Addressing the Challenge of Exaflopic Computation

Workshop on Coupling Technologies for Earth System Modelling: Today and Tomorrow

December 2010, Toulouse CERFACS
Jean-Yves Berthou, EDF R&D – Jack Dongarra/Pete Beckman
EESI coordinator IESP coordinators

Jean-Claude André
www.eesi-project.eu
Summary of the presentation

- International Exascale Software Project (IESP)
- European Exascale Software Initiative (EESI)
- Exascale Software Center (ESC)
# Potential System Architecture Targets

<table>
<thead>
<tr>
<th>System attributes</th>
<th>2010</th>
<th>“2015”</th>
<th>“2018”</th>
<th>Difference Today &amp; 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>System peak</td>
<td>2 Pflop/s</td>
<td>200 Pflop/s</td>
<td>1 Eflop/sec</td>
<td>O(1000)</td>
</tr>
<tr>
<td>Power</td>
<td>6 MW</td>
<td>15 MW</td>
<td>~20 MW</td>
<td></td>
</tr>
<tr>
<td>System memory</td>
<td>0.3 PB</td>
<td>5 PB</td>
<td>32-64 PB</td>
<td>O(100)</td>
</tr>
<tr>
<td>Node performance</td>
<td>125 GF</td>
<td>0.5 TF</td>
<td>7 TF</td>
<td>10 TF</td>
</tr>
<tr>
<td>Node memory BW</td>
<td>25 GB/s</td>
<td>0.1 TB/sec</td>
<td>1 TB/sec</td>
<td>4 TB/sec</td>
</tr>
<tr>
<td>Node concurrency</td>
<td>12</td>
<td>O(100)</td>
<td>O(1,000)</td>
<td>O(10,000)</td>
</tr>
<tr>
<td>Total Concurrency</td>
<td>225,000</td>
<td>O(10^5)</td>
<td>O(10^6)</td>
<td>O(10,000)</td>
</tr>
<tr>
<td>Total Node Interconnect BW</td>
<td>1.5 GB/s</td>
<td>20 GB/sec</td>
<td>200 GB/sec</td>
<td></td>
</tr>
<tr>
<td>MTTI</td>
<td>days</td>
<td>O(1 day)</td>
<td>O(1 day)</td>
<td>- O(10)</td>
</tr>
</tbody>
</table>
Factors that Necessitate Redesign of Our Software

- Steepness of the ascent from terascale to petascale to exascale
- Extreme parallelism and hybrid design
  - Preparing for million/billion way parallelism
- Tightening memory/bandwidth bottleneck
  - Limits on power/clock speed implication on multicore
  - Reducing communication will become much more intense
  - Memory per core changes, byte-to-flop ratio will change
- Necessary Fault Tolerance
  - MTTF will drop
  - Checkpoint/restart has limitations

Software infrastructure does not exist today
A Call to Action

- Hardware has changed dramatically while software ecosystem has remained stagnant
- Previous approaches have not looked at co-design of multiple levels in the system software stack (OS, runtime, compiler, libraries, application frameworks)
- Need to exploit new hardware trends (e.g., manycore, heterogeneity) that cannot be handled by existing software stack, memory per socket trends
- Emerging software technologies exist, but have not been fully integrated with system software, e.g., UPC, Cilk, CUDA, HPCS
- Community codes unprepared for sea change in architectures
- No global evaluation of key missing components

www.exascale.org
International Community Effort

- We believe this needs to be an international collaboration for various reasons including:
  - The scale of investment
  - The need for international input on requirements
  - US, Europeans, Asians, and others are working on their own software that should be part of a larger vision for HPC.
  - No global evaluation of key missing components
  - Hardware features are uncoordinated with software development

www.exascale.org
IESP Goal

Improve the world’s simulation and modeling capability by improving the coordination and development of the HPC software environment

Workshops:

Build an international plan for developing the next generation open source software for scientific high-performance computing

www.exascale.org
Roadmap Purpose

- The IESP software roadmap is a planning instrument designed to enable the international HPC community to improve, coordinate and leverage their collective investments and development efforts.

- After we determine what needs to be accomplished, our task will be to construct the organizational structures suitable to accomplish the work.
Roadmap Components

4.1 Systems Software

4.1.1 Operating systems
4.1.2 Runtime Systems
4.1.2 I/O systems
4.1.3 External Environments
4.1.4 Systems Management

4.2 Development Environments

4.2.1 Programming Models
4.2.2 Frameworks
4.2.3 Compilers
4.2.4 Numerical Libraries
4.2.5 Debugging tools

4.3 Applications

4.3.1 Application Element: Algorithms
4.3.2 Application Support: Data Analysis and Visualization
4.3.3 Application Support: Scientific Data Management

4.4 Crosscutting Dimensions

4.4.1 Resilience
4.4.2 Power Management
4.4.3 Performance Optimization
4.4.4 Programmability
Where We Are Today:

- SC08 (Austin TX) meeting to generate interest
- Funding from DOE’s Office of Science & NSF Office of Cyberinfrastructure and sponsorship by Europeans and Asians
- US meeting (Santa Fe, NM) April 6-8, 2009
  - 65 people
- European meeting (Paris, France) June 28-29, 2009
  - Outline Report
- Asian meeting (Tsukuba Japan) October 18-20, 2009
  - Draft roadmap and refine report
- SC09 (Portland OR) BOF to inform others
  - Public Comment; Draft Report presented
- European meeting (Oxford, UK) April 13-14, 2010
  - Refine and prioritize roadmap; look at management models
- Maui Meeting October 18-19, 2010
- SC10 (New Orleans) BOF to inform others (Wed 5:30, Room 389)
- Kyoto Meeting – April 6-7, 2011
Motivations for launching EESI

**Coordinate** the European contribution to IESP

**Enlarge** the European community involved in the software roadmapping activity

**Build and consolidate** a vision and roadmap at the European Level, including applications, both from academia and industry
Characteristics of the EESI project

Coordination and support action – FP7/Infrastructures

Coordinator: EDF R&D, Jean-Yves Berthou
Starting date: 1st of June 2010, for 18 months
Requested EC contribution: 640 000 €
Consortium: 8 contractual partners:

17 associated participants
11 contributing participants

The project has received funding from the European Community’s Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 261513
Build a European **vision and roadmap** to address the challenge of performing scientific computing on the new generation of computers which will provide **multi-Petaflop** performances in 2010 and **Exaflop** performances in 2020

- investigate how Europe is located, its strengths and weaknesses, in the overall international HPC landscape and competition
- identify priority actions
- identify the sources of competitiveness for Europe induced by the development of Peta/Exascale solutions and usages
- investigate and propose programs in education and training for the next generation of computational scientists
- identify and stimulate opportunities of worldwide collaborations
EESI main tasks

Coordination of the European participation in IESP
- Make a thorough assessment of needs, issues and strategies
- Develop a coordinated software roadmap
- Provide a framework for organizing the software research community
- Engage and coordinate vendor community in crosscutting efforts
- Encourage and facilitate collaboration in education and training

Cartography of existing HPC projects and initiatives in Europe, US and ASIA

Coordination of “disciplinary working groups” at the European level
- Four groups “Application Grand Challenges”
- Four groups “Enabling technologies for Petaflop/Exaflop computing”

Synthesis, dissemination and recommendation to the European Commission
European Exascale Software Initiative AGENDA

**Enabling technologies for Exaflop computing**
- Hardware roadmap, links with vendors
- Software eco-systems
- Numerical libraries, solvers and algorithms
- Scientific software engineering

**Application Grand Challenges**
- Industrial and Engineering Applications (Transport, Energy)
- Weather, Climatology and Earth Sciences
- Fundamental Sciences (Chemistry, Physics)
- Life science, Health, BPM

**Constitution of WG, Setup of guidelines, organisation modes**

**Initial cartography of existing HPC projects, initiatives in Europe, US and ASIA**

**Synthesis of all contributions and production of a set of recommendations**

**Updated cartography of existing HPC projects, initiatives in Europe, US and ASIA**

**Internal workshop: presentation of each working group results and roadmaps**

**Final conference: public presentation of project result**

**Presentation of EESI results to the EC**

**T0**
- Constitution of WG
- Setup of guidelines
- Organisation modes
- Initial cartography of existing HPC projects, initiatives in Europe, US and ASIA

**T0+5**
- Enabling technologies for Exaflop computing
- Initial International workshop

**T0+12**
- Internal workshop: presentation of each working group results and roadmaps

**T0+13**
- Final conference: public presentation of project result

**T0+16**
- Synthesis of all contributions and production of a set of recommendations

**T0+17**
- Updated cartography of existing HPC projects, initiatives in Europe, US and ASIA

**T0+18**
- Presentation of EESI results to the EC

**June 1, 2010**
**October 2010**
**June 2011**
**November 2011**
Enabling technologies for Exaflop computing

EESI Working Groups

- **Drivers (JSC):**
  - Assess novel HW and SW technologies for Exascale challenges
  - Review **IESP roadmap** and discuss in broader EU context
  - Economic impact & European competitiveness
  - Build a European vision and a roadmap

- **4 working groups**
  - **WG 4.1:** Hardware roadmap, links with Vendors
    H. Huber (Chair, STRATOS/LRZ) & S. Bassini (Vice Chair, CINECA)
  - **WG 4.2:** Software eco-systems
    F. Cappello (Chair, INRIA) & B. Mohr (Vice Chair, JSC)
  - **WG 4.3:** Numerical libraries, solvers, and algorithms
    I. Duff (Chair, SFTC) & A. Grothey (Vice chair, Univ. Edinburgh)
  - **WG 4.4:** Scientific software engineering
    M. Ashworth (Chair, STFC) & A. Jones (Vice Chair, NAG)
Application Grand Challenges

EESI Working Groups

- Drivers (GENCI):
  - Identify the apps drivers for Peta and Exascale
  - Needs & expectations of scientific applications
  - Economic impact & European competitiveness
  - Build a European vision and a roadmap

- 4 working groups
  - WG 3.1: Industrial & Engineering Apps (Transport, Energy)
    P. Ricoux (Chair, Total) & JC. André (Vice Chair, CERFACS)
  - WG 3.2: Weather, Climatology and Earth Sciences
    G. Aloisio (Chair, ENES-CMCC) & M. Cocco (Vice Chair, INGV)
  - WG 3.3: Fundamental Sciences
    G. Sutmann (Chair, CECAM-JSC) & JP. Nominé (Vice chair, CEA)
  - WG 3.4: Life Sciences and Health
    M. Orozco (Chair, BSC) & J. Thorton (Vice Chair, EBI)
Lead by: P. Ricoux (Chair, Total) & JC. André (Vice Chair, CERFACS)

Main challenges (F/0)

- **Aeronautics**: full MDO, CFD-based noise simulation real-time CFD-based in-flight simulation: the digital aircraft
- **Structure calculation**: design new composite compounds, …
- **Special Chemistry**: atom to continuum simulation for macro parameters estimation in catalyst, surfactants, tribology, interfaces, nano-systems, …
- **Energy**: computations with smaller and smaller scales in larger and larger geometries: Turbulent combustion in closed engines and opened furnaces, explosion prediction, nuclear plants, hydraulics, …
- **Oil and gas industries**: full 3D inverse waveform problem, multi-scale reservoir simulation models, …
- **Engineering (in general)**: multi-scale CFD, multi-fluids physics modelling, complex systems modelling, …
The WCES (Weather, Climate & Earth Sciences)  

Main Goals

- High-resolution Climate and Earth System Models to better simulate the interactions and feedbacks among the physical & biological complex processes controlling natural phenomena
  - atmosphere
  - ocean
  - land, soils, permafrost, and vegetation (specified and interactive) cover
  - sea ice
  - carbon and other biogeochemical cycle
  - clouds and related microphysics
  - hydrology
  - atmospheric chemistry
  - aerosols
  - ice sheets
  - human systems

- Innovative approaches for modelling solid Earth processes to better understand the physical processes controlling earthquakes, volcanic eruptions and tsunamis as well as those driving tectonics and Earth surface dynamics
  - land ice
  - sea ice

- Unified next-generation atmospheric simulation systems for Weather and Climate scientists, allowing a strong reduction in climate prediction uncertainty

Several complex components to be considered !!!
## WG 3.2 : Weather, Climatology and Earth Sciences

<table>
<thead>
<tr>
<th>Organization</th>
<th>Email</th>
<th>Country</th>
<th>Area of Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENES-CMCC</td>
<td><a href="mailto:giovanni.aloisio@unisalento.it">giovanni.aloisio@unisalento.it</a></td>
<td>IT</td>
<td>Exascale Computing</td>
</tr>
<tr>
<td>INGV</td>
<td><a href="mailto:massimo.cocco@ingv.it">massimo.cocco@ingv.it</a></td>
<td>IT</td>
<td>Seismology</td>
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<tr>
<td>CMCC</td>
<td><a href="mailto:n.pinardi@sincem.unibo.it">n.pinardi@sincem.unibo.it</a></td>
<td>IT</td>
<td>Oceanography</td>
</tr>
<tr>
<td>IPSL</td>
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<td>FR</td>
<td>Earth-system modelling</td>
</tr>
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<td>CERFACS</td>
<td><a href="mailto:valcke@cerfacs.fr">valcke@cerfacs.fr</a></td>
<td>FR</td>
<td>Coupled Climate Models</td>
</tr>
<tr>
<td>IPG</td>
<td><a href="mailto:vilotte@ipgp.jussieu.fr">vilotte@ipgp.jussieu.fr</a></td>
<td>FR</td>
<td>Solid Earth, Seismology</td>
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<tr>
<td>BADC</td>
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<td>UK</td>
<td>Climate Data Management</td>
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<td>UK</td>
<td>High Performance Computing</td>
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<tr>
<td>ECMWF</td>
<td><a href="mailto:nar@ecmwf.int">nar@ecmwf.int</a></td>
<td>UK</td>
<td>Data Assimilation</td>
</tr>
<tr>
<td>MPI</td>
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<td>DE</td>
<td>Earth System Modeling</td>
</tr>
<tr>
<td>DKRZ</td>
<td><a href="mailto:biercamp@dkrz.de">biercamp@dkrz.de</a></td>
<td>DE</td>
<td>High Performance Computing</td>
</tr>
<tr>
<td>LMU</td>
<td><a href="mailto:heiner.igel@geophysik.uni-muenchen.de">heiner.igel@geophysik.uni-muenchen.de</a></td>
<td>DE</td>
<td>Solid Earth, Geophysics</td>
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<tr>
<td>SMHI</td>
<td><a href="mailto:colin.jones@smhi.se">colin.jones@smhi.se</a></td>
<td>SE</td>
<td>Climate Change modeling</td>
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<tr>
<td>FMI</td>
<td><a href="mailto:johan.silen@fmi.fi">johan.silen@fmi.fi</a></td>
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<td>Meteorology</td>
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<tr>
<td>BSC</td>
<td><a href="mailto:jose.baldasano@bsc.es">jose.baldasano@bsc.es</a></td>
<td>ES</td>
<td>Earth Sciences</td>
</tr>
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</table>

**Chair**
- INGV massimo.cocco@ingv.it  
- CMCC n.pinardi@sincem.unibo.it  

**Vice-Chair**
- IPSL sylvie.joussaume@lsce.ipsl.fr  

(Final) Topics Group
- Group

### EESI International Initial Meeting, Amsterdam 9 Nov 2010
WG3.2 Next steps

- **October 16, 2010 - November 30, 2010**
  **Work:** Roadmap preparation
  **Outcome:** Preliminary draft v0.1 (we will basically collect all of the contributions putting them together in the first draft and making general revisions)

- **December 1, 2010 - January 10, 2011**
  **Work:** Roadmap preparation
  **Outcome:** Draft v0.9 (new version of the roadmap)

- **January 18, 2011**
  **Meeting:** First EESI WG3.2 meeting in Paris
  **Outcome:** Draft v1.0
Multiscale
WG 3.3: Fundamental Sciences

Lead by: G. Sutmann (Chair, CECAM-JSC) & JP. Nominé (Vice chair, CEA)

Fundamental sciences: Physics, Chemistry, Material Sciences, Astrophysics
WG 3.4 : Life Sciences and Health

Lead by: M. Orozco (Chair, BSC) & J. Thorton (Vice Chair, EBI)

Simulation scenario in Life Sciences

- Molecular simulations
  - Structural prediction
  - Docking
  - Atomistic simulation
  - Cell-scale mesoscopic simulations
- Gene inter-relations
- Cell simulation
- Organ simulation
- Ecosystem simulation
- Drug design
# Meeting Timeline

<table>
<thead>
<tr>
<th>When</th>
<th>Where (who)</th>
<th>Purpose</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>18/19 Oct 10</td>
<td>Maui (IESP)</td>
<td>IESP meeting</td>
<td>IESP invitees</td>
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<tr>
<td>9/10 Nov 10</td>
<td>Amsterdam</td>
<td>EESI Initial Workshop</td>
<td>ALL</td>
</tr>
<tr>
<td>Dec 10/Jan 11</td>
<td>Europe (C)</td>
<td>1st Work Meeting</td>
<td>Each WG separate</td>
</tr>
<tr>
<td>9/10 Feb 2011</td>
<td>Munich or Bologna (WP34)</td>
<td>WG Coordination Meeting</td>
<td>WP34, C, some experts</td>
</tr>
<tr>
<td>Mar/Apr 2011</td>
<td>Europe (C)</td>
<td>2nd Work Meeting</td>
<td>Each WG separate</td>
</tr>
<tr>
<td>Apr 2011</td>
<td>Kyoto (IESP)</td>
<td>IESP Meeting</td>
<td>IESP invitees</td>
</tr>
<tr>
<td>Jun 2011</td>
<td>Paris (Ter@tec)</td>
<td>Internal Workshop</td>
<td>ALL</td>
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<tr>
<td>Summer 2011</td>
<td>Germany (IESP)</td>
<td>IESP Meeting</td>
<td>IESP invitees</td>
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<tr>
<td>Sep 2011</td>
<td></td>
<td>Final Report Coordination</td>
<td>WP34, C</td>
</tr>
<tr>
<td>10/11 Oct 11</td>
<td>Barcelona (BSC)</td>
<td>Public Conference</td>
<td>ALL</td>
</tr>
</tbody>
</table>

**WP34:** Work package 3 + 4 leaders (Stephane Requena, Bernd Mohr)  
**C:** Working group chair and vice chair + few experts  
**ALL:** Everyone interested
The Exascale Software Center Planning Team

Pete Beckman
Director, Exascale Technology and Computing Institute (ETCi)
Argonne National Laboratory

+ Large team of folks from national laboratories and universities
Context: Planning for Exascale

Platforms
• Systems: 2015
• Systems: 2018

Cross-cutting Technologies

Co-Design Application Teams

Exascale Software

Goal: Ensure successful deployment of coordinated exascale software stack on Exascale Initiative platforms
Exascale Software Center (in 1 slide)

- **Scope**
  - Deliver high quality system software for exascale platforms
    - ~2015, ~2018
  - Identify software gaps, research & develop solutions, test and support deployment
  - Increase the productivity and capability and reduce the risk of exascale deployments

- **Cost:**
  - Applied R&D:  ~10-20 distributed teams of 3 to 7 people each
  - Large, primarily centralized QA, integration, and verification center

- **Schedule Overview**
  - 2010 – Q1 2011: Planning and technical reviews
  - April 2011: *Launch Exascale Software Center!*
  - 2014, 2017: SW ready for integration for 2015, 2018 systems respectively
Application Co-Design Model

- Want ESC to coordinate and take *real* responsibility for features and milestones
  - Improved leverage over projects that are currently less responsive than needed
- Want to know specifics about hardware and available software
- Applications will provide best estimates of needs for exascale science:
  - Data movement, memory sizes, programming models, etc
- Applications will test and evaluate prototype system software
- Formalized roles between ESC and App Co-Design Centers for development, risk, support, and acceptance
- Feedback and progress tracking between ESC and App Co-Design Centers
- Coordinate discussions of system software through ESC
- NDA material for roadmaps, across co-design centers, etc will be difficult to coordinate
Community Engagement

IESP Activities
European Exascale Initiative
Japanese Exascale Initiative

ASCR/NNSA Institutes
Domain Science Institutes
Computer Science Institutes

ESC

Co-design Centers
Applications Co-design
Hardware Co-design

Third Party Software
Thanks
WG 3.1 : Industrial & Engineering Apps (Transport, Energy)

Henri CALANDRA  (TOTAL, F)  Geophysics, Oil and gas  
Keld NIELSEN  (ENI, I)  Multiphase flows, Oil and gas  
Thierry POINSOT  (CERFACS, F)  Combustion, CFD  
Eric CHAPUT  (EADS/Airbus, F)  Flight physics, Aeronautics  
Demetrios PAPAGEORGIOU  (Imp.College, GB)  Applied math., Physics  
Ulrich RUDE  (U. Erlangen, D)  HPC, Particle dynamics  
Jean-Daniel MATTEI  (EDF, F)  CFD, Hydraulics  
Christian HASSE  (BMW, D)  Propulsion and engine flows, Automotive  
Heinz PITSCH  (Univ. Aachen, D)  Propulsion, Engine flows  
Norbert KROLL  (DLR, D)  CFD, Aeronautics  
Tanguy COURAUD  (EDF, F)  Neutronics, Nuclear industry  
Ali TABBAL  (ALSTOM, F)  Surface transportation, Trains  
Chuan-yu WU  (U. Birmingham, C)  Chemical Engineering
WG 3.3: Fundamental Sciences

- Objectives (1)
  - Identify **exascale challenging problems** like
    - Quantum chemistry: electronic structure calculations for large systems, excited states
    - Materials Science: ceramics, semi-conductors, design of nano-particles, catalysis
    - Soft matter physics: simulation of long polymers, self organisation
    - Astrophysics: cosmology, high-resolution solar physics
    - Plasma physics: fusion and laser-plasma interactions
    - Particle physics

What is the impact of: fundamental understanding, industrial impact
Ultimately responsible for success of software:

- Identify required software capabilities
  - Identify gaps
  - Design and develop open-source software components
    - Both: evolve existing components, develop new ones
    - Includes maintainability, support, verification
  - Ensure functionality, stability, and performance
  - Collaborate with platform vendors to integrate software
  - Coordinate outreach to the broader open source
  - Track development progress and milestones
Massive (human) genomic projects

50 cancers
25000 cancer genomes
WG 3.4 : Life Sciences and Health

Helmut Grubmüller, Max Planck Institute
Paolo Carloni, German Research School
Wolfgang Wenzel, Karlsruhe Institute of Technology
Reinhard Schneider, EMBL

Erik Lindahl, Stockholm University
Janet Thorton, EMBL-EBI
Charles Laughton, University of Nottingham

Richard Lavery, University of Nottingham
Nicolas Baurin, Sanofi-Aventis

Modesto Orozco, BSC
Alfonso Valencia, CNIO

Henry Markram, Ecole Polytechnique Fédérale de Lausanne
Manuel Peitsch, Swiss Institute of Bioinformatics

Julian Tirado-Rives, University of Yale
Adrian E. Roitberg, University of Florida

Anna Tramontano, University of Roma
Common guidelines for groups activity

- Common templates in order to
  - Facilitate exchanges between WP3 and WP4
  - Identify and classify key issues *(What-Who-Where-When-How much)*
    - Description of the scientific and technical perimeter of the WG (*)
    - Social benefits, societal, environmental and economical impact (*)
    - Scientific and technical hurdles
    - Address cross cutting issues: Resilience, Power Mngt, Programmability, Perf optimisation and Reproducibility of the results, …
    - European strengths and weaknesses in the worldwide competition
    - Sources of competitiveness for Europe
    - Needs of education and training
    - Potential collaborations outside Europe
    - Existing funded projects and funding agencies
    - Timeline, needs of HR, provisional costs, …
    - Building an (or several) exa-scale prototype in Europe? By when?
    - Communication plan, dissemination actions
  - Facilitate elaboration of intermediate and final reports

(*) for Application WGs, description in terms of Application Grand Challenges
Expert distribution

- 115 experts excluding Chairs/Vice chairs
  - 14.4 experts/group av without Chairs/Vice Chairs
  - Still possible to enrol up to 5 additional experts

- 14 countries, good European coverage

- Participation of 2 US, 1 Israeli and 1 Lithuanian experts
### Assumptions

- Several vendor platform partnerships
- ~2015 early scalability demonstration systems
  - Arch 2010-2011; System build 2015
- ~2018 exascale system
  - Arch 2014-2015; System build 2018
- Co-design centers provide initial applications
- ESC:
  - Partnership funding agencies, labs, and universities
  - Responsible for the common software environment for EI systems
  - All development will be open source, with BSD-style license preferred over GPL
  - Some components will be integrated and supported by vendor, others will be provided atop basic platform, supported by ESC
  - Vendor-specific components will be part of their platform strategy
    - E.g.: system management, RAS, compiler, etc

**Common ESC Software**

Vendor a, Partnership
- Platform-specific software
- Platform Hardware

Vendor b, Partnership
- Platform-specific software
- Platform Hardware
Need to Accomplish

- Develop a governance model for IESP that has broad buy-in from the community and agencies
- Validate the roadmap in discussions with applications, math and vendors
  - Develop a schedule with firm target dates and resource estimates
- Develop a program execution plan that is firm enough that other parts of the EI can use it for leverage
- Address the “unspoken” concerns via short white papers, manifestos and community outreach
- Start acting like a “project” to exercise the governance model
## WG 3.3: Fundamental Sciences

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
<th>Country</th>
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