agreements with other regions [e.g. 24]

### 3 The Process

We chose to present all of the European HPC projects together, regardless of their programme origin (i.e. FP7 or Horizon 2020) as most of the partners of the FP7 projects are also involved in H2020 projects and the origin of a project is of little importance to the international audience.

The process selected is based on two types of activities:

- **Increasing Visibility** – Enabling a platform that would allow the Project to advertise their achievements and initiate contacts with other regions
- **Direct Contact** – Interactions with the representatives of other regions in order to share updates on HPC-related developments

We also approached all the projects and offered them an opportunity to participate in the preparation and delivery of these elements. The final result reflects the opinion of the projects involved. Some projects contributed directly by e.g. delivering parts of the work.

**ETP4HPC maintains a web page – <http://www.etp4hpc.eu/euexascale.html> – at which updated information the EXDCI international collaboration activities is stored.**

#### 3.1 Increasing Visibility

The Supercomputing Conference (SC, <http://www.supercomp.org/>), held annually in the U.S., has been selected as the main vehicle to increase the visibility of the European HPC Technology Projects. It is the largest event of this type in the world and it attracts all the main stakeholders from all parts of the world. We decided to use the Birds-of-a-Feather (BOF) sessions organised within the SC as the optimal tool for presenting such work. In addition, ETP4HPC had previously held successful BOFs at SC'12, '13, '14 and '15, hence some accumulated experience was available within the project. ETP4HPC has also participated in other events with some level of international exposure.

#### 3.2 Direct Contact

ETP4HPC has also begun the process of interacting directly with other regions by identifying the main contacts and organising meetings with them. It has a focus on Japan – as relations with the US are already sufficiently mature they have been advanced through a number of events and organisations (e.g. SC and BDEC).

### 4 Implementation and Results

#### 4.1 Increasing Visibility

##### 4.1.1 SC'15 BOF

The following text is the abstract of the BOF session prepared by ETP4HPC which was held at the SC'15 conference (Austin, Texas) on 19<sup>th</sup> November 2015.

*The established EU-funded Exascale projects and initiatives (CRESTA, DEEP/DEEP-ER, Mont-Blanc, NUMEXAS, EXA2CT, EPiGRAM and NESUS) will present their status, lessons learnt and potential cross-region synergies.*



## D6.2 Analysis of international collaboration opportunities for the European projects

*In addition, the long-term EU effort to develop, produce and exploit Exascale platforms continues with 19 projects within the first part of the Horizon 2020 programme addressing: HPC core technologies and architectures, programming methodologies, languages and tools, APIs and system software, new mathematical and algorithmic approaches.*

The programme of this session included:

1. A presentation of the European HPC landscape – 15 min
2. A presentation of all the European HPC Technology projects – divided into three groups (and presented by three speakers): 1/*Compute & Interconnect*; 2/*Memory & Storage and 3/Data-intensive Real-Time* and Programming Tools, Algorithms & Mathematics – 30 min. (This part was delivered by selected representatives of the projects involved).
3. Panel Discussion: International Collaboration Opportunities arising and mechanisms needed – 45 min – with the involvement of international guests (see the Figure below).

### Programme

Introduction 15 min	<b>Overview on the European Exascale Landscape</b> By Jean-François Lavignon, ETP4HPC Chairman and Atos
Talks 30 min	<b>Presentation of Focus Technology Research Areas</b>  <b>Area 1: Architecture &amp; Compute</b> By Filippo Mantovani, Technical Project Coordinator Mont-Blanc, Barcelona Supercomputing Centre  <b>Area 2: Interconnect, Memory &amp; Storage and Data-intensive Real-Time</b> By Prof. Jesus Carretero, Computer Architecture Professor, Computer Science and Engineering Dep. University Carlos III of Madrid  <b>Area 3: Programming Tools, Algorithms &amp; Mathematics</b> By Stefano Markidis, Assistant Professor, KTH Royal Institute of Technology
Panel Discussion 45 min	<b>International Collaboration Opportunities arising and mechanisms needed</b>  <i>Featuring distinguished international guests:</i>  Mitsuhsa Sato, Co-project leader of Post-K, University of Tsukuba & RIKEN AICS  Franck Capello, Argonne National Laboratory, Senior Computer Scientist, Director of the INRIA, UIUC, ANL, BSC, JSC and Riken Joint Laboratory on Extreme Scale Computing  Eric Van Hensbergen, Senior Principal Research Engineer, ARM  <i>Moderated by Sai Narasimhamurthy, Staff Engineer, Research, Seagate</i>

Figure 9 - The Programme of our SC'15 BOF as appearing on the flyer used to promote the event.

Prior to the BOF, the Projects had taken part in a survey in which the following questions were asked:

- Project Profile (What do you do? What kind of project are you?):

## D6.2 Analysis of international collaboration opportunities for the European projects

- Which areas does your project target? (it is possible to mark more than option)
- What areas of your project do you think have a potential for cross-continent synergies - please explain why.
- What tools and mechanisms do you think could be used to facilitate the cross-continent synergies your project could produce?
- Has any such collaboration been initiated to date? Please provide details if so.
- BONUS QUESTION - What areas of your project do you think have a potential for synergies WITHIN EUROPE - please explain why.
- BONUS QUESTION - What tools and mechanisms do you think could be used to facilitate the intra-European synergies your project could produce?
- Has any such collaboration been initiated to date? Please provide details if so.

Based on the responses collected, the Projects were able to identify areas of potential international collaboration; however, only one project had already initiated such work by contacting an international partner. Joint workshops were identified as the most suitable tool to facilitate this process.

The material gathered was used to produce a **European Projects Handbook** (included in the Annex), printed copies of which were made available at the BOF (also downloadable from: <http://www.etp4hpc.eu/euexascale.html>). It contains project summaries and a description of the areas where the Projects can collaborate internationally. This publication will be updated prior to the next BOF (at SC'16)

The BOF was advertised through the ETP4HPC marketing channels (the web, LinkedIn, Twitter and our contact lists) and also at SC'15 before the event. A flyer was produced and a dedicated web page was set up on the ETP4HPC web site. Some projects (e.g. DEEP/ER) produced their own leaflet and used their own network of contacts to advertise the event.



# Taking on Exascale Challenges: Key Lessons & International Collaboration Opportunities

Birds-of-a-Feather Session at SC15

Jointly organised by European Exascale Projects and ETP4HPC

Date: Thursday, November 19

Time: 3:30-5:00pm

Location: Room 13A, Austin Convention Centre

## Abstract

The European HPC Technology eco-system has entered a stage of rapid development. This acceleration is due to the progress of the established EU-funded projects ((CRESTA, DEEP/DEEP-ER, Mont-Blanc, NUMEXAS, EXA2CT, EPIGRAM and NESUS) and also the 19 new projects within the first part of the Horizon 2020 programme addressing: HPC core technologies and architectures, programming methodologies, languages and tools, APIs and system software, new mathematical and algorithmic approaches.

This session will present the work of these projects in the areas of: Compute, Interconnect, Memory and Storage, Data intensive real-time, Programming Tools, Mathematics and Algorithms, summarising the achievements to date, future objectives and the potential areas of collaboration with other regions.



*The landscape of the European HPC Technology R&D*

This will be followed by a panel discussion on the international opportunities generated by this eco-system and the mechanisms needed to facilitate this process.

**Figure 10 - A snapshot of our SC'15 flyer.**

**The BOF was a huge success** with over 120 attendees, well above the capacity of the room. A full report on this event was published after SC'15 and is available at <http://www.etp4hpc.eu/en/sc15-bof.html>. The discussion was short (less than 20 min) and its results do not reflect the breadth of the topics related to international collaboration. The main conclusions drawn from the discussion are:

- The fragmentation of the European HPC resources is a key issue;
- We should not try to address all areas but select some key areas on which to focus;
- Alignment of different funding across continents is an issue (e.g. there were some good projects which were not continued due to the lack of sufficient cross-continent funding);

## D6.2 Analysis of international collaboration opportunities for the European projects

- It is difficult to set up common, cross-continent calls for HPC technology in Europe due to policy constraints;
- Support actions in the EU may help cover some of these fragmentation issues (e.g. EXDCI);
- EU needs to be taking risks, which other regions would not take (this is the way we can compete against other regions which are better funded).



Figure 11 - The proceeding of the SC'15 BOF on European HPC Technology.

### 4.1.2 Other events

In addition, ETP4HPC was also present at the following events, with some level of international exposure:



## D6.2 Analysis of international collaboration opportunities for the European projects

- **ICT'15** (Innovate, Connect, Transform [25]), Lisbon, 20-22 Oct 2015 – we had a stand and we organised a networking session<sup>5</sup>;
- **Think.BDPST**, Budapest, 8-10 March 2016 – we delivered a talk on the European HPC Technology Ecosystem;
- **The European HPC Summit Week 2017**, Prague, 9-12 May 2016 – we delivered a talk on the European HPC Technology Ecosystem<sup>3</sup>;
- The 4<sup>th</sup> Closed Workshop of **BDEC** (Big Data and Extreme Computing, [www.exascale.org](http://www.exascale.org)), Frankfurt, 16-17 June 2016 – we introduced the European HPC technology environment to the international audience;
- The **International Supercomputing Conference '16** (<http://www.isc-hpc.com>), Frankfurt, 18-22 June 2016 – we had a stand<sup>3</sup>;
- **TERATEC 2016**, Palaiseau, France, 28-29 June 2016 – we had a booth.

### 4.2 Direct Contact

Two meetings with Riken have been held:

- An introductory meeting at ISC'15 (14<sup>th</sup> Jul 2015, Frankfurt), and
- A formal meeting on 16<sup>th</sup> March 2016 in Paris, involving ETP4HPC and the following personnel from RIKEN AICS (Advanced Institute for Computational Science):
  - Mr. Shigeo Okaya, Director, Flagship 2020 Project (the main Japanese HPC system project) Planning and Coordination Office
  - Prof. Dr. Yutaka Ishikawa, Project Leader, Flagship 2020 Project
  - Prof. Dr. Mitsuhsa Sato, Deputy Project Leader, Flagship 2020 Project
  - Mr. Ichiro Suzuki, Deputy Manager, Flagship 2020 Project Planning and Coordination Office
  - Dr. Miwako Tsuji, Research Scientist, Flagship 2020 Project

Updates were shared on the development of the EU and Japanese HPC Ecosystems.

## 5 Future Actions

### 5.1 SC'16 BOF (Preparations)

As of the time of writing this report, preparations are in progress for the next SC'16 BOF. The following is the abstract used in the submission process:

*The European HPC technology projects will showcase their work, aiming to seed new collaborations with international partners, to accelerate progress in Exascale research and development.*

*Within the European HPC Technology effort, a number of projects are running plus funding has been guaranteed for further investments in a variety of areas covering the entire HPC system stack and application expertise (see <http://www.etp4hpc.eu/euexascale.html> for a full description).*

*We will highlight the most important areas of these technologies, discuss opportunities for international collaboration, and identify key mechanisms*

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<sup>5</sup> At this event ETP4HPC represented EXDCI.

## D6.2 Analysis of international collaboration opportunities for the European projects

*required to facilitate this process. Project representatives will be present to facilitate networking.*

An emphasis is being placed on the preparation of introductory material to be made available in advance of the event (e.g. at the EXDCI booth or at the stands of the ETP4HPC members), and the presence of project representatives in order to free up time at the actual event for a discussion and the definition of further steps.

### Description of the session format

*Description of the session format (Maximum 150 words):*

5% - A brief summary of the development of European HPC and its Technology eco-system

5% - The key successes of the European HPC technology projects

15% - An overview of the international collaboration opportunities created by the European HPC Technology Projects

75% - A discussion (involving a panel of experts from Europe and other regions, e.g. US and Japan) on 1/ the opportunities for international collaborations (e.g. in what areas would other regions like to collaborate) and 2/ the mechanisms needed to stimulate this process (e.g. are there any networking opportunities? What is needed to strengthen this process?). Material will be available summarising our current knowledge on such opportunities (e.g. existing workshops, conferences, etc.). A post-BOF report will be published and will serve as the source of recommendations for future actions in order to stimulate the international collaboration of the European HPC technology projects.

**Figure 12 - A snapshot of the SC'16 BOF submission.**

Based on the success of last year's BOF, we have requested a larger room and a longer session in order to meet the expected demand.

## 5.2 EXDCI Survey

The EXDCI survey launched in Q1 2016 constitutes an important milestone in determining the preparedness of the European HPC Projects for international collaboration. It targets all the European FETHPC projects. The following are the questions of the part of the survey related to international collaboration and the answers provided (16 projects in total):

- Have you initiated any international collaboration?
  - 63% of the Projects have already engaged with overseas partners.
- Please describe the partners and the work in question.
  - Most of the Projects (37%) are collaborating with other HPC technology or related projects, followed by universities or research centres and standard bodies (e.g. the MPI Forum).
- What area of your technology project could benefit from work with international partners?<sup>6</sup>

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<sup>6</sup> The following list is a summary of the answers – the exact response depends on the profile of the project

## D6.2 Analysis of international collaboration opportunities for the European projects

- Parallelizing compilers, runtime system technology, resilience and performance analysis techniques
- The MPI communication layer
- Linear algebra solutions
- Data management, data transfer, data throughput
- Exploitation of hardware platforms
- Auto-tuning for energy-efficiency.
- The applicability of new programming models to HPC prototypes
- NWP and climate model development
- Refactoring for future generations of hardware
- Establishing API's enabling the features of future systems
- Obtaining input from application users, and algorithms and programming models.
- Development of advanced accelerators to boost performance of applications
- Reconfigurable technology platform
- New application domains
- Understand the specific, software challenges facing the international community
- Engagement with standards bodies and community working groups
- Maturation of task-based programming models
- What would be the expected result of this collaboration?<sup>6</sup>
  - Joint proposals and projects
  - Developing common tools, metrics, model components.
  - Improved performance of project results (e.g. the underlying communication mechanism)
  - Improved functionality, improved hardware
  - Improved performance of data operations
  - Portability, demonstration of the portability and demonstration of performance in a real-world application
  - Better industrial impact and critical mass for continued collaboration, and improved algorithms and programming models.
  - Deployment of advanced accelerators to boost performance of applications
  - New research on run-time reconfiguration
  - Enabling solutions for new application domains
  - User outreach and input, ensuring that the needs of computational scientists are met
  - Broadening the ecosystem of potential tools and users of the platform developed in the project

## D6.2 Analysis of international collaboration opportunities for the European projects

- Impact – greater visibility and wider acceptance of project outputs
- What partners are you looking for?
  - Industrial Applications users
  - Hardware and software vendors
  - Application experts and providers
  - Computational resource providers
  - Research organisations
  - HPC centres
- What tools/mechanisms could help you? (e.g. a joint workshop, a region-to-region agreement, etc.)
  - 31% of all the Projects express a need for a tool to that would help implement this process. These Projects work mainly in the Programming Tools area (67% - followed by Algorithms and Memory/Storage). All of these Projects identify **joint workshops as an appropriate mechanism**, followed by research visits. **EXDCI should help by facilitating such workshops and visits and securing appropriate funding.**

### 5.3 Direct Contact

The project will continue developing a relation with the US and Japan with an objective to obtain more detailed information on the development of their ecosystems. We will also approach other regions (e.g. Australia, South Africa, Brazil) in order to initiate cooperation and obtain information. We will issue a summary document on each region, identifying the opportunities for international collaborations with their Projects and other initiatives.

The Task will also analyse how the other regions approach the issue of developing international collaborations by their projects. We will summarise those findings in a separate document.

## 6 Conclusions

As the Projects mature and the European HPC Ecosystem enters the phase of validating the results of its work (e.g. by using the technologies developed to build supercomputer prototypes – such as the concept of European Extreme-Scale Demonstrators [26] now being developed by ETP4HPC), some of the projects will require assistance, in order to take advantage of their increased international visibility and the contacts that have been initiated.

Any continuation of EXDCI should focus on analysing the results of the EXDCI survey, drawing conclusions from the outcome of the SC'16 BOF, and delivering tools, resources and funding needed by the Projects. This might take the form of:

- Joint workshops (e.g. including European and overseas projects dealing with similar topics or in related areas, in particular in the area of Programming Tools),
- Further dissemination of the work of the Projects with the global community, targeting other projects, research centres, resource providers and industrial users. This activity should be based on a dissemination plan agreed with the Projects.



## **D6.2 Analysis of international collaboration opportunities for the European projects**

- An analysis of the research programmes in various regions (which might lead to joint project calls and cross-regional projects), or
- Setting up platforms for the commercialisation of project results in other regions.

**We should take advantage of the momentum created by the activities to date.**

## 7 Annex

### 7.1 Annex 1 – The European HPC Technology Handbook

# European HPC Technology Handbook

23 August 2016

Supercomputing'15 Bird-of-a-Feather session on 19<sup>th</sup> Nov 2015



The following project details are included:

Project name • Web address • Partners Involved • Contact Name • Contact email • Contact phone • Project Profile • Which areas does your project target? • What areas of your project do you think have a potential for cross-continent synergies?

For additional information and project summaries please visit:

A list of the European Horizon 2020 projects:

[http://cordis.europa.eu/search/result\\_en?q=contenttype%3D%27project%27%20AND%20%27FETHPC%27&p=1&num=10&srt=/project/contentUpdateDate:decreasing](http://cordis.europa.eu/search/result_en?q=contenttype%3D%27project%27%20AND%20%27FETHPC%27&p=1&num=10&srt=/project/contentUpdateDate:decreasing)

[http://cordis.europa.eu/projects/home\\_en.html](http://cordis.europa.eu/projects/home_en.html) (search for FETHPC)

[www.etp4hpc.eu](http://www.etp4hpc.eu) - the website of ETP4HPC (the European Technology Platform for HPC)

<http://exascale-projects.eu/> - an overview on FP7-funded projects

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### AllScale

**Web address**

<http://www.allscale.eu>

**Partners Involved**

University of Innsbruck

Friedrich-Alexander-University of Erlangen

Nuremberg Queen's University of Belfast

Royal Institute of Technology

Numea International S.A.

IBM Ireland Limited

**Contact Name**

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**Project Profile**

Extreme scale HPC systems impose significant challenges for developers aiming at obtaining applications efficiently utilising all available resources. In particular, the development of such applications is accompanied by the complex and labour-intensive task of managing parallel control flows, data dependencies and underlying hardware resources – each of these obligations constituting challenging problems on its own. The AllScale environment, the focus of this project, will provide a novel, sophisticated approach enabling the decoupling of the specification of parallelism from the associated management activities during program execution. Its foundation is a parallel programming model based on nested recursive parallelism, opening up the potential for a variety of compiler and runtime system based techniques adding to the capabilities of resulting applications. These include the (i) automated porting of application from small- to extreme scale architectures, (ii) the flexible tuning of the program execution to satisfy trade-offs among multiple objectives including execution time, energy and resource usage, (iii) the management of hardware resources and associated parameters (e.g. clock speed), (iv) the integration of resilience management measures to compensate for isolated hardware failures and (v) the possibility of online performance monitoring and analysis. All these services will be provided in an application independent, reusable fashion by a

## **D6.2 Analysis of international collaboration opportunities for the European projects**

combination of sophisticated, modular, and customizable compiler and runtime system based solutions.

AllScale will boost the development productivity, portability, and runtime, energy, and resource efficiency of parallel applications targeting small to extreme scale parallel systems by leveraging the inherent advantages of nested recursive parallelism, and will be validated with applications from fluid dynamics as well as environmental hazard and space weather simulations provided by SME, industry and scientific partners.

### **Which areas does your project target?**

Programming methodologies, environments, languages and tools

### **What areas of your project do you think have a potential for cross-continent synergies?**

Programming small to extreme scale parallel systems

Resilience management for exascale systems

Online performance analysis

Runtime systems for extreme scale HPC

## **ANTAREX - AutoTuning and Adaptivity appRoach for Energy efficient eXascale HPC systems**

### **Web address**

<http://www.antarex-project.eu/>

### **Partners Involved**

- 1) Politecnico di Milano (Italy)
- 2) ETH Zurich (Switzerland)
- 3) Universidade do Porto (Portugal)
- 4) INRIA Rennes (France)
- 5) Consorzio Interuniversitario CINECA (Italy)
- 6) ITŠInnovations (Czech Republic)
- 7) Dompé Farmaceutici SPA (Italy)
- 8) Sygic (Slovakia)

### **Contact Name**

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### **Project Profile**

To reach Exascale computing (10<sup>18</sup> FLOPs), current supercomputers must achieve an energy efficiency “quantum leap” that allows this level of computation to be done at around 20 Megawatts. This will only be possible if we can target all layers of the system, from the software stack to the cooling system.

ANTAREX will solve these challenging problems by proposing a disruptive holistic approach spanning all the decision layers composing the supercomputer software stack and exploiting effectively the full system capabilities (including heterogeneity and energy management). The main goal of the ANTAREX project is to provide a breakthrough approach to express by a Domain Specific Language the application self-adaptivity and to runtime manage and autotune applications for green and heterogeneous High Performance Computing (HPC) systems up to the Exascale level.

## **D6.2 Analysis of international collaboration opportunities for the European projects**

### **Which areas does your project target?**

Programming methodologies, environments, languages and tools

APIs and system software for future extreme scale systems

### **What areas of your project do you think have a potential for cross-continent synergies?**

The proposed approach based on Domain Specific Language the application self-adaptivity and to runtime manage and autotune applications for green and heterogeneous HPC systems has a high potential for cross-continent synergies.

## **Collaborative Research into Exascale Systemware, Tools and Applications (CRESTA)**



**Web address**

<http://www.cresta-project.eu>

**Partners Involved**

Åbo Akademi University (ABO)

Allinea Software

Cray UK Limited (CRAY)

DLR

Ecole Centrale Paris (ECP)

EPCC, The University of Edinburgh

Kungliga Tekniska Högskolan (KTH)

The Center for Information Services and High Performance Computing (ZIH)

The European Centre for Medium-Range Weather Forecasts

The University of Jyväskylä, Department of Physics

The University of Stuttgart (USTUTT)

Tieteen Tietotekniikan Keskus OY (CSC)'s IT Center For Science LTD.

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## **D6.2 Analysis of international collaboration opportunities for the European projects**

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### **Project Profile**

The Collaborative Research into Exascale Systemware, Tools and Applications (CRESTA) project develops techniques and solutions for some of the most difficult technical challenges that computing at the exascale can present. The project has two integrated strands: one focused on enabling a key set of applications for exascale, the other focused on building and exploring appropriate systemware for exascale platforms. All of the applications had demonstrated a need for exascale performance with associated scientific challenges of global significance that cannot be solved on current petascale systems, but require exascale performance.

At the heart of the project is the co-design process, with the co-design applications providing guidance and feedback to the exascale software development process, and integrating and benefitting from this development. CRESTA employs incremental and disruptive approaches throughout – sometimes following both paths for a particular problem to compare and contrast the challenges associated with the approach.

### **Which areas does your project target?**

HPC core technologies and architectures

Programming methodologies, environments, languages and tools

APIs and system software for future extreme scale systems

New mathematical and algorithmic approaches

Enabling Applications for future extreme scale systems

### **What areas of your project do you think have a potential for cross-continent synergies?**

CRESTA's efforts to enable future applications for extreme scale systems are universal and similar efforts are being carried out across continents. Applications that can test extreme scale prototypes are rare and of interest world-wide.

Programming models for future extreme scale systems require international backing and standardization; hence cross-continent engagement is essential.

## **ComPat**

**Web address**

<http://www.compat-project.eu>

**Partners Involved**

<http://www.compat-project.eu/consortium/>

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**Project Profile**

see <http://www.compat-project.eu/wp-content/uploads/2015/06/ComPat-project-overview-Sept-2015.pdf>

**Which areas does your project target?**

New mathematical and algorithmic approaches

**What areas of your project do you think have a potential for cross-continent synergies?**

Overall development of the High Performance Multiscale Computing paradigm, and the development of the Multiscale Computing Patterns.

In more detail, the applications that drive the research as well as ComPat middleware and tools have lots of potential.

**DEEP (Dynamical Exascale Entry Platform) & DEEP-ER (Dynamical Exascale Entry Platform - Extended Reach)**



**Web address**

<http://www.deep-project.eu>

<http://www.deep-er.eu>

**Partners Involved**

Jülich Supercomputing Centre

Intel

Eurotech

Barcelona Supercomputing Center

Leibniz Supercomputing Centre

University Heidelberg (via spin-off EXTOLL)

ParTec

Seagate

Fraunhofer ITWM

University of Regensburg

KU Leuven

École polytechnique fédérale de Lausanne

The Cyprus Institute

German Research School for Simulation Sciences

CERFACS

CINECA

CGG

Astron

## **D6.2 Analysis of international collaboration opportunities for the European projects**

Inria

Mellanox

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### **Project Profile**

The DEEP project and its follow-up project DEEP-ER present an innovative solution for next generation supercomputer addressing various Exascale challenges by following a stringent Co-Design approach. The consortium has developed a novel, Exascale-enabling supercomputing architecture with a matching software stack and a set of optimized grand-challenge simulation applications.

DEEP takes the concept of compute acceleration to a new level: instead of attaching accelerator cards to cluster nodes, DEEP has built a cluster of accelerators, called Booster, to complement a conventional HPC system and increase its compute performance. Accompanied by a software stack focused on meeting Exascale requirements - comprising adapted programming models, libraries and performance tools - the architecture enables unprecedented scalability. The cluster-level heterogeneity of the system attenuates the consequences of Amdahl's law allowing users to run applications with kernels of high scalability alongside kernels of low scalability concurrently on different sides of the system.

DEEP-ER advances the Cluster-Booster architecture developed in DEEP from a hardware point of view in terms of processor technology, network interconnect, and storage. On the software side DEEP-ER focuses on two central research topics: highly scalable parallel I/O and resiliency.

Both DEEP and DEEP-ER validate their concepts on the prototype systems built within the projects. The DEEP prototype system with a peak performance of 500 TFlop/s is already up and running at Jülich Supercomputing Centre.

### **Which areas does your project target?**

HPC core technologies and architectures

Programming methodologies, environments, languages and tools

APIs and system software for future extreme scale systems

### **What areas of your project do you think have a potential for cross-continent synergies?**

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HPC core technologies: the Cluster-Booster concept can be generalised into a modular approach for HPC. Different components are combined to provide the system functionalities exploiting the best characteristics of each technology.

Prototype development: exchange of lessons learned.

Programming models and application porting: the DEEP programming model is based on standards (MPI and OpenMP) and has been designed to make application porting between platforms as seamless as possible.

Application scientists: invited to test their codes on the DEEP System. Exchange of experience in code modernisation

### ECOSCALE

#### Web address

<http://www.ecoscale.eu/>

#### Partners Involved

Telecommunication Systems Institute, Greece

Queen's University Belfast, United Kingdom

STMicroelectronics, France

Acciona Infraestructuras S.A., Spain

University of Manchester, United Kingdom

Politecnico di Torino, Italy

Chalmers University of Technology, Sweden

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#### Project Profile

In order to reach exascale performance, current HPC systems need to be improved. Simple hardware scaling is not a feasible solution due to the increasing utility costs and power consumption limitations. Apart from improvements in implementation technology, what is needed is to refine the HPC application development flow as well as the system architecture of future HPC systems.

ECOSCALE tackles these challenges by proposing a scalable programming environment and architecture, aiming to substantially reduce energy consumption as well as data traffic and latency. ECOSCALE introduces a novel heterogeneous energy-efficient hierarchical architecture, as well as a hybrid many-core+OpenCL programming environment and runtime system. The ECOSCALE approach is hierarchical and is expected to scale well by partitioning the physical system into multiple independent Workers (i.e. compute nodes). Workers are interconnected in a tree-like fashion and define a contiguous global address space that can be viewed either as a set of Partitioned Global

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Address Space (PGAS) partitions, or as a set of nodes hierarchically interconnected via an MPI protocol.

To further increase energy efficiency, as well as to provide resilience, the Workers employ reconfigurable accelerators mapped into the virtual address space utilizing a dual stage System Memory Management Unit with coherent memory access. The architecture supports shared partitioned reconfigurable resources accessed by any Worker in a PGAS partition, as well as automated hardware synthesis of these resources from an OpenCL-based programming model.

### **Which areas does your project target?**

HPC core technologies and architectures

Programming methodologies, environments, languages and tools

### **What areas of your project do you think have a potential for cross-continent synergies?**

The main areas of ECOSCALE are High Level Synthesis and Reconfigurable Computing. Several commercial systems provide FPGA-based supercomputing nodes, namely Maxeler's MPC series, Convey's HC-2, BeeCube's BEE4, SRC's MAPstation, and Timelogic's DeCypher. The importance of the utilization of reconfigurable computing for future HPC systems is also demonstrated by the fact that there is a special National Science Foundation (NSF) research center in the USA consisting of more than 30 industrial and academic partners focusing only on this topic; the outcome is the most powerful HPC system in the world utilizing reconfigurable technology (Novo-G). Altera and Xilinx have also shown significant interest in reconfigurable computing providing High Level Synthesis tools. It is obvious that High Level Synthesis and Reconfigurable Computing are two close areas of global interest and thus there is a great potential for cross-continental synergies.

## **EPiGRAM - Exascale ProGRAMming Models**



**Web address**

<http://www.epigram-project.eu/>

**Partners Involved**

KTH Royal Institute of Technology

Technische Universität Wien

EPCC - University of Edinburgh

Cray UK

Fraunhofer

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**Project Profile**

We are preparing Message Passing and PGAS programming models for exascale systems by addressing their main current limitations. By providing prototype implementations for both MP and PGAS concepts we will contribute to advancement in programming models for extreme-scale computing.

**Which areas does your project target?**

Programming methodologies, environments, languages and tools



## **D6.2 Analysis of international collaboration opportunities for the European projects**

**What areas of your project do you think have a potential for cross-continent synergies?**

Our work on MPI could have cross-continent synergy with Argonne National Laboratory projects on MPICH.

## **ESCAPE: Energy-efficient Scalable Algorithms for Weather Prediction at Exascale**



### **Web address**

<http://www.hpc-escape.eu>

### **Partners Involved**

European Centre for Medium-Range Weather Forecasts

Meteo-France

Institut Royal Meteorologique de Belgique

Danmarks Meteorologiske Institut

Eidgenoessisches Departement des Innern Deutscher Wetterdienst

Loughborough University

National University of Ireland, Galway

Instytut Chemii Bioorganicznej Polskiej Akademii Nauk

Bull SAS

AGEIA Technologies Switzerland AG

Optalysys

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### **Project Profile**

ESCAPE is funded under FET-HPC and is a Research and Innovation project. ESCAPE will develop world-class, extreme-scale computing capabilities for European operational numerical weather prediction (NWP) and future climate models. ESCAPE aims at developing next generation IFS numerical building blocks and compute intensive algorithms, implement and compute/energy efficiency diagnostics; identify new approaches and implementation on novel architectures and perform testing in operational configurations.

### **Which areas does your project target?**

Programming methodologies, environments, languages and tools

New mathematical and algorithmic approaches

### **What areas of your project do you think have a potential for cross-continent synergies?**

The fundamental algorithmic building blocks are common to most weather and climate prediction models. There is therefore a potential to share the ESCAPE outcome with operational and research centres in other countries.

## **EXA2CT**



### **Web address**

<http://www.exa2ct.eu>

### **Partners Involved**

- 1 INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW IMEC Belgium
- 2 UNIVERSITEIT ANTWERPEN UA Belgium
- 3 UNIVERSITA DELLA SVIZZERA ITALIANA USI Switzerland
- 4 VYSOKA SKOLA BANSKA - TECHNICKA UNIVERZITA OSTRAVA VSB-TUO Czech Republic
- 5 INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE INRIA France
- 6 UNIVERSITE DE VERSAILLES SAINT-QUENTIN-EN-YVELINES. UVSQ France
- 7 T-SYSTEMS SOLUTIONS FOR RESEARCH GMBH TS-SFR Germany
- 8 FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V
- 9 INTEL CORPORATION SAS France
- 10 NUMERICAL ALGORITHMS GROUP LTD NAG United Kingdom

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## **D6.2 Analysis of international collaboration opportunities for the European projects**

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### **Project Profile**

The EXA2CT project brings together experts at the cutting edge of the development of solvers, related algorithmic techniques, and HPC software architects for programming models and communication. We will produce modular open source proto-applications that demonstrate the algorithms and programming techniques developed in the project, to help boot-strap the creation of genuine exascale codes.

### **Which areas does your project target?**

Programming methodologies, environments, languages and tools

APIs and system software for future extreme scale systems

New mathematical and algorithmic approaches

### **What areas of your project do you think have a potential for cross-continent synergies?**

The work on solvers is disseminated in PETSc which is used world-wide. The work on GASPI has influence on the MPI standard, which is used world-wide. We are collaborating with TACC in the USA via Intel

### ExaFLOW

#### Web address

<http://exaflow-project.eu>

#### Partners Involved

The Royal Institute of Technology - KTH - Sweden - PDC Center for High Performance Computing - Department of Mechanics

Imperial College - IC - United Kingdom

University of Southampton - SOTON - United Kingdom

The University of Edinburgh - EPCC - United Kingdom

Universitaet Stuttgart - USTUTT - Germany - Institut für Aero- und Gasdynamik - IAG - High Performance Computing Center Stuttgart - HLRS

Ecole Polytechnique Federale de Lausanne -

EPFL - Switzerland

McLaren Racing Ltd - McLaren - United Kingdom

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#### Project Profile

We are surrounded by moving fluids (gases and liquids), be it during breathing or the blood flowing in arteries; the flow around cars, ships, and airplanes; the changes in cloud formations or the plankton transport in oceans; even the formation of stars and galaxies are closely modelled as phenomena in fluid dynamics. Fluid Dynamics (FD) simulations provide a powerful tool for the analysis of such fluid flows and are an essential element of many industrial and academic problems.

The complexities and nature of fluid flows, often combined with problems set in open domains, implies that the resources needed to computationally model problems of industrial and academic relevance is virtually unbounded. FD simulations therefore are a natural driver for exascale

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computing and have the potential for substantial societal impact, like reduced energy consumption, alternative sources of energy, improved health care, and improved climate models.

The main goal of this project is to address algorithmic challenges to enable the use of accurate simulation models in exascale environments. Driven by problems of practical engineering interest we focus on important simulation aspects including:

- error control and adaptive mesh refinement in complex computational domains,
- resilience and fault tolerance in complex simulations
- heterogeneous modeling
- evaluation of energy efficiency in solver design
- parallel input/output and in-situ compression for extreme data.

The algorithms developed by the project will be prototyped in major open-source simulation packages in a co-design fashion, exploiting software engineering techniques for exascale. We are building directly on the results of previous exascale projects (CRESTA, EPiGRAM, etc.) and will exploit advanced and novel parallelism features required for emerging exascale architectures. The results will be validated in a number of pilot applications of concrete practical importance in close collaboration with industrial partners.

### **Which areas does your project target?**

New mathematical and algorithmic approaches

### **What areas of your project do you think have a potential for cross-continent synergies?**

Working on challenges and codes of global importance.

## **ExaHyPE - An Exascale Hyperbolic PDE Engine**

### **Web address**

<http://www.exahype.eu>

### **Partners Involved**

Technische Universität München (Coordinator) - Prof. Dr. Michael Bader (High Performance Computing)

Università degli Studi di Trento - Prof. Dr.-Ing. Michael Dumbser (Numerical Analysis)

Durham University - Dr. Tobias Weinzierl (High Performance Computing)

Frankfurt Institute for Advanced Studies - Prof. Dr. Luciano Rezzolla (Theoretical Astrophysics)

Ludwig-Maximilians-Universität München - Dr. Alice-Agnes Gabriel, Prof. Dr. Heiner Igel (Computational Seismology)

RSC Technologies, Moscow - Alexander Moskovsky

Bavarian Research Alliance GmbH, - Dipl.-Ing. Robert Iberl, Teresa Kindermann

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### **Project Profile**

ExaHyPE develops a novel Exascale-ready engine to simulate large-scale problems that may be expressed via hyperbolic systems of conservation laws. It relies on latest and further developments of the ADER-DG (Arbitrary high-order derivative discontinuous Galerkin) numerical scheme, dynamically adaptive Cartesian meshes, agile load balancing and hardware-oriented optimization of the respective algorithms and implementations. While a generic PDE engine is targeted, ExaHyPE will in its project period focus on two well-defined grand challenge scenarios from computational geo- and astrophysics: the first scenario is the simulation of rotating (and collapsing) binary neutron stars, which are primary suspects for causing phenomena such as gamma ray bursts or gravitational waves; the second scenario considers regional earthquake simulation with a special focus on dynamic rupture processes, which may lead to better understanding of earthquake processes and thus to improved seismic hazard assessment for critical infrastructure, e.g. On the methodological side,



## **D6.2 Analysis of international collaboration opportunities for the European projects**

ExaHyPE seeks to demonstrate the necessity for high-order approximation in space and time to optimize time- and energy-to-solution, and the excellent suitability of these methods for future supercomputing platforms.

### **Which areas does your project target?**

New mathematical and algorithmic approaches

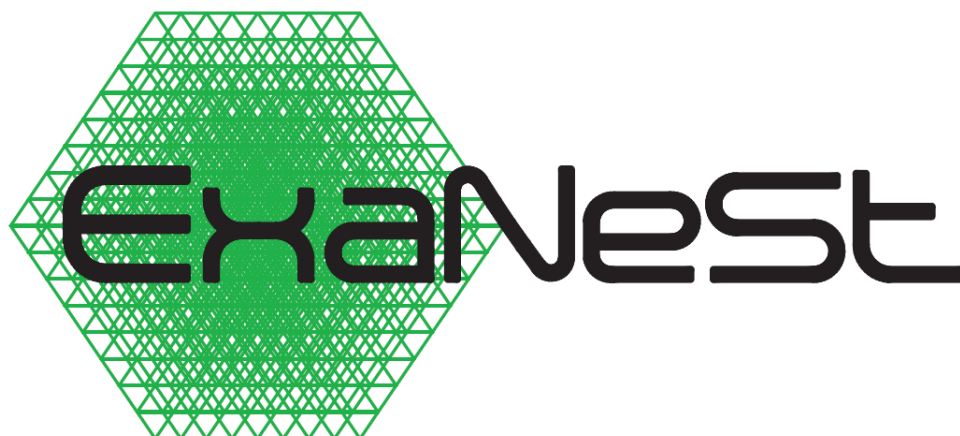
### **What areas of your project do you think have a potential for cross-continent synergies?**

For general areas of collaboration, see 12.

High-order numerics and parallel adaptive mesh refinement is still a computational challenge, and addressed by supercomputing groups in the US, e.g.

In terms of supercomputing architectures, ExaHyPE will concentrate on homogeneous designs, such as envisaged for NERSC's Cori system or the CORAL platform "Aurora". The ExahyPE software will be designed as a compute-bound application that fully exploits the capabilities of these machines.

## **ExaNeSt - European Exascale System Interconnect and Storage**



### **Web address**

<http://www.exanest.eu>

### **Partners Involved**

Foundation for Research and Technology - Hellas (FORTH)

Iceotope Technologies Ltd

Allinea Software Ltd

EnginSoft S.p.A.

eXact lab srl

MonetDB Solutions (MDBS)

Virtual Open Systems (VOSYS)

Istituto Nazionale di Astrofisica (INAF)

National Institute for Nuclear Physics (INFN)

The University of Manchester (UoM)

Universitat Politècnica de València (UPV)

Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung E.V (Fraunhofer)

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## **D6.2 Analysis of international collaboration opportunities for the European projects**

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### **Project Profile**

ExaNeSt develops and prototypes solutions for Interconnection Networks, Storage, and Cooling, as these have to evolve in order for the production of exascale-level supercomputers to become feasible. We tune real HPC Applications, and we use them to evaluate our solutions.

Interconnection Network: exascale performance can only be reached by interconnecting millions of computing cores, their (volatile) memories and (non-volatile) storage, special-purpose accelerator hardware, and their input/output (I/O) devices, in a way such that all of them can cooperate tightly and effectively in solving one huge problem in a reasonable amount of time. This amounts to huge challenge for the network that implements this interconnection and its interface to the hardware and software components of the entire system: it has to be fast, resilient, and low-cost, both in term of cost-to-build and energy-to-operate.

We develop and prototype innovative hardware and software for such networks to become tightly integrated with the system components, to become faster, to offer better quality-of-service (QoS) – especially congestion mitigation, to be resilient to failures, and to consume less energy.

Storage: traditional supercomputers used a large number of magnetic disks for storing non-volatile and permanent checkpoints and data, where these disks appeared as I/O devices to the computing cores. Storage technologies now change to flash and non-volatile memories (NVM), featuring dramatically lower latencies; interconnection and software architecture have to also change, in order to take advantage of such much faster access times.

We develop and prototype a distributed storage system where NVM's are local to the compute cores hence fast to access at low energy cost, yet the aggregate NVM's in the entire system form a unified storage.

Cooling: communicating at low delay and energy cost requires physical proximity, i.e. packing thousands of cores and their components into a blade board and packing about a hundred blades into a rack (which also economizes on installation floor area). The by-product, unfortunately, is a large heat density to be removed.

We develop and prototype innovative Packaging and Cooling technology, based on total immersion in a sophisticated, non-conductive, engineered coolant fluid that allows the highest possible packing density while maintaining reliability.

Applications: we evaluate all these technologies using real High-Performance Computing (HPC) and Big Data Applications –from HPC simulations to Business Intelligence support– running on a real prototype at the scale of many hundred nodes containing thousands of compute cores.

Furthermore, we tune our firmware, the systems software, libraries, and such applications so that they take the best possible advantage of our novel communication and storage architecture: we support task-to-data software locality models, to ensure minimum data communication energy

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overheads and property maintenance in databases; and we provide a platform management scheme for big-data I/O to our resilient, unified distributed storage compute architecture.

### **Which areas does your project target?**

HPC core technologies and architectures

Programming methodologies, environments, languages and tools

APIs and system software for future extreme scale systems

### **What areas of your project do you think have a potential for cross-continent synergies?**

Areas where world-wide API's are needed to take advantage of new technologies:

Applications Tuning, API's and Systems Software for: zero-copy, user-level, RDMA-based interprocessor communication, and for taking advantage of a Global Address Space.

Storage Systems and their API's and Systems Software for: distributed storage systems where NVM's are local to the compute cores.

API's and OS mechanisms for congestion mitigation and resilience in interconnection networks.

### ExaNoDe

**Web address**

not yet defined

**Partners Involved**

CEA

ARM

ETH Zürich

FORTH

Fraunhofer

SCAPOS

UNIVERSITY OF MANCHESTER

BULL

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**Project Profile**

ExaNoDe is a collaborative European project within the “Horizon 2020 Framework Programme”, that investigates and develop a highly integrated, high-performance, heterogeneous System-on-a-Chip (SoC) aimed towards exascale computing. It is addressing these important challenges through the coordinated application of several innovative solutions recently deployed in HPC: ARM-v8 low-power

## **D6.2 Analysis of international collaboration opportunities for the European projects**

processors for energy efficiency, 3D interposer integration for compute density and an advanced memory scheme for exabyte level capacities. The ExaNoDe SoC will embed multiple silicon “chiplets”, stacked on an active silicon interposer in order to build an innovative 3D-Integrated-Circuit (3D-IC). A full software stack allowing for multi-node capability will be developed within the project. The project will deliver a reference hardware that will enable the deployment of multiple 3D-IC System-on-Chips and the evaluation, tuning and analysis of HPC mini-apps along with the associated software stack.

### **Which areas does your project target?**

HPC core technologies and architectures

### **What areas of your project do you think have a potential for cross-continent synergies?**

By decreasing development costs with 3D integration and ARM cores, ExaNoDe will enable more companies to develop application-targeted advanced computing solutions. This will have a potential for cross-continent synergies between our European project and US or Japan companies.

**ExCAPE (Exascale Compound Activity Prediction Engines)**



**Web address**

<http://www.excape-h2020.eu>

**Partners Involved**

Imec vzw (Belgium)

JANSSEN CILAG SA (Spain)

IT4I (Czech Republic)

ASTRAZENECA AB (Sweden)

UNIVERSITAT LINZ (Austria)

Aalto University (Finland)

Intel (Belgium)

IDEAconsult (Bulgaria)

Royal Holloway (UK)

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### **Project Profile**

Our project focuses on developing better machine learning algorithms for predicting biological activity of drugs, by taking advantage of large amounts of computation. A secondary concern is making easier the deployment of new machine learning algorithms on supercomputers, whilst keeping the implementations efficient so that the models benefit from the computation available. The project brings together machine learning experts to develop the new algorithms, scale-up experts to make prototype implementations and pharmaceutical industry partners to test the new algorithms and implementations.

### **Which areas does your project target?**

Programming methodologies, environments, languages and tools

New mathematical and algorithmic approaches

### **What areas of your project do you think have a potential for cross-continent synergies?**

- 1) Machine learning component for biological activity. The Japanese HPC community has already looked at the same use case, and sharing experiences with them would be very beneficial.
- 2) Machine learning in general. There are many groups around the world looking at large scale machine learning, although typically in data centres. Any other groups doing ML on supercomputers would be very useful to speak to, regardless of the actual use-case.
- 3) HPC challenges in the pharmaceutical industry. The same challenges are being faced globally in the pharmaceutical industry, so international collaboration with other industry partners would make sense, to understand their experiences with HPC and their future plans.
- 4) Programming models. Machine learning (and the life sciences) do not typically use the classical programming models from HPC (MPI, OpenMP, C, Fortran etc). Discussion with other groups looking at programming models (and associated frameworks and implementations) for these domains would be useful.



## **EXTRA**



**Web address**

<http://www.extrahpc.eu>

**Partners Involved**

Ghent University Belgium

Telecommunications Systems Institute Greece

Imperial College London UK

Politecnico di Milano, Italy

University of Amsterdam, The Netherlands

Ruhr-University Bochum, Germany

Maxeler, UK

Synelixis, Greece

University of Cambridge, UK

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**Project Profile**

EXDCI - FETHPC-671558

## **D6.2 Analysis of international collaboration opportunities for the European projects**

EXTRA focuses on the fundamental building blocks for run-time reconfigurable exascale HPC systems: new reconfigurable architectures with very low reconfiguration overhead, new tools that truly take reconfiguration as a design concept, and applications that are tuned to maximally exploit run-time reconfiguration techniques. Our goal is to provide the European platform for run-time reconfiguration to maintain Europe's competitive edge and leadership in run-time reconfigurable computing.

### **Which areas does your project target?**

HPC core technologies and architectures

Programming methodologies, environments, languages and tools

Reconfigurable Computing for HPC

### **What areas of your project do you think have a potential for cross-continent synergies?**

The main concept of reconfigurable computing is studied all over the world, with a large body of work being done in the US and Canada, due to the main suppliers of FPGA technology (Xilinx and Altera) being headquartered in the US. We focus more on higher level reconfiguration aspects and HPC applications that make efficient use of reconfiguration (possibly through innovations in the reconfiguration architectures) which can also benefit other fields of applications using reconfigurable technology.

**green flash**



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**Partners Involved**

Observatoire de Paris

University of Durham

Microgate

PLDA

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### **Project Profile**

The main goal of Green Flash is to design and build a prototype for a Real-Time Controller (RTC) targeting the European Extremely Large Telescope (E-ELT) Adaptive Optics (AO) instrumentation. The E-ELT is a 39m diameter telescope to see first light in the early 2020s. To build this critical component of the telescope operations, the astronomical community is facing technical challenges, emerging from the combination of high data transfer bandwidth, low latency and high throughput requirements, similar to the identified critical barriers on the road to Exascale. With Green Flash, we will propose technical solutions, assess these enabling technologies through prototyping and assemble a full scale demonstrator to be validated with a simulator and tested on sky. With this R&D program we aim at feeding the E-ELT AO systems preliminary design studies, led by the selected first-light instruments consortia, with technological validations supporting the designs of their RTC modules. Our strategy is based on a strong interaction between academic and industrial partners. Components specifications and system requirements are derived from the AO application. Industrial partners lead the development of enabling technologies aiming at innovative tailored solutions with potential wide application range. The academic partners provide the missing links in the ecosystem, targeting their application with mainstream solutions. This increases both the value and market opportunities of the developed products. A prototype harboring all the features is used to assess the performance. It also provides the proof of concept for a resilient modular solution to equip a large scale European scientific facility, while containing the development cost by providing opportunities for return on investment.

### **Which areas does your project target?**

HPC core technologies and architectures

Programming methodologies, environments, languages and tools

### **What areas of your project do you think have a potential for cross-continent synergies?**

The baseline strategy for AO real-time control, involving MVM with a wavefront reconstructor matrix, relies extensively on dense linear algebra (DLA) both for the Real-Time box task and the supervisor module tasks. In the case of the former, the problem can be distributed efficiently over several independent nodes processing portions of the matrix with a single data concentration step at the end of the computation. While the strong constraint is on determinism and end-to-end latency of the overall, the job scheduling is relatively easy and follows a bulk synchronous parallel approach, driven by the data transfer from the sensors and the explicit synchronization by data concentration before it can be sent to the optics. The strategy in this case is to optimize the process execution on a single node and overlap communication with sensors and first processing steps. The algorithm is memory bound and the local implementation should rely on optimized utilization of the compute device's memory bus. Concerning the supervisor module, the most compute intensive task is the computation of the reconstructor matrix. It involves the inversion of a large covariance matrix either through matrix factorization or through direct inversion. In the latter case, an embarrassingly parallel problem with a numerical complexity scaling with  $N^3$ , an optimized implementation should optimize the usage of computing cores rather than the memory bus. However, the underlying algorithms

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require frequent synchronizing of global communications, which represents a bottleneck that limits performance. This bottleneck will be further exacerbated when concurrency will reach billions of core in Exascale systems and should be addressed as a general issue for the HPC community.

## **INTERTWinE (Programming Model INTERoperability ToWards Exascale)**



**Web address**

<http://www.intertwine-project.eu/>

**Partners Involved**

EPCC, University of Edinburgh, UK (Lead)

Barcelona Supercomputing Center, Spain

Kungliga Tekniska Högskolan (KTH), Sweden

Inria, France

Fraunhofer, Germany

Deutsches Zentrum für Luft und Raumfahrt, Germany

TS-SFR Solutions for Research, Germany

Universitat Jaume I de Castellón, Spain

University of Manchester, UK

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## **D6.2 Analysis of international collaboration opportunities for the European projects**

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### **Project Profile**

The INTERTWinE project addresses the problem of programming model design and implementation for the Exascale. It is funded through the European Commission Horizon 2020 program, FET-HPC 2014 Research and Innovation Action.

The first Exascale computers will be very highly parallel systems, consisting of a hierarchy of architectural levels. To program such systems effectively and portably, application programming interfaces (APIs) with efficient and robust implementations will be required.

A single, “silver bullet” API which addresses all the architectural levels does not exist and seems very unlikely to emerge soon enough. We must therefore expect that using combinations of different APIs at different system levels will be the only practical solution in the short to medium term.

Although there remains room for improvement in individual programming models and their implementations, the main challenges lie in interoperability between APIs. It is this interoperability, both at the specification level and at the implementation level, which we seek to address and to substantially improve.

INTERTWinE brings together the principal European organisations driving the evolution of programming models and their implementations. We will focus on seven key programming APIs: MPI, GASPI, OpenMP, OmpSs, StarPU, QUARK and PaRSEC, each of which has a project partner with extensive experience in API design and implementation.

Interoperability requirements and evaluation of implementations will be driven by a set of kernels and applications, each of which has a project partner with a major role in their development.

INTERTWinE will implement a co-design cycle, by feeding advances in API design and implementation into the applications and kernels, thereby driving new requirements and hence further advances.

### **Which areas does your project target?**

Programming methodologies, environments, languages and tools

### **What areas of your project do you think have a potential for cross-continent synergies?**

- Engagement with (international) standards bodies in the area of programming models for HPC applications (GASPI, MPI, OpenMP).

- Collaboration with researchers in other regions, including:

- University of Tennessee, USA - Jack Dongarra is a project investigator.

- Argonne National Labs, USA:

- Pavan Balaji is collaborating with project partner BSC on GLES? (funded G8 project).

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- Marcus Neil actively researching better interoperability between the two most popular HPC programming models (that is, MPI and OpenMP).



## **Mont-Blanc**



### **Web address**

<http://www.montblanc-project.eu/>

### **Partners Involved**

BSC

Bull/Atos

ARM

LRZ

Juelich

Allinea

CEA

HLRS

Inria

Universidad de Cantabria (Santander)

GENCI

University of Bristol

ETH Zurich

CRNS (Centre national de la Recherche Scientifique) / LIRMM

AVL

Institute for Scientific Computing of KF Univ. Graz

Université de Versailles Saint Quentin

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### Project Profile

The Mont-Blanc and Mont-Blanc2 projects are FP7 EU projects sharing the vision of developing a European Exascale approach leveraging commodity power- and cost-efficient embedded technologies.

In the frame of these two projects the first large ARM-based prototype dedicated to HPC has been deployed. The 1000+ computational nodes are operational since May 2015 at Barcelona Supercomputing Center and open to the partner access. The projects have also developed a complete HPC system software stack for ARM-based compute nodes tested on prototype and commercial platforms.

The rapid progress of Mont-Blanc towards defining a scalable and efficient pre-Exascale platform has revealed a number of challenges and opportunities to broaden the scope of investigations and developments. Particularly, the growing interest of the HPC community in accessing the Mont-Blanc platform calls for increased efforts to setup a production-ready environment. Within the Mont-Blanc 2 project, therefore effort is focused on:

- improvement of the system software stack, with emphasis on programmer tools (debugger, performance analysis)
- research in system resiliency (from applications to architecture support)
- test and support of ARM 64 bit architecture
- porting and testing of new industrial and academic applications

Within the H2020 Programme, the brand new Mont-Blanc 3 project is continuing on the way paved by the previous two projects, targeting the development of a scalable and balanced high-end compute node for future HPC systems, based on low-power embedded technology. It will adopt a co-design approach to make sure that the hardware and system innovations are readily translated into benefits for HPC applications. This approach integrates architectural aspects together with simulation efforts to feed and validate the architectural studies, in parallel with work on system software ecosystem and applications. Effort is focussed on the following targets:

- Defining the architecture of an Exascale-class compute node based on the ARM architecture, and capable of being manufactured at industrial scale;
- Assessing the available options for maximum compute efficiency;
- Developing the matching software ecosystem to pave the way for market acceptance of ARM solutions.

### Which areas does your project target?

HPC core technologies and architectures

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Programming methodologies, environments, languages and tools

### **What areas of your project do you think have a potential for cross-continent synergies?**

We consider the following topics as powerful tools and starting points for future collaborations (with no geographical limitations):

- To access the computing platforms (ARM-based prototypes) made available to partners and to a selected pool of End-Users of the Mont-Blanc project.
- To adopt and contribute to the system software stack developed within the Mont-Blanc project over the years, that is needed for future ARM based Exascale systems
- To organize training and workshop promoting the interchange of experiences in area related to the project (prototyping, ARM-based computing, innovative programming models, etc.).

### **Network for Sustainable Ultrascale Computing (NESUS)**

#### **Web address**

<http://www.nesus.eu>

#### **Partners Involved**

"Technische Universität Wien University of Innsbruck IMEC University of Mons (UMONS) University of Sarajevo International University of Sarajevo Institute for Parallel Processing Rudjer Boskovic Institute University of Cyprus SIX Research Center Technical University of Denmark University of Tartu Abo Akademi University CSC – IT Center of Science Ltd. INRIA Centre National de la Recherche Scientifique University Paul Sabatier University Ss. Cyril and Methodius “St. Paul the Apostle” University University Bayreuth Technische Universität Chemnitz Johannes Gutenberg-Universität Mainz Aristotle University of Thessaloniki Harokopio University of Athens University of Macedonia University of Ioannina Foundation for Research and Technology – Hellas (FORTH) MTA SZTAKI Budapest University of Technology and Economics University College Dublin University College Cork Università della Calabria CNR-ICAR Università di Modena e Reggio Emilia University of Torino Vilnius Gediminas Technical University University of Luxembourg University of Malta University of Donja Gorica University of Amsterdam University of Bergen Norwegian University of Science and Technology Oslo and Akerrshus University College University of Tromso Czestochowa University of Technology Poznan Supercomputing and Networking Center INESC ID INESC TEC University Politehnica of Bucarest West University of Timisoara University of Nis Comenius University in Bratislava University of Zlilina Jožef Stefan Institute University of Ljubljana La Laguna University Universidad Jaime I University of A Coruña University Carlos III of Madrid Barcelona Supercomputing Center Universidad de Murcia Universidad Católica San Antonio de Murcia Universidad de Valladolid University of Extremadura CIEMAT KTH Royal Institute of Technology Uppsala University University of Neuchatel University of Applied Sciences of Western Switzerland Istanbul Technical University University of Cambridge University of Derby University of Manchester University of York Polytechnic University of Tirana National Academy of Sciences of the Republic of Armenia Research and Educational Networking Association of Moldova Moscow State University Lviv Polytechnic National University The University of Sydney St Francis Xavier university Universidad de los Andes Indraprastha Institute of Information Technology (IIIT) Centro de investigación y Estudios Avanzados del Instituto Politécnico Nacional (CINVESTAV) Northwestern University "

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#### **Project Profile**

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### **Which areas does your project target?**

NESUS is ICT COST action. (IC1305).

The objective is to promote cooperation and networking to create a research community focused on sustainability in extreme scale/ultrascale computing systems. Understanding sustainability in a holistic way, not only energy efficiency.

The goal of the NESUS Action is to establish an open European research network targeting sustainable solutions for ultrascale computing aiming at cross fertilization among HPC, large scale distributed systems, and big data management. The network will contribute to glue disparate researchers working across different areas and provide a meeting ground for researchers in these separate areas to exchange ideas, to identify synergies, and to pursue common activities in research topics such as sustainable software solutions (applications and system software stack), data management, energy efficiency, and resilience. Some of the most active research groups of the world in this area are members of this proposal. This Action will increase the value of these groups at the European-level by reducing duplication of efforts and providing a more holistic view to all researchers, it will promote the leadership of Europe, and it will increase their impact on science, economy, and society.

### **What areas of your project do you think have a potential for cross-continent synergies?**

Programming methodologies, environments, languages and tools

APIs and system software for future extreme scale systems

New mathematical and algorithmic approaches

Sustainability in extreme scale systems

### **What tools and mechanisms do you think could be used to facilitate the cross-continent synergies your project could produce?**

NESUS has working groups related to: Programming models and runtimes; Resilience of applications and runtime environments; Sustainable data management; Energy efficiency; and Applications. Research on sustainable programming and execution models in the context of rapidly changing underlying computing architecture is a major goal in NESUS. The idea is to explore synergies among emerging programming models and run-times from HPC, distributed systems, and big data management communities that can be portable and (almost) transparent to application programmers.

This research line is very important in Exascale if we want them to be adopted. We have to provide programming models supporting different kind of underlying systems and helping to reduce the effort to redesign existing applications.

Data management techniques is also a major area having potential for cross-continental synergies, provided that nowadays data management is a major challenge to reach Extreme scale. The goal of

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NESUS is to contribute to the evolution of the storage I/O stack towards higher-levels of scalability and sustainability by enhancing data sharing/integration (globalization of data), improving the programmability of data management and analysis, and by providing adaptivity to manage data workload and uncertainty.

Energy efficiency is another area with high potential for cross-continent synergies. NESUS is contributing to develop techniques for monitoring and energy analysis of large scale infrastructures and to propose new holistic models of energy consumption for ultrascale systems. The goal is to provide those models and information to the several layers of the system to help in the design of energy aware software components that can allow users to specify energy issues in their applications.

Finally, there is also potential for cooperation in the applications area, as a NESUS goal is to study the impact of application requirements on the ultrascale system design. It is mandatory to evaluate the needs of the HPC applications concerning scalability, programmability, portability and resilience, trying to identify computational patterns for expressing the applications at a higher level of abstraction for leveraging programming for ultrascale systems. The final goal is to reduce design and programming efforts, while building portable programs that can live longer.

## **NEXTGenIO**



**Web address**

<http://www.nextgenio.eu>

**Partners Involved**

EPCC

Intel

Fujitsu

BSC

TU Dresden

ECWMF

Allinea

Arctur

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### **Project Profile**

The overall objective of the Next Generation I/O Project (NEXTGenIO) is to design and prototype a new, scalable, high-performance, energy efficient computing platform, based on non-volatile memory technologies, designed to address the challenge of delivering scalable I/O performance to applications at the Exascale. These hardware and systemware developments will be coupled to a co-design approach driven by the needs of some of today's most demanding HPC applications. By meeting this overall objective, NEXTGenIO will solve a key part of the Exascale challenge and enable HPC and Big Data applications to overcome the limitations of today's HPC I/O subsystems.

Today most high-end HPC systems employ data storage separate from the main system and the I/O subsystem often struggles to deal with the degree of parallelism present. As we move into the domain of extreme parallelism at the Exascale we need to address I/O if such systems are to deliver appropriate performance and efficiency for their application user communities.

The NEXTGenIO project will explore the use of non-volatile memory technologies and associated systemware developments through a co-design process with three 'end-user' partners: a high-end academic HPC service provider, a global numerical weather centre and a commercial on-demand HPC service provider. These partners will develop a set of I/O workload simulators to allow quantitative improvements in I/O performance to be directly measured on the new system in a variety of research configurations. Systemware software developed in the project will include performance analysis tools, improved job schedulers that take into account data locality and energy efficiency, optimised programming models, and APIs and drivers for optimal use of the new I/O hierarchy.

The project will deliver immediately exploitable hardware and software results and show how to deliver high performance I/O at the Exascale.

#### **Which areas does your project target?**

HPC core technologies and architectures

Programming methodologies, environments, languages and tools

APIs and system software for future extreme scale systems

#### **What areas of your project do you think have a potential for cross-continent synergies?**

All areas of the project have that potential.



## **NLAFET: Parallel Numerical Linear Algebra for Future Extreme-Scale Systems**

### **Web address**

N/A - NLAFET web will be developed after kick-off meeting (see below).

### **Partners Involved**

- Umeå University, Sweden (coordinator of NLAFET)
- The University of Manchester, UK
- Institute National de Recherche en Informatique et en Automatique, France
- Science and Technology Facilities Council, UK

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NLAFET Coordinator: Bo Kågström

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### **Project Profile**

The aim is to enable a radical improvement in the performance and scalability of a wide range of real-world applications relying on linear algebra software, by developing novel architecture-aware algorithms and software libraries, and the supporting runtime capabilities to achieve scalable performance and resilience on heterogeneous architectures. The focus is on a critical set of fundamental linear algebra operations including direct and iterative solvers for dense and sparse linear systems of equations and eigenvalue problems. The main research objectives of NLAFET are:

- (i) development of novel algorithms that expose as much parallelism as possible, exploit heterogeneity, avoid communication bottlenecks, respond to escalating fault rates, and help meet emerging power constraints;
- (ii) exploration of advanced scheduling strategies and runtime systems focusing on the extreme scale and strong scalability in multi/manycore and hybrid environments;

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(iii) design and evaluation of novel strategies and software support for both offline and online auto-tuning. The validation and dissemination of results will be done by integrating new software solutions into challenging scientific applications in materials science, power systems, study of energy solutions, and data analysis in astrophysics. The deliverables also include a sustainable set of methods and tools for cross-cutting issues such as scheduling, auto-tuning, and algorithm-based fault tolerance packaged into open source library modules.

### **Which areas does your project target?**

Programming methodologies, environments, languages and tools

New mathematical and algorithmic approaches

See focus topics in Project profile above.

### **What areas of your project do you think have a potential for cross-continent synergies?**

NLAFET is a co-design effort for designing, prototyping, and deploying new linear algebra software libraries

- Exploration of new algorithms
- Investigation of advanced scheduling strategies
- Investigation of advanced auto-tuning strategies
- Validation of results in challenging scientific and engineering HPC applications
- Open source library software

NLAFET will undertake and encourage different types of collaborations with different stakeholders, including library software users, academia, as well as HW and SW vendors. These collaborations could certainly lead to potential cross-continent synergies.

## **NUMEXAS**



### **Web address**

<http://www.numexas.eu>

### **Partners Involved**

1-CIMNE (CENTRE INTERNACIONAL DE METODES NUMERICS EN ENGINYERIA) SPAIN

2-CSUC (CONSORCI DE SERVEIS UNIVERSITARS DE CATALUNYA) SPAIN

3-LUH (GOTTFRIED WILHELM LEIBNIZ UNIVERSITAET HANNOVER) GERMANY

4-NTUA (NATIONAL TECHNICAL UNIVERSITY OF ATHENS) GREECE

5-QUANTECH ATZ SA SPAIN

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### **Project Profile**

The overall aim of NUMEXAS is to develop, implement and demonstrate the next generation of numerical simulation methods to be run under exascale computing architectures. This cannot be done by just scaling currently available codes, but by implementing new algorithms for advanced numerical methods to really exploit the intrinsic capabilities of the future exascale computing infrastructures.

The specific goal of NUMEXAS is the development of numerical methods based on validated models that enable scaling to millions of cores along the complete simulation pipeline. The main outcome of NUMEXAS will be a new set of numerical methods and computer codes that will allow industries, governments and academia to routinely solve multidisciplinary large-scale class problems in applied

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sciences and engineering with high efficiency and the simplicity of the best nowadays user-friendly computer codes.

In order to achieve the above mentioned goals, improvements are required along the whole simulation pipeline, including parallel pre-processing of analysis data and mesh generation, parallel, scalable, parallel field solvers in fluid, solid mechanics and coupled problems, optimum design parallel solvers considering uncertainties and parallel post-processing of numerical results

### **Which areas does your project target?**

Programming methodologies, environments, languages and tools

New mathematical and algorithmic approaches

### **What areas of your project do you think have a potential for cross-continent synergies?**

New Numerical methods and programming algorithms that constitute the next generation of numerical simulation techniques that are scalable to millions of cores so that exascale class problems can be solved routinely. The goal is the development and implementation of new numerical simulation techniques amenable to scalability to millions of cores along the complete simulation pipeline for a variety of large-scale multidisciplinary problems in applied sciences and engineering: parallel pre-processing and grid generation, parallel structured/unstructured field solvers of high order, parallel optimum design solvers considering uncertainties and parallel in-solver visualization and feature extraction

## **READEX - Runtime Exploitation of Application Dynamism for Energy-efficient eXascale computing**

### **Web address**

<http://www.readex.eu>

### **Partners Involved**

Technische Universität Dresden/ZIH

Norges Tekniski-Naturvitenskapelige Universitet

Vysoka Skola Banska - Technicka Univerzita Ostrava

National University of Ireland/Galway

Intel Corporation SAS

Technische Universität München

Gesellschaft für numerische Simulation mbH

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### **Project Profile**

The READEX project aims at developing a tools-aided methodology for dynamic auto-tuning of HPC applications to exploit the dynamically changing resource requirements for improved energy-efficiency. It connects technologies from both ends of the computing spectrum: the methodology will be based on the System Scenario Methodology for dynamic tuning developed in the Embedded Systems domain paired with the technology from the Periscope Tuning Framework (PTF) developed in the FP7 AutoTune project for static auto-tuning in the area of HPC.

## **D6.2 Analysis of international collaboration opportunities for the European projects**

READEX is a H2020-FETHPC-2014 project funded under topic b) Programming methodologies, environments, languages and tools and focuses entirely on the development of methodology and required software; no hardware development will be done.

### **Which areas does your project target?**

Programming methodologies, environments, languages and tools

### **What areas of your project do you think have a potential for cross-continent synergies?**

There are groups working on auto-tuning in the US. While none of them is considering the System Scenario Methodology as a basis, some collaboration on the topic of tuning strategies and tuning parameters can provide viable synergies. Some of these groups have been invited to the workshop on code auto-tuning to be held at CGO 2016. The meeting will also be used to explore possible synergies.

## **REPARA: Reengineering and Enabling Performance and power of Applications<sup>7</sup>**

### **Web address**

<http://www.repara-project.eu>

### **Partners Involved**

University Carlos III of Madrid, Spain

HSR Rapperswil, Switzerland

Technical University of Darmstadt, Germany

University of Szeged, Hungary

Univeristy of Pisa, Italy

Evopro Innovation, Hungary

Ixion Industry and aerospace, Spain

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### **Project Profile**

Parallel heterogeneous architectures have emerged as a promising option in terms of performance and energy efficiency. However programability is a real wall for them to be adopted.

The REPARA project aims to help the transformation and deployment of new and legacy applications in parallel heterogeneous computing architectures while maintaining a balance between application performance, energy efficiency and source code maintainability.

We foresee that the REPARA project will provide a workflow in which source code of applications will be transformed and deployed on parallel heterogeneous platforms allowing to make the proper

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<sup>7</sup> This project is funded within the Seventh Framework Programme (FP7) but is not part of the The European Exascale Projects initiative (<http://exascale-projects.eu/>)

## **D6.2 Analysis of international collaboration opportunities for the European projects**

balance between performance and energy. We currently support specific platforms consisting of multi-cores, GPGPUs, FPGAs and DSPs.

### **Which areas does your project target?**

HPC core technologies and architectures

Programming methodologies, environments, languages and tools

### **What areas of your project do you think have a potential for cross-continent synergies?**

#### **SOURCE CODE ANALYSIS**

Source code is the key asset that is handled in the REPARA workflow. Consequently, source code representation provides the means for performing application partitioning and source code transformations. In the context of the project we have defined an intermediate representation of C++ translation units. It conforms to the REPARA-AIR open specification which is capable of including all the needed information for performing transformations to specific software programming models or hardware reconfigurable architectures.

#### **APPLICATION PARTITIONING**

In order to annotate computational kernels, we have defined a set of source code annotations, by means of C++11 attributes. Those attributes are used to provide information about the main characteristics from the kernels. Once an application is annotated partitioning is performed to allocate different kernels to available computing devices.

#### **SOFTWARE TRANSFORMATION**

REPARA attributes, annotate C++ code that can be transformed to a corresponding version suitable for execution on target accelerators or to code that can be mapped to a specified parallel execution pattern. C++ code can be augmented with attributes through a separate analysis tool, or added manually. They imply a transformation of the source code to exploit the potential parallelism in the code.

We developed various kinds of transformations for different purposes like transformations enabling code to be compiled or synthesized for a target accelerator and transformations for converting code to a parallel counterpart, that aim for an increase in performance. For alleviating the task of applying such transformations we provide a set of tools to automate them in an integrated development environment.

#### **RUNTIMES FOR PARALLEL HETEROGENEOUS ARCHITECTURES**

The REPARA runtime is implemented by properly integrating the existing structured parallel programming framework FastFlow in such a way the resulting integrated parallel programming framework supports all the devices targeted and orchestrates the kernel execution on different



## **D6.2 Analysis of international collaboration opportunities for the European projects**

devices providing all those mechanisms and policies needed to dynamically reconfigure kernel execution parameters

As a whole, the FastFlow runtime represents an abstraction layer decoupling the top level decisions making process from the low-level mechanisms to target specific devices.

## **SAGE ( Percipient StorAGE for Exascale Data Centric Computing)**



**Web address**

<http://www.sagestorage.eu>

**Partners Involved**

1. Allinea, UK
2. Atos, France
3. CEA, France
4. CCFE(UK Atomic Energy Agency), UK
5. DFKI, Germany
6. Diamond Light Source , UK
7. Juelich (FZJ), Germany
8. KTH, Sweden
9. Seagate ( Co-ordinator), UK
10. STFC, UK

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### **Project Profile**

Worldwide data volumes are exploding and islands of storage remote from compute will not scale. We will demonstrate the first instance of intelligent data storage, uniting data processing and storage as two sides of the same rich computational model. This will enable sophisticated, intention-aware data processing to be integrated within a storage systems infrastructure, combined with the potential for Exabyte scale deployment in future generations of extreme scale HPC systems. Enabling only the salient data to flow in and out of compute nodes, from a sea of devices spanning next generation solid state to low performance disc we enable a vision of a new model of highly efficient and effective HPC and Big Data demonstrated through the SAGE project.

### **Objectives**

- Provide a next-generation multi-tiered object-based data storage system (hardware and enabling software) supporting future generation multi-tier persistent storage media supporting integral computational capability, within a hierarchy.
- Significantly improve overall scientific output through advancements in systemic data access performance and drastically reduced data movements.
- Provides a roadmap of technologies supporting data access for both Exascale/Exabyte and High Performance Data Analytics.
- Provide programming models, access methods and support tools validating their usability, including 'Big-Data' access and analysis methods
- Co-Designing and validating on a smaller representative system with earth sciences, meteorology, clean energy, and physics communities
- Projecting suitability for extreme scaling through simulation based on evaluation results.

### **Which areas does your project target?**

HPC core technologies and architectures

Programming methodologies, environments, languages and tools

APIs and system software for future extreme scale systems

### **What areas of your project do you think have a potential for cross-continent synergies?**

SAGE targets a range of applications & data intensive use cases for co-design (Bio-informatics, Space Weather, Satellite Data Processing, Visualization, Fusion Energy Use Cases, Synchrotron Use Cases, etc).

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SAGE aims for a new storage architectures, with outstanding performance and new features which could be exploited by a broad range of applications. Within this project the set of applications will be analysed with respect to their I/O requirements. The methodologies developed in SAGE could also be applied to selected applications from the DoE CoEs.

Fusion energy use cases in SAGE will target the ITER fusion experiment, expected to have very wide international reach and impact (with seven partners. China, EU, India, Japan, Korea, Russia & the US).

The programming model areas will look at innovations in MPI & PGAS to bring about the effective utilization of NVRAM. These innovations can be looked at by the MPI consortium.

The object storage APIs developed in the project has the potential for international standardisation as an Exascale Object storage API.

The international data analytics community can take note of innovations in complex data analytics workflows and NVRAM usage with Apache Flink in SAGE. Apache Flink will pursue international cross-continent collaborations in this area.