THE "MEANING" OF ELECTRICAL ENGINEERING

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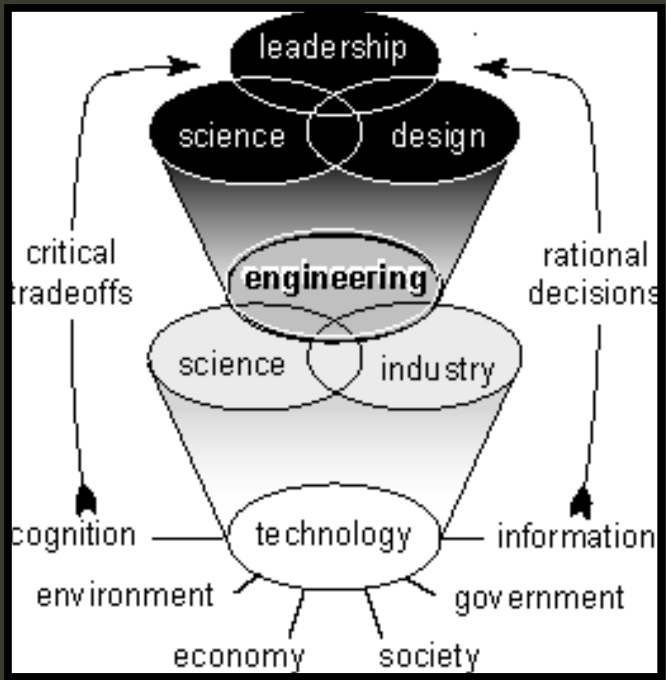
The meaning of Engineering

"The art and science of production"



"Engineering transforms nature to serve large numbers of people"

To transform nature effectively requires knowledge in natural science; to serve people adequately requires knowledge about socioeconomic factors.

From: http://www.creatingtechnology.org/eng.htm

The multiple faces of

- Use advances in basic sciences
- To create novel components
- That can be combined efficiently and reliably
- Into increasingly complex systems
- Addressing relevant societal problems

The Origins of

- 1638: Galileo's "Two New Sciences"

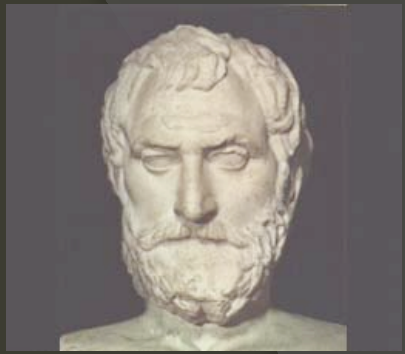
  Advocates scientific approach to practical problems – beginning of structural analysis

- 1800-1850: First industrial revolution
  - Civil engineering (France)
  - Mechanical Engineering (Great-Britain)
- 1850 – 1930's : Second industrial revolution
  - Chemical, Mining, Electrical Engineering (Also marine, aeronautical)

Engineering Education

- Started as informal studies, based on apprenticeships
- French "polytechnic model" led the way to the development of engineering education as separate entity
- United States:
  - 1847: First engineering undergraduate degrees in Yale and Harvard
  - Morrill Act of 1862 provides federal support (that is, land) to encourage the agricultural and mechanical arts. Led to development of schools such as MIT, Penn State, Cornell, …

The Origins of EE



- 400BC: Thales of Miletus discovers electrifying effects of amber
- 1601: William Gilbert invents the term “electricity”
- 1801: Volta develops the first “battery”
- 1826: Ohm formulates his famous law
- 1831: Faraday formulates the induction law (and hence lays the base for transformers)
- 1873: Maxwell publishes unifying theory of electricity and magnetism
- 1876: Bell develops the first telephone

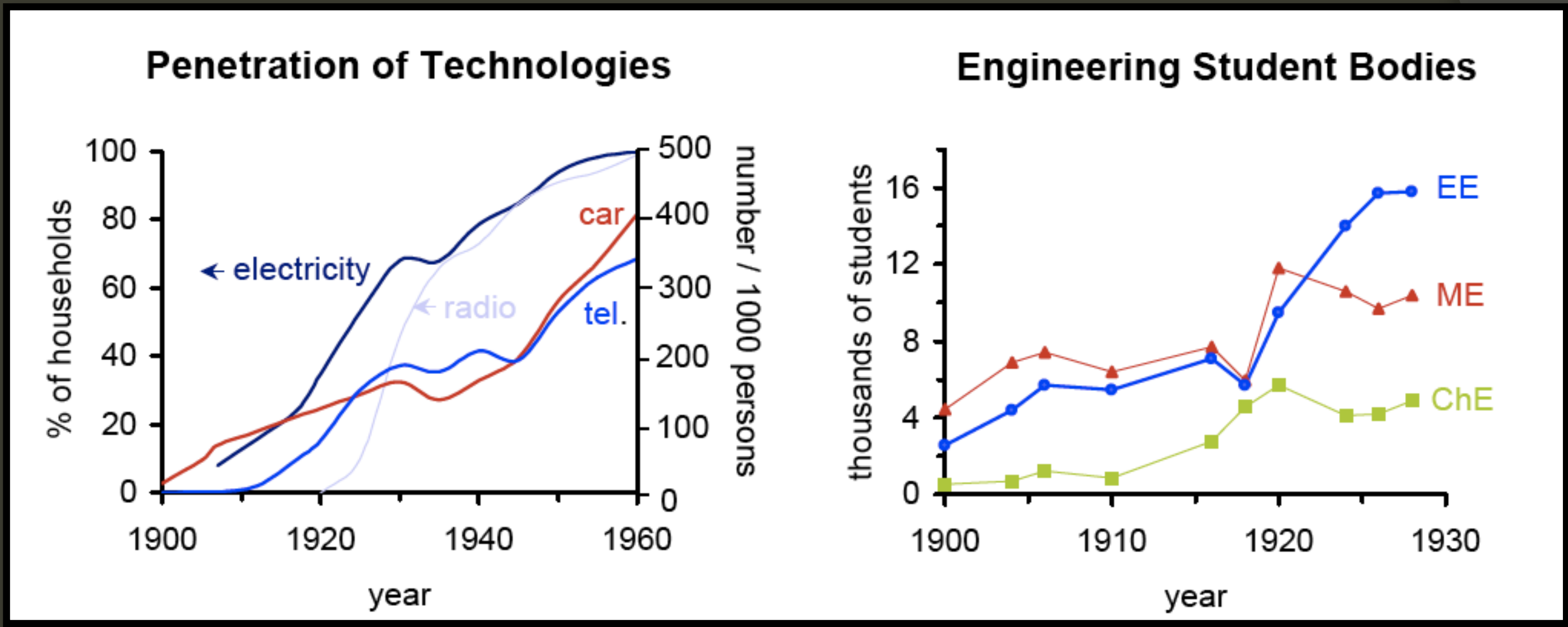
The Origins of EE

- 1882: Darmstadt University of Technology founds first chair and faculty in electrical engineering
- 1882: MIT offers first option of electrical engineering within a physics department
- 1883: Darmstadt offers first courses in electrical engineering
- 1886: University of Missouri creates first department of electrical engineering in the US

From a frustation with physics' incapability of solving practical problems

- *"It is a well known fact that alternating currents do not follow Ohm's Law and that nobody knows what law they do follow"*, Engineer George Prescott (1888)
- *"Maxwellian Theory does not exist in practice, but merely haunts as a phantom transformer in text-books and mathematical treatises,"* Electrical engineer Charles Steinmetz (1893)

The 2nd Industrial Revolution



(United States only)

Electrical Engineering at

Frederick Hesse, the Dean of the College of Mechanic Arts in the 1890s, was farsighted enough to see the importance of the growing field of electrical engineering and was determined that such work be added to the curriculum of his College. He was fortunate indeed in choosing Clarence L. Cory from among many applicants to fill the chair of Electrical Engineering.

College of Mechanic Arts, 1900

3	Professors of Mathematics
2	Professors of English
2	Professors of Physics
1	Professor of German
1	Professor of French and Spanish
1	Professor of Military Science and Tactics
1	Professor of Geology and Natural Science
1	Professor of Chemistry
1	Professor of Mechanical Engineering (Hesse)
1	Professor of Civil Engineering

Faculty Composition, 1886-1887

Clarence L. Cory

Cory arrived in Berkeley in September, 1892, and at once organized courses in electrical engineering. His principal work during the first two years was connected with plans for the Electrical Laboratories which were to be installed in the new Mechanics Building, then being erected. When this building was finished in 1894, he was active in pushing through the work so that within a few years he had completed the installation of electrical equipment which was surpassed by few universities of the country.

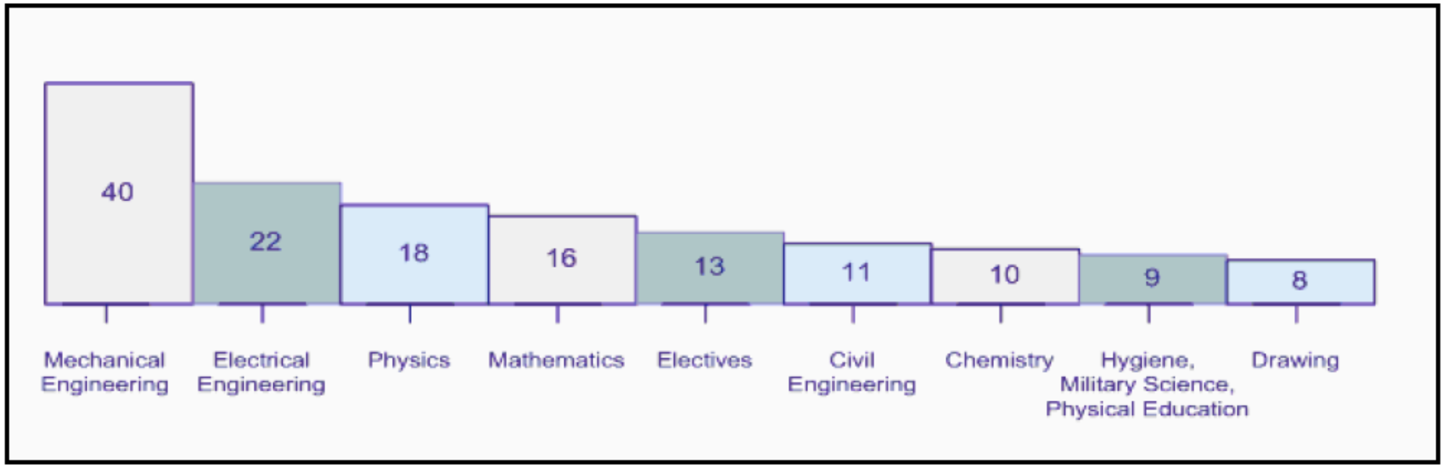
He also extended the electrical service outside of the Mechanics Building and supplied light and power to the entire campus from the laboratory plant. Cory was made Dean of the College of Mechanics in 1908.

From Power to Radio

Electrical Engineering at Berkeley (cntd)

- 1903: Formation of Mechanical and Electrical Engineering Department
  - 1910s: Development of high-voltage transmission (hydro-power to SF)
  - 1920s: Expansion to Radio and Consumer Electronics
- 1930: Formation of Electrical Engineering Department
  - EE drifting away from mechanics

Electrical Engineering



147 Units to Graduate

1920s

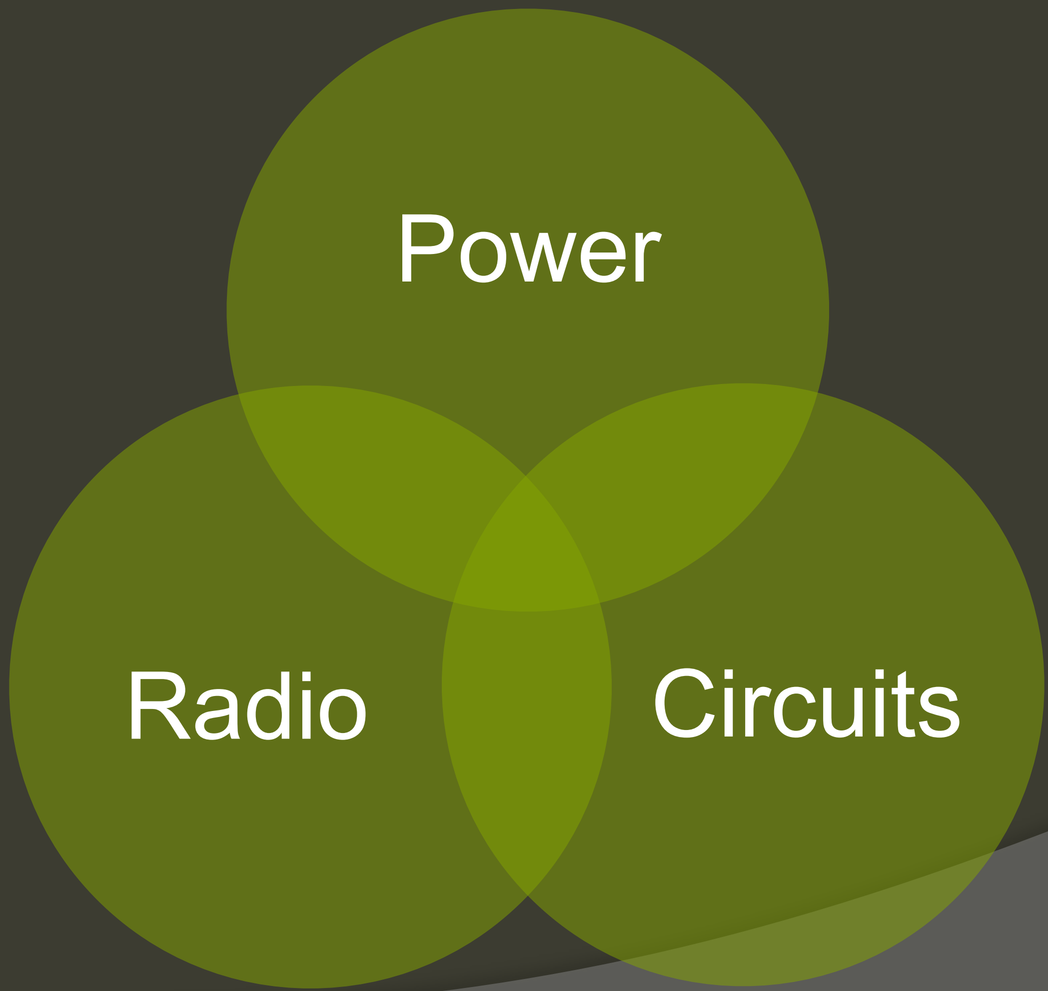
- Center of mass shifting from power generation and distribution to transportation (trains, planes, automotive) and consumer (vacuum cleaners)
- Radio of rapidly growing interest

"*Following WWI, schools of electrical engineering found they had two types of students: '60-cycle students' and 'odd-ball students'. However, the future was to belong to the odd-ball engineers who had an interest in things that could be done with vacuum tubes such as radio.*" L.A. Geddes

Divergence between electrical and mechanical engineering – Radio as first true EE domain

GE Ad in "Blue and Gold" Yearbook (1921)

Electrical Engineering – 1930s



1930s:

The Emergence of Systems Theory

Control Theory

While control has been used for a long time, it is only in the late 1920s that the “mathematical language” of control systems took off

- 1922: The first PID controller (N. Minorsky)
- 1930: Usefulness of feedback control demonstrated (Black)
- 1940: Bode introduced the “Bode Plot”

Communications and Signal Processing

- 1948: Annus Mirabilis
  - Claude Shannon, "A mathematical theory of communications"
  - Oliver, Pierce and Shannon, "The Philosophy of PCM"
  - Formation of the Professional Group on Audio of the Institute of Radio Engineers (would later become the signal processing society)

(also in 1948: the invention of the transistor, first operational stored-program computer Mark I)

The Computer Age – Second Half of the 20th Century

Moore's Law as the Driving Force

- Advent of the Computer (1940s)
- Semiconductor technology (1950s)
- Networking (1970s)

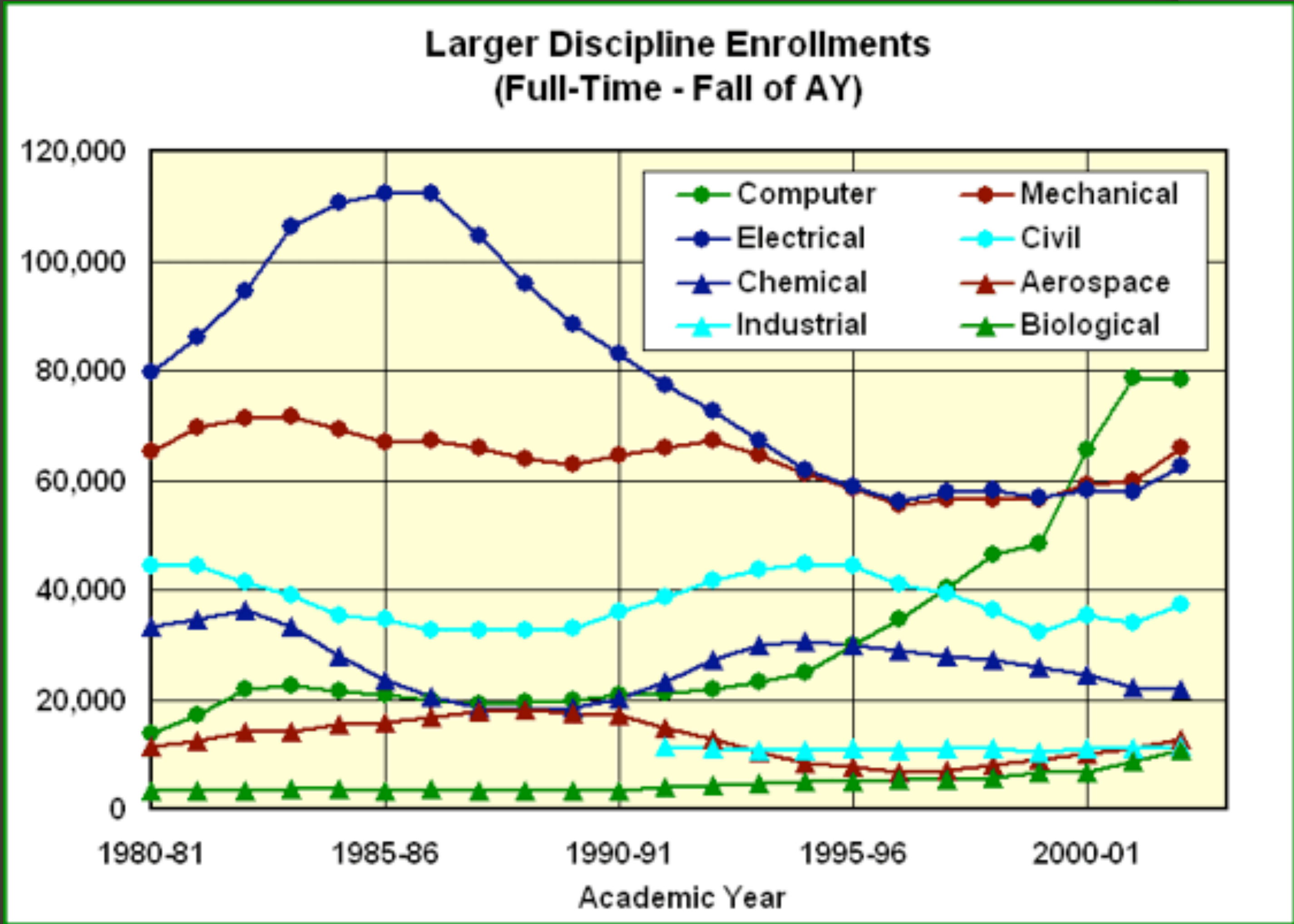
All found their source in electrical engineering. Eventually led to the emergence of "Computer Science" as a separate engineering branch.

Computer Science

"The study of theoretical foundations of information and computation, and of practical techniques for their implementation and application in computer systems. The systematic study of algorithmic processes that create, describe and transform information."

- 1936: Allan Turing wrote "On Computable Numbers"
- 1940s: The dawning age of computers (ACM founded in 1947)
- 1945: John Von Neumann envisions the "Von Neumann Machine"
- First Computer Science Departments emerge in early 1960s
- Berkeley History:
  - In 1968, number of faculty left Berkeley EE Dept to from the CS Department in the School of Sciences and Letters
  - EE and CS merged back together in 1973 to form EECS

(MIT established EECS Dept in 1975)



US Engineering Enrollments, from Engineering Workforce Commission of the American Association of Engineering Societies

Total EECS rose from 95,000 to 140,000 students between 1980 and 2000 (with net flow from EE to CS)

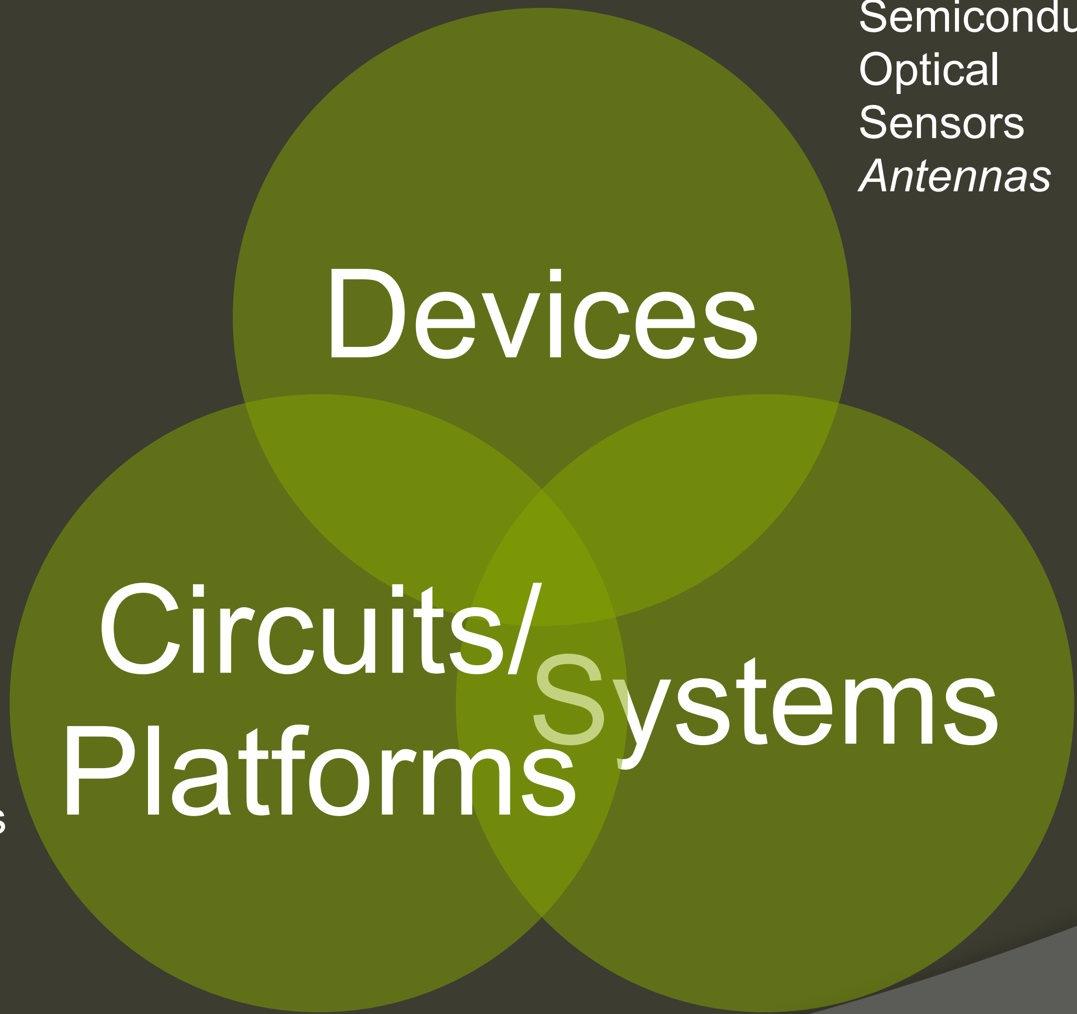
US engineering workforce (1999)

Field	Workers (000)			Median salary ($000)			% in R&D	
	BSc	MS	PhD	BSc	MS	PhD	BSc	PhD
Engineering total	**907**	**377**	**84.2**	**60**	**70**	**79**	**45**	**76**
Aerospace	36	26	4.6	69	75	84	41	85
Chemical	51	21	8.1	65	70	80	51	75
Civil	161	57	5.1	55	65	70	36	67
Electrical & electronic	233	109	18.4	65	75	86	49	76
Industrial	63	17	1.0	55	60	85	30	62
Mechanical	197	62	9.1	60	68	75	55	80
Computer/information	**715**	**305**	**32.4**	**61**	**70**	**81**	**34**	**72**
Mathematics	12	16	7.9	56	60	74	21	67
Physical sciences	140	73	84.9	45	52	70	37	73
Life sciences	136	73	121.1	37	41	62	23	68
Social & human sciences	71	156	126.9	30	43	60	13	46

From National Science Board, *Science and Engineering Indicators 2002, Tbs. 3-10, 3-12, 3-22; S&E Indicators 2000, Tb. 3-27*

Electrical Engineering End 20^{th} Century

Semiconductor
Optical
Sensors
Antennas

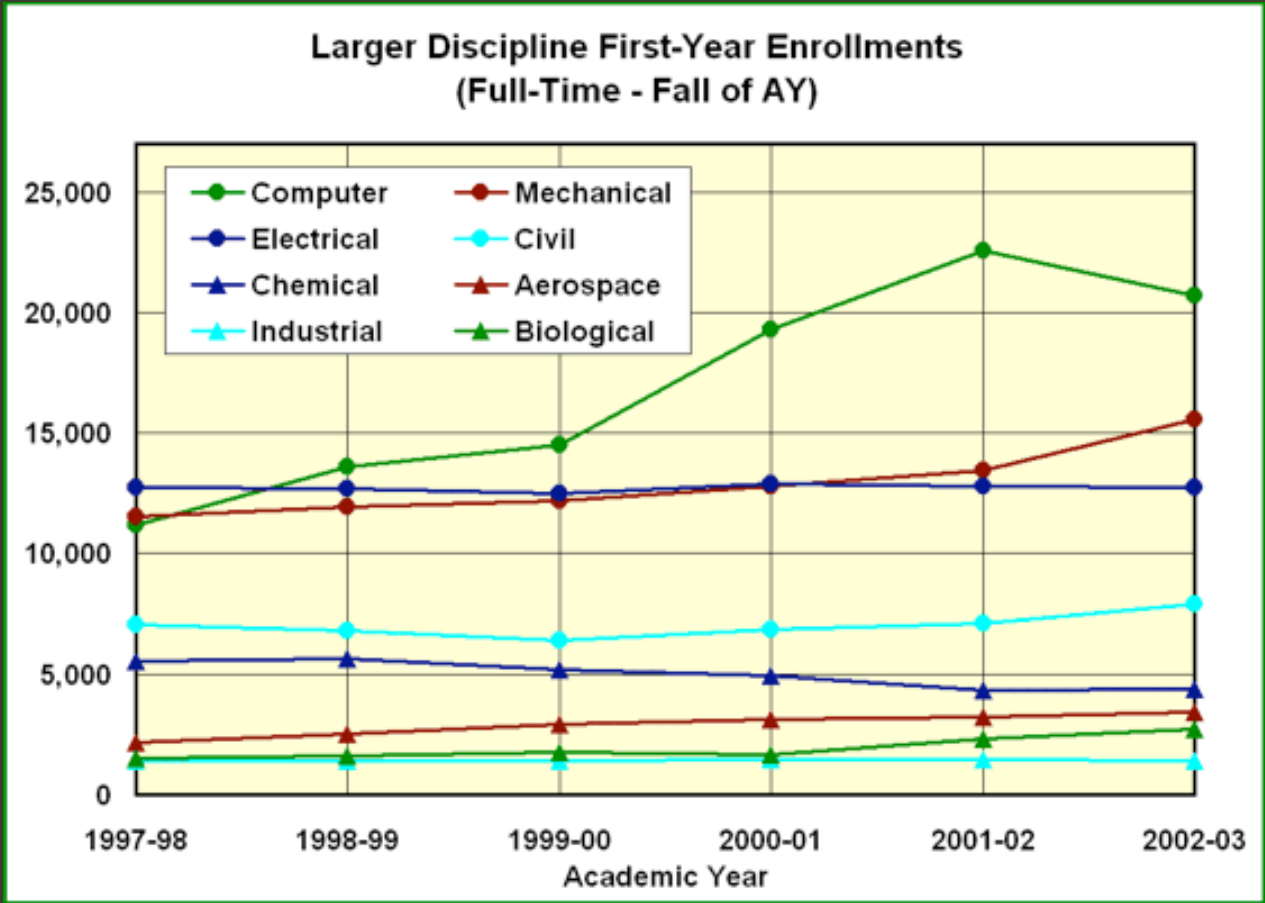


Analog/Digital
Computer
Communications
Networking
Power

Control
Signal Processing
Communications
Networking

Power and Electromagnetism have shrunk to insignificant levels
Many activities in EE have nothing to do with "electrical"

Early 2000: Some



This trends have continued: CS has substantially shrunk
EE flat or declining
ME, Chem and BioE up

What is changing ?

- The foundations shifting from electromagnetism and solid-state physics to nano-technology, NEMS, chemistry and biology
- Moore's law is waning
- Driving force shifting from computers and productivity enhancement to societal impact
  - Energy, environment, health, mobility, etc

None of these are directly associated with EE(CS) (or even engineering)

Public Perception of

Attributes	Engineers	Scientists
Creates economic growth	69%	25%
Would make a strong leader	56%	32%
Cares about the community	37%	51%
Sensitive to societal concerns	28%	61%
Improves the quality of life	22%	77%
Protects the environment	17%	71%
Saves lives	14 %	82%

From J. Cohn (ISSCC 2009 Keynote) – Information from Harris Poll

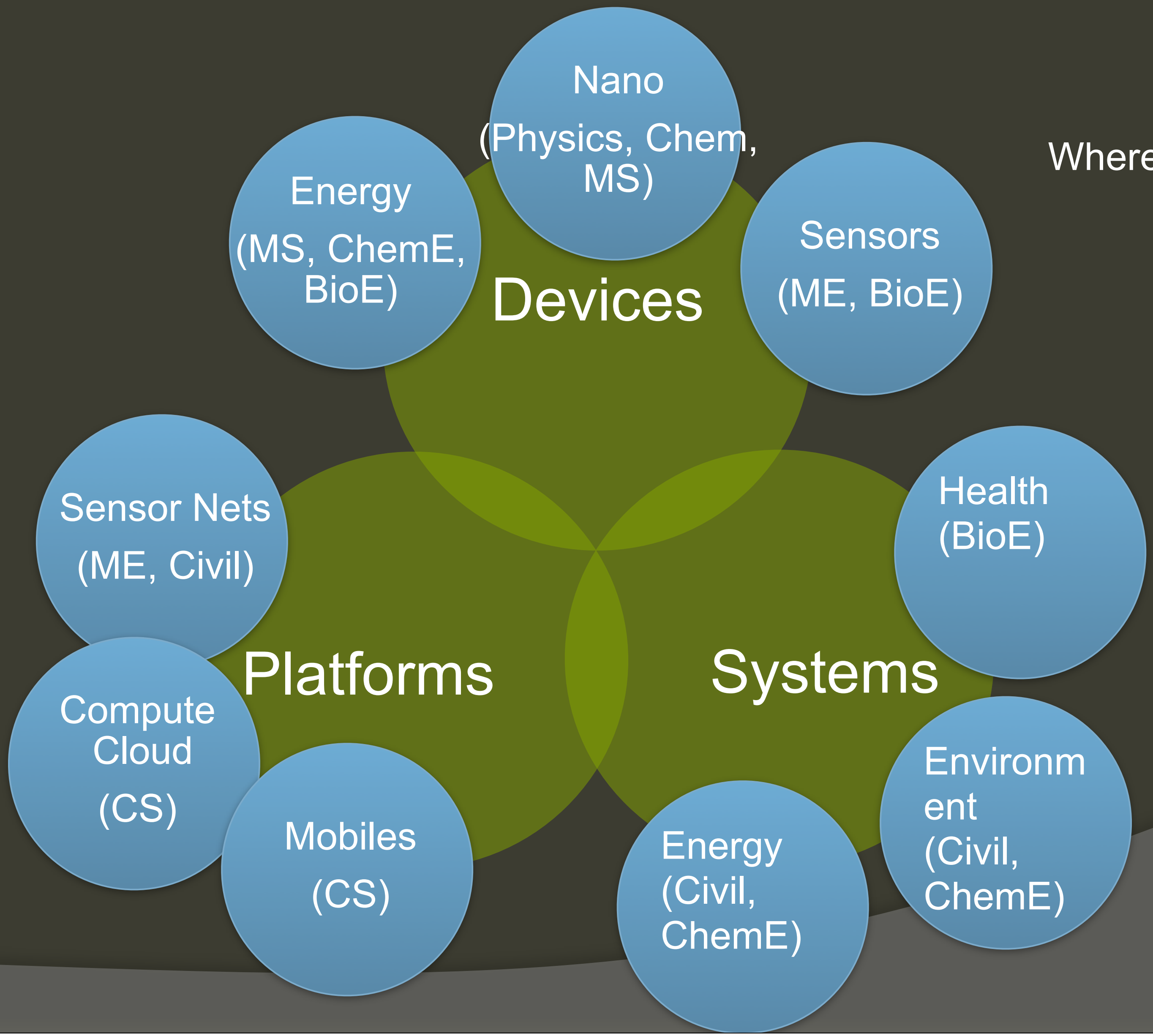
Perceived Core of EECS Considered to be in

- Design is being outsourced to Asia
- This has already happened to fabrication and manufacturing
- Integrated circuits become a commodity
- The same is true for programming

The “attractor function” is mostly gone!

EE(CS) Loosing its

Where is the electrical?



EE(CS) Loosing its

The current scenario

- Expansion and change of scope addressed by multi-disciplinary research centers and institutes (nano, NEMS, energy, health, …) crossing the boundaries of engineering disciplines (and reaching out to science and humanities)
  - Works semi-well at the graduate level (research)
  - Fails to develop and present an attractive undergraduate curriculum
  - Challenging (but potentially rewarding) career path for young faculty

Need flexible structure to enable cross-disciplinary education and research

The Need for Rebranding

- This is being successfully done in some branches of engineering
  - Civil and Chemical Engineering transforming to Environmental and Energy Engineering disciplines
  - The new perception of Mechanical Engineering (robotics, transportation, energy generation and harvesting)

The Core of the EE(CS) Mission Today

"Enable the development and deployment of complex systems that acquire and process information and act on it to address large societal problems"

- Electrical Engineering does not cover the contents
- Computer Science is a misnomer as well

The truth of the matter is that information technology in its broadest sense is what EE(CS) is all about

Hence, why don't we call ourself IT Engineers?

The IT Platform of the coming decades

Trillions of Connected Devices, executing distributed (control) applications

J. Rabaey, ASPDAC Keynote, 2008

Information Technology for "CyberPhysical" Systems

Sciences (Biology, Physics, Chemistry, Materials)

↓

Interfaces to the Physical and Biological World	Engineering of innovative devices
Distributed Platforms	Computing, Storage, Connectivity Embedded systems Distributed computing
Services	Signal processing Machine learning, AI Distributed control Information management

↑

Societal Applications (Environment, Energy, Health, Mobility, Safety, …)

Core Skills

- Development, modeling and realization of innovative devices (components)
  - Modeling and analysis
  - Manufacturing
  - Metrics
- Designing, analyzing, deploying and managing complex hierarchical systems
  - Abstraction, analysis, verification and synthesis techniques
  - Hierarchical and heterogeneous composition
  - Metrics: Quantifying performance, energy, productivity, etc
- Advanced services, providing signal interpretation, synthesis, recognition, classification and management

Re-engineering EE(CS)
What does it mean from a curriculum

- CREATE EXCITEMENT EARLY ON (FRESHMAN)
  - Exposure to development in sciences: nano, bio, (technology push) in addition to the traditional ones (physics, chem, math)
  - Exposure to application pull
  - Exposure to how engineering links the two through true hands-on
- Generalize the three pillars: components, platforms, services so that they address the broad range of emerging information-processing systems – FORGO THE EE-CS DIVISION
- Narrow down the barriers with the other engineering disciplines
- Rethink how much and how to introduce the traditional “core” skills
- Do not forget the other aspect of engineering: building leadership

Summary Reflections …

- Status Quo is not an option
- Need to act soon to keep (electrical) engineering at the forefront of human development
- But … the axels of academic reform grind slowly
- A full out strategy has little chance of success, hence need to start gradually – COLLABORATE!

A World without Electrical Engineers