• March 7-11, 2011 in San Diego, CA
• PI meeting for
  – Advanced Architecture, X-Stack, Scientific Data Management and Analysis at Extreme Scales awardees
  – Xstack planning team: An Open Integrated Software Stack for Extreme Scale Computing (PIs: Pete Beckman (ANL), Kathy Yelick (LBNL), Al Geist (ORNL), Mike Heroux (SNL), Jack Dongarra (UTK))
  – Seven Co-Design proposal teams
• Expected Outcomes:
  – Awareness within each solicitation communities and ASCR what members are doing and areas where they can leverage and supplement their work
  – Awareness across solicitation communities of what is going on and where each project fits in relation to the broad spectrum
  – Identification of gaps in ASCR exascale research portfolio
  – Lay groundwork for collaboration/cooperation with NNSA Exascale Roadmapping activities

Meeting material at
http://exascaleresearch.labworks.org/ascr2011
The PI meeting was facilitated & choreographed

• Day 1: ASCR presentations (starting at 1:30 pm)
• Day 2 – Day 3 morning: 3 poster sessions
  – each project representative made a 5-minute intro to the poster prior to poster session; project teams were to use poster sessions for networking
• Day 3 afternoon: working groups to identify crosscutting topics + outbrief
  – Each attendee was assigned to one of 8 Working Groups;
  – each WG was moderated by an NNSA facilitator, with two (ASCR PIs) reporters to present working group outbrief and a scribe (a student) to take notes
  – Day 3 dinner: ASCR & NNSA program offices identify five main topics
• Day 4: further discussions of crosscutting topics + outbrief
  – Morning: definition & interrelations (in same working group)
  – Afternoon: issues (in self-identified working groups)
• Day 5: gap analysis
  – Each attendee was assigned to a different WG
• In addition, there were homework assignments (due before 1st working session)
  – Exascale Research Coverage Assessment
  – Dance cards
• Results are being tabulated & analyzed
The frontiers of science

- Supporting research that led to over 100 Nobel Prizes during the past 6 decades—22 in the past decade alone
- Providing 45% of Federal support in the physical sciences
- Supporting over 27,000 Ph.D.s, graduate students, undergraduates, engineers, and support staff at more than 300 institutions

Energy and environmental science and technology

- Fostering research integration and supporting specialized facilities for collaborative studies

21st century tools of science

- Providing the world’s largest collection of scientific user facilities to over 26,000 users each year
The mission of the Advanced Scientific Computing Research (ASCR) program is to discover, develop, and deploy the computational and networking capabilities that enable researchers to analyze, model, simulate, and predict complex phenomena important to the Department of Energy.

A particular challenge of this program is fulfilling the science potential of emerging multi-core computing systems and other novel “extreme-scale” computing architectures, which will require significant modifications to today’s tools and techniques.
DOE Progress toward Exascale

- Proposals processed in Exascale related topic areas:
  - Applied Math: Uncertainty Quantification (90 proposals requesting ~$45M/year; 6 funded at $3M/yr)
  - Computer Science: Advanced Architectures (28 proposals requesting ~$28M/year, 6 funded at $5M/yr)
  - Computer Science: X-Stack (55 proposals requesting ~$40M/year, 11 funded at $8.5M/yr)
  - Computer Science: Scientific Data Management and Analysis (37 proposals requesting ~$22M/year; 11 projects funded at $5M/year)
  - Computational Partnerships: Co-Design (21 Proposals requesting ~$160M/year)

- Exascale Coordination meetings with other Federal Departments and Agencies

- Formalizing Partnership with National Nuclear Security Administration (NNSA) within DOE
Exascale in Practice

- Codseign Teams
- Algorithms and Uncertainty Quantification
- Data Management at Extreme Scales
- X-Stack Software
- Advanced Architecture Research
- Open Simulation Tools
- Vendors and Critical Technologies
Why Exascale is not just 1,000 X Petascale

- End of increases in clock speed means that all increases in performance come through concurrency (billion-way);
- Floating point operations cost less power than data movement on and off chip, therefore:
  - Remap multiphysics to put as much work per location on same chip;
  - Include embedded UQ to increase concurrency;
  - Reformulate to trade flops for memory use.
  - Weak scaling approaches (constant memory/flop) probably will not work;
- I/O to disk will be relatively slower than it is today, therefore:
  - Part of the file system may be on the node;
  - Include in-line data analysis if you can for more concurrency
  - Trigger output to only move important data off machine;
- There will be silent errors as well as lower mean time to interrupt:
  - Uncertainty Quantification including hardware variability;
  - New approaches to checkpointing and resilience.
Why Exascale is not just 1,000 X Petascale Power Challenges

- Between now and 2018 the energy required on industry roadmaps for:
  - 1 double precision flop decreases from ~100 picoJoules to ~25 picoJoules; but
  - Moving 1 bit from cpu to memory stays constant at ~30pJ/bit.
- Therefore a 1EF system with a 20MW power envelope can only have ~.1 Bytes per flop!
- To maintain ~.3 Bytes per flop need to decrease memory energy per bit ~4X from current commercial roadmap!
Why Exascale is not just 1,000 X Petascale Potential System Architectures

<table>
<thead>
<tr>
<th>Systems</th>
<th>2009</th>
<th>2015 +1/-0</th>
<th>2018 +1/-0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System peak</strong></td>
<td>2 Peta</td>
<td>100-300 Peta</td>
<td>1 Exa</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>6 MW</td>
<td>~15 MW</td>
<td>~20 MW</td>
</tr>
<tr>
<td><strong>System memory</strong></td>
<td>0.3 PB</td>
<td>5 PB</td>
<td>64 PB (+)</td>
</tr>
<tr>
<td><strong>Node performance</strong></td>
<td>125 GF</td>
<td>0.5 TF or 7 TF</td>
<td>1-2 or 10TF</td>
</tr>
<tr>
<td><strong>Node memory BW</strong></td>
<td>25 GB/s</td>
<td>1-2TB/s</td>
<td>2-4TB/s</td>
</tr>
<tr>
<td><strong>Node concurrency</strong></td>
<td>12</td>
<td>O(100)</td>
<td>O(1k) or 10k</td>
</tr>
<tr>
<td><strong>Total Node Interconnect BW</strong></td>
<td>3.5 GB/s</td>
<td>100-200 GB/s 10:1 vs memory bandwidth 2:1 alternative</td>
<td>200-400GB/s (1:4 or 1:8 from memory BW)</td>
</tr>
<tr>
<td><strong>System size (nodes)</strong></td>
<td>18,700</td>
<td>50,000 or 500,000</td>
<td>O(100,000) or O(1M)</td>
</tr>
<tr>
<td><strong>Total concurrency</strong></td>
<td>225,000</td>
<td>O(100,000,000) *O(10)-O(50) to hide latency</td>
<td>O(billion) * O(10) to O(100) for latency hiding</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>15 PB</td>
<td>150 PB</td>
<td>500-1000 PB (&gt;10x system memory is min)</td>
</tr>
<tr>
<td><strong>IO</strong></td>
<td>0.2 TB</td>
<td>10 TB/s</td>
<td>60 TB/s (how long to drain the machine)</td>
</tr>
<tr>
<td><strong>MTTI</strong></td>
<td>days</td>
<td>O(1day)</td>
<td>O(1 day)</td>
</tr>
</tbody>
</table>
Aspects of Codesign

• Need to allocate complexity between hardware, systems software, libraries, and applications;
• Potential for applications to modify designs at all levels;
• Need to consider reformulating as well as re-implementing;
• Need to include uncertainty quantification, in line data analysis, and resilience in applications;
• Co-adapt applications to new programming models and perhaps languages;
• Impact of massive multithreaded nodes and new ultra-lightweight operating systems.
The PI meeting was facilitated & choreographed

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  - Exascale Research Coverage Assessment
  - Dance cards
- Results are being tabulated & analyzed
Complete throughout the week (press firmly)
Turn in top copy by end of lunch on Wednesday

### Exascale Research Coverage Assessment

**Name:**

<table>
<thead>
<tr>
<th>Issues</th>
<th>Importance (Hi/Med/Lo)</th>
<th>Coverage in ASCR FOAs (Yes / No)</th>
<th>Coverage in ASCR Exascale Projects (Adequate/Inadequate)</th>
<th>Coverage by Other Agencies' Projects (Agency &amp; Project Title)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hardware Architecture and I/O</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fault detection and resilience</td>
<td></td>
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<tr>
<td>File systems and I/O</td>
<td></td>
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<td></td>
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<tr>
<td>Memory systems</td>
<td></td>
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</tr>
<tr>
<td>Power management</td>
<td></td>
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<tr>
<td>Simulators</td>
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<tr>
<td>Synchronization</td>
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<tr>
<td>Testbeds</td>
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<td></td>
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<td></td>
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<tr>
<td>Other:</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
1. ASCR Researchers
   - 1 per program affiliation (extras at registration desk)
   - Use for Wednesday lunch

2. ASCR Project Lead PIs
   - Project Summary version (complete during Wednesday lunch with project team)
   - Turn in top copy on Thursday morning (press firmly)

3. Government/Other Invitees
   - Turn in top copy on Thursday morning (press firmly)
In each working group the facilitator, reporters, and the scribe are given instructions on Day 1. For each working session, there is a template to facilitate and capture the discussions, and another for the outbrief.
For the identification of crosscutting topics, each working group is given these seed questions (developed by ASCR).

A responsible person writes the topics on flip charts. The participants in the room get to decide the level of granularity and wording of these topics.
Participants vote on topics

Each participant gets 3 blue and 3 red sticky dots to put next to flip charts.

Votes are tallied (red + blue) and entered into the outbrief presentation.
Participants get to wax eloquent

Observations

1. What observations do you have in general about the priorities?

2. Were there any surprises regarding the items with the highest numbers of votes?

3. Were there any significant differences between the placement of the different colored dots – i.e., mostly one color vs. a combination of both colors?

4. Why do participants worry about the topics that drew the most red dots?

Two common observations by participants:

**blue** = what I’m working on (therefore important);

**red** = what nobody is working on (therefore worrisome)
Five crosscutting topics are identified based on researcher input:

1. Programming Models
2. Resilience and Fault Tolerance
3. Data Management & I/O Architecture
4. Memory / Data Movement and Energy Efficiency
5. Application Architecture
Participants are then asked to define these crosscutting topics.

### Defining Crosscutting Topics Working Session

- **Crosscutting topic priorities identified**
  1. Programming Models
  2. Resilience and Fault Tolerance
  3. Data Management & I/O Architecture
  4. Memory / Data Movement and Energy Efficiency
  5. Application Architecture

- **For each crosscutting topic above:**
  - Define the problem space
  - Characterize the major challenges

- **Identify which two pair-wise interdependencies among these crosscutting topics you believe to be most important, and why**
  - Explain your answers in a sentence or two

**Timing guidance:**
- ~25 minutes per topic
- 15-minute break after 2nd topic (~10:00 am)
- Remainder for pair-wise question

**Same room assignments as on Wednesday for everyone**
After an outbrief, the participants work in self-selected groups for further discussions.

- Only first 4 topics are discussed (to force codesign application scientists to spread out)
- No working group assignments were made (thus those who wish to only participate in discussions of their areas of specialty may do so)
- Five questions are used to guide the discussions (next slide)
1. Dependencies, Interactions, and Bottlenecks
   A. What functional dependencies have you discovered?
      • What are many people depending on that might require further resources in order to prevent bottlenecks?
   B. What new interactions are needed (e.g., hardware/software, people)?
   C. (Optional) What have you learned that you may need to provide to other people?

2. Emerging Needs
   A. Based on what you have learned so far this week, what has caught you by surprise?
   B. What new requirements for hardware, software, or both have you identified?

3. What aspects of this topic do you need to understand more completely in order for your project to be a success?

4. Have you identified any solutions as a result of this working session? If so, what are they?

5. Path Forward
   A. Does this working group need to continue; if so, how?
   B. What else should ASCR do to help facilitate linkages and address outstanding questions?
The participants work on gap analysis on the last day. 

**Discussion Questions**

1. **Gap Analysis**
   - A. What did you expect to hear that wasn’t covered in any of this week’s discussions?
   - B. What computer science challenges for exascale are not being addressed (adequately) in efforts currently being funded?
   - C. What are the major risks you see?

2. **Schedule and Timelines**
   - A. Should a shared timeline be established that defines what research teams plan to accomplish at specific times so that people adopting the technology can plan?
     - If so, when and how?
   - B. Given scope/schedule/resources tradeoffs, where is there slack? What can be deferred?

3. **What should ASCR do to help these diverse projects build towards an integrated Exascale Initiative?**

Separately, the Research Assessment form has been tallied and the result is being analyzed.
It was a good start

ASCR POC: Lucy Nowell

ASCR CS Program Managers: Lucy Nowell, Sonia Sachs

Event Facilitator & Organizer: Lee Ann Dudney, PNNL, assisted by Kris Cook, PNNL

Administrative Support: Trina Pitcher & Kelly Sandretto

Meeting material at
http://exascaleresearch.labworks.org/ascr2011
Backup
## Seven Co-Design proposal teams are here this week

<table>
<thead>
<tr>
<th>TITLE</th>
<th>LEAD PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center for Exascale Simulation of Advanced Reactors (CESAR)</td>
<td>Rosner (ANL)</td>
</tr>
<tr>
<td>FLASH High Energy Density Physics Exascale Codesign Center</td>
<td>Lamb (ANL)</td>
</tr>
<tr>
<td>The CERF Center: Co-design for Exascale Research in Fusion</td>
<td>Koniges (LBNL)</td>
</tr>
<tr>
<td>Exascale Co-Design Center for Materials in Extreme Environments: Engineering-Scale Predictions</td>
<td>Germann (LANL)</td>
</tr>
<tr>
<td>Chemistry Exascale Co-Design Center</td>
<td>Harrison (ORNL)</td>
</tr>
<tr>
<td>Combustion Exascale Co-Design Center</td>
<td>Chen (SNL)</td>
</tr>
<tr>
<td>Exascale Performance Research for Earth System Simulation (EXPRESS)</td>
<td>Jones (LANL)</td>
</tr>
</tbody>
</table>
(Exa)Scale Changes Everything

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2018</th>
<th>Factor Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>System peak</td>
<td>2 Pf/s</td>
<td>1 Ef/s</td>
<td>500</td>
</tr>
<tr>
<td>Power</td>
<td>6 MW</td>
<td>20 MW</td>
<td>3</td>
</tr>
<tr>
<td>System Memory</td>
<td>0.3 PB</td>
<td>10 PB</td>
<td>33</td>
</tr>
<tr>
<td>Node Performance</td>
<td>0.125 Gf/s</td>
<td>10 Tf/s</td>
<td>80</td>
</tr>
<tr>
<td>Node Memory BW</td>
<td>25 GB/s</td>
<td>400 GB/s</td>
<td>16</td>
</tr>
<tr>
<td>Node Concurrency</td>
<td>12 cpus</td>
<td>1,000 cpus</td>
<td>83</td>
</tr>
<tr>
<td>Interconnect BW</td>
<td>1.5 GB/s</td>
<td>50 GB/s</td>
<td>33</td>
</tr>
<tr>
<td>System Size (nodes)</td>
<td>20 K nodes</td>
<td>1 M nodes</td>
<td>50</td>
</tr>
<tr>
<td>Total Concurrency</td>
<td>225 K</td>
<td>1 B</td>
<td>4,444</td>
</tr>
<tr>
<td>Storage</td>
<td>15 PB</td>
<td>300 PB</td>
<td>20</td>
</tr>
<tr>
<td>Input/Output bandwidth</td>
<td>0.2 TB/s</td>
<td>20 TB/s</td>
<td>100</td>
</tr>
</tbody>
</table>

FY10 Computer Science Funding Opportunity Announcements (FOAs)

• Advanced Architectures and Critical Technologies for Exascale Computing -- ~$5M / year for 3 years to fund 5 awards, Closed March 26, 2010
  – Design of energy-efficient, resilient hardware and software architectures and technology for high performance computing systems at Exascale.

• X-Stack Software Research -- ~$8.5M / year for 3 years to fund 11 awards, Closed April 2, 2010
  – Development of a scientific software stack that supports extreme scale scientific computing, from operating systems to development environments.

• Scientific Data Management and Analysis at the Extreme Scale -- ~$5M / year for 3 years for 10 awards, Closed March 18, 2010
  – Management and analysis of extreme-scale scientific data in the context of Petascale computers and/or Exascale computers with heterogeneous multi-core architectures.
Advanced Architectures Topics of Interest

- Approaches for reducing and/or managing power requirements for high performance computing systems, including the memory and storage hierarchy
- Approaches for reducing and/or managing heat in high performance computing systems
- Methods for improving system resilience and managing the component failure rate, including approaches for shared information and responsibility among the OS, runtime system, and applications
- Co-design of systems that support advanced computational science at the extreme scale
- Scalable I/O systems, which may include alternatives to file systems
- Approaches to information hiding that reduce the need for users to be aware of system complexity, including heterogeneous cores, the memory hierarchy, etc.
Advanced Architectures Awards
(28 proposals requesting ~$28M/yr, 6 projects funded at ~$5M/yr)

• Blackcomb: Hardware-Software Co-design for Non-Volatile Memory in Exascale Systems
  – Jeffrey S. Vetter (Oak Ridge National Laboratory), Robert Schreiber (Hewlett Packard Labs), Trevor Mudge (University of Michigan), Yuan Xie (Penn State University)

• Enabling Co-Design of Multi-Layer Exascale Storage Architectures
  – Robert B. Ross, William Allcock, and Samuel Lang (Argonne National Laboratory), and Christopher D. Carothers (Rensselaer Polytechnic Institute)

• NoLoSS: Enabling Exascale Science through Node Local Storage Systems
  – Robert B. Ross, Darius Buntinas, and Kamil Iskra (Argonne National Laboratory), Bronis R. de Supinski and Maya B. Gokhale (Lawrence Livermore National Laboratory)
Advanced Architectures Awards
(28 proposals requesting ~$28M/yr, 6 projects funded at ~$5M/yr)

- **CoDEx: A Hardware/Software Co-Design Environment for the Exascale Era**
  - John Shalf, David Donofrio, Alice Koniges, Leonid Oliker, Samuel Williams (Lawrence Berkeley National Laboratory), Curtis Janssen, Helgi Adalsteinsson, Damian Dechev, Ali Pinar (Sandia National Laboratories), Dan Quinlan, Chunhua Liao, Thomas Panas (Lawrence Livermore National Laboratory), Sudhakar Yalamanchili (Georgia Institute of Technology)

- **Data Movement Dominates: Advanced Memory Technology to Address the Real Exascale Power Problem**
  - Arun Rodrigues, Richard C. Murphy, Brian Barrett, and Scott Hemmert (Sandia National Laboratories), Paul Hargrove and John Shalf (Lawrence Berkeley National Laboratory), David Resnick (Micron Technologies), Keren Bergman (Columbia University), and Bruce Jacob (University of Maryland)

- **Thrifty: An Exascale Architecture for Energy-Proportional Computing**
  - Josep Torrellas (UIUC), Daniel Quinlan (LLNL), Allan Snavely (UCSD), and Wilfred Pinfold (Intel)
X- Stack Topics of Interest

- **System software**, including operating systems, runtime systems, adaptable operating and runtime systems, I/O systems, system management/administration, resource management and means of exposing resources, and external environments;

- **Fault management**, both by the operating and runtime systems and by applications;

- **Development environments**, including programming models, frameworks, compiler, & debugging tools;

- **Application frameworks**;

- **Cross-cutting dimensions**, including resilience, power management, performance optimization, and programmability; and

- **Design and/or development of high-performance scientific workflow systems that incorporate data management and analysis capabilities**
X-Stack Awards
(55 proposals requesting ~$40M/year, 11 projects funded at ~8.5M/year)

- A Fault-oblivious Extreme-scale Execution Environment
  - Ronald G Minnich, Curtis L. Janssen (Sandia National Laboratories), Sriram Krishnamoorthy and Andres Marquez (Pacific Northwest National Laboratory), Maya Gokhale (Lawrence Livermore National Laboratory), P. Sadayappan (Ohio State University), Eric Van Hensbergen (IBM Research), Jim McKie (Alcatel-Lucent Bell Labs), and Jonathan Appavoo (Boston University)

- Auto-tuning for Performance and Productivity on Extreme-scale Computations
  - Samuel W. Williams and Leonid Oliker (Lawrence Berkeley National Laboratory), John Gilbert (University of California, Santa Barbara), Stephane Ethier (Princeton Plasma Physics Laboratory)

- Software Synthesis for High Productivity ExaScale Computing
  - Armando Solar-Lezama (MIT) and Rastislav Bodik and James Demmel (UC Berkeley)
X-Stack Awards

(55 proposals requesting ~$40M/year, 11 projects funded at ~8.5M/year)

- **ExM: System support for extreme-scale, many-task applications**
  - Michael Wilde, Ewing Lusk, and Ian Foster (Argonne National Laboratory), Daniel S. Katz (University of Chicago), and Matei Ripeanu (University of British Columbia)

- **COMPOSE-HPC: Software Composition for Extreme Scale Computational Science and Engineering**
  - David E. Bernholdt (Oak Ridge National Laboratory), Matt Sottile (Galois, Inc.), Tom Epperly (Livermore National Laboratory), Manojkumar Krishnan (Pacific Northwest National Laboratory), and Rob Armstrong (Sandia National Laboratories)

- **Damsel: A Data Model Storage Library for Exascale Science**
  - Alok Choudhary and Wei-keng Liao (Northwestern University), Robert Latham, Robert Ross, and Timothy Tautges (Argonne National Laboratory), Nagiza Samatova (North Carolina State University and Oak Ridge National Laboratory), and Quincey Koziol (The HDF Group)
X-Stack Awards
(55 proposals requesting ~$40M/year, 11 projects funded at ~8.5M/year)

• Vancouver: Designing a Next-Generation Software Infrastructure for Productive Heterogeneous Exascale Computing
  – Jeffrey S. Vetter (Oak Ridge National Laboratory), Wen-mei Hwu (University of Illinois at Urbana Champaign), Allen D. Malony (University of Oregon), and Rich Vuduc, (Georgia Institute of Technology)

• Enabling Exascale Hardware and Software Design through Scalable System Virtualization
  – Patrick G. Bridges (University of New Mexico), Peter Dinda (Northwestern University), Kevin Pedretti (Sandia National Laboratories), and Stephen Scott (Oak Ridge National Laboratory)
X-Stack Awards
(55 proposals requesting ~$40M/year, 11 projects funded at ~8.5M/year)

- **ZettaBricks: A Language, Compiler and Runtime Environment for Anyscale Computing**
  - Saman Amarasinghe, Alan Edelman, Una-May O’Reilly, Martin Rinard, and Chris Hill (MIT)

- **Compiled MPI: Cost-Effective Exascale Application Development**
  - Grigory Bronevetsky and Daniel Quinlan (Lawrence Livermore National Lab), Andrew Lumsdaine (Indiana University) and Torsten Hoefler (University of Illinois at Urbana-Campaign)

- **An Open Integrated Software Stack for Extreme Scale Computing**
  - Pete Beckman (Argonne National Laboratories) in collaboration with several PIs at UTK, UCB, UIUC, University of Houston, LBNL, Rice University, University of Oregon, and Sandia National Laboratories
• Extreme-scale data storage and access systems that are functional at the granularity and massive scale of scientific endeavors, that support data models that are consistent with scientists’ view of their data, and that minimize the need for scientists to have detailed knowledge of system hardware and operating systems;

• Scalable data triage, summarization, and analysis methods and tools, including adaptive, power-aware algorithms and software for in-situ data reduction and/or analysis of massive multivariate data sets;

• Semantic integration of heterogeneous scientific data, including support for integrated analysis of multi-scale, multi-physics data from multiple types of devices and experiments, and/or simulations and spanning multiple scientific disciplines;

• Knowledge representation and automated machine reasoning and/or data mining methods and tools that support automated analysis and integration of large scientific data sets, especially those that include tensor flow fields, and/or representation of and reasoning about uncertainty and sources of uncertainty; and

• Visual analysis of extreme-scale scientific data, including multi-user visual analysis methods and tools for scientist users who may or may not be co-located, and interactive visual steering of computational processes.
Data Mgmt & Analysis at Extreme Scale Awards
(37 proposals requesting ~$22/yr, 10 projects funded at ~5M)

- **Dynamic Non-Hierarchical File Systems for Exascale Storage**
  - Darrell Long and Ethan Miller (University of California, Santa Cruz)

- **Runtime System for I/O Staging in Support of In-Situ Processing of Extreme Scale Data**
  - Scott Klasky, Nagiza Samatova, Matthew Wolf, and Norbert Podhorszki (Oak Ridge National Laboratory), Arie Shoshani and John Wu (Lawrence Berkeley National Laboratory), and Karsten Schwan and Greg Eisenhauer (George Tech)

- **ExaHDF5: An I/O Platform for Exascale Data Models, Analysis and Performance**
  - Prabhat (Lawrence Berkeley National Lab), Karen Schuchardt (Pacific Northwest National Lab) and the HDF Group

- **Adding Data Management Services to Parallel File Systems**
  - Scott A. Brandt (University of California, Santa Cruz) and Maya Gokhale (Lawrence Livermore National Laboratory)
Scalable and Power Efficient Data Analytics for Hybrid Exascale Systems

- Alok Choudhary and Wei-keng Liao (Northwestern University), Nagiza Samatova (Oakridge National Laboratory), and Kesheng (John) Wu (Lawrence Berkeley National Laboratory)

A Pervasive Parallel Processing Framework for Data Visualization & Analysis at Extreme Scale

- Kenneth Moreland (Sandia National Laboratories), Kwan-Liu Ma (University of California, Davis) and Berk Geveci (Kitware, Inc.)

An Information-Theoretic Framework for Enabling Extreme-Scale Science Discovery

- Han-Wei Shen (Ohio State University), Robert Ross and Thomas Peterka (Argonne National Laboratory) and Yi-Jen Chiang (Polytechnic Institute of New York University)
Enabling Scientific Discovery in Exascale Simulations

- Dr. Chandrika Kamath (Lawrence Livermore National Laboratory) and Prof. George Karypis (University of Minnesota)

Graph-Based 3D Flow Field Visual Analysis

- Pak Chung Wong (Pacific Northwest National Laboratory), Han-Wei Shen (Ohio State University) and Daniel Chavarría (Pacific Northwest National Laboratory)

Topology-Based Visualization & Analysis of Multidimensional Data & Time-Varying Data at the Extreme Scale

- Gunther Weber (Lawrence Berkeley National Laboratory)