Why Exascale instead of Exaflops?

• Peak speed of computers has traditionally been measured by the maximum number of floating point operations that can be performed in a second (FLOPS), or peak flops
  – Exaflops is $10^{18}$ flops = 1,000 Petaflops
  – But on current computer architectures most applications can achieve only a modest fraction of the peak speed

• Therefore we are transitioning to a less precise but more useful measurement: Exascale, which is based on the ratio of execution time of full applications (not simple benchmarks) on today’s petaflops systems (e.g., Mira 10 PF) and future systems

• So if a system can run a real app 100X faster than it runs on Mira, we would say it is an exascale system
The National Strategic Computing Initiative* and DOE’s role

Through Executive Order 13702 he signed July 29, 2015, President Obama established the National Strategic Computing Initiative (NSCI) to maximize the benefits of HPC for US economic competitiveness and scientific discovery.

DOE is a lead agency within NSCI with the responsibility that the DOE Office of Science and DOE National Nuclear Security Administration will execute a joint program focused on advanced simulation through a capable exascale computing program emphasizing sustained performance on relevant applications.

Approach to executing that DOE role in NSCI

• Starting this year, the Exascale Computing Project (ECP) was initiated as a DOE-SC/NNSA-ASC partnership, using DOE’s formal project management processes

• The ECP is a ten-year project led by DOE laboratories and executed in collaboration with academia and industry

• The ECP leadership team has staff from six U.S. DOE labs
  – Staff from most of the 17 DOE national laboratories will take part in the project

• The ECP will collaborate with the facilities that operate DOE’s most powerful computers
Why is a project needed?

• We have reached technology and physics limits that mean it is not business as usual
  – In fact, it has not been business as usual since 2004

• The holistic approach of advancing all aspects of the HPC ecosystem requires the structure of a project
  – Co-design
  – Integrated planning and execution
  – Milestones
  – Joint milestones
Progress in CMOS CPU Technology

Moore’s Law continues
- Transistor count still doubles every ~24 months

Dennard scaling stalls
- Voltage
- Clock Speed
- Power
- Performance/clock
From Giga to Exa, via Tera & Peta*

Relative Transistor Performance


Giga Tera Peta Exa

32x from transistor
32x from parallelism
8x from transistor
128x from parallelism
1.5x from transistor
670x from parallelism

Performance from parallelism

*S. Borkar, Intel
Top Ten Technical Challenges for Exascale
(Advanced Scientific Computing Advisory Committee Findings)

1. **Energy efficiency**: Creating more energy efficient circuit, power, and cooling technologies.

2. **Interconnect technology**: Increasing the performance and energy efficiency of data movement.

3. **Memory technology**: Integrating advanced memory technologies to improve both capacity and bandwidth.

4. **Scalable System Software**: Developing scalable system software that is power and resilience aware.

5. **Programming systems**: Inventing new programming environments that express massive parallelism, data locality, and resilience.

6. **Data management**: Creating data management software that can handle the volume, velocity and diversity of data that is anticipated.

7. **Exascale algorithms**: Reformulating science problems and refactoring their solution algorithms for exascale systems.

8. **Algorithms for discovery, design, and decision**: Facilitating mathematical optimization and uncertainty quantification for exascale discovery, design, and decision making.

9. **Resilience and correctness**: Ensuring correct scientific computation in face of faults, reproducibility, and algorithm verification challenges.

10. **Scientific productivity**: Increasing the productivity of computational scientists with new software engineering tools and environments.

Our definition of “capable exascale computer”

• A capable exascale system is defined as a supercomputer that
  – can solve science problems 50X faster (or more complex) than on the 20PF systems (Titan, Sequoia) of today or 100X faster than on Mira
  – in a power envelope of 20-30 MW
  – is sufficiently resilient that user intervention due to hardware or system faults is on the order of a week on average, and
  – has a software stack that meets the needs of a broad spectrum of applications and workloads.
To achieve capable exascale requires the integration of multiple complex elements working together.
## U.S. Strategic Advantage: NSCI Critical Applications
NSCI Vision: Supported by a national tech base, integrated capabilities, R&D foundation

<table>
<thead>
<tr>
<th>National Security</th>
<th>Economic Competitiveness</th>
<th>Scientific Discovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stockpile Stewardship</td>
<td>Energy Production</td>
<td>Climate Science</td>
</tr>
<tr>
<td>Decision Support</td>
<td>Advanced Manufacturing</td>
<td>Fusion Science</td>
</tr>
<tr>
<td>Battlefield Command</td>
<td>Digital Engineering</td>
<td>Materials Genome</td>
</tr>
<tr>
<td>Counter-Terrorism</td>
<td>Drug Design</td>
<td>Particle Physics</td>
</tr>
<tr>
<td>Secure Communication</td>
<td>Personalized Medicine</td>
<td>Neuroscience</td>
</tr>
<tr>
<td>Cyber Defense</td>
<td>Health Care</td>
<td>Weather Prediction</td>
</tr>
<tr>
<td>Signals Intelligence</td>
<td>Business Analytics</td>
<td>Genomic Discovery</td>
</tr>
<tr>
<td></td>
<td>Financial Services</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E-Commerce</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Social Networking</td>
<td></td>
</tr>
</tbody>
</table>

- Climate Science
- Fusion Science
- Materials Genome
- Particle Physics
- Neuroscience
- Weather Prediction
- Genomic Discovery
Applications Development activities

• Fund applications development teams
  – Each aiming at capability and specific challenge problems
  – Following software engineering practices
  – Tasked to provide software and hardware requirements
  – Execute milestones jointly with software activities

• Establish co-design centers for commonly used methods
  • E.g., Adaptive Mesh Refinement, Particle-in-Cell

• Developer training
The central role of software
Conceptual ECP Software Stack

- Application Correctness
- Visualization
- Data Analysis
- Co-Design
- Tools
- Math Libraries and Frameworks
- Memory and Burst buffer
- Data Management, I/O and File System
- System Software, Resource Management, Threading, Scheduling, Monitoring, and Control
- Programming Models, Development Environment, and Runtimes
- Node OS, low-level runtimes
- Hardware interfaces

Addresses Top Ten Challenges 4, 5, 6, 7, 8, and 10
Bay Bridge, San Francisco Bay

Old span on left, new on right
Hardware Technology Activities

• PathForward: support DOE-vendor collaborative R&D activities required to develop exascale systems with at least two diverse architectural features; quote from RFP:
  – PathForward seeks solutions that will improve application performance and developer productivity while maximizing energy efficiency and reliability of an exascale system.
  – Aimed at addressing Top Ten Challenges 1, 2, 3, and 9

• Design Space Evaluation
  – Apply laboratory architectural analysis capabilities and Abstract Machine Models to PathForward designs to support ECP co-design interactions
Summary

• The DOE Exascale Computing Project aims to advance to exascale
  – a broad class of applications,
  – the software ecosystem,
  – hardware design, and
  – the facilities that will operate the initial exascale systems
  using a holistic approach with a strong focus on co-design and
  integration
• The work will be carried out by the DOE national laboratories, industry, and academia
  – With involvement by other U.S. government agencies
Closing remarks

• Risk 2001: Unable to recruit and/or retain qualified staff needed to execute R&D

• You might someday work for the ECP project
  – It is an exciting project that I believe will have positive impacts on many aspects of society
  – Its broad scope makes it likely you will find topics you would like to work on

• Tomorrow Doug Kothe will give a talk on the ultimate payoff of ECP: applications
  – That is why I did not give much detail on applications
Questions?