U.S. DEPARTMENT OF ENERGY | Office of Science

A Bridge in Time

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Scientific Discovery

The Reason We Are Here

- **The computing capability needed for scientific discovery is bounded only by human imagination**
- **Next generation scientific breakthroughs**
  - Require major new advances in computing technology
  - Energy-efficient hardware, algorithms, applications, system software
- **Driven by ubiquitous data explosion**
  - Experimental, observational, sensor networks, and simulation

- **Computing / data throughput challenges**
  - Well documented in numerous studies
  - Can no longer scale up from or modify existing solutions

Three Decades of Leadership & Service

- **For three decades, Argonne has helped lead the way**
- **Reference implementations of critical software**
  - MPICH, LINPACK, GLOBUS, …
- **A partner in the future of HPC**
- **Strategy and Culture**
  - Did things differently
  - Worked in partnership
  - Brought skills
  - Established standards of quality
- **A flagship of the Office of Science**
  - Commitment to quality of progress
  - Forward looking
  - Community serving

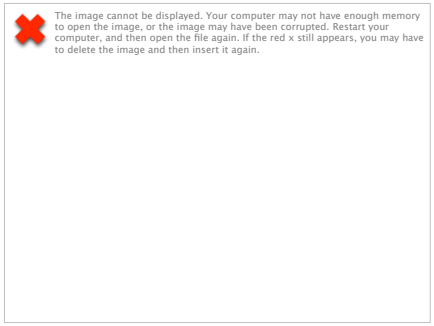
The Looming Challenge, Thirty Years Ago

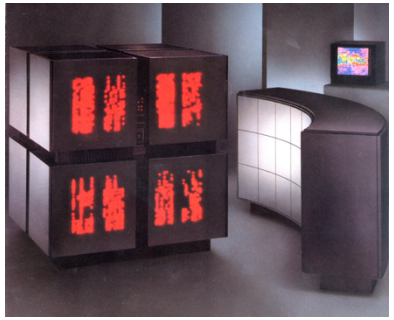
- **Technology driver transition**
  - LSI to VLSI
  - Emergence of CMOS, RISC microprocessors
  - Availability of dense semiconductor DRAM
  - Local area and system area networks (LAN, SAN)

- **Paradigm Shift required**
  - Exploit "killer micro"
  - Increase performance, reduce cost
  - Transition away from vector, PVP, and SIMD-array
  - How to structure and program new class of systems
- **Everything was about to change**
  - How do we program future class of systems?
  - Do we keep a shared memory model?
  - New programming methods; what about legacy codes?

The Future Was Uncertain

- BBN TC-2000 NUMA
- Denelcor HEP multithreaded
- Intel Touchstone Delta
- TMC CM-2
- Alliant FX/8
- KSR-1
- Cray T3D/E
- Ncube
- Cray C90
- UIUC/CSRD Cedar
- Programming Languages





What Happened?

- **When the dust settled**
  - Surviving scalable execution model was Communicating Sequential Processes (CSP)
  - Scalable architectures were COTS-based distributed memory systems
  - Programming model was MPI
- **ANL was a major leader, providing**
  - The reference implementation of MPI (MPICH)
  - Tools (e.g., JUMPSHOT)
  - Math libraries (e.g., LINPACK, PETSc)
  - Applications

It's Happening Again

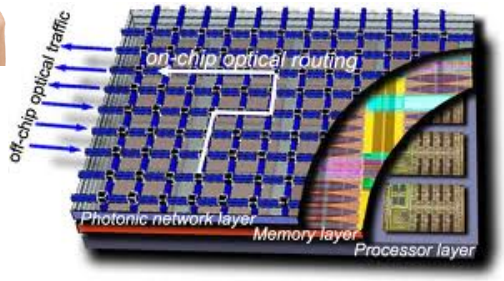
- **Dennard scaling has ended**
- **End of Moore's Law looming**
- **New Technologies on the near horizon**
  - Phase change memories
  - Stacked dies
- **Exponential growth in parallelism in our HPC systems**
  - IBM Blue Gene is leading the charge (e.g., Mira)
  - Heterogeneous systems delivering higher performance/watt (e.g., Titan)
- **Power is a constraint**
- **Resilience is a very real concern**
- **Programmability**
  - System complexity
  - Inefficient compilers

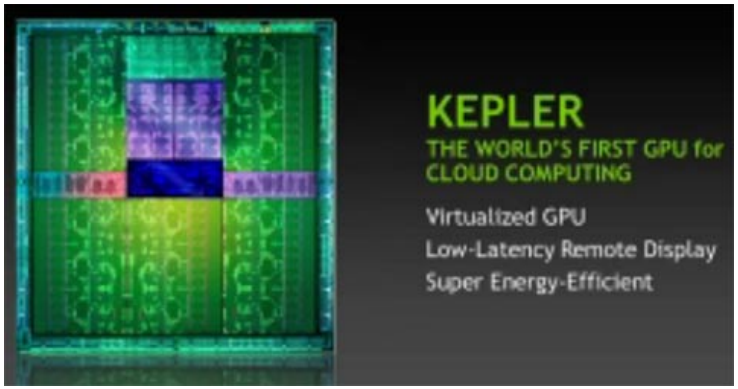
Extreme Diversity in Computing

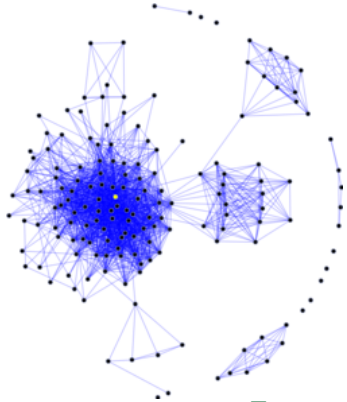
- Apple iPhone / iPad
- Big Data
- Massive Commercial Data Centers
- GPUs
- Silicon Photonics
- IBM Watson
- Quantum Computing
- ARM Cores
- SoCs
- Explosion of data
- Security

ARM

D-Wave
The Quantum Computing Company™







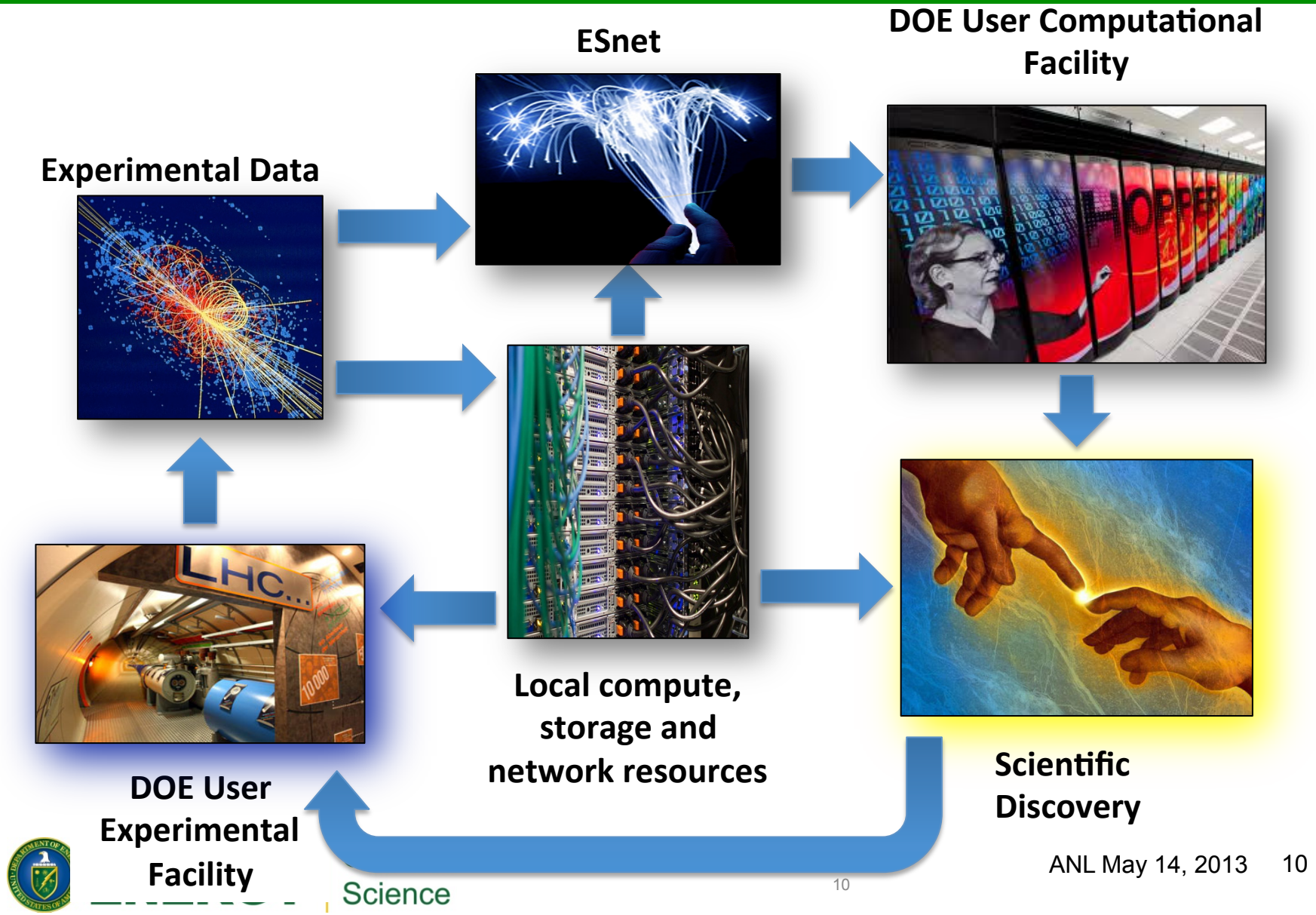
Defining the Future

- **DOE is the leader of US HPC goals and programs**
- **Success will require**
  - Lab leaders who have vision and skill
  - Lab researchers willing to push beyond the past
  - Partnerships between DOE HQ and the DOE labs
  - Teaming with industry towards mutual goals
  - Support from Congress, OSTP, other Federal agencies
  - International collaboration
- **While the future for the next few years may seem clear, we don't really know where we will be in the next 20 years**
- **Ultimately market forces will determine the future**
- **We need to turn this into a positive force for high end computing**

Essential Attributes for the Future Computational Systems

- Systems designs based on marketable technology
- Systems that allow the users to not be overwhelmed by the system complexity
- Accelerating scientific discovery that will transform scientific data into actionable knowledge
- Systems that DOE can use for its mission of science, engineering, and national security

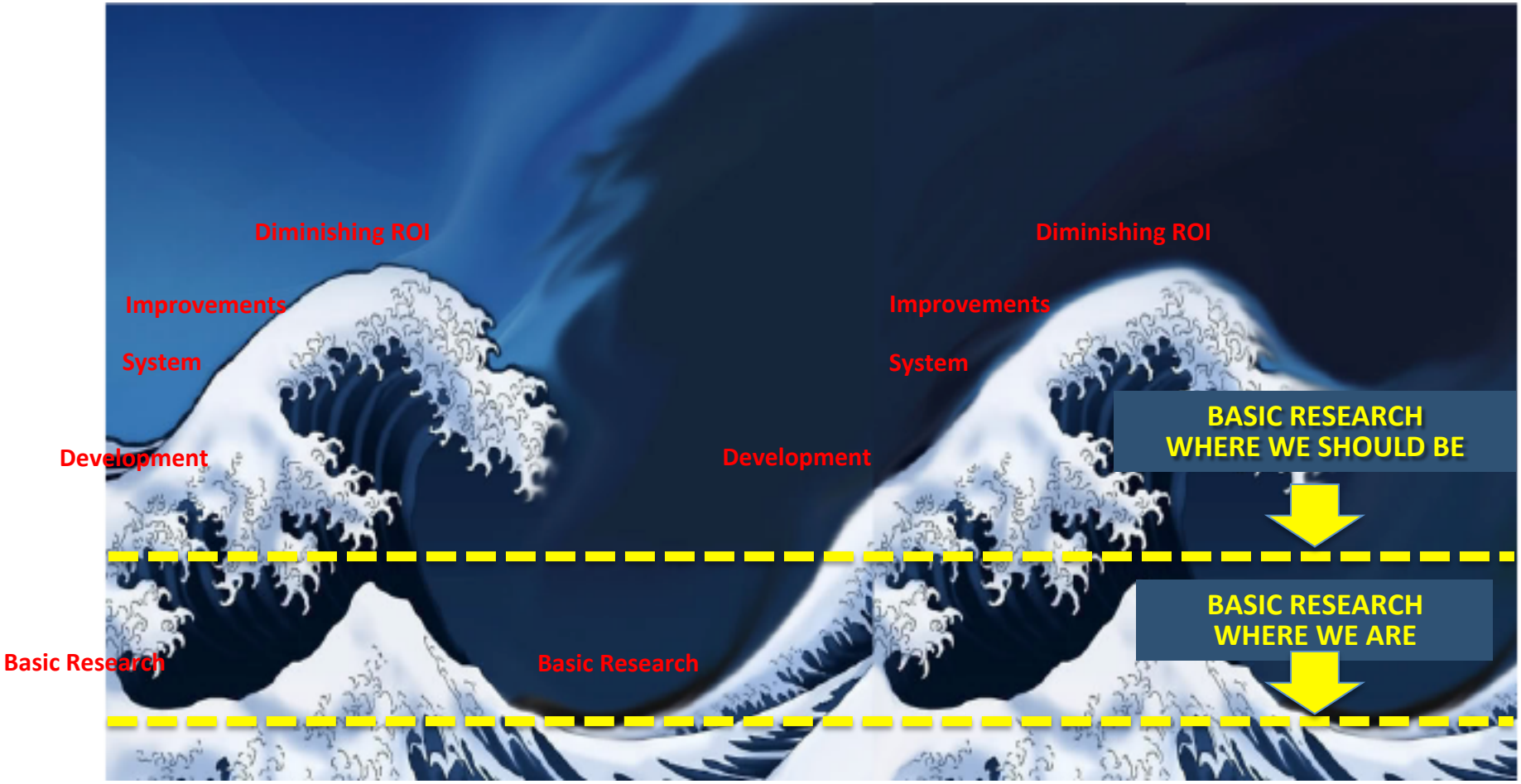
Data Intensive Science
Optimizing the Full Data Path



ASCR Goals

- **Provide computational facilities for the extreme scale era**
  - Promote and establish coordinated set of ASCR programs to further this goal
  - Provide diversity of computing assets to tackle the spectrum of DOE applications
  - Ensure "*smooth*" transition to exascale computers
- **Develop a research portfolio that enables application developers to achieve their goals**
  - Establish fundamental infrastructure for optimal utilization of computational and experimental user facilities
  - Transition legacy science codes to the extreme scale era
  - Enable application codes to exploit new extreme scale assets
- **Fund research efforts to explore the unknown future**
  - New execution models for computing systems
  - New exascale mathematical algorithms
  - Execution and development time productivity

Riding the Wave of Progress



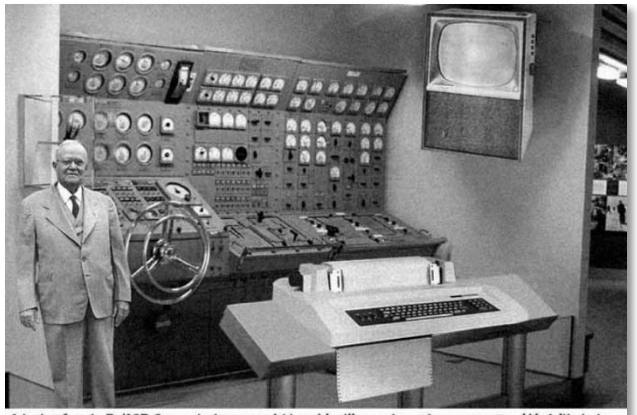
DOE Highway to the Future

- **Current investments**
  - Mission driven applications, and systems to run them
  - Based on industrial technology and system roadmaps
  - Software tools for increased productivity

- **Near-term directions**
  - Trans-Petaflops era
  - Responsible, pragmatic, forward looking improvements
  - Extension of conventional practices plus emerging yet unproven innovations
  - Challenges are parallelism, efficiency, reliability, power, and productivity
- **Long-term strategy**
  - Trans-Exaflops, nano-scale era
  - Planning for the unknown, preparing for uncertain alternatives
  - Encourage industry to explore visionary advanced technologies
  - Managing the transition between current and future paradigms

Near-Term Future – 2015 to 2025

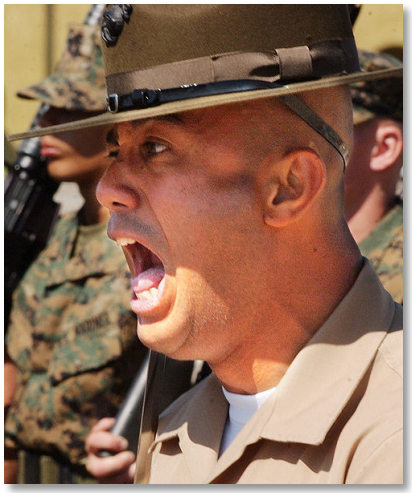
- **Emerging Technologies**
  - Nano-scale devices
  - Stacked Dies
- **Proposed Architectures**
  - Processor in (or near) memory
  - Lightweight processor cores
  - Merged heterogeneity
- **New Programming Methodologies**
  - Evolution protects existing investments
  - Domain Specific Languages
- **System Environments**
  - Data movement dominates costs
  - Separation of concerns between:
    - Transitional physical system components and structures, and
    - Stable virtual system model/image



Scientists from the RAND Corporation have created this model to illustrate how a "home computer" could look like in the year 2004. However the needed technology will not be economically feasible for the average home. Also the scientists readily admit that the computer will require not yet invented technology to actually work, but 50 years from now scientific progress is expected to solve these problems. With teletype interface and the Fortran language, the computer will be easy to use.

Longer Term Vision – 2025 to 2035

- **End of Moore's Law**
  - A few angstrom's
  - Vertical deposition
- **Name space unification**
  - From clouds to cores to cells
- **Paradigm leaps**
  - Revolutionary execution models that leverage new technology frontiers
- **Quantum effect technologies**
  - Quantum computer architecture components for NP-hard problems
  - High-base SQUID logic
- **DNA data storage**



Longer Term Vision – 2025 to 2035

- **Fully declarative "programming"**
  - Tell it what you need to accomplish
  - Not how to do it
- **Self-organizing systems**
  - Synergistic and symbiotic
    - Interaction of multiple elements of a system to achieve an effect greater than any one is capable
    - Yielding emergent behavior in functionality and capability exceeding any of its parts
  - Dynamically adaptive
    - Responsive to objective function by perturbing component operation
    - Active measurement and control of system state and progress
  - Self repairable
    - Dark silicon can contain replacement components on semiconductor dies

Conclusions and Summary

- **Thirty years ago, computational science was at a crossroads, and ANL researchers played a major role in leading the World into a new era of distributed-memory systems and MPI.**
- **The next thirty years, with the end of Moore's Law, promises to be just as exciting as the last.**
- **We look forward to the contributions ANL will make as its researchers help lead us though the revolution that will take us to exascale, and beyond.**
- **We must "*assemble the technology pieces in a way that it succeeds*"**