Reconstructing Electrical and Computer Engineering for the 21st Century

David G. Messerschmitt
Department of Electrical Engineering and Computer Sciences
University of California at Berkeley

Goal

Can we anticipate how changes in technology, context, and needs affect our profession in the 21st century?

2

Preview

"In the 19th and 20th centuries, technology was about coercing physical devices to do man's bidding. In the 21st century it will be about coercing abstract human constructions. Where the laws of physics used to define the constraints, now it is complexity, computability, and chaos, plus the all-too-human barriers of logical flaws, awkward languages, (in)human interfaces, regulatory artifacts, information overload, limited attention span, and limited domain knowledge."

– E.A.Lee and D.G. Messerschmitt, *IEEE Proceedings*, Sept. 1999

3

Fair warning

My predictions and prescriptions are radical, designed to get you thinking!

4

Change

- The only constant is change...
  - applications and systems
  - societal context
  - education
- The rate of change is accelerating, in no small part due to our own technologies!

5

20th century: changing lives

- Radio
- Electric power
- Telephone
- Television
- Personal computing

6

21st century: changing society

- Telephony and the Internet
- Satellite TV broadcast
- E-commerce
- Enterprise computing
- Electronic polling

7

21st century: changing society

- The Internet (and telephony before it)
- Satellite TV broadcast
- E-commerce
- Enterprise computing
- Electronic polling

Contrast the societal impact of transportation and structural engineering

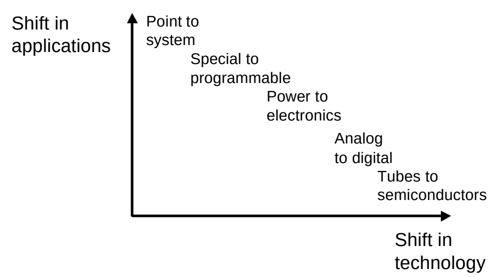
8

Historical shifts in emphasis

- Power ➜ electronics
- Tubes ➜ semiconductors
- Analog ➜ digital
- Special purpose ➜ programmable
- Point solution ➜ system

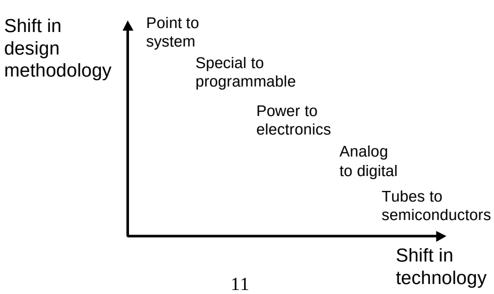
9

Target applications



10

Design methodology



11

Methodology

- Today, most hardware design uses a programming-like methodology
  (pushing performance boundaries excepted)
- Other issues often take precedence over performance and manufacturing cost
  – managing complexity
  – design cost
  – time to market

12

Systems

- The shift in emphasis from point solutions to systems has the biggest impact of all
  - Major challenges are heterogeneity, complexity, scalability, availability….
  - Design methodology fairly ad hoc
  - Need familiarity with all constituent technologies
  - Challenges are bookkeeping and organization as much as technology

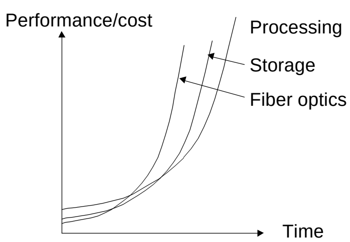
13

To consider

How appropriate is today's education in light of the shift in emphasis toward programmability and systems?

14

Three key technologies

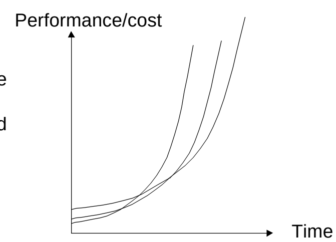


15

Keeping it going

• Keeping these trends going is challenging and critical

• This we do relatively well

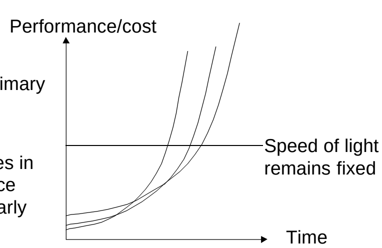


16

The speed of light

• Physical size becomes the primary performance determinant

• New challenges in high performance design, particularly for distributed systems



17

A good assumption

Ample and affordable processing, storage, and bandwidth will be available whenever and wherever we need them. What are the implications?

18

The “what” question

- In the past, the emphasis was on **how** to design high performance or low cost solutions for existing applications
- Increasingly, the emphasis is on **what** to do with our suite of impressive (processing, storage, and communication) technologies

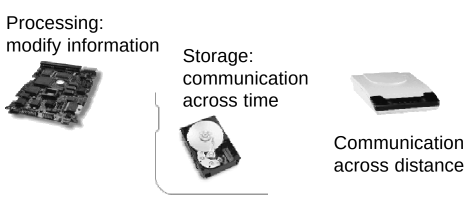
19

To consider

The increasing importance of the “what” question has profound implications to education, process, organization, culture, etc. What are they?

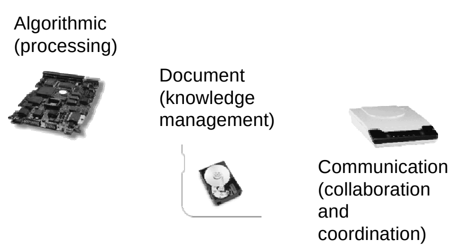
20

Technical contributions



21

Three existing traditions



22

Examples

- Algorithmic:
  – financial engineering, data mining, scientific computing
- Knowledge:
  – scholarship, knowledge, entertainment, commerce
- Collaboration and coordination:
  – organization, design, socialization

23

Prediction

Many major applications will tightly intermingle traditional computing (algorithmic and document) and communications (collaboration and coordination) traditions.

24

Sociotechnical applications

- A sociotechnical system is an integration of
  - information technology
  - people and organizations
  - information and knowledge
  - paper, material, finished goods, etc
- Sociotechnical applications are a big opportunity for combining our powerful processing, storage, and communication technologies

25

To consider

Information technology is merely embedded within a sociotechnical system (much as a controller is embedded within a mechanical system). How does our profession adjust to this increasing reality?

26

Severe challenges

- Rethink organizations and processes to make best use of information technology
- Rethink information technology itself to best meet the needs for functionality, flexibility, reliability, performance, etc.
- Do these together

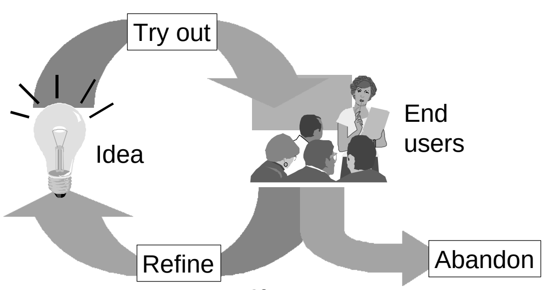
27

An observation

- How we answer the “what” question impacts society greatly
- The engineering profession cannot do this properly by itself

28

Let a thousand ideas bloom



29

Division of effort

Universities and startup companies	Answer the “what” question by trying a thousand ideas
Big companies	Design, deploy, operate, service customers
Standards bodies	Coordinate necessary interoperability in the infrastructure

30

To consider

Research labs (and especially in universities) are an excellent place to experiment with new applications. Are we prepared to meet this challenge?

31

Example

The Internet is

- An inspirational example of a wildly successful technology…..
- …...where research had greater impact than
  - international standardization processes
  - corporate marketing
  - venture capitalists
- Why?

32

Technology factors favoring the Internet

- First mover advantage
  - “embrace and interconnect” previous networks
- Separation of infrastructure from application
  - let those thousand ideas bloom
  - embrace application diversity

33

Process advantages of the Internet

- Continuous improvement and experimental approach, continuous user feedback
- Informal standards process open to all encourages the best ideas

34

To consider

How can our research embrace successful processes (illustrated by the Internet or others) to increase its reach and impact? Can we learn from our colleagues in computer science?

35

The changing context

- Greater focus on systems and applications increases the importance of context
- Startups (combining business and technical skills)
- Design outsourcing (including third world countries)

36

Many important non-technical issues

- Economics: network externalities and lock-in, etc.
- Law: intellectual property, antitrust, etc.
- Policy: privacy, universal service, regulation, etc.
- Business strategy: competitors and complementors, standardization, etc.
- Psychology: human-centered technology
- Sociology: organization-centered technology

37

Another challenge

- Technical systems and applications and non-technical issues are deeply intertwined
- Non-technical issues deeply impact design choices, success, and impact
- Engineers cannot afford to be uninterested about or uninvolved in these issues

38

Working together

- Left to themselves
  - Non-technical disciplines take a retrospective view of technology
  - Engineering disciplines tend to avoid the realities and complexities of the context
- Collaboration is an answer

39

To consider

Collaboration with other disciplines is obviously welcome, but are intermediary professions (analogous to architecture and civil engineering) needed?

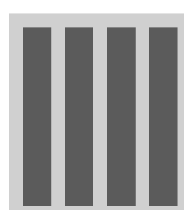
40

A challenge to the individual

Human knowledge grows exponentially, but human capacity to absorb it does not.

41

Knowledge classification

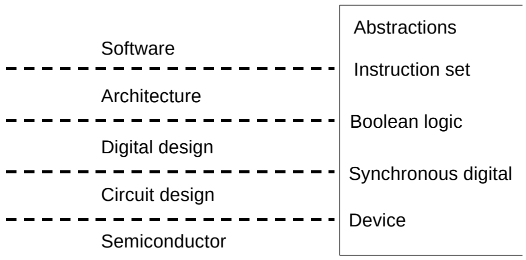


Specialization

Layering (abstraction)

42

Example of layering



43

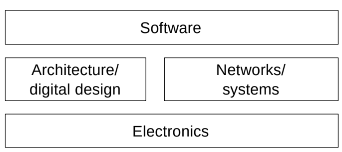
Assertion

- The increasing emphasis on applications, systems, and importance of non-technical issues puts a premium on individual “breadth”
- Layering (emphasizing abstraction, rather than specialization) is thus the appropriate classification for knowledge to emphasize in an education and career

44

New Berkeley EECS programs

- All students take a core course in each area
- The tradition that “an EE knows about electricity” has been abandoned



- Greater diversity among student’s education
- Two middle programs combine EE and CS perspectives

45

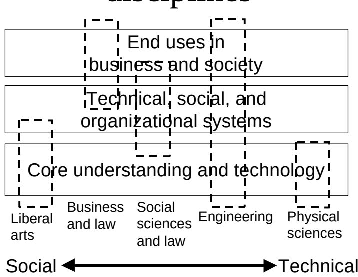
Observations

If abstraction is to be taken seriously

- an important research issue for each “layer” is the development of effective abstractions to convey to adjacent layers
- an important educational goal is to convey the methodology of abstraction

46

A layered classification of disciplines



47

A modest proposal

College of Application Studies

College of Systems Studies

College of Foundational Studies

48

Your likely question

"According to you, engineers must become broader. To be effective, they must maintain a core expertise. Our education is already stretched to the limit. Something has to give!"

49

Our response

The notion that education is only for the young is no longer viable. We must get serious about extending it over a lifetime.

50

Problems that lifetime education can address

- (Increasingly rapid) change is the only constant...
  - expanding human knowledge
  - changing context
  - changing roles over a career

51

Other problems

- Front loading (an increasingly lengthy) education delays career/family too long
- Increasing life expectancies extend careers longer (increasing the change to be accommodated)
- Greater job mobility results in less employer responsibility in retraining but magnifies the changing career

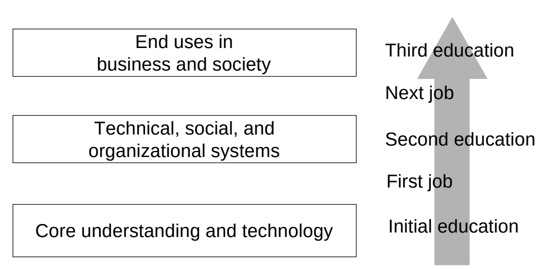
52

To consider

An obvious answer is to seriously stretch one's education over a lifetime. How can this be accomplished in consonance with other constraints, like a career and family obligations? How must universities change to meet this need?

53

Possible career progression



54

A prediction

- Workers and employers will come to accept more time spent in self development (part time through the net as well as by career interruption)
- Going back to school for new professional degrees -- twice and even thrice -- will become commonplace

55

Further information

- "Engineering an Education for the Future", *IEEE Computer*, Jan. 1998.
- "A Highest Education in the Year 2049", *IEEE Proceedings*, Sept. 1999.

56

Epilog

"The techno-nerd of the 20th century will become cool in the 21st century, the renderer of culture rather than its refugee."

– E.A.Lee and D.G. Messerschmitt, *IEEE Proceedings*, Sept. 1999

57

58