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.
Key Trends

- Increasing Concurrency
- Reliability Challenging
- Power dominating designs
- Heterogeneity in a node
- I/O and Memory: ratios and breakthroughs

Requirements on X-Stack

- Programming models, applications, and tools must address concurrency
- Software and tools must manage power directly
- Software must be resilient
- Software must address change to heterogeneous nodes
- Software must be optimized for new Memory ratios and need to solve parallel I/O bottleneck
### Roadmap Components (1/2)

<table>
<thead>
<tr>
<th>System SW</th>
<th>OS</th>
<th>Pete</th>
<th>Beckman</th>
</tr>
</thead>
<tbody>
<tr>
<td>System SW</td>
<td>Runtime</td>
<td>Jesus</td>
<td>Labarta</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rajeev</td>
<td>Thakur</td>
</tr>
<tr>
<td>System SW</td>
<td>I/O</td>
<td>Alok</td>
<td>Choudhary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yutaka</td>
<td>Ishikawa</td>
</tr>
<tr>
<td>System SW</td>
<td>External Env</td>
<td>Giovanni</td>
<td>Aloisio</td>
</tr>
<tr>
<td></td>
<td></td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>System SW</td>
<td>System Mgmt</td>
<td>Bill</td>
<td>Kramer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bob</td>
<td>Wisniewski</td>
</tr>
<tr>
<td>Devel Env.</td>
<td>Prog. Models</td>
<td>Barbara</td>
<td>Chapman</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mitsuhisa</td>
<td>Sato</td>
</tr>
<tr>
<td>Devel Env.</td>
<td>Frameworks</td>
<td>Mike</td>
<td>Heroux</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Robert</td>
<td>Harrison</td>
</tr>
<tr>
<td>Devel Env.</td>
<td>Compiler</td>
<td>Barbara</td>
<td>Chapman</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mitsuhisa</td>
<td>Sato</td>
</tr>
<tr>
<td>Devel Env.</td>
<td>Libraries</td>
<td>Jack</td>
<td>Dongarra</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anne</td>
<td>Trefethen</td>
</tr>
<tr>
<td>Devel Env.</td>
<td>Debugging</td>
<td>Wolfgang</td>
<td>Nagel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>David</td>
<td>Skinner</td>
</tr>
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</table>
# Roadmap Components (2/2)

<table>
<thead>
<tr>
<th>Applications</th>
<th>App Pioneers</th>
<th>Bill</th>
<th>Tang</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Richard</td>
<td>Kenway</td>
</tr>
<tr>
<td>Applications</td>
<td>Algorithms</td>
<td>Bill</td>
<td>Gropp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fred</td>
<td>Streitz</td>
</tr>
<tr>
<td>Applications</td>
<td>Data &amp; Vis</td>
<td>John</td>
<td>Taylor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rick</td>
<td>Stevens</td>
</tr>
<tr>
<td>Cross-Cuts</td>
<td>Resilience</td>
<td>Franck</td>
<td>Cappello</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sudip</td>
<td>Dosanjh</td>
</tr>
<tr>
<td>Cross-Cuts</td>
<td>Power</td>
<td>Satoshi</td>
<td>Matsuoka</td>
</tr>
<tr>
<td></td>
<td></td>
<td>John</td>
<td>Shalf</td>
</tr>
<tr>
<td>Cross-Cuts</td>
<td>Performance</td>
<td>Bernd</td>
<td>Mohr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jeffrey</td>
<td>Vetter</td>
</tr>
<tr>
<td>Cross-Cuts</td>
<td>Programmability</td>
<td>Thomas</td>
<td>Sterling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hiroshi</td>
<td>Nakashima</td>
</tr>
</tbody>
</table>
## Priority Research Direction (use one slide for each)

<table>
<thead>
<tr>
<th>Scientific and computational challenges</th>
<th>Summary of research direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brief overview of the underlying scientific and computational challenges</td>
<td>What will you do to address the challenges?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential scientific impact</th>
<th>Potential impact on SCIENCE DOMAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>What new scientific discoveries will result?</td>
<td>How will this impact key open issues in SCIENCE DOMAIN?</td>
</tr>
<tr>
<td>What new methods and techniques will be developed?</td>
<td>What’s the timescale in which that impact may be felt?</td>
</tr>
</tbody>
</table>
CFD Simulation for mechanical and vibratory behaviour of the fuel assemblies inside a nuclear core vessel

Expert name/affiliation - email: Yvan Fournier/EDF – yvan.fournier@edf.fr

**Scientific and computational challenges**

Computations with smaller and smaller scales in larger and larger geometries for a better understanding of physical phenomena

⇒ A better optimisation of the production (margin benefits)

**2007:** 3D RANS, 5x5 rods, 100 millions cells, 2 M cpu.hours (4000 cores during 3 weeks)

**2015:** 3D LES Full vessel (17x17x196 rods) unsteady approach, >50 billion cells, 1000000 cores during few weeks

**Software issues – long term 2015/2020**

New numerical methods (stochastic, SPH, FV)

Scalability of linear solvers, hybrid solvers Code optimisation: wall of the collective communications, load balancing

Adaptive methods (may benefit all of computation/visualisation/meshing)

Data redistribution, IO (if flat MPI-IO model OK, good, otherwise require new “standard” data models)

Fault tolerance

Machine independent code optimisation & performance


Mesh generation, visualization

Scalability, load balancing

Solvers (multi-grid, better&simpler pre-conditioner, ..)

Mixing programming models (ex. MPI/OpenMP)

Stability and robustness of the software stack (MPI, ..)

API of scientific libraries (ex. BLAS!)

Standardisation of compiler optimisation level pragmas

Computing environment standardization (batch system, MPIExec,

**Impact of last machine change**

(x10 Gflops -> 100 Tflops)

Pre/post adaptation

Reinforcement of the HPC expertise

Few extra “simple” programming rules

No rewriting, same solvers, same programming model, same software architecture thanks to technological evolution anticipation

Expected impact (100 Tflops -> Xpflops): i.e. 2015 software issues
### Computational Challenges and Needs for Academic and Industrial Applications

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Consecutive thermal fatigue event</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The whole vessel reactor</td>
</tr>
<tr>
<td>Computations enable to better understand the wall thermal loading in an injection.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9 fuel assemblies</td>
</tr>
<tr>
<td>Knowing the root causes of the event ⇒ define a new design to avoid this problem.</td>
<td>Computation with an L.E.S. approach for turbulent modelling</td>
<td>Part of a fuel assembly</td>
<td>3 grid assemblies</td>
<td>No experimental approach up to now</td>
<td>Will enable the study of side effects implied by the flow around neighbour fuel assemblies.</td>
</tr>
<tr>
<td></td>
<td>Refined mesh near the wall.</td>
<td></td>
<td></td>
<td></td>
<td>Better understanding of vibrator phenomena and wear-out of the rods.</td>
</tr>
</tbody>
</table>

#### Computations with smaller and smaller scales in larger and larger geometries

⇒ a better understanding of physical phenomena ⇒ a more effective help for decision making

⇒ A better optimisation of the production (margin benefits)

<table>
<thead>
<tr>
<th>Scale</th>
<th>Fujitsu VPP 5000</th>
<th>Cluster, IBM Power5</th>
<th>IBM Blue Gene/L « Frontier »</th>
<th>600 Tflops during 1 month</th>
<th>10 Pflops during 1 month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cells</td>
<td>10⁶</td>
<td>10⁷</td>
<td>10⁸</td>
<td>10⁹</td>
<td>10¹⁰</td>
</tr>
<tr>
<td>Operations</td>
<td>3.10¹³</td>
<td>6.10¹⁴</td>
<td>10¹⁶</td>
<td>3.10¹⁷</td>
<td>5.10¹⁸</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage/ Memory</th>
<th>1 Gb of storage</th>
<th>15 Gb of storage</th>
<th>200 Gb of storage</th>
<th>1 Tb of storage</th>
<th>10 Tb of storage</th>
</tr>
</thead>
<tbody>
<tr>
<td># Gb of storage</td>
<td>25 Gb of memory</td>
<td>250 Gb of memory</td>
<td>2.5 Tb of memory</td>
<td>25 Tb of memory</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pre-processing not parallelized</th>
<th>Pre-processing not parallelized</th>
<th>Mesh generation</th>
<th>IESP/Application Subgroup</th>
<th>Scalability / Solver</th>
<th>Visualisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power of the computer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Understanding Nuclear Structure

Image courtesy of James P. Vary (Iowa State University).
Microscopic Nuclear Fission Solutions

Image courtesy of James P. Vary (Iowa State University).
Neutron Star – Extreme Nuclei

Image courtesy of James P. Vary (Iowa State University).
Quantum Chromodynamics -Cold

Image courtesy of Thomas Luu (LLNL) and David Richards (Jlab)
Quantum Chromodynamics - Hot

Image courtesy of BNL, Thomas Luu (LLNL) and David Richards (JLab)
NASA Example

Modeling → Algorithms → Uncertainty Mgt. → Decisioning → Health Reasoning → V&V

Integration
- Validate proper operation of prognostic algorithms
- Combine and process information from different interacting subsystems

Controller Reconfiguration
- Decision making based on prognostic information

Uncertainty Management
- Quantification and containment of uncertainty

Distributed Prognostics
- Divide and conquer of algorithm processing

Prognostics for Electronics
- Modeling of semiconductor components
- Experimental validation

Prognostics for Batteries
- Testbed for algorithm development
- Data Collection

Prognostics for Actuators
- Detailed modeling of mechanics of physics-of-failure (ball jam, backlash, etc.)

now → +1 year → +2 years → +3 years → +4 years → +5 years → +6 years
NASA Example

- **Controller Reconfiguration**
  - Status: single objective prototype available
  - Next: MOO for action tradeoff
  - Collaborations: Impact Tek (complete); smi (STTR)

- **EPS – Battery Health Management**
  - Status: prototype test stand built
  - Next: data acquisition
  - Collaborations: Global Solutions (complete)

- **Prognostics for Electronics**
  - Status: prototype test stand built
  - Next: automate aging; data acquisition
  - Collaborations: UMD; Impact Tek (IPP); Ridgetop (NRA)

- **Distributed Prognostics**
  - Status: equipment procured
  - Next: investigate state of the art

- **Data-Driven Prognostics**
  - Status: R/V: NN-driven; proprietary data
  - Next: CART; GPR; Kalman Filter; build demo

- **Prognostics Repository**
  - Status: Mill data: IMS data
  - Next: increase number of data sets

- **Actuator Prognostics**
  - Status: nominal behavior modeled
  - Next: ball jam model
  - Collaborations: moog (SAA); Impact Tek (NRA)

- **Prognostics for Solid Rocket Motors**
  - Status: model complete
  - Next: provide demo

- **Uncertainty Management**
  - Status: initial methods investigated
  - Next: build suite of techniques
<table>
<thead>
<tr>
<th>CMOS Node</th>
<th>130nm</th>
<th>90nm</th>
<th>65nm</th>
<th>45nm</th>
<th>32nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithography</td>
<td>KrF + HT</td>
<td>ArF + HT → ArF + PSM → ArF + Immersion</td>
<td>EUV or ArF+HRI*</td>
<td>STI (another gap fill)</td>
<td>STI (another gap fill)</td>
</tr>
<tr>
<td>Isolation</td>
<td>STI(HDP-CVD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gate Electrode</td>
<td>poly Si</td>
<td></td>
<td></td>
<td></td>
<td>Metal</td>
</tr>
<tr>
<td>Insulator</td>
<td>SiON</td>
<td>SiON/High-k → High-k</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Junction</td>
<td>CoSi2 RTA → Spike Anneal</td>
<td>Spike Anneal → Laser Anneal</td>
<td></td>
<td>Raised S/D NiSi</td>
<td></td>
</tr>
<tr>
<td>Barrier/Metal</td>
<td>PVD-Ta/Cu</td>
<td>CVD-Ta(N)/Cu</td>
<td>CVD or Direct plating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inter-Layer Dielectric</td>
<td>FSG(k=3.6)</td>
<td>SiOC(k=3.0 → 2.6:option)</td>
<td>low-k (k=2.6-2.4)</td>
<td>low-k (k=2.4-2.2)</td>
<td></td>
</tr>
</tbody>
</table>

- Booster Technology: Mobility ↑, SD-resistance ↓
- Strain Si Channel → StrainSi On Insulator(SSOI) → (100)-face-TR → (110)-face-TR
- Ge channel? Metal-SD?
- *HRI: High Refractive Index Materials: Lens, Fluid and Resist
### Technology Roadmap

<table>
<thead>
<tr>
<th>Category</th>
<th>Applications</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
</tr>
<tr>
<td>HV BiCMOS (40V)</td>
<td>LCD gate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AC/DC</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>DC/DC controller</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5um Stack Via</td>
<td>In Product verification</td>
<td>In shuttle verification</td>
<td></td>
</tr>
<tr>
<td>BiCD (40V)</td>
<td>DC/DC converter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WLED driver</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1um/1P2M (LTBCDII)</td>
<td>BV&gt;40V, Rds=80mohm-mm2@Vgs=5V</td>
<td>1.0um/2P2M (LBCD040II)</td>
<td>BV&gt;50V, Rds=95mohm-mm2@Vgs=5V; w/Schottky</td>
</tr>
<tr>
<td>BiCD (600V)</td>
<td>AC/DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0um/1P2M (LBCD600I)</td>
<td>BV&gt;700V, Rds=0.2ohm-cm2@Vgs=15V; w/Schottky</td>
<td>0.5um/2P2M (LBCD600II)</td>
<td>BV&gt;700V, Rds=0.2ohm-cm2@Vgs=15V; w/Schottky</td>
</tr>
<tr>
<td>ESD+Filter</td>
<td>ESD protection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ESD+Filter ESD&gt;8KV</td>
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</tr>
</tbody>
</table>

- Focus on the HV market, from 40V to 600V
Fundamentals of Technology Roadmapping

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Abstract

Technology planning is important for many reasons. Globally, companies are facing many competitive problems. Technology roadmapping, a form of technology planning, can help deal with this increasingly competitive environment. While it has been used by some companies and industries, the focus has always been on the technology roadmap as a product, not on
Four Goals for IESP

- **Strategy for determining requirements**
  - clarity in scope is the issue

- **Comprehensive software roadmap**
  - goals, challenges, barriers and options

- **Resource estimate and schedule**
  - scale and risk relative to hardware and applications

- **A governance and project coordination model**
  - Is the community ready for a project of this scale, complexity and importance?
  - Can we be trusted to pull this off?
Goals for IESP

- Develop a comprehensive community software roadmap for Exascale systems
  - Identify those software capabilities that will be needed for fully functional exascale systems, what are the barriers and how can we overcome them
  - Determine which elements will occur naturally and which elements need R+D investment
  - Determine those components that have solid starting points and which that need ab initio efforts
  - Determine which components are suitable for an open community development model
Goals for IESP

- Develop an estimate of the resources required and timeline needed to develop the required software
  - Need to put the software element of exascale in appropriate budget and schedule context
  - Need to understand the risks (technical, schedule and organizational)
  - Need to distinguish between the applications software efforts and the systems software
  - The software timeline should be aligned with that of the hardware (and precede it where possible)
Deliverables:

- **Note:** Slice-n-dice: Need two perspectives
  - Application needs (science requirements)
  - System hardware / software capabilities
  - Key regional interests

- **For this workshop:**
  - Quad Chart(s) (two to four)
  - PPT slide with major capabilities
  - PPT outline of roadmap text

- **In two weeks:**
  - 2 pages of roadmap text
**Priority Research Direction** (use one slide for each)

**Key challenges**

- Brief overview of the barriers and gaps

**Summary of research direction**

- What will you do to address the challenges?

**Potential impact on software component**

- What capabilities will result?
- What new methods and components will be developed?

**Potential impact on usability, capability, and breadth of community**

- How will this impact the range of applications that may benefit from exascale systems?
- What’s the timescale in which that impact may be felt?
4.0 <component>

<single short description of the area>

New capability 1
New capability 2
New capability 3
New capability 4
New capability 5
New capability 6


Your Metric
4.x <component>

• Technology drivers

• Alternative R&D strategies

• Recommended research agenda

• Cross-cutting considerations