



The Computational "Paradigm" of Science

ECSS 2015

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This Talk

1. Computer science: Definition
2. Why did computing need to be an academic discipline?
3. What characterizes computing as a discipline?
4. Is everything computing?

Computer Science Is...

Computer Science Is...

The art and science of representing and
processing information [, and...]

Forsythe (1967)

Computer Science Is...



The study of computing machines (actual or potential)

Finerman (1970)

Computer Science Is...



The study of computers and the phenomena surrounding them

Newell, Perlis & Simon (1969)

Computer Science Is...



The study of algorithms [and related phenomena]

Knuth (1974)

Computer Science Is...



The academic study of what you can do with computers and logic together

Bornat (2006)

Computer Science Is...



The study of information structures and processes and how [they] can be implemented on a digital computer

ACM Curriculum (1968)

Computer Science Is...



A study of the theory and practice of programming computers

Khalil & Levy (1978)

Computer Science Is...



The science devoted to the extension of the uses of machines in the service of mankind

Hammer (1970)

Computer Science Is...



A science that studies naturally and artificially occurring information processes

Denning (2007)

Computer Science Is...



A natural science

Denning (2007)

Computer Science Is...



An artificial science

Simon (1969)

Computer Science Is...



An unnatural science

Knuth (2001)

Computer Science Is...



A speculative science

Genova (2010)

Computer Science Is...



A laboratory science

Basili (1996)

Computer Science Is...



A social science

Goldweber et al. (1997)

Computer Science Is...



A synthetic discipline

Brooks (1996)

Computer Science Is...



The fourth, new domain of science

Rosenbloom (2013)

Computer Science Is...



the study of [...] information structures

Wegner (1972)

Computer Science Is...



A spectrum [...] with "science" on the one end and "engineering" on the other

Parlante (2005)

Computer Science Is...



The body of knowledge dealing with [...] processes that transform information

Denning (1985)

Computer Science Is...



[about] "what can be automated"

Arden (ed., 1980)

Computer Science Is...



[about] “what can be (efficiently) automated”

Denning et al. (1989)

Computer Science Is...



The science of abstraction

Aho & Ullman (1995)

Computer Science Is...



The study of procedures

Shapiro (2001)

Computer Science Is...



Procedural epistemology

Abelson & Sussman (1996)

Computer Science Is...



A branch of philosophy

Wartik (2010)

Computer Science Is...



The science of the relations between parts and wholes

Minsky (1979)

Computer Science Is...



An exact [or axiomatic] science

Hoare (1969)

Computer Science Is...



A mathematical science

cf. McCarthy (1962)

Computer Science Is...



A new species of engineering

Loui (1995)

Computer Science Is...



Information engineering

Bajcsy & Reynolds (2002)

Computer Science Is...



Engineering of mathematics

Hartmanis (1981)

Computer Science Is...



Conceptual engineering

Wegner (1970)

Computer Science Is...



A technological discipline

Wegner (1976)

Computer Science Is...



A language of technology

Cohen & Haberman (2007)

Computer Science Is...



Cognitive technology

Kadvany (2010)

Computer Science Is...



Mechanization of abstraction

Aho & Ullman (1995)

Computer Science Is...



Automation of our abstractions

Wing (2008)

Computer Science Is...



A new paradigm of science.

Denning & Freeman (2009)

Emperor or Plumber?



Who is this emperor?



Software engineering?
Information systems?
(Theoretical) computer science?
Computer engineering?
Information technology?
Computational science /
scientific computing?

...And Whose Emperor?

of Natural Science?
of Mathematics? Logic?
of Humanities? Social Sciences?
of Political Science? Theology?
of Business? Innovation?
of Engineering?



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Computing: The Discipline



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How Much Back Should We Look?

When Exactly Is a Discipline
Born?



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Birth of Computing as a Discipline: A Timeline



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1. Why Did It Need to Be a Discipline?

1950s–1960s: The Birth

Some Cornerstone Ideas From Universities

- From engineering projects
 - programmable computer
 - digital and fully electronic operation
 - treating instructions as data
- From mathematics + logic
 - binary arithmetic (simplified design)
 - computable functions
 - instructions = data

1940s: A New Kind of Computer

- Universities: important role in computer revolution
 - Differential Analyzers (MIT)
 - ABC Computer (Iowa State)
 - Harvard Mark(s) (Harvard)
 - ENIAC (U. of Pennsylvania)
 - SSEM “Baby” (Manchester)
 - IAS (Princeton)

In Established Disciplines

Electrical
engineering

- From engineering projects
 - programmable computer
 - digital and fully electronic operation
 - treating instructions as data

Mathematics
And Logic

- From mathematics + logic
 - binary arithmetic (simplified design)
 - computable functions
 - instructions = data

1950s: Outsourcing Innovation

- Private sector R&D labs take over hardware development
 - IBM (hard drive, etc.)
 - Bell Labs (transistor, etc.)
 - Texas Instruments (integrated circuit, etc.)
 - Xerox PARC (e.g. GUI)



Problems for Academic Computing Pioneers

- The field's foundations already well covered by established disciplines
- Why start a new field for a *tool*?
- No warm welcome in research universities



Driving Agenda: Independence!

- Own budgets
- Own student quota
- Own staff quota
- Leverage in university politics
- Societal influence



Driving Agenda: Independence!

- Representation: national / intn'l boards, policy committees
- Academic + public image
- Directed grants
- Field's own funding calls



The Dilemma of Reducibility

- To convince university administrators, computing had to be:
 1. Strongly connected with mathematics so that it is treated as fundamental research (and not as technology!)
 2. Different from mathematics so that it's not treated as another branch of mathematics



"Science of Computing" Emerged...

- McCarthy: It's going to be like Physics
- Hoare: It's a natural science
- Dijkstra: Computing science

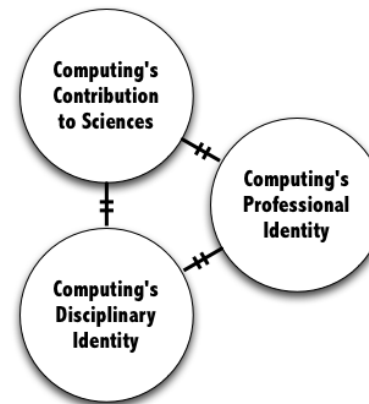


...But Things Weren't What They Seemed

- Mathematical theory of computation (McCarthy)
 - *Not empirical science (like physics)*
- Axiomatic basis for programming (Hoare)
 - *No empirical research (like natural sciences)*
- Computing science (Dijkstra)
 - *Implementation details are irrelevant*
 - *Far from software engineering*



Gulfs of Rhetoric



What's in a Name? (Impressions, at least...)



Hypology	Computer science(s)	Autonomics
Turology	Computerology	Bionics
Applied epistemology	Intellectronics	Cybernetics
Applied metamathematics	Technetronics	Synnoetics
Computing science	Turingineering	
Comptology	Computics	
Informatics		
Algorithmics		
Datalogy		

'50s-60s: Plumber or Emperor?



- Physics: the King of sciences
- Mathematics: the Queen of sciences
- Computing in the Royal Court?

Summary: Computing's Entry to Academia



- Born out of a need to govern its own research agenda and resources
- Competing visions for development and resources
- A strong instrumentalist identity
- Emerging intellectual identity



2. What Characterizes Computing as a Discipline?

1970s–1990s: Search for Disciplinary Identity

Diversification and Change

- Some branches diminish
- New branches are born
- Computing's user base diversifies
- Concept appropriation into CS concepts
 - Graphs, matrices, etc.

What Is It Science *of*?

- Computers
- Classes of computations
- Automation
- Procedures
- Complexity
- Programming
- Programs (executable)
- Data
- Information
- Algorithms

What *Kind* of Science Is It?

- *Axiomatic*
- *Mathematical*
- *Artificial*
- *Synthetic*
- *Unnatural*
- *Experimental*
- *Natural*
- *"Fourth domain"*
- *"A new paradigm"*

Curricula Follows the Training Needs

ACM CC 1968	ACM CC'78 Preliminary Report
"...academic program in computer science must be well based in mathematics"	"...no mathematical background beyond the ability to perform simple algebraic manipulation is a prerequisite to an understanding of the topics"

Experimental Computer Science

- Attempted to change how we talk about computing (~1979)
 - Fueled by the mid-1980s great epistemic change in science
- Numerical analysis on the rise



Mistakes

- Failure to establish terminology
 - No consensus over “experimental”
- Politicized term from the beginning
 - Tied to funding and influence
 - A rush to label one’s work “expcs”



“Experiment” in CS?

Thought experiment	“What should logically happen?” E.g. “Chinese Room” against SAI
Feasibility experiment	“Can it be done?” Demonstration, proof of concept
Trial experiment	“Does it meet the specifications?” Prototypes, laboratory / partial tests
Field experiment	“Does it meet the requirements?” Tests with real environment and users
Comparative experiment	“Does A outperform B?” Comparisons between solutions
Controlled experiment	“Do the hypotheses hold under X?”, “What variables affect Y?”, etc.



’70s-’80s: Emperor or Plumber?

- Physics: the King of sciences
- Mathematics: the Queen of sciences
- Computing?
 - Increasingly important for science
 - Contributions to mathematics
 - Not very coherent within



Summary: Computing's Rapid Diversification

- Rapidly diversified and progressed
 - Descriptions lagged behind
 - Visions missed the rapid changes
- Disciplinary terminology got established



3. The Emperor's Old Clothes

Or how we learned to love reductionism:
1990s—Today

New Challenges

- Computing stabilized its place in the international academic community
- Growth and diversification continued
 - Computing curricula split into many
 - IT, SW, IS, CS, CE, etc.



Methodology To Limelight

- Critical discussions about methodology in computer science research
- But still no curricular impact!

False Emperors

- 1990s—2000s methodological meta-analyses
 - Thousands of CS articles
 - Many articles from other fields
- Computing was different
 - Verdict:
We should “mature” to be more like those other fields

Closing In

- Science and computing started to converge
- Sciences started to resemble computing
 - Since mid-1980s sciences developed computational branches
 - Computational biology (Baltimore)
 - Computational physics (Wilson)

55 Years of “Computational Thinking” Come to Fruition

“Algorithmizing”	Perlis, 1960
“Computing is a general-purpose thinking tool”	Forsythe, 1968
“Algorithmic thinking”	Statz & Miller, 1975; Knuth, 1985
“Computational thinking”	Papert, 1996; Wing, 2006

Computing Triumphant

- Computational science: Laboratory norm today
 - Computers, simulations, modeling
 - Even digital humanities
- Sometimes called “*the third pillar*” of science (Vardi: “*science [still] has only two legs*”)

4. The Emperor

The computational “paradigm”
of science

A Computational World

- “Algorithmization of sciences” (Easton)

A Computational World

- “The idiom of modern science” (Chazelle)

A Computational World

- “The age of computer simulation” (Winsberg)

A Computational World

- Computing and algorithmic thinking are “*dragging at least some of the erstwhile soft sciences*” towards the throne of mathematics, the queen of science (Easton).



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Two Views of Natural Computing

The weak view	Computers are a great tool for studying the world, and computing can learn from the nature
The strong view	The world computes (information processes)



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Natural Computing

- Everything computes
 - “...**living organisms** perform computations” (Mitchell)
 - **Water molecules** “compute’ that the angle between the two bonds should be 107 degrees” (Hillis)
 - **The universe** is a digital computer (or cellular automata) (Zuse, Chaitin, Wolfram, etc.)



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The Book of Nature

- “The book of nature is written in mathematics” (Galilei)
- “The book of nature is written in algorithms” (Weak Natural Computing)
- “The book of nature is an e-book” (Dodig-Crnkovic)



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Back to Reductionism: The Circle Closes

- The 1950s–1970s concern:
 - “*Computing can’t be reduced to mathematics!*”
- The 2010s enthusiasm:
 - “*Everything can be reduced to computing!*”
 - Computing is truly the emperor



Computing as a Science: Recap

- The field was born 50-70 years ago
- Quest for independence
 - Detach from the parent fields
 - Formulate a coherent disciplinary identity
 - Keep up with continuous expansion



Computing as a Science: Recap

- Many sticking points
 - Subject matter
 - Theory and practice
 - Naming
 - Academic family
 - Methodology
 - Etc.



Computing as a Science: Recap

- Internal debates: Just froth on the wave?
- Revolutionized science twice:
 1. With a versatile, powerful tool
 2. With a new way of thinking and practicing



Computing as a Science: Recap



- Computing:
A triumph of
 - Innovation
 - Eclecticism
 - Anarchism
 - Opportunism

Computing as a Science: Recap



- Does the strong version of natural computing go a step too far?
 - Does the world compute?
 - Is the world fundamentally about information processes?



Thanks!

Questions, comments, critique?
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