Simulating Plasmas for Fusion Science

Plasma Fest, Plasma Science and Technology Institute, UCLA

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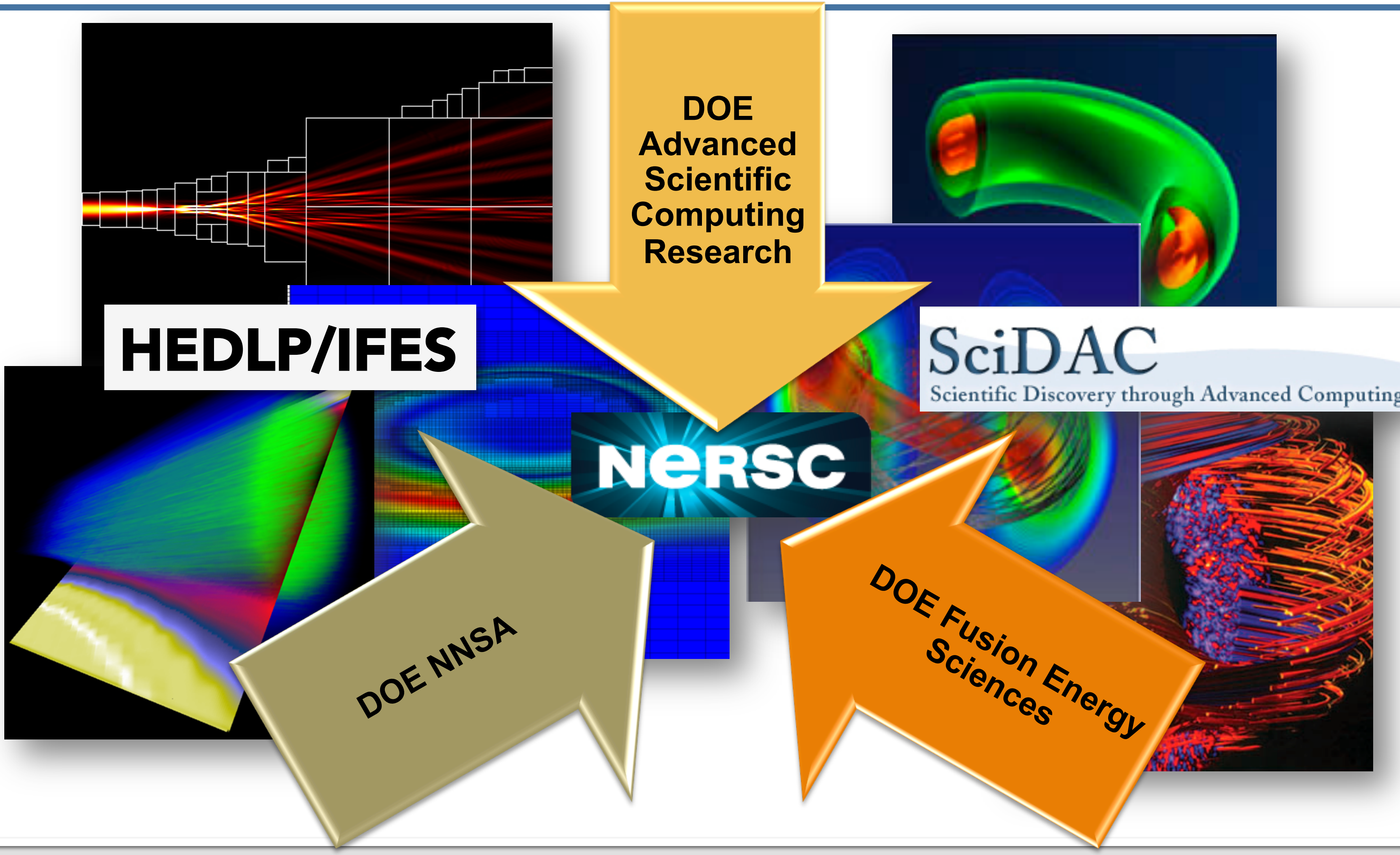
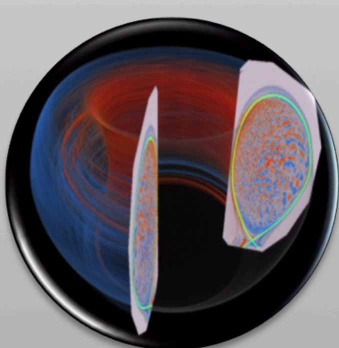
DOE has embraced simulation as an import part of fusion science research



DOE Fusion Energy Science program has held a series of Community Planning Workshops



Integrated Simulations for Magnetic Fusion Energy Sciences

- Validated integrated predictive simulation capability
- Reduce risk in design and operation
- Enhance value of participation in ITER

Plasma-Material Interactions

- Address extreme harshness of burning plasma environment at the plasma-material interface

Transients

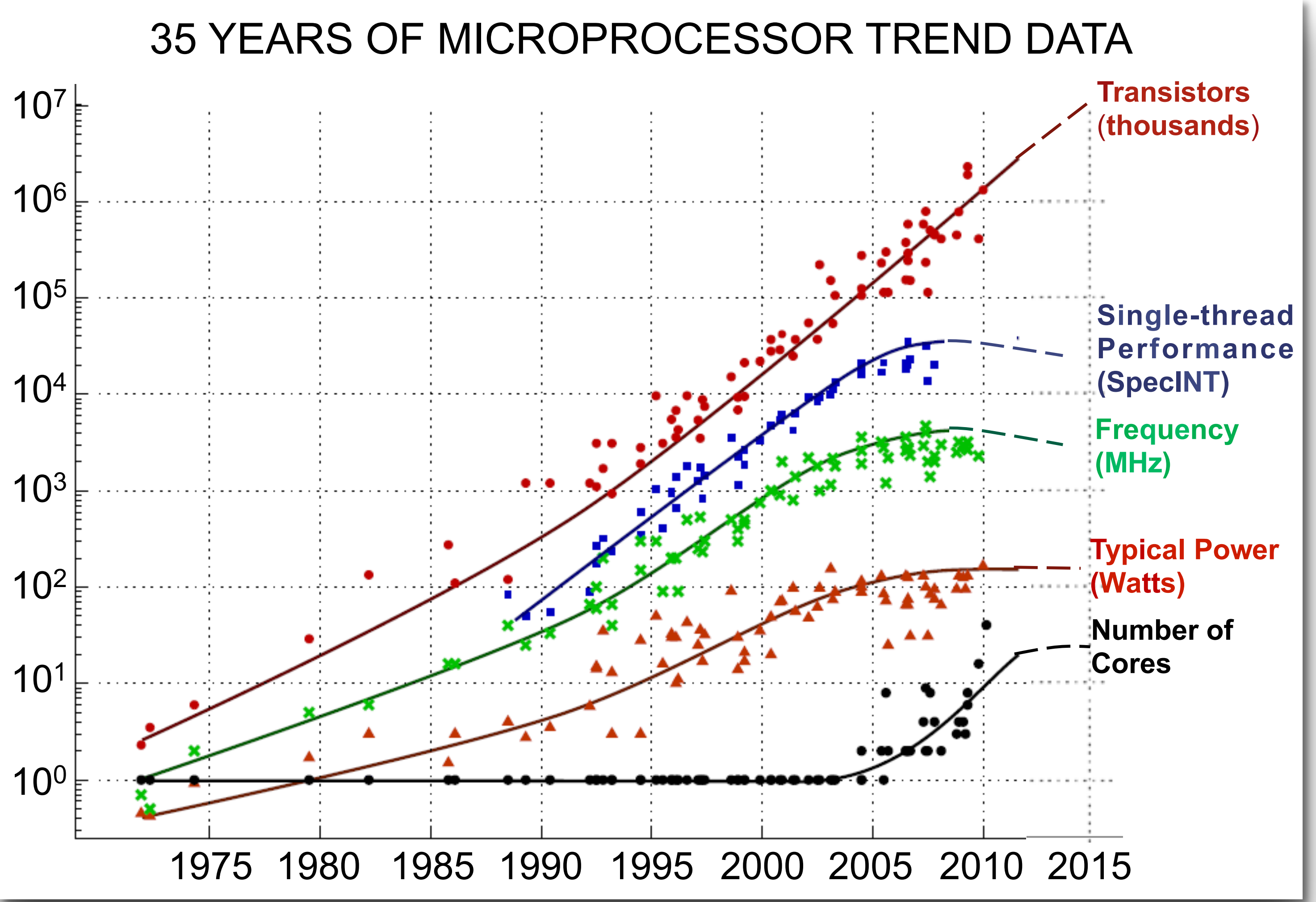
- Understand and control deleterious transient events that disrupt plasma operation and damage fusion devices

Plasma Science Frontiers

- General plasma science
- High Energy Density Laboratory Plasma
- Exploratory Magnetized Plasma

Simulation is a cross-cutting theme

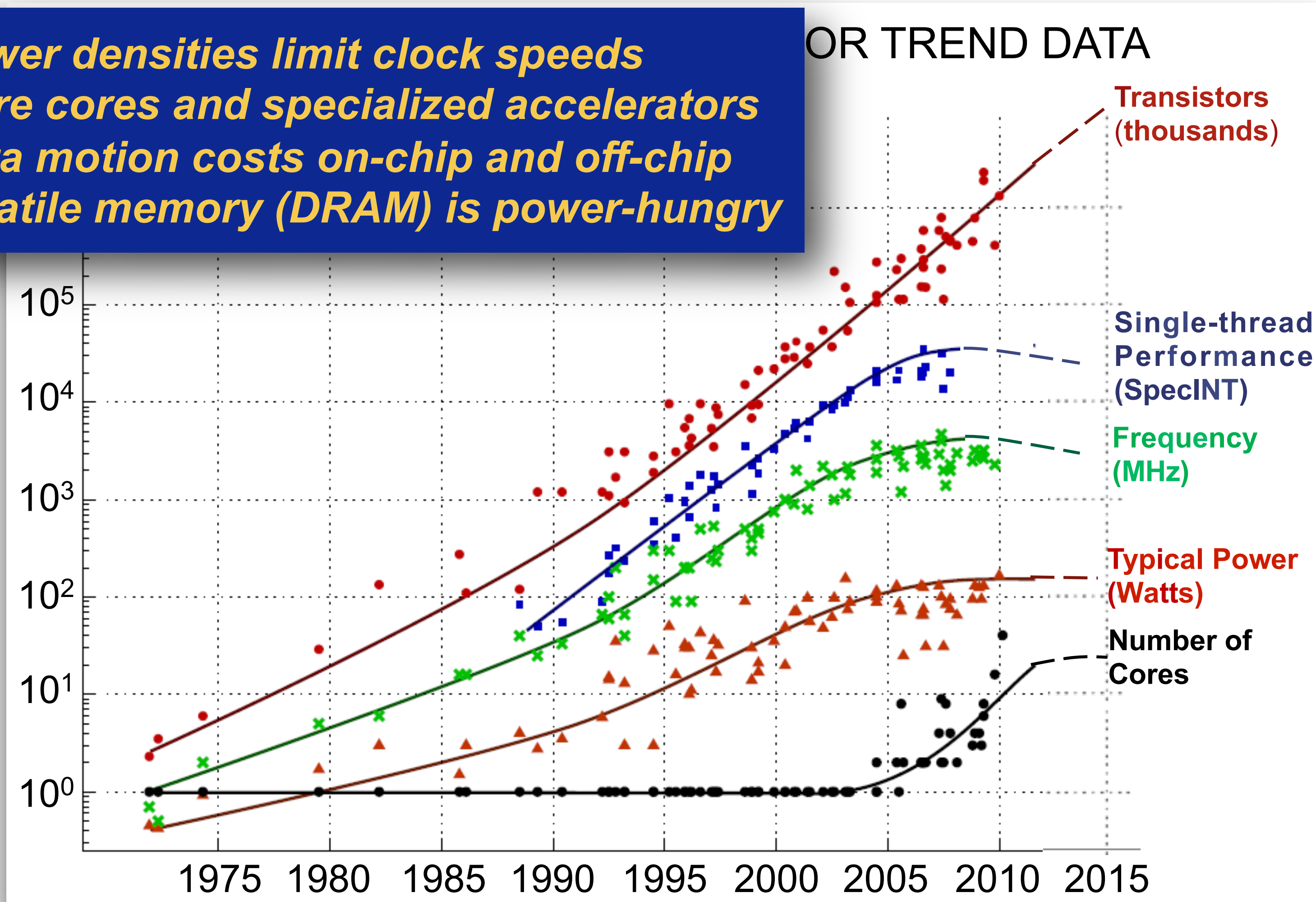
Power issues are driving architecture changes in the High Performance Computing ecosystem



Original data collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond and C. Batten.
Dotted line extrapolations by C. Moore. From C. Moore, "Data Processing in Exascale-Class Computer Systems," Salishan, 2014

Power issues are driving architecture changes in the High Performance Computing ecosystem

- *Power densities limit clock speeds*
- *More cores and specialized accelerators*
- *Data motion costs on-chip and off-chip*
- *Volatile memory (DRAM) is power-hungry*



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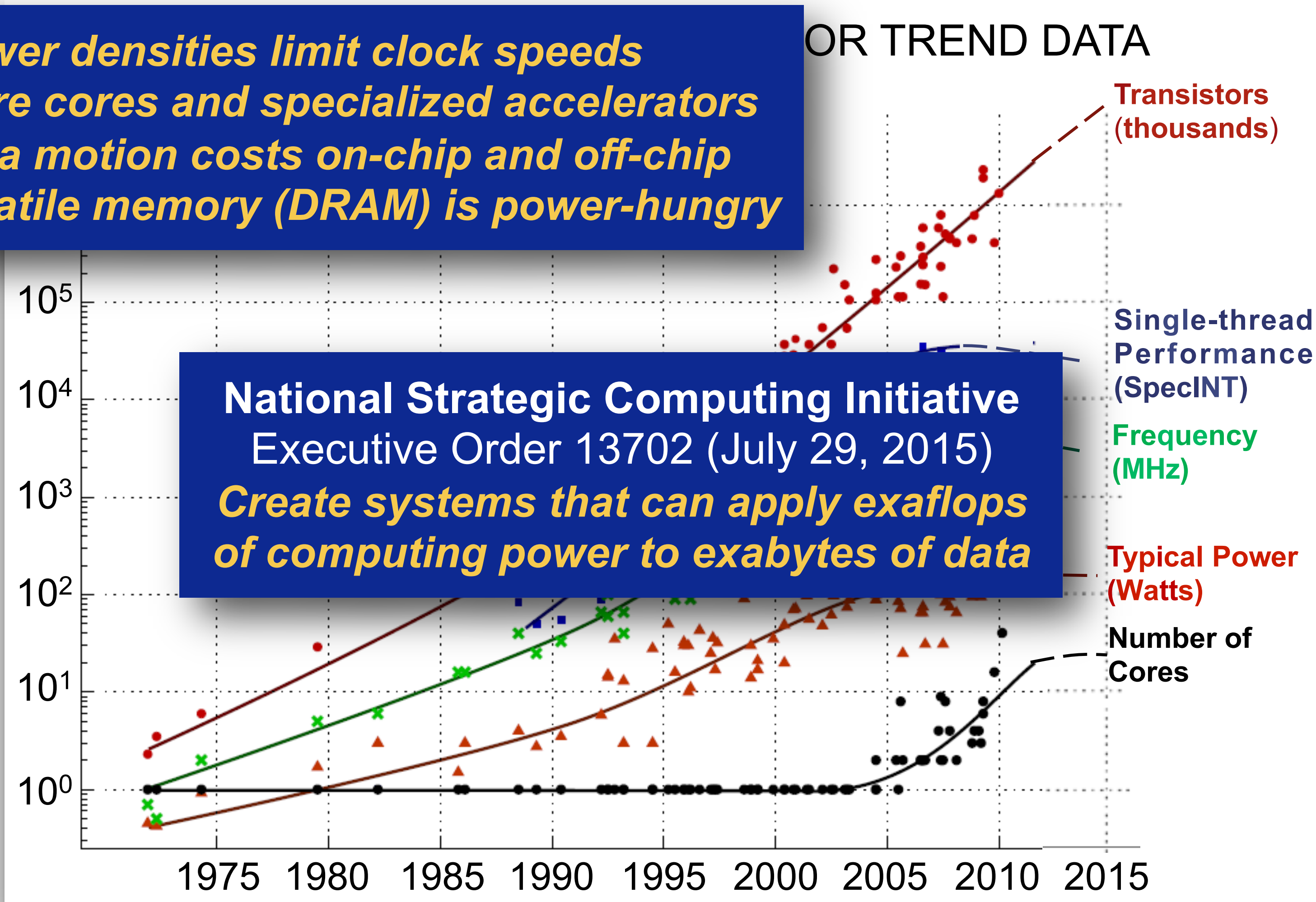
National Strategic Computing Initiative
Executive Order 13702 (July 29, 2015)
Create systems that can apply exaflops of computing power to exabytes of data



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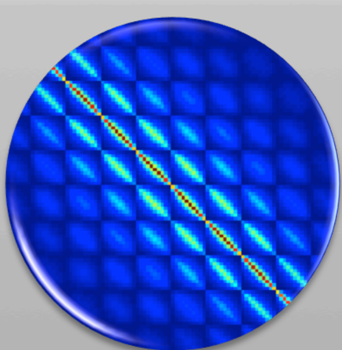
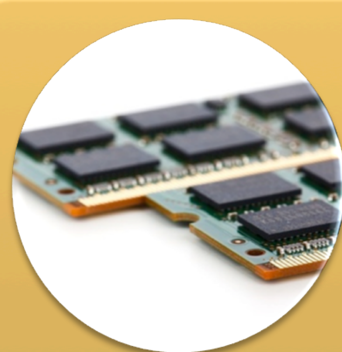
Exascale computing introduces several fundamental challenges



Extreme Concurrency

- Processing units ↑
- Bulk-synchronous will not scale
- Concurrency ↑
- Synchronization ↓
- Communication ↓
- Dynamic task parallelism



Limited Memory

- Memory gains less than processing
- Memory/core ↓
- Minimize memory usage
- Deeper , heterogeneous memory hierarchies

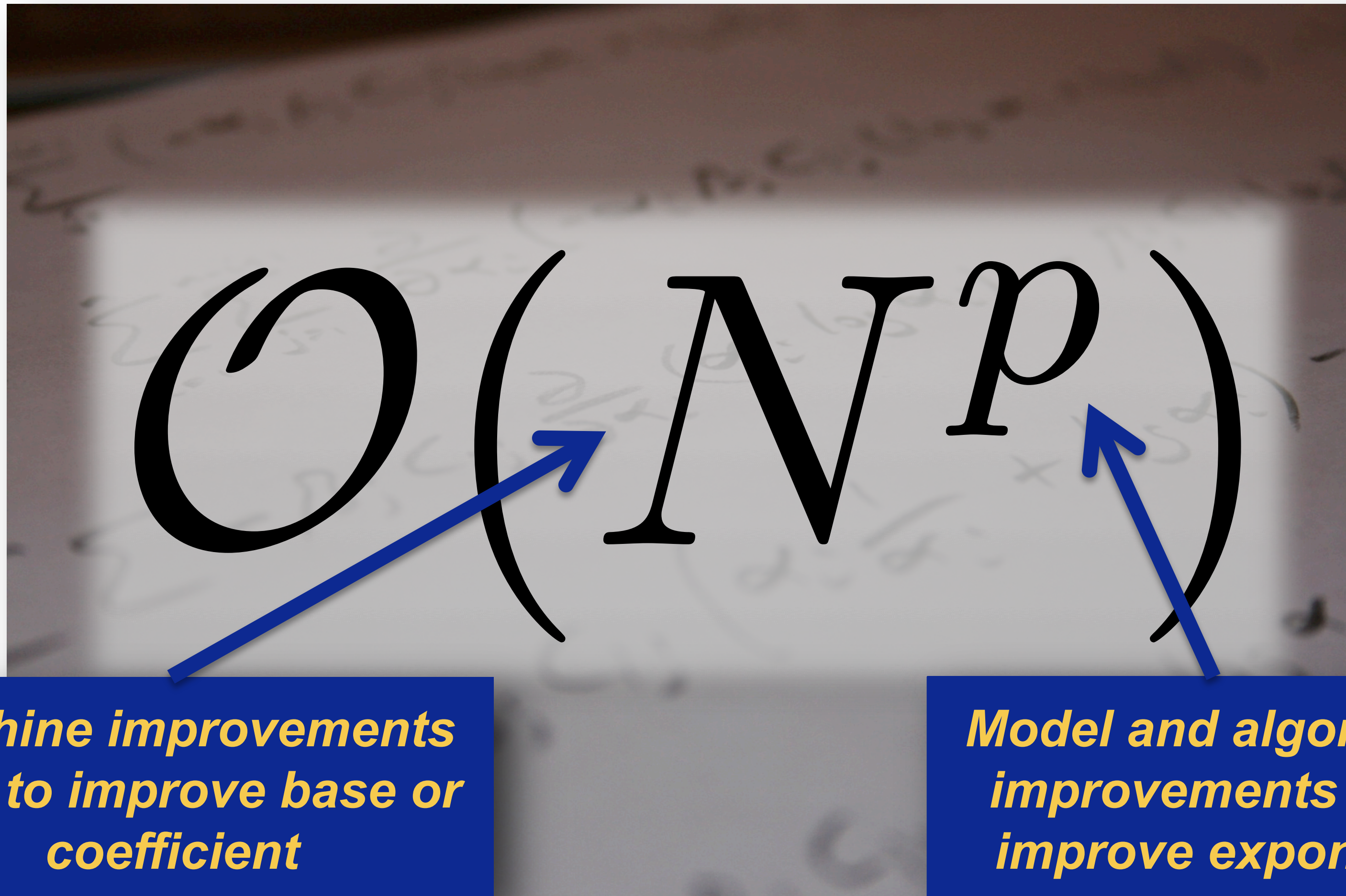
Data Locality

- Transfer gains less than processing
- Bandwidth/core ↓
- Energy and time penalties for data motion
- Greater need for data locality
- Reduce data transfers

Resilience

- Massive number of components: hard faults ↑
- Running closer to threshold voltage: soft faults ↑
- Bulk-synchronous checkpoint restart is dead

Hardware improvements are not enough

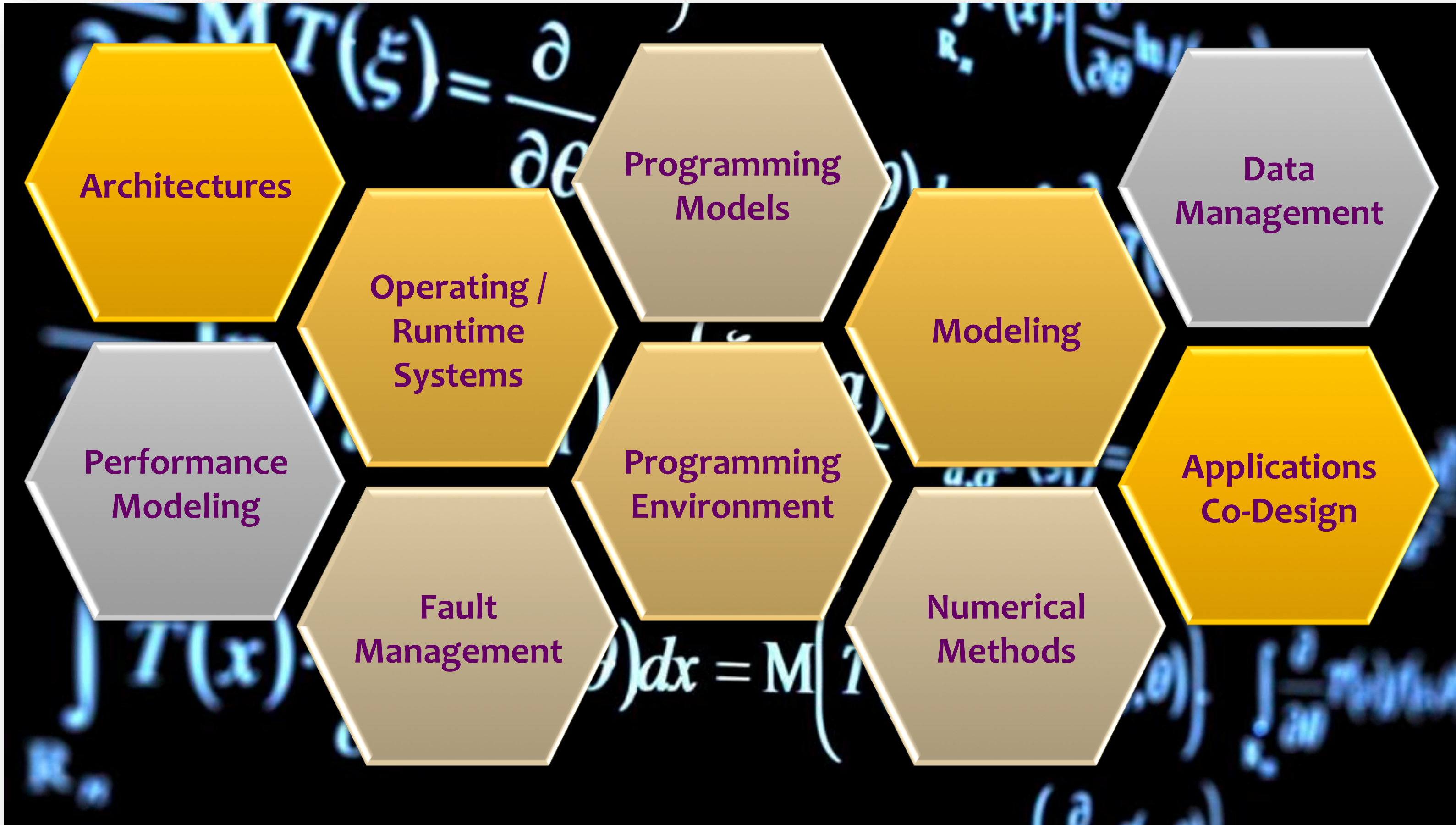


$$\mathcal{O}(N^p)$$

Machine improvements tend to improve base or coefficient

Model and algorithm improvements can improve exponent

Success will require close collaboration to address exascale challenges



Physicists, engineers, applied mathematicians, and computer scientists must work together

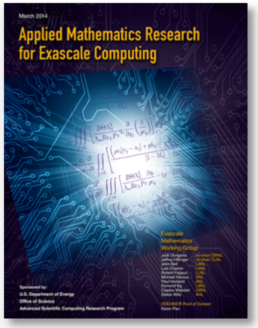
Many additional resources are available

Exascale Mathematics Report

science.energy.gov/ascr/news-and-resources/program-documents

Exascale Mathematics Working Group Website

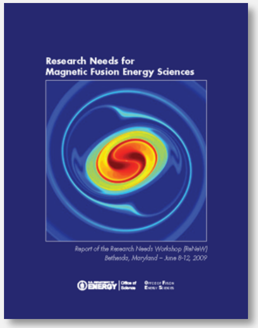
collab.mcs.anl.gov/display/examath/Exascale+Mathematics+Home

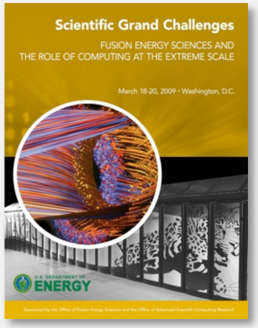


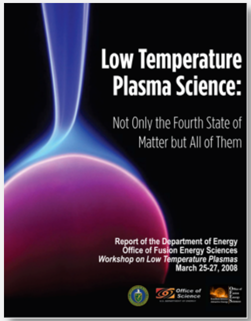
US Burning Plasma Organization

www.burningplasma.org

DOE Fusion Energy Sciences Program







science.energy.gov/fes/

Credits for scientific images

- Slide 2: (clockwise from top left)
  - Laser filamentation, ALPS project, LLNL (Hittinger)
  - NSTX Sawtooth, Center for Extended MHD Modeling, http://w3.pppl.gov/cemm/nstxm1.m9.jpg
  - National Fusion Collaboratory, http://www.scidac.gov/FES/FES_FGcollab.jpg
  - http://w3.pppl.gov/fsp/images/Fusion-Global-TurbulencePH.png
  - VALHALLA project, LLNL, (Hittinger)
  - pF3d simulation of NIF beam (Hinkle)

- Slide 3: (left to right)
  - Center for Edge Physics Simulation, http://epsi.pppl.gov/
  - Leena Aho-Mantila and Jyrki Hokkanen, http://iopscience.iop.org/0741-3335/labtalk-article/55909
  - MAST, Culham Centre for Fusion Energy, https://www.iter.org/newsline/229/1229
  - Trident Laser Facility, http://www.lanl.gov/science-innovation/science-facilities/trident-laser-facility/index.php

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