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

Dennard scaling stalls – key parameters flatline:
- Voltage
- Clock Speed
- Power
- Performance/clock
## HPC System Characteristics
(The Road to Exascale)

<table>
<thead>
<tr>
<th></th>
<th>ASCI Red</th>
<th>Road Runner</th>
<th>K Computer</th>
<th>Sequoia</th>
<th>Exascale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak (Tflops)</strong></td>
<td>1.3</td>
<td>1,700</td>
<td>11,280</td>
<td>20,133</td>
<td>1,200,000</td>
</tr>
<tr>
<td><strong>Linpack (Tflops)</strong></td>
<td>1</td>
<td>1,000</td>
<td>10,510</td>
<td>16,325</td>
<td>1,000,000</td>
</tr>
<tr>
<td><strong>Total Cores</strong></td>
<td>9,298</td>
<td>130,464</td>
<td>705,024</td>
<td>1,572,864</td>
<td>1,000,000,000</td>
</tr>
<tr>
<td><strong>Processors</strong></td>
<td>9,298</td>
<td>12,960 +6,912</td>
<td>88,128</td>
<td>98,304</td>
<td>1,000,000</td>
</tr>
<tr>
<td><strong>Cores/Processor</strong></td>
<td>1</td>
<td>9, 2</td>
<td>8</td>
<td>16</td>
<td>1,000</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>0.85 MW</td>
<td>2.35 MW</td>
<td>9.89 MW</td>
<td>7.9 MW</td>
<td>~20 MW</td>
</tr>
<tr>
<td><strong>Year</strong></td>
<td>2000</td>
<td>2008</td>
<td>2011</td>
<td>2012</td>
<td>2020+</td>
</tr>
</tbody>
</table>
Exascale Software Challenges

- Parallelism
- Data Movement
- Programmability
- Resiliency
ECI Program Strategy

- Conduct critical R&D efforts.
- Develop exascale software stacks.
- Fund computer technology vendors to move required technology from research to product space.
- Fund the design and development of exascale computer systems.
- Joint effort with NNSA.
- Collaboration with other United States government agencies and other countries.
FY12 Major Exascale Research Efforts

- **Runtime systems** to exploit unused/available resources through dynamic adaptive resource management and task scheduling (self aware)

- **Innovative operating system**, with a global perspective, for scalability, energy and reliability management, resource allocation and recovery, efficiency and protection

- **Architectures for cores and systems** to minimize latencies, preclude bottlenecks, reduce energy of data movement and control, IO systems, task instantiation and management, and address handling

- **Abstract machine models and performance models** to guide design and development of future Exascale machines
DOE/ASCR Progress Toward Exascale

- **FY2010:**
  - **Applied Math:** Uncertainty Quantification
  - **Computer Science:**
    - Advanced Architectures / X-Stack / Scientific Data Management and Analysis

- **FY2011:**
  - **Computational Partnerships:** 3 Exascale Co-Design Centers Funded
  - **Request for Information:** critical and platform technologies

- **FY2012:**
  - **Computer Science:** Programming Environments
  - **Applied Math:** Resilient, Extreme scale algorithms
  - **FastFoward:** Critical / Cross Cutting technologies (joint with NNSA)

- **FY2013**
  - Exascale Strategy Plan to Congress
  - Exascale Software Plan
  - **Computer Science**
    - Operating System Software / Storage System Software / ?
  - **Computational Partnerships:** Data Intensive Co-Design Centers
The OS Technical Council

Council: comprised of DOE lab researchers

Goal:

• Investigate issues, challenges and solutions for the DOE software plan for Exascale OS and runtime
• Develop conceptual OS & Runtime architectures and APIs

OS Software Preliminary Plan: November, 2012

Council Meetings:

• March 21, 2012: general council strategies, architectures, APIs
• May 14, 2012: vendor and facilities engagement strategies
• June 11-12, 2012: vendor engagement decisions, workshop planning, architectures, APIs
• July 19-21, 2012: meeting with vendors, workshop planning
• August 21-22, 2012: facilities and applications engagement planning
• September 12-14, 2012: vendor, facilities, and applications engagement final plan, architectures, APIs
• October 4-5, 2012: OS and Runtime Workshop
RX-Solvers


Resilient Extreme-Scale Solvers (“RX-Solvers”)

- Scalable, resilient algorithms
- Support applications during the next 5-10 years
- Establish foundation for research of extreme-scale scientific computing.”

Programmatic Details

- FOA Issued: 8 June 2012; closed: 13 August 2012
- Funding to start in FY13
- Total funds available: $4.5M per year for up to three years
- Proposals are being received; initial reviews underway
X-Stack: Programming Challenges, Runtime Systems, and Tools


Focus Areas

• Programming models, languages, runtime systems, and related technologies
• New energy-efficient and resilient programming techniques that are portable across future machine generations

Expected research investments

• That address fundamental Exascale challenges, while offering a transition path for existing scientific applications to fully explore the challenges and rewards of Exascale platforms.

Programmatic Details

• Nov 22, 2011 Solicitation Issued
• Dec 20, 2011 Amendment FOA
• Dec 21, 2011 Pre-applications received
• Feb 6, 2012 Full proposals received
• Apr 3-6, 2012 Peer Review
• May 29 - 30, 2012 Call Back Review
• June 8, 2012 Funding recommendations completed
X-Stack Proposals

Proposals were expected to:

• Articulate complete solutions addressing multiple components of the system software stack and address Exascale challenges:
  • Scalability
  • Programmability
  • Performance Portability
  • Resilience
  • Energy Efficiency

Proposal were required to have:

• Description of plans for developing prototypes of the proposed solution;
• Description of the proposed path to integration and/or interoperation with existing programming environments;
• Evaluation plan using compact applications, mini-applications
Project Goals & Objectives

- Initiate partnerships with multiple companies to accelerate the R&D of critical technologies needed for extreme-scale computing.
- DOE applications place extreme requirements on computations, data movement, and reliability.
- Fund innovative new and/or accelerated R&D of technologies targeted for productization in the 5–10 year timeframe.

Funded Projects

- AMD
- IBM
- Intel
- NVIDIA
- WhamCloud

For additional Details: Teri Quinn, LLNL, ASCAC presentation
Exascale Software Technology: Programming Environment, OS & Runtimes

Exascale Co-Design Centers: Driving the design of Exascale hardware and software

Integration Research, Development and Engineering Phase

Prototype Build Phase

Fast Forward

Path Forward Phase

ECI Funding


ECI Timeline
(actual lengths of phases could be longer)
The Real Challenges

Avoiding mediocre solutions
• Evolving existing systems

Practicing Co-Design

Developing a new software stack for exascale systems
• Not treating it as an “after thought”

Need to explore radical concepts, but develop practical solutions

New computers designs based on a new execution model
• Must be based on COTS technology
• Exotic technology is not an option
ECI Timeline

(actual lengths of phases could be longer)