Transformation of Modern Science and Engineering

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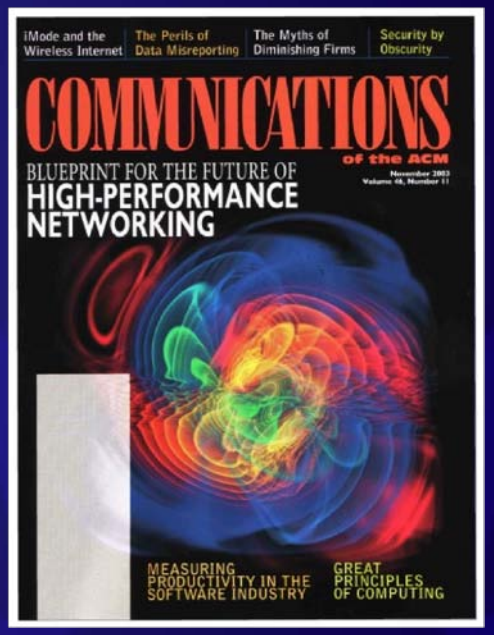
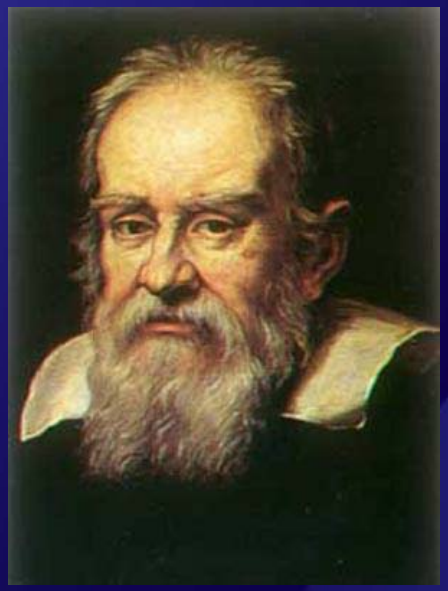
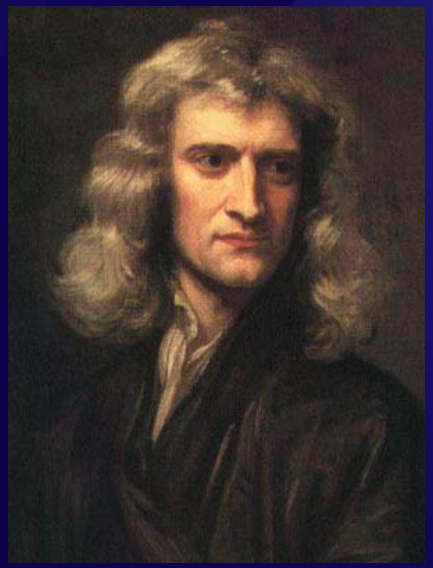


Profound Transformation of Science
Gravitational Physics

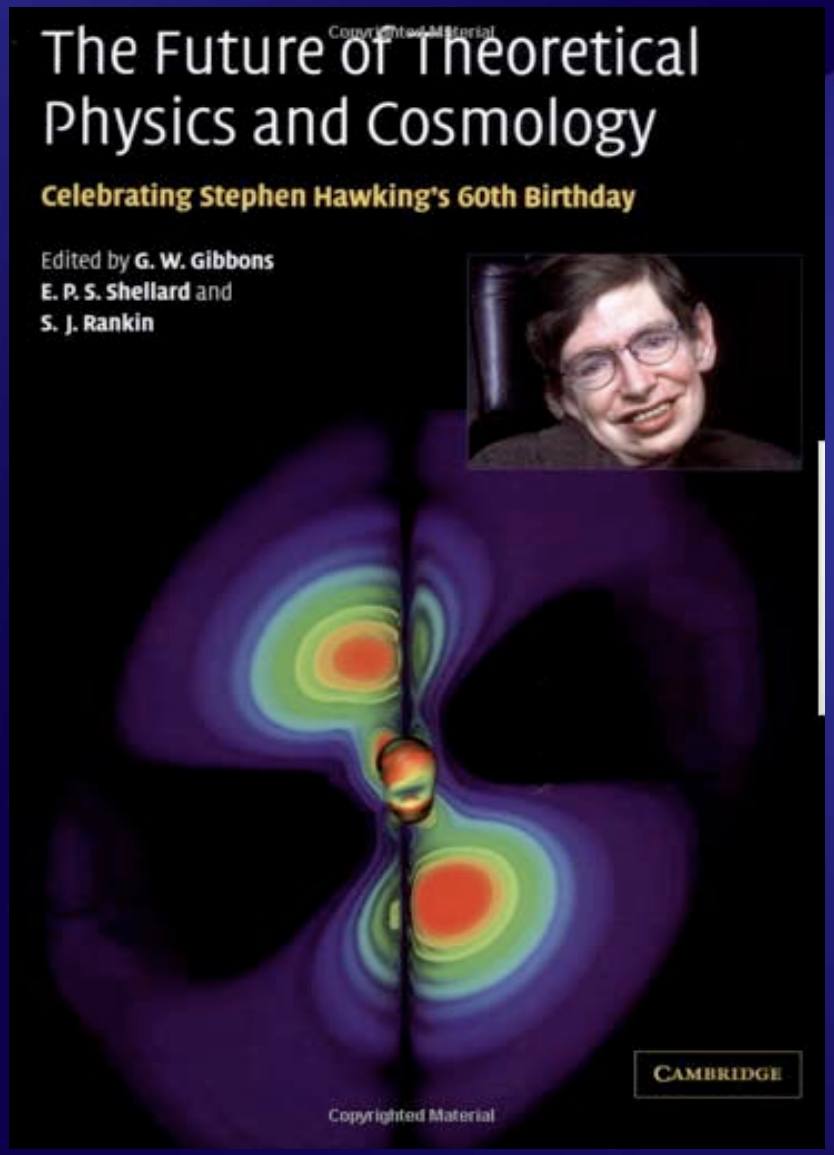


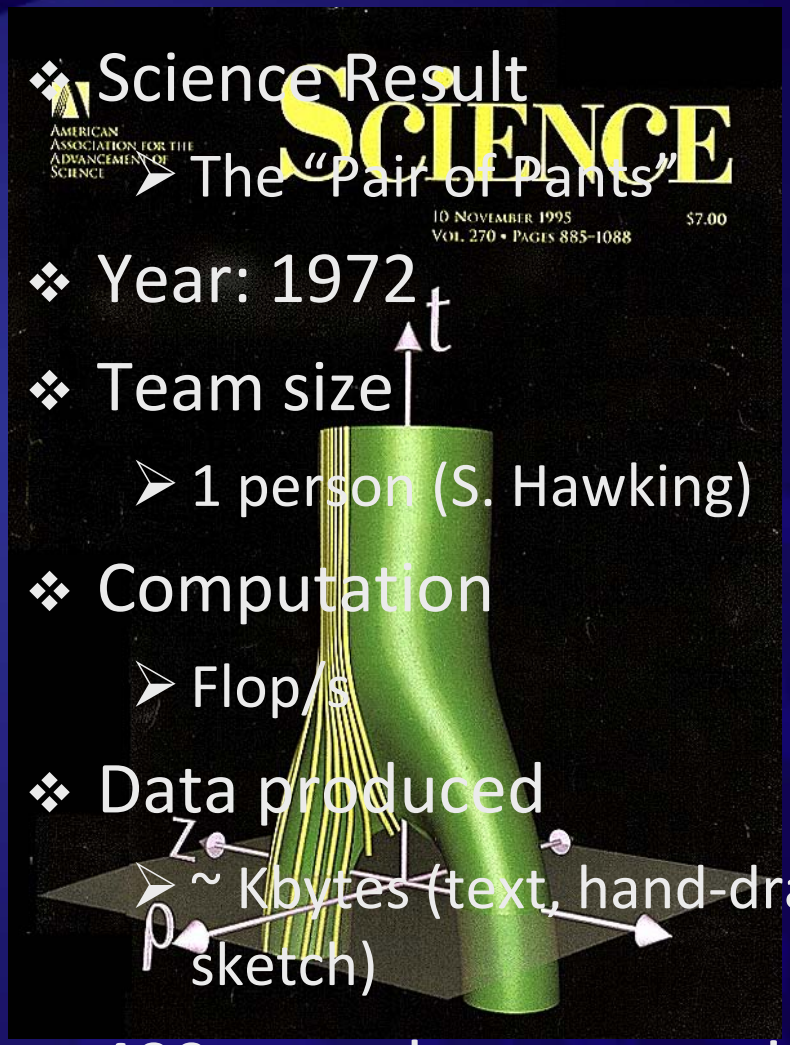


- Galileo, Newton usher in birth of modern science: c. 1600
- Problem: single "particle" (apple) in gravitational field (General 2 body-problem already too hard)
- Methods
  - Data: notebooks (Kbytes)
  - Theory: driven by data
  - Computation: calculus by hand (1 Flop/s)
- Collaboration
  - 1 brilliant scientist, 1-2 student

Profound Transformation of Science

Collision of Two Black Holes





- Science Result
  - The "Pair of Pants"
- Year: 1972
- Team size
  - 1 person (S. Hawking)
- Computation
  - Flop/s
- Data produced
  - ~ Kbytes (text, hand-drawn sketch)
- 400 years later…same!

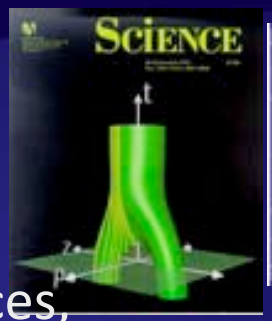
Now: Complexity of Universe
LHC, Gamma-ray bursts!

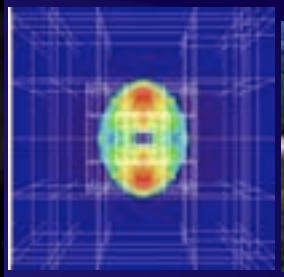
Now, compare with observation...LIGO, GEO, VIRGO! GR becomes a collaborative data-driven science

- Gamma-
  - GR n
    relati
  - All ene
    bursts o
    they?! Co
  - GR, hydrodynamics, nuclear physics, radiation transport, neutrinos, magnetic fields: globally distributed collab!
  - Scalable algorithms, complex AMR codes, viz, PFlops*week, PB output!
- LHC: What is the nature of mass? Higgs particle?
  - ~10K scientists, 33+ countries, 25PB data, distributed!
  - Planetary lab for scientific discovery!

Data-Driven Multiscale Collaborations* for Complexity Great Challenges of 21st Century

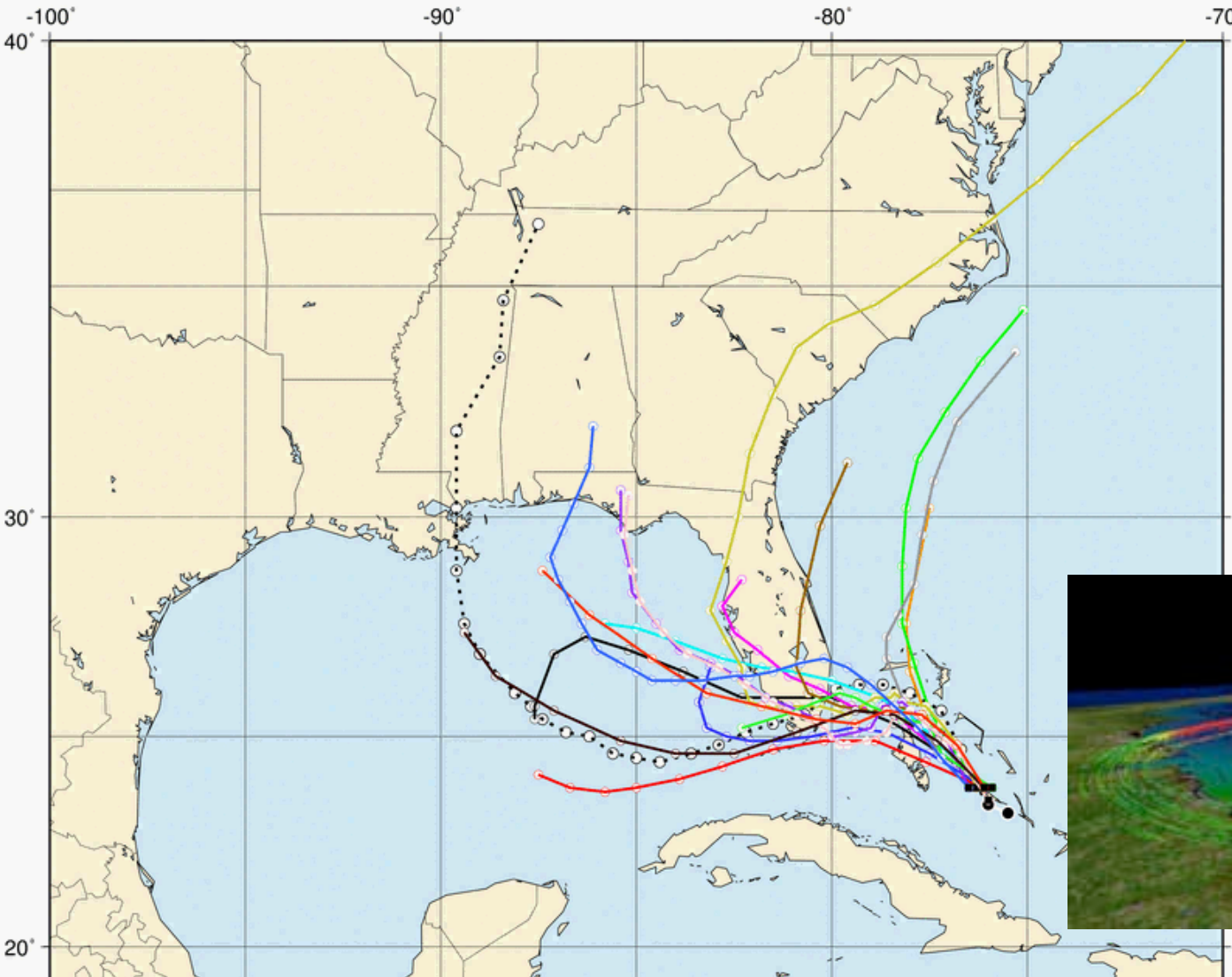
- Profound revolution in 25 years: Grand Challenge Communities build on fundamental discoveries
  - Multiscale Collaborations
    - General Relativity, Particles, Geosciences, Bio, Social Sciences, Humanities…
    - Complex problems: all combinations of basic sciences, groups, communities working together in new ways
  - Science and Society transformed by CI and Data
    - Compute, data, networks grow 9-12 orders of magnitude in two decades after 400 years virtually unchanged
    - Completely new methodologies
    - Fundamental shift to data-driven science: will be different
- Requires rethinking of programs, policy at federal, state, campus level

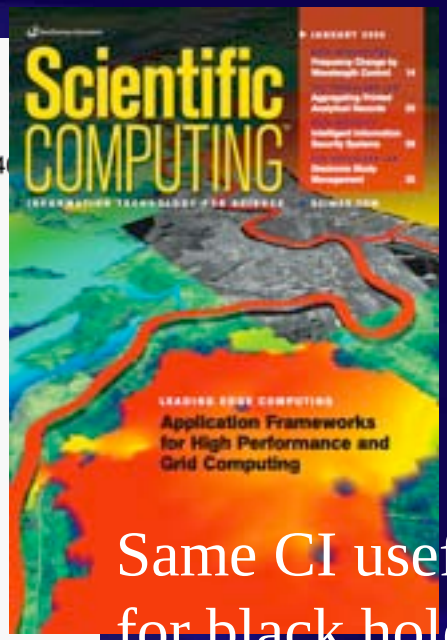




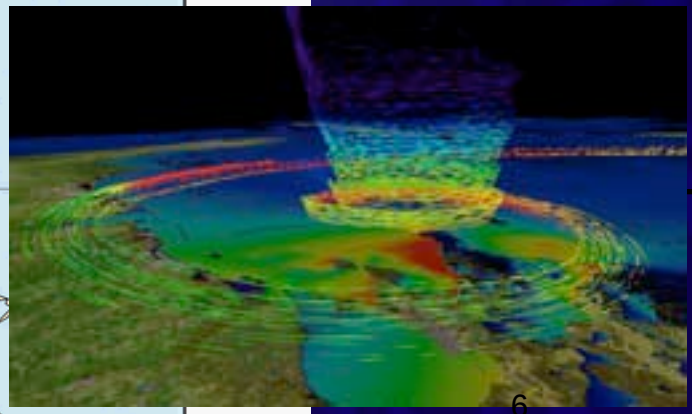
*Small groups still important!

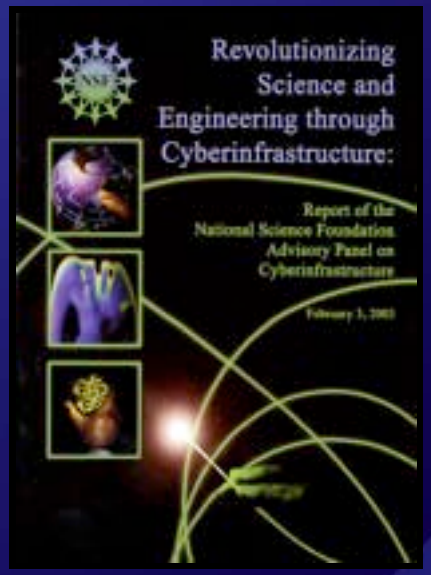
Grand Challenge Communities Combine it All…
Where is it going to go?





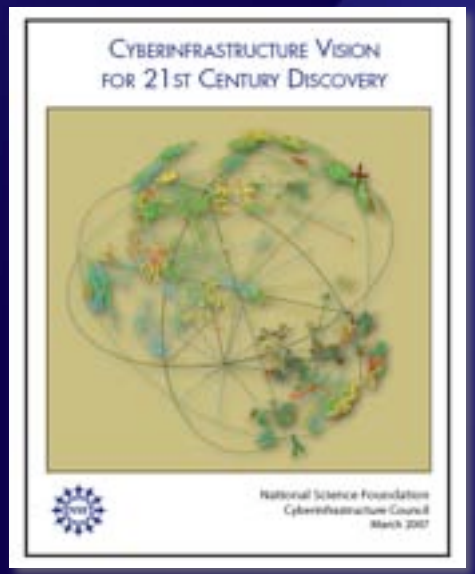
Same CI usefu
for black holes
hurricanes

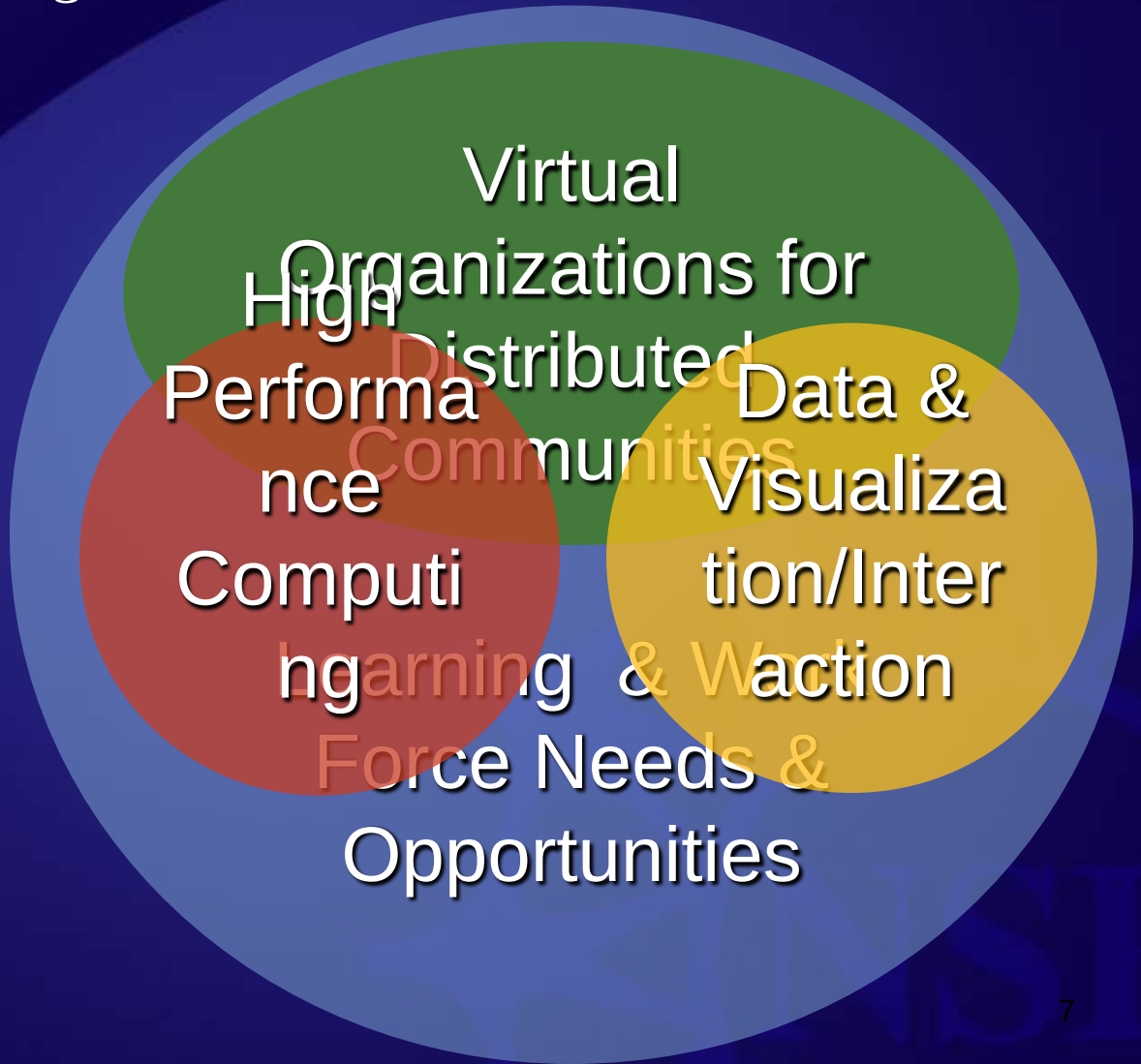




NSF Vision

"National-level, integrated system of hardware, software, data resources & services... to enable new paradigms of science"





Data Crisis: Information Big Bang

PCAST Digital Data

Industry

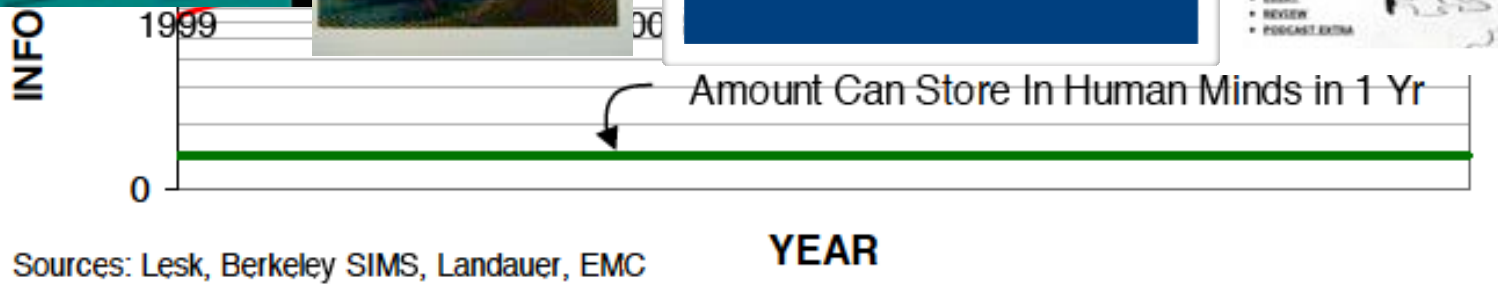
Wired, Nature

NSB Report: Long-Lived Digital Data Collections Enabling Research and Education in the 21st Century

NSF Experts Study

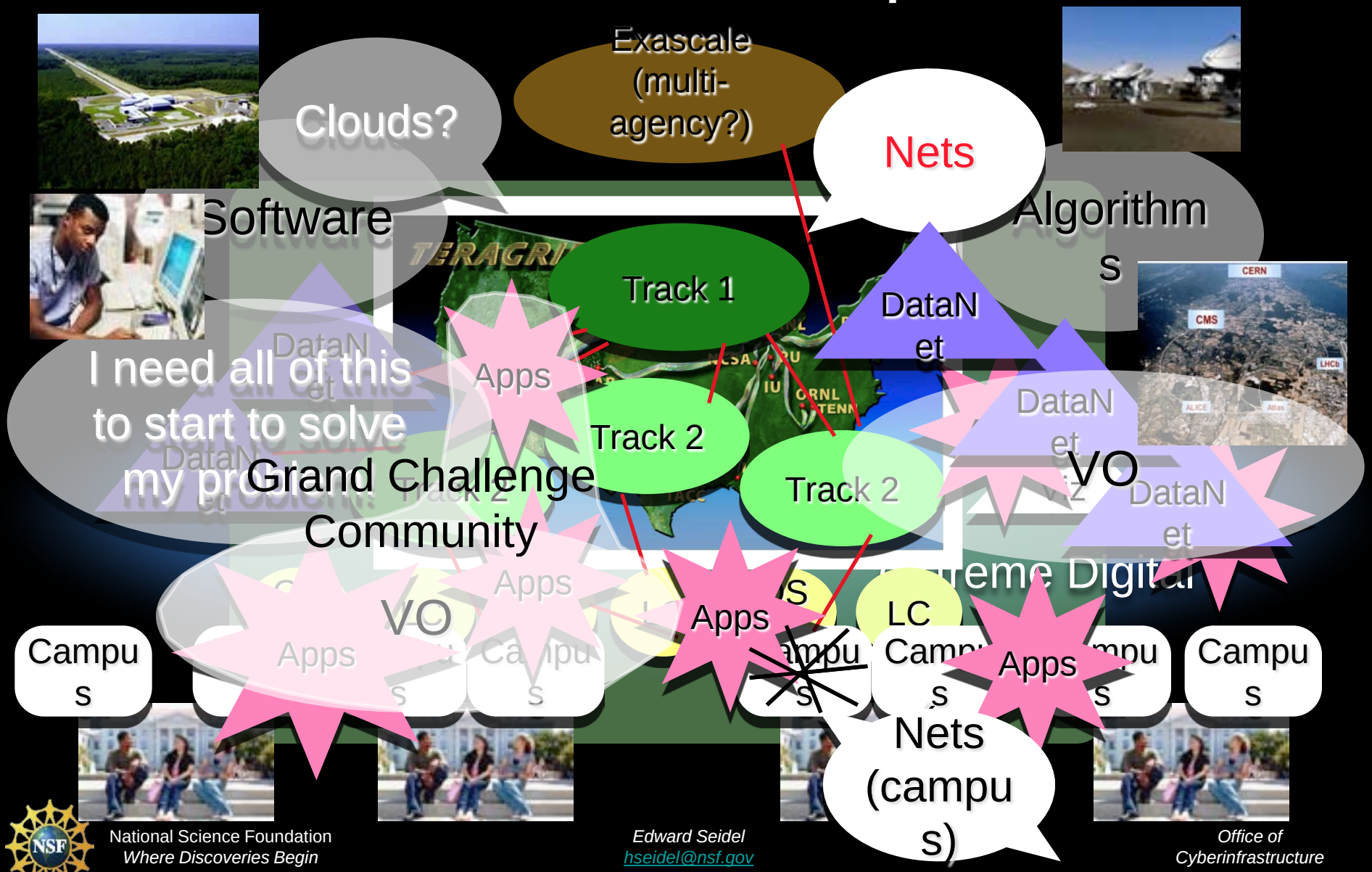
Storage Networking Industry Association (SNIA) *100 Year Archive Requirements Survey Report*

"there is a pending crisis in archiving… we have to create long-term methods for preserving information, for making it available for analysis in the future." 80% respondents: >50 yrs; 68% > 100 yrs



Sources: Lesk, Berkeley SIMS, Landauer, EMC

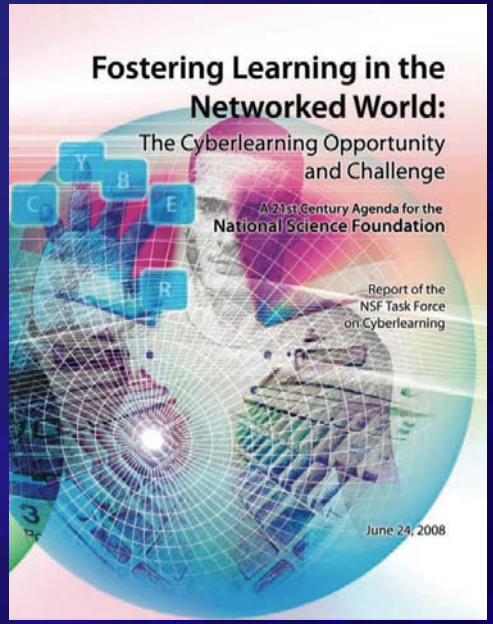
National CI Blueprint



Education Crisis

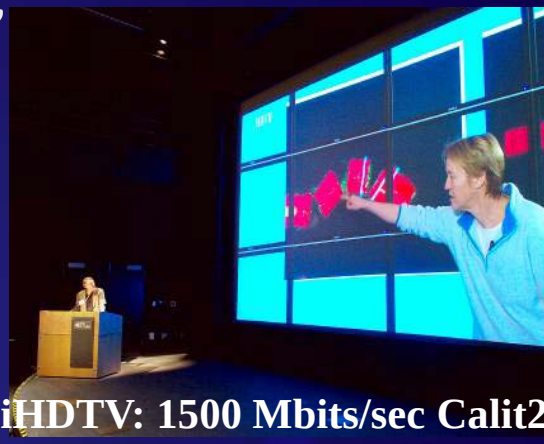
- The CI environment is running away from us!
- How do we develop a workforce to work effectively in this world?

We must be much more aggressive about training people to use this, to deal with this data, and to work in this collaborative environment



What about Campuses?

- Next generation science requires huge data to be manipulated, retrieved, stored, analyzed
- Collaborative environments will need unprecedented levels of sophistication
  - Can barely do low-end video conferencing today! HD, Optiportal-level environments needed
- We need to seriously rethink our campus environments and how they can support new modalities of research, collaboration, education
- Federated ID management!

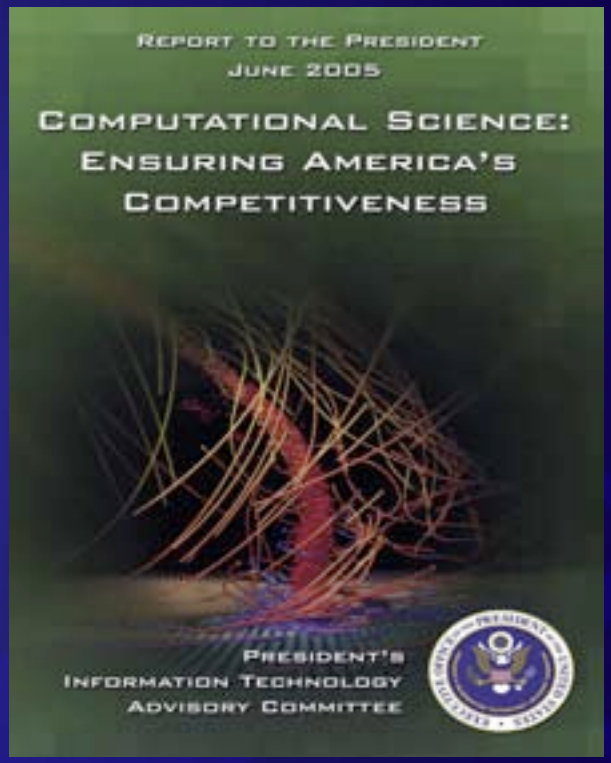


iHDTV: 1500 Mbits/sec Calit2 Research Channel Over NLR/CENIC/PW

InCommon

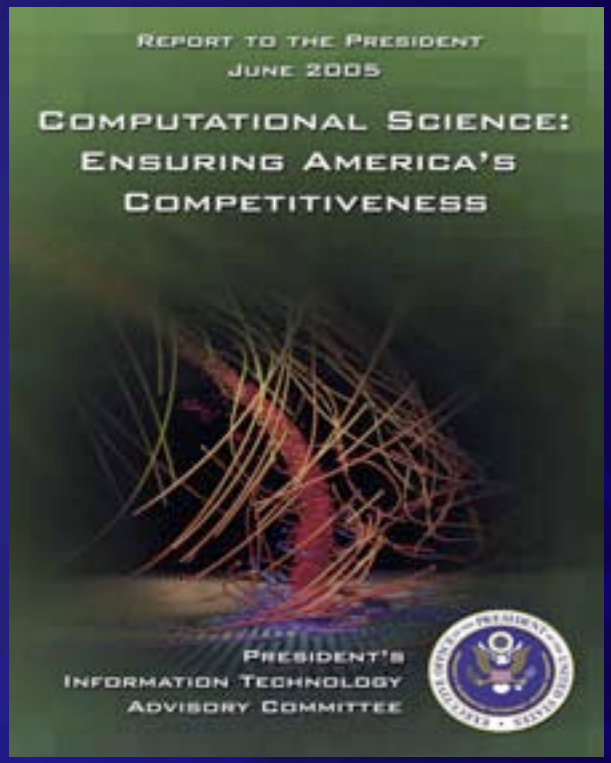
Computational Science
PITAC Report Summary

"Together with theory and experimentation, computational science now constitutes the "third pillar" of scientific inquiry..."



Computational Science
PITAC Report Summary

"Universities must significantly change organizational structures: multidisciplinary & collaborative research are needed [for US] to remain competitive in global science"



Critical Lessons to Take Home

- Comprehensive approach to CI needed to addres complex problems of 21st century
  - All elements have to be addressed, not just a few; cannot even start to address problems
  - CI itself extraordinarily complex, and rapidly getting moreso; not just supercomputers!
  - Many exponentials: data, compute, collaborate
  - Data, Software, Hardware Challenges in this order
- Must educate next gen: collaborative & CI-savvy for science and society
  - Grand Challenge Communities emerging
  - New organizational structures needed
  - Need a home for computational science