

# COMPUTER SCIENCE: *The Key to Future Advances in Science and Engineering*

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# THESIS:

*Computer Science (CS) is poised to revolutionize traditional science and engineering*



## CORROLARY:

*It will continue to revolutionize  
our personal lives as well.*



# AGENDA for THIS AFTERNOON

- What is CS and where is it headed?
- The essence of CS
- Revolutionary examples
- Additional observations
- Advancing beyond today



# WHAT IS COMPUTER SCIENCE?

- Is it a *branch* of mathematics?
- Is it really a *science*?
- Or, is it just another engineering field?
- Or, *maybe*, it isn't a scholarly discipline at all and we will get everything we need from Google, Microsoft, Intel, ... !



# CS IS *NOT* . . .

- Just about computers
- Or programs
- Or programming
- Or networks
- Or what is sold in the marketplace



*The routine use of computers*

*- machines, programs, programming languages, data formats, etc. -*

*is becoming a technology that soon won't be taught in good universities, except as an "ordinary" tool.*



# IT /S ABOUT . . .

Complex issues that require new concepts and processes:

- Coordination of millions of processors
- Management of enormous data sets
- Representation of extremely complex processes and objects
- Identification of patterns across multi-dimensional & multi-modal information items
- Real-time control of sophisticated equipment
- Theoretical characteristics of what can be computed, limits, invariant transformations, etc.
- Characterizing and dealing with complexity



# THE ESSENCE OF COMPUTER SCIENCE

- Representation of any and everything in a common form
- Processes that describe dynamic behavior
- Machines that can execute processes
- Relationships among representations, processes, and machines
- Procedures for creating representations, processes, machines, and relationships



# A SIMPLE QUIZ

- What is science about?
  - Describing, making sense of reality, and predicting/changing reality
- What are the interesting parts of reality?
  - Large numbers of complex objects
  - Dynamic behavior of those objects over time
  - Relationships between objects
  - Systems of objects
- Quiz: Can you think of a discipline whose intellectual core focuses on such things?



*The power of computer science to describe complex objects and behaviors and to simulate reality in a controllable and observable manner is the key to an entirely new level of scientific progress.*



# SOME EXAMPLES

*(Sketches only!)*

- Physical concepts
- Earth's life-support systems
- Biology



# PHYSICAL CONCEPTS

- Sussman & Wisdom use CS concepts to communicate concepts of EE, physics, & other subjects
- Expressing laws of advanced classical mechanics computationally insures preciseness & provides computational effectiveness
- Students required to formulate analyses as algorithms
- Result is a powerful learning tool
- Seth Lloyd and others go much further

# EARTH'S LIFE-SUPPORT SYSTEMS

- It is imperative that we understand & be able to predict/control the systems around us
  - biotic: biodiversity, ecosystems, human activity, etc.
  - abiotic: atmosphere, oceans, plate tectonics, etc.
- Clearly it is a system of systems in which the individual systems and especially the interactions between them must be understood
- Increasingly computing is essential (*e.g.* climate)
  - sensing, data management, analysis & modeling
- Beyond these tools, CS provides theories & concepts for describing complex systems of systems and their interactions

# BIOLOGY



- We have an exponentially increasing amount of knowledge about biological “parts” (cells, genes, membranes, subsystems, biochemistry, etc.)
- Yet, we do not understand even how a cell works sufficiently to modify it or repair it based on first principles

*Having a “parts list” doesn’t explain “how”*

- Systems Biology objectives:
  - gather more data (genomics, proteomics, etc.) & analyze it (bioinformatics)
  - build a science of the principles of operation of biological systems
- Biological systems share much with hardware/software systems (e.g. discrete, hierarchical, complex, information-driven) and can be partially modeled by abstract machines, formal languages, etc.



# ENGINEERING & MATHEMATICS

- The role of CS in advancing engineering should be obvious and is left as an exercise for the listener!
- The interplay between CS and mathematics is not as clear and thus the future is not as clear (at least to me!).
- The fact that CS deals largely with discrete behavior while math deals largely with continuous behavior, but CS is able to combine the two modes may be a clue to one way in which CS will help advance mathematics.



# COMPUTATIONAL THINKING\*

- Broad set of ways of thinking: abstraction, thinking recursively, reformulating a problem, modularization, etc.
- Most already in use
- Can/should be taught
- Are sharpened as CS concepts
- Is a fundamental skill for the 21st century

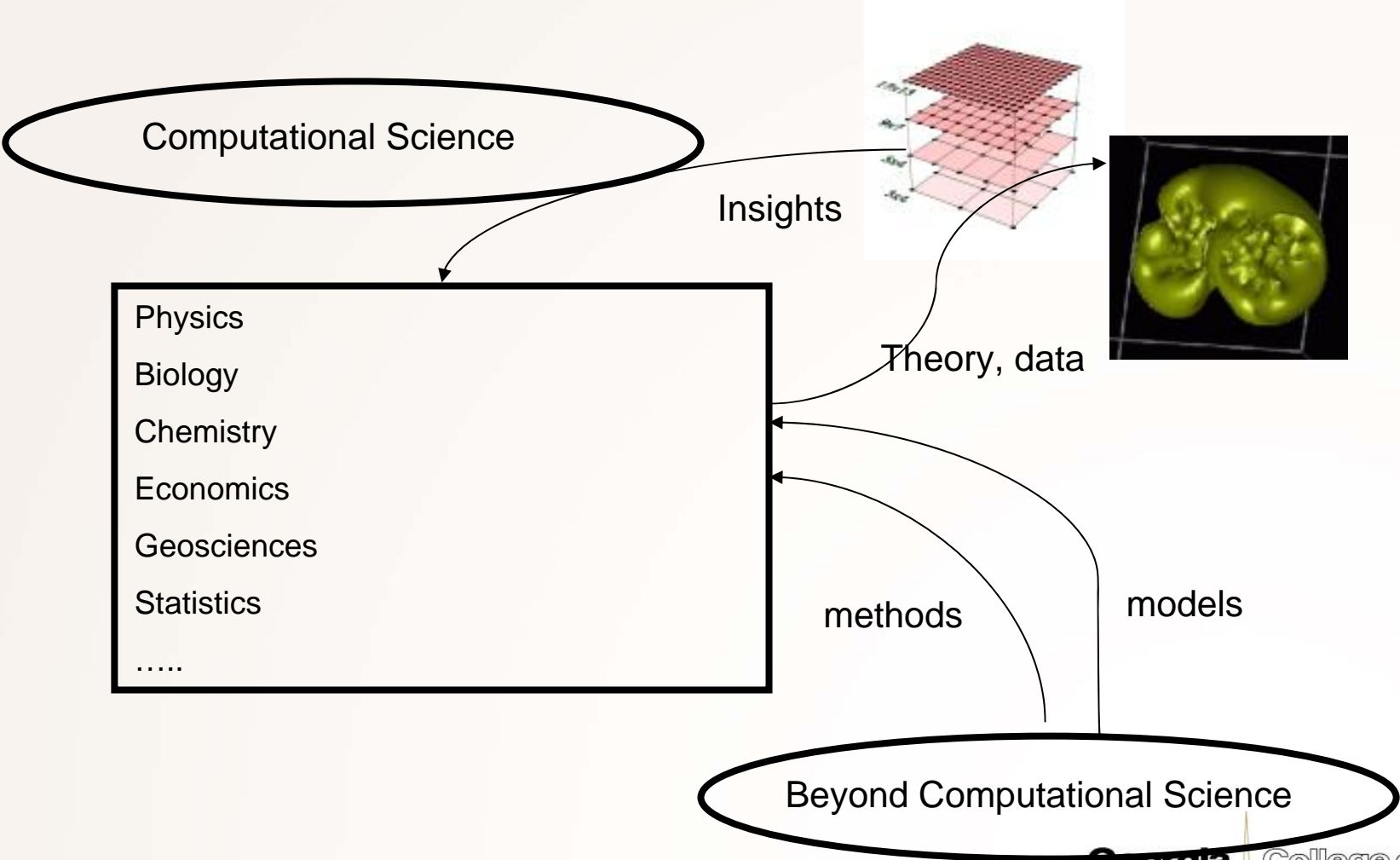
\* Term coined by Jeannette Wing



*COMPUTER SCIENCE  
IS NOT THE SAME AS  
COMPUTATIONAL SCIENCE*



# CS Is Beyond Computational Science





IS THERE REALLY SOMETHING NEW  
HERE?

*YES!!*



- Use of ICT in many ways in all areas of science and engineering
  - this alone is advancing research far beyond what we could imagine
- Use of CS concepts, not programs, to formalize, conceptualize, and theorize in extremely powerful new ways
  - perhaps the most powerful intellectual tool for science since the calculus
- Computational thinking, taught as a general educational subject, could change performance in all areas of human endeavor



# THE WAY FORWARD

**For computer scientists:** Continue to develop good tools, but where possible also develop *our* science to provide the intellectual tools for the future (*cf.* CDI Initiative from NSF (US only))

**For other scientists & engineers:** Utilize the best computational tools you can and try to apply CS concepts where you are able to advance your understanding and research

**For everyone:** Try to utilize computational thinking where appropriate in all of your activities



*DANKE SCHÖN!*

# For More Information (starter list)



## Science 2020 study

[www.research.microsoft.com/towards2020science/background\\_overview.htm](http://www.research.microsoft.com/towards2020science/background_overview.htm)

[www.nature.com/nature/focus/futurecomputing/index.html](http://www.nature.com/nature/focus/futurecomputing/index.html)

## Computational thinking

“Computational Thinking, *Communications of the ACM*, vol. 49, no. 3, March 2006, pp. 33-35.

<http://www.cs.cmu.edu/~wing/>

## Expressing physical concepts in CS terms

*Structure and Interpretation of Classical Mechanics*, Gerald Jay Sussman and Jack Wisdom, with Meinhard E. Mayer, MIT Press, 2001.

*Programming the Universe: A Quantum Computer Scientist Takes on the Cosmos*, Seth Lloyd, Knopf, 2006

[www.nytimes.com/2006/04/02/books/review/02powell.html](http://www.nytimes.com/2006/04/02/books/review/02powell.html)

## Cyber-enabled Discovery and Innovation (CDI) Initiative

[www.nsf.gov/crssprgm/cdi/](http://www.nsf.gov/crssprgm/cdi/)

## Cyber-enabled Discovery and Innovation (CDI)



[CDI Program Overview](#)

[Calendar of Events](#)

[Examples of Desired Outcomes](#)

[Frequently Asked Questions](#)

[References/Resources](#)

[CDI Program Page](#)

[CDI Solicitation](#)

## Cyber-enabled Discovery and Innovation (CDI)

Cyber-Enabled Discovery and Innovation (CDI) is NSF's bold five-year initiative to create *revolutionary* science and engineering research outcomes made possible by innovations and advances in computational thinking. Computational thinking is defined comprehensively to encompass computational concepts, methods, models, algorithms, and tools. Applied in challenging science and engineering research and education contexts, computational thinking promises a profound impact on the Nation's ability to generate and apply new knowledge. Collectively, CDI research outcomes are expected to produce paradigm shifts in our understanding of a wide range of science and engineering phenomena and socio-technical innovations that create new wealth and enhance the national quality of life.

### CDI SOLICITATION

CDI solicitation can be found on

[http://www.nsf.gov/publications/pub\\_summ.jsp?ods\\_key=nsf07603](http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf07603). With an emphasis on bold multidisciplinary activities that, through computational thinking, promise radical, paradigm-changing research findings, CDI is unique within NSF. CDI projects are expected to build upon productive intellectual partnerships involving investigators from academe, industry and/or other types of organizations, including international entities.

### CDI Themes

CDI seeks ambitious, transformative, multidisciplinary research proposals within or across the following three thematic areas:

- **From Data to Knowledge:** *enhancing human cognition and generating new knowledge from a wealth of heterogeneous digital data;*
  - **Understanding Complexity in Natural, Built, and Social Systems:** *deriving fundamental insights on systems comprising multiple interacting elements; and*
  - **Building Virtual Organizations:** *enhancing discovery and innovation by bringing people and resources together across institutional, geographical and cultural boundaries.*
- The Cyber-Enabled Discovery and Innovation (CDI) initiative has been designed to yield revolutionary science and engineering research outcomes made possible by innovations and advances in computational thinking.



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