



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

Indiana University
School of Informatics

April 4, 2008

Peter A. Freeman
Emeritus Dean & Professor
(Former) Assistant Director, NSF

Georgia Tech College of Computing


THESIS:

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

Georgia Tech College of Computing



CORROLARY:

It will continue to revolutionize our personal lives as well.

Georgia Tech College of Computing


AGENDA for THIS AFTERNOON

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

Georgia Tech College of Computing


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, … !

Georgia Tech College of Computing



CS IS *NOT* . . .

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

Georgia Tech College of Computing


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.

Georgia Tech College of Computing



IT *IS* 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

Georgia Tech College of Computing


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

Georgia Tech College of Computing

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?

Georgia Tech College of Computing


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.

Georgia Tech College of Computing


SOME EXAMPLES

(Sketches only!)

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

Georgia Tech College of Computing



PHYSICAL CONCEPTS

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

Georgia Tech College of Computing

EARTH'S LIFE-SUPPORT SYSTEMS

- It is imperative that we understand and 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 and modeling

- Beyond these tools, CS provides theories and concepts for describing complex systems of systems and their interactions

Georgia Tech College of Computing

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.) and 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.

Georgia Tech College of Computing



ENGINEERING and 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.

Georgia Tech College of Computing


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

Georgia Tech College of Computing

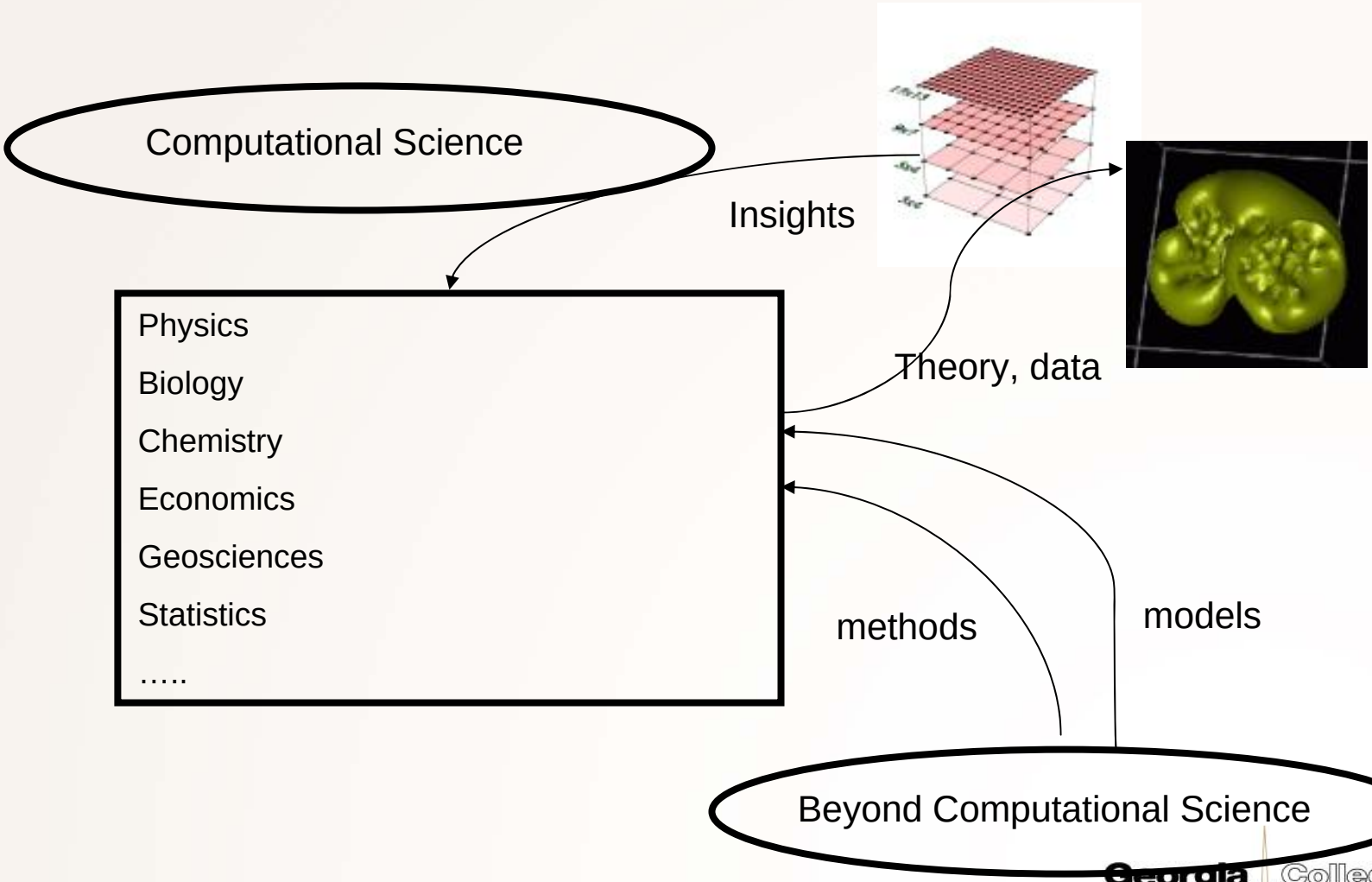

COMPUTER SCIENCE

IS NOT THE SAME AS

COMPUTATIONAL SCIENCE

Georgia Tech College of Computing

CS Is Beyond Computational Science





IS THERE REALLY SOMETHING NEW HERE?

YES!!

Georgia Tech College of Computing


- 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 and 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

Georgia Tech College of Computing



THANK YOU!

Georgia Tech College of Computing

For More Information (starter list)

Science 2020 study

www.research.microsoft.com/towards2020science/background_overview.htm

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

Cyber-enabled Discovery and Innovation (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. 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.



CONTACT

Peter A. Freeman

freeman@cc.gatech.edu

Georgia Tech College of Computing