What's Up at CISE

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BMSA
2 November 2007

Outline

- Looking Far Out
  - Vision for computing
  - Science, technology, and societal drivers
- Looking Ahead
  - Themes and programs
  - CISE and Math

Looking Far Out:
My Vision for Computing

My Grand Vision for the Field

- Computational thinking will be a fundamental skill used by everyone in the world by the middle of the 21st Century.
  - Just like reading, writing, and arithmetic.
  - Imagine every child knowing how to think like a computer scientist!
  - Incestuous: Computing and computers will enable the spread of computational thinking.
  - In research: scientists, engineers, …, historians, artists
  - In education: K-12 students and teachers, undergrads, …

J.M. Wing, "Computational Thinking," *CACM* Viewpoint, March 2006, pp. 33-35.
Paper off CISE AC website; paper and talks off http://www.cs.cmu.edu/~wing/

Computational Thinking

- Computational thinking is the science underlying computer and information science
  - algorithms, concepts, methods, models, languages, principles, and tools
- enabling us to build complex hardware and software systems
- usable by humans and society at large.

Fortuitous Timing for Me

CDI: Cyber-Enabled Discovery and Innovation

- Computational Thinking for science and engineering
- Paradigm shift
  - Yesterday: metal tools (transistors and wires)
  - Today: mental tools (abstractions and methods)
    - "Algorithms" is becoming a household word, e.g., NY Times, Forbes magazine, Harvard Business Review, Economist, …
- It's about partnerships and transformative research.
  - To innovate in/innovatively use computational thinking; and to advance more than one science/engineering discipline.
- Three dimensions
  1. Extracting knowledge from data
  2. Understanding complexity in natural, built, and social systems
  3. Virtual organizations
- FY08: $52M agency-wide, $20M CISE

Looking Far Out:

Technology Drivers
Societal Drivers
Science Drivers

Technology Trends

- Computing substrates
  - Moore's Law will end in 10-15 years [Gordon Moore 9/18/07]
  - Nanocomputing is here.
    - March 2006, IBM researchers build the first complete IC around a single carbon nanotube molecule.
  - Biocomputing is here.
    - 1994, Adleman solves 7-point Hamiltonian path problem with DNA computing
    - 2004, Shapiro, Benenson, Gil, Ben-Dor, and Adar of Weizmann Institute announce in *Nature* the construction of a DNA computer
  - Quantum is coming?
    - "Quantum Cryptography to Secure Ballots in Swiss Election," *Network World,* Oct 11 2007
  - Bio-Nano-Quantum
    - "Fabrication of Photonic Transfer DNA-Quantum Dot Nanostructures," Heller, Sullivan and Dehling, Nanotech 2005.
    - "Economical Fabrication of Quantum Dot-Electronics Using Biofunctionalized Protein Nanotubes as Building Blocks, Masui, NSF CAREER award
- Devices
  - 2 billion cell phones in the world; RFID tags; sensors everywhere
  - A BMW is "now actually a network of computers" [R. Achatz, Seimens, Economist Oct 11, 2007]
  - Robots in your home
- Information
  - Drowning in data; sensors everywhere; storage is cheap; information overload
- Communication
  - Web 3.0 (semantic web)
  - Virtual worlds: Second Life is today's Mosaic
- Brainy machines
  - IBM and EPFL's Blue Brain Project: to create a biologically accurate, functional model of the brain
  - www.numenta.com : software platform for intelligent computing modeled after human neocortex

Users and Society

- Expectations: 24/7 availability, 100% reliability, 100% connectivity, instantaneous response, store anything and everything forever, ...
- Classes: young to old, able and disabled, rich and poor, literate and illiterate, …
- Numbers: individual → cliques → acquaintances → social networks → cultures → populations
- The Internet/Web is a great equalizer.
  - What about privacy? Anonymity to accountability
  - When will it stop being free?
  - Will it continue to be self-regulating?

Deep Questions for Computer Science

- P = NP ?

- What is computable?
  - What is a computer?
    - Not just a PC anymore: The Internet, server farms, supercomputers, multi-cores, …, nano, bio, quantum, etc.
  - What is the power of computing, by machine and human together?

- What is intelligence?
  - Understanding the brain. What is the mind?

- What is information?
  - From nature to knowledge

- How can we build complex systems simply?
  - Can we build systems with simple designs, that are easy to understand, modify, and maintain, yet provide the rich complexity in functionality of systems that we enjoy today?
  - Is there a complexity theory for real-world systems as there is for algorithms?
  - Is there a notion of complexity that spans the theory and practice of computing?

Looking Ahead:
CISE Research Themes
CISE and Math

Looking Ahead: Themes

- Computing ↔ Math [P = NP?, computable, information]
  - Statistics, game theory, topology, spectral graph analysis, …
- Parallel and Distributed Thinking [computable, information]
  - Multi-core, the Internet, …, molecular, nano, quantum
- Engineering Software for Complex Systems [complexity]
  - Credit software for its power, blame it for its complexity
- Human+Machine Computation [computable, intelligence]
  - Human-in-the-loop, humanoid robots, …, social networks
- Understanding the Brain [computable, intelligence, complexity]
  - Robust intelligence

Theme: Math ↔ Computing

- Statistics
  - Evidence of computational thinking influence already
    - Statistics departments in the US are hiring computer scientists
    - Schools of computer science in the US are starting or embracing existing Statistics departments
  - Data mining, machine learning
    - Applications in and outside of computing, from computer vision to natural language processing, from astronomy to biology, from neuroscience to the social sciences, from law to sports, …

Theme: Math ↔ Computing

- Game Theory
  - Computational microeconomics
    - e.g., ad placement, on-line auctions, organ exchange
  - Networking
    - e.g., congestion control, adaptive wireless networks
  - Security
    - e.g., two-party games (adversary and administrator)

- Topology
  - Distributed systems, sensor nets
  - Robotics, e.g., self-configurable, robot arms, motion planning
  - Protein structure, e.g., knot theory

Theme: Math ↔ Computing

- Spectral Graph Analysis (algebraic graph theory meets linear algebra)
  - Image segmentation, e.g., medical, face recognition
  - Data clustering, e.g., data mining, market research, social networks
  - Scientific computing, e.g., energy and angular momentum of electrons; absorption spectrum of chemicals

- Analysis (e.g., real analysis, harmonic analysis, ergodic theory) meets combinatorics
  - Math → CS: probabilistic checkable proofs, provable pseudorandomness, property testing, sub-linear algorithms
  - CS → Math: coding-theoretic and property-testing techniques from complexity theory used by mathematicians, e.g., Terry Tao

CISE and Math

Math-related CISE Programs

- Theoretical Foundations
  - Algorithms, complexity, and theory that enables scientific advances in and reveals the potential limitations of computation, communications, signal processing, numerical computing and optimization, symbolic and algebraic computation, and the applications of these insights to other areas of science and engineering.
- Mathematical Sciences: Innovations at the Interface with Computer Sciences [$2.3M FY07]
  - Focus: mathematical and statistical challenges posed by large data sets, managing and modeling uncertainty, and modeling complex nonlinear systems.
- Foundations of Data and Visual Analytics (joint with Department of Homeland Security) [$2.25M/yr for 5 yr project]
  - Focus: math and CS foundations to transform data in ways that permit visual-based understanding

- Foundations of Computing also funded through:
  - CCF: Computing and Processing Artifacts Cluster
  - CCF: Emerging Models and Technologies Cluster
  - IIS: models and algorithms in robotics, speech, vision, natural languages, data and information systems, …

Thank you!