The Goals for IESP

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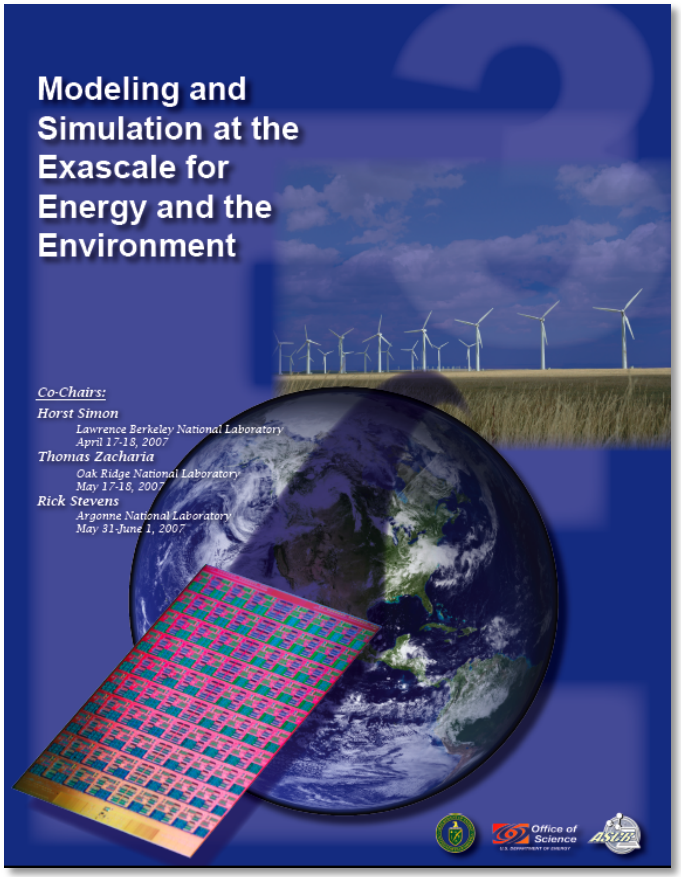
Overview of Planning for Exascale

- Since 2007 US Agencies (DOE, NSF and DARPA) have started planning for a *possible* Exascale Initiative
- The goal is to develop an exascale simulation and modeling capability by 2020
- Our vision includes significant international partnership
- The scope of the initiative concept includes
  - Applications Development
  - Systems Software and Programming Models
  - Multiple Hardware Platforms

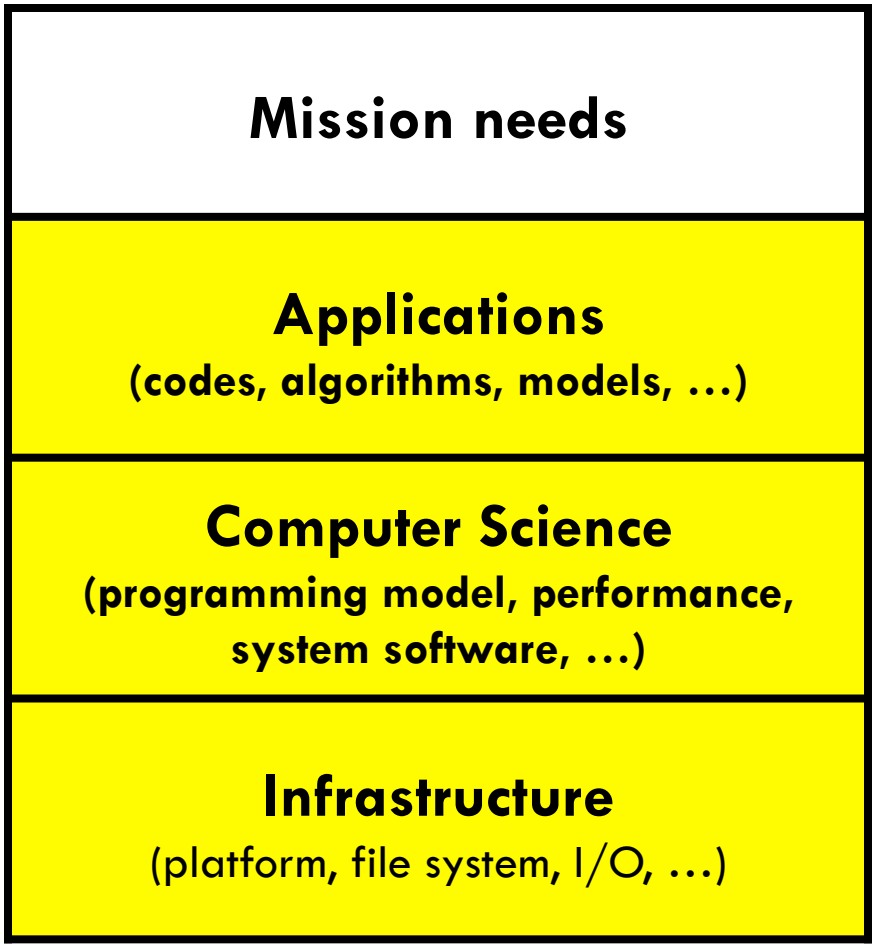
US Exascale Planning Activities

- Started in spring 2007
- DOE Lab Town Hall Meetings
  - Energy and Environment
- DARPA studies
  - Hardware and Software
- DOE and NSF Launch IESP
  - Roadmap for Software
- DOE Lab Steering Committee
  - Science Case (Applications)
  - Technical Roadmap



DOE's focus on mission needs in Energy, Environment, Science and Security

- DOE Exascale Steering Committee
  - ANL, LANL, LBNL, LLNL, SNL, ORNL + PNL, BNL
  - Charter: Decadal plan to provide exascale applications and technologies for DOE mission needs
- Workshops @ ~100 People
  - Climate Science (11/08)
  - High Energy Physics (12/08)
  - Nuclear physics (1/09)
  - Fusion Energy (3/09)
  - Nuclear Energy (5/09)
  - Biology (8/09)
  - Basic Energy Science (8/09)
  - Joint National Security (10/09)
  - Computer Science
  - Mathematics
  - Computer Architecture

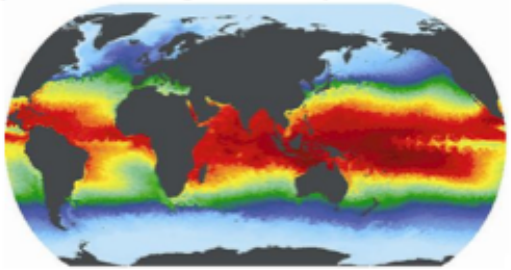


Applications Targets

- Energy
  - Solar, Grid, Wind, Storage
  - CFD and Combustion
  - Fission and Fusion
- Environment
  - Climate and Ecosystems
  - Carbon Sequestration and Storage
- Security
  - Stockpile Stewardship
  - Non-proliferation
- Basic Science
  - High-Energy and Nuclear Physics
  - Astrophysics and Cosmology
  - Biology, Chemistry, Materials
- Health
  - Neuroscience
  - Protein science
  - Genomics
  - Cells, Tissues and Organisms

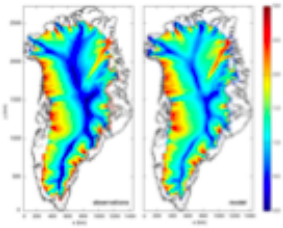
Simulations are critical for understanding climate change and predicting its impacts

- Sea level, sea-ice and ocean circulation
  - Develop a predictive land-ice model
  - Increase resolution of ocean < 1/10°
- Distribution and cycles of water, ice & clouds
  - Global, cloud resolving models
- Extreme events on local and regional scales
  - Hierarchical multiscale models
- Carbon, methane and nitrogen cycles
  - Biogeochemistry in oceans
  - Dynamic land surfaces changes



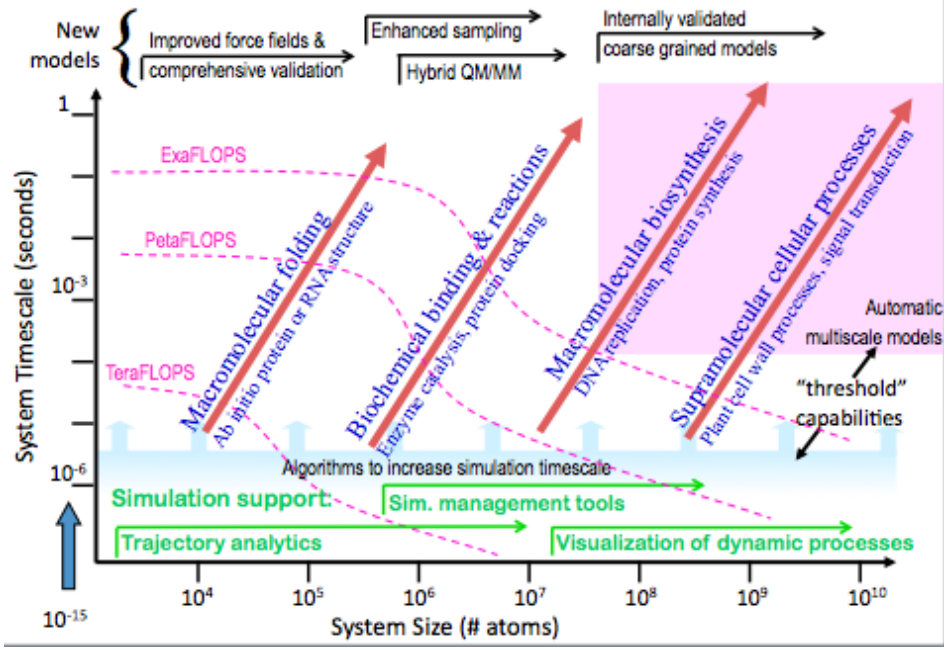
Eddy-resolving ocean simulations required to give accurate simulation of global ocean circulation

Advanced sea ice and ice sheet models

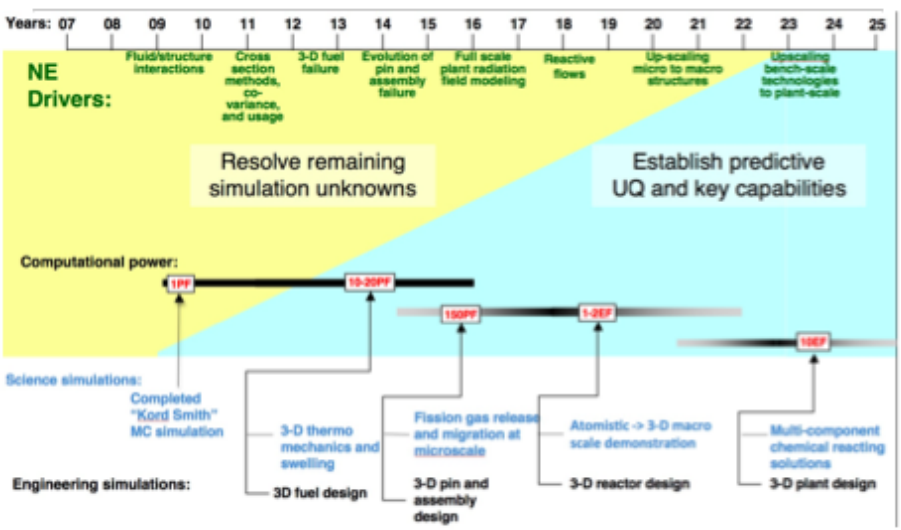


"Given these drivers … it is clear that exascale computers and ultra fast networks, data systems and computational infrastructure will be required by 2020." *Challenges in Climate Change Science and the Role of Computing at Extreme Scale, November, 2008*

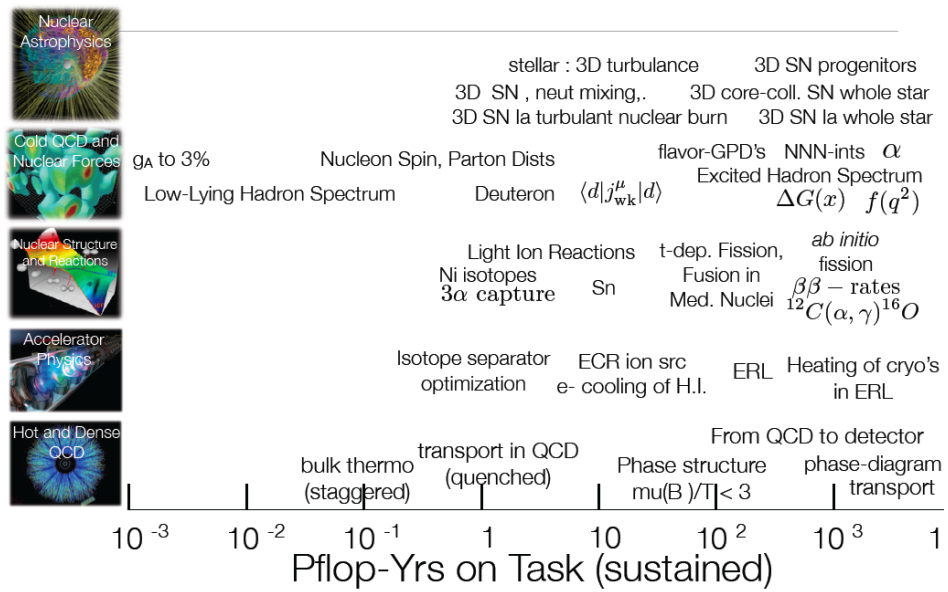
Towards Exascale Biochemical Simulations



Computational Requirements for Nuclear Energy Modeling



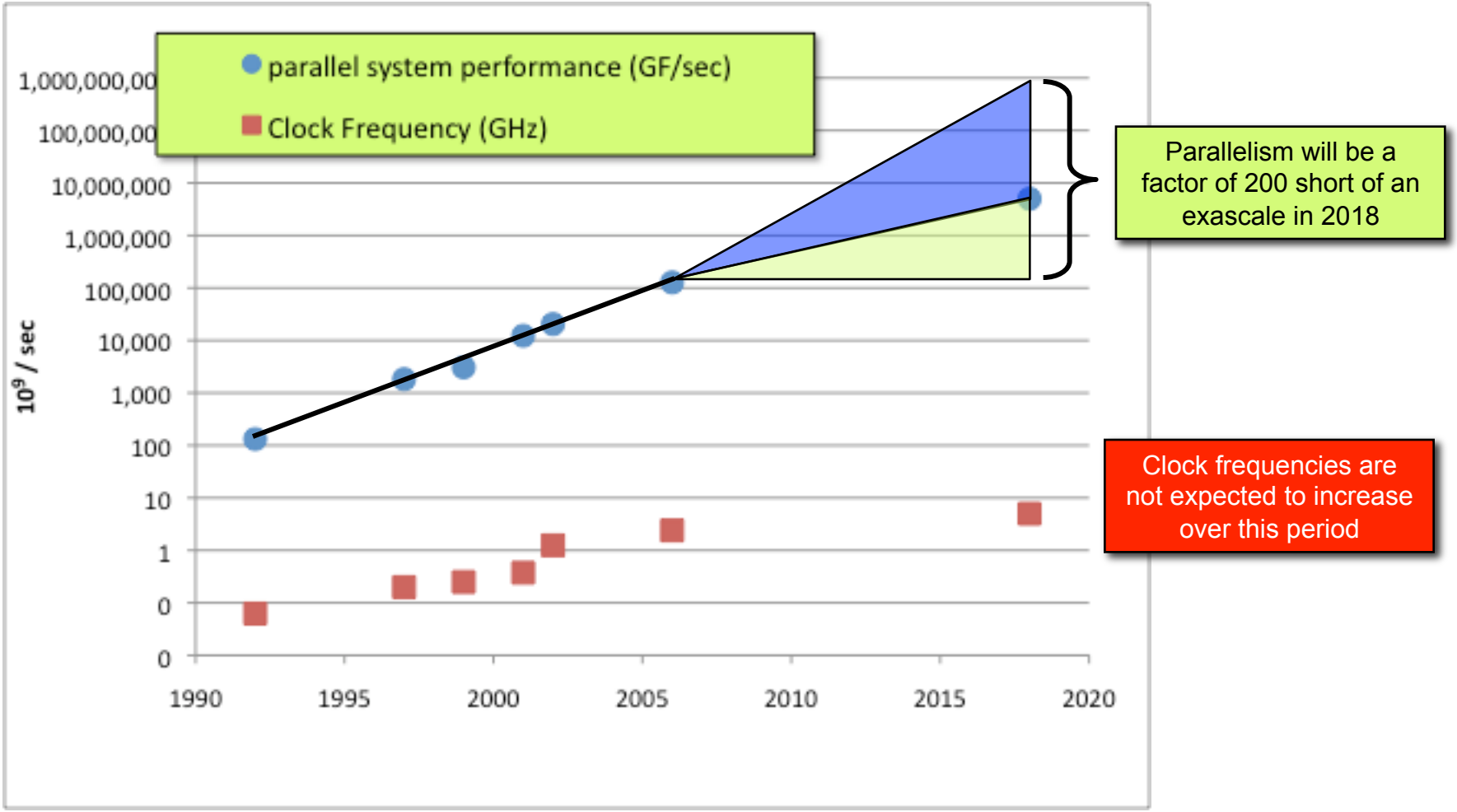
Nuclear Physics Requires Exa-scale Computation



Systems Scaling Projections

Begin Full System Delivery (Yr)	2004	2007	2012	2015	2019
Design Parameters	**BG/L**	**BG/P**	**25PF**	**300PF**	**1200PF**
Cores / Node	2	4	8-24	32-64-128	96-128-500
Clock Speed (GHz)	0.7	0.85	1.6-4.1	2.3-4.8	2.8-6.0
Flops / Clock / Core	4	4	8-32	8-32	16-64
Nodes / Rack	1024	1024	100-1024	256-1024	256-1024
Racks / Full System Config	64	72	128-350	128-400	256-400
MB RAM/core	256	512	1024-4096	1024-4096	1024-4096
Total Power	2.5MW	4.8MW	8MW-20MW	20MW-50MW	30MW-80MW
Flops / Node (GF)	5.6	14	128-640	640-2000	2000-6000
Flops / Rack (TF)	5.7	14	200-400	400-1200	1600-4800
LB Concurrency	5.E+05	1.E+06	10E6-64E6	100E6-1E9	1E9-10E9
Full System					
Total Cores (Millions)	0.13	0.3	.3M-1.5M	1M-50M	4M-200M
Total RAM (TB)	33.6	151	2,000-4,400	3,000-10,000	5,000-50,000
Total Racks	64	72	128-350	128-400	256-400
Peak Flops System (PF)	**0.37**	**1**	**25**	**300**	**1200**

A Hybrid Programming Model Will Likley Be Required To Reach An Exaflop/Sec



The Concurrency Challenge

- **How will 1000x increase in concurrency be delivered to Extreme Scale Systems?**
  - Weak Scaling by increase in data size, W_S
  - Weak Scaling by increase in computation per datum, W_T
  - Strong Scaling by increasing parallelism in fixed computation, S

- **Over Provisioning required for Latency Hiding, L**
  - L is determined by latency hiding requirements --- memory access time, fraction of memory operations (parameterized by memory hierarchy level
  - Assume L ~ 100x

- **How much additional parallelism must come from software, relative to today's applications?**
  - ***W_S*W_T*S needs to be > 10^5***

From Vivek Sarkar SC08 Exascale Workshop

The Concurrency Challenge

- **W_S is limited by DRAM cost and memory-computation ratio**
  - Petascale ~ 1 byte/FLOPS
  - Exascale ~ 0.01 bytes/FLOPS ??
  - Improving memory-computation balance is expensive
    - 50-50 cost balance dictates 0.004 bytes/FLOPS
    - 90-10 cost balance dictates 0.04 bytes/FLOPS
  - Assume W_S ~ 10x

- **W_T is limited by application domain and algorithm**
  - Assume W_T ~ 10x

➔ Software must deliver S ~ 1000x increase in Strong Scaling to use full capability of Extreme Scale systems

From Vivek Sarkar SC08 Exascale Workshop

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

- **Strategy for determining and refining "systems" software requirements**
  - Agencies need to understand how scope is being determined and how definitive that scope is
  - Need strong coupling to the applications science and engineering groups to better understand their problems
  - Need coupling to architecture development teams
  - Need to understand what the private sector will be able to deliver and when
  - Need to understand the role of research in generating options for the future

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)

Goals for IESP

- **Develop a governance and coordination model that encourages international participation and open development and yet capable of meeting the deadlines for deploying on real systems**
  - The software aspect of Exascale is likely to be as difficult and expensive as the hardware and applications development
  - The agencies can not afford to try a new community model if they don't have confidence it will result in delivering the needed software on time and on budget

Final Words

- This is an important project
- Its success will have lasting impact on the planet and people all around the world and for generations into the future
- I believe our community is ready to step up to the challenge to engage in a worldwide effort to build the common software that will benefit all
- If we do this right it will also be fun!