EE3: Introduction to Electrical Engineering

Lecture 9: Research Frontiers

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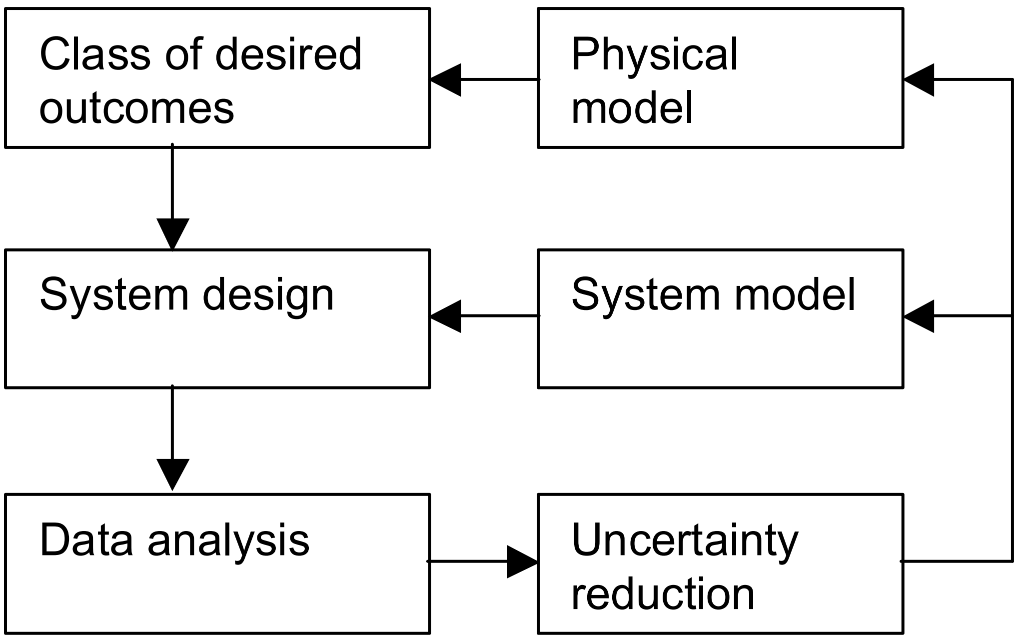
Outline

- The design process
  - From mechanisms to electricity to biology
- Smart Grid
- Bio-info-nano
  - Keeping Moore’s Law going
  - Interfacing electronic and photonic devices with biological systems
  - Medical applications

Universal Design Procedure

- Begin with what we know
  - E.g., trusted reference experiment, prior model(s)
- Validate a more efficient procedure
  - Exploit prior knowledge to test selected cases
  - Construct tools to assist debugging
- Bake-off the rival designs or hypotheses
  - Requires tools for rapid evaluation of data
  - End result is solution of an inference problem
- Iterate
  - Different model components become trusted at different stages



Example: The Arc of Technology

Age of the mechanical machine: 1700's and 1800's saw development of machines that could produce energy, improve transportation, and even compute

Development of electrical alternatives used these examples, existing measurement techniques, and new theory

Age of electricity: 1800's and 1900's saw fast iterative development of new communications, energy and computational systems with corresponding theory

Proliferation of scientific instruments enabled radical transformation of science of biology

In your lifetime you will see a merging of biological and electronic systems, leveraging advances in understanding of both

Evolution to the Smart Grid

Have extensive infrastructure, theory of operation, and measurement devices

But owing to past computational and communication limits, the grid operates in a centralized manner with many human inputs required for control

The smart grid will leverage lower cost measurement, communication, control and computation to enable a more distributed structure

Due to the huge capital costs, this must be done while leveraging the existing distribution network, with new components paying off over reasonable time periods

Smart Grid Components

Meters: remotely readable meters, able to monitor both electrical consumption and generation on short time scales; Also desirable to be able to command generation/energy conservation to improve grid stability

Flexible distribution: power now flows from centralized generators to customers; excess power produced by customers (e.g., solar cells) needs local storage as it will not flow back into grid. This requires numerous expensive upgrades.
But in short term, solar works well in California: peak demand is due to air conditioning, corresponding to solar generation peak. Thus it can reduce peak load without large changes in the distribution network.

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Why is solar power a reasonable short-term fix in California, even without extensive storage or infrastructure changes?

Solution: peak demand is due to air conditioning, corresponding to solar generation peak. Thus it can reduce peak load without large changes in the distribution network.

Smart Grid Components II

Dealing with variable sources: wind is at its peak at night, when demand is low. This requires some combination of better storage technology, improved distribution, and price incentives to shift demand to off-peak times

Heating/cooling and changing the level of water is now the main means to store energy.

Conservation: the two elements are improved design (particularly of heating/cooling in buildings, efficiency of electronics), and incentivizing conservation behavior

Bio-Info-Nano

One consequence of integrated circuits/photonics technology is that we have become skilled at making very small things at low cost in large quantity.

We can now interface electronics with biological entities such as cells and enzymes; as electronics shrink, even more intimate connections will be possible

The merging of biological and information systems through nano technology will be a characteristic accomplishment of 21st century engineering.

The Future of Moore's Law

CMOS can only be extended for some finite number of generations; an alternative basic technology is required

Many candidates have been suggested over the past 30 years, but it has now become urgent

Prominent UCLA possibilities:

1) spintronics: use of magnetic spins of electrons as the "state" variable that enables storage and computation

2) Graphene devices: carbon fibers used for transistors and wiring

Information Technology in Medicine

The present health system is unsustainable; too much human expert input needed, lack of information feedback.

Some UCLA research in this domain includes

1) Electronic health records: merging of high resolution graphics with annotations, interfacing with diagnostic engines, privacy preservation

2) Wireless health: embedded systems such as smartphones and wireless sensors used to monitor patients between doctor visits; provides feedback on health status, performance of exercises, ability to conduct vast clinical studies at low cost

Interfacing Electrical and Biological Systems

Because size scales of electronic elements and cells are similar, there are many possibilities for combining the two

This is one of the premises of the California Nano Systems Institute, which links engineering, medicine and the sciences

Research in this domain includes:

1) New biochemical sensors: very high specificity can be obtained using biological components

2) Better implantable devices: drug delivery, electrostimulation, active prostheses

3) Synthetic biology: using standard biological parts in manner similar to assembly of electronic parts

Biological Ideas in Engineering

Our worldview is heavily influenced by technology; the machine and electrical devices affect how we perceive ourselves

E.g., people as standard educational parts, mind as computer

The broader understanding of biology and ecology is bringing new thinking to many realms of endeavor. We can now think of complex systems more like heterogeneous biological systems, with highly complicated feedback

This will have broad implications for robust large scale system design, including coordination of large numbers of robotic elements

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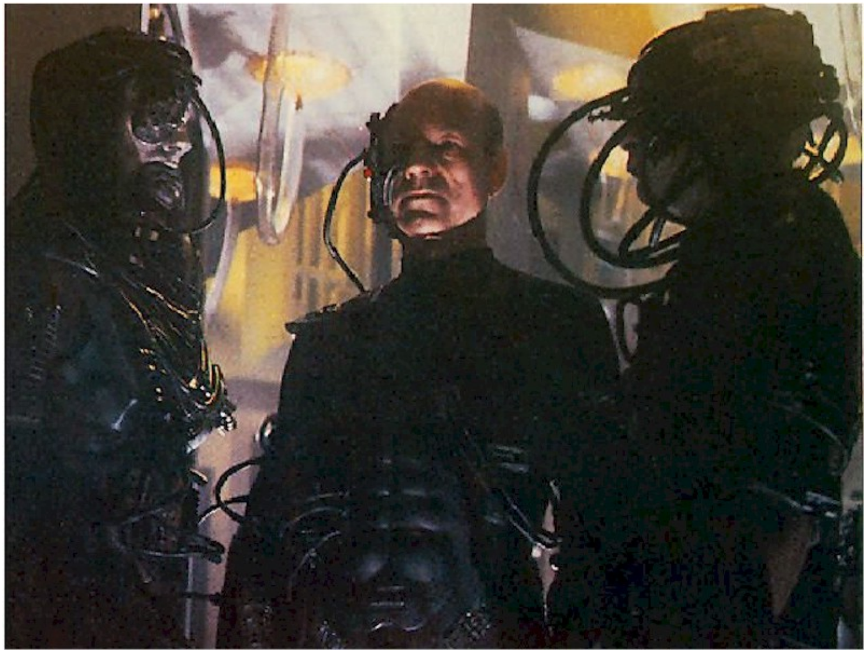

How are we like the Borg; what economic benefits would result from Borg-like technology?

- The industrial infrastructure arises from a symbiotic relationship of humans and machines
- It assimilates raw materials and reproduces on a global scale
- The whole is connected by a non-biological telecommunications network, with decision-making increasingly the result of a wide variety of inputs
- It extends to other planets
- Advancing this symbiotic relationship (e.g., offloading more cognitive tasks onto machines, improving health care) promises huge cost reduction

Summary

- Electrical engineering rests on foundations of the machine age and will be an important contributor to the coming biotech age
- Research has shifted from how to use vast resources to how to more intelligently use them
  - Sustainability in energy, health care
- An exciting future awaits

Wrap-up

- Circuit fundamentals: theory and hands-on experience used for explanation of:
  - Telecommunications
  - Electrical Grid
  - Computing and Control
  - Devices: pn-junction (diodes, transistors, photonics)
  - Technology trends
- Goal was to provide a non-trivial explanation of great EE inventions and provide an opportunity in the lab to become familiar with devices described in lecture, and produce a working design.