Predictions from the past

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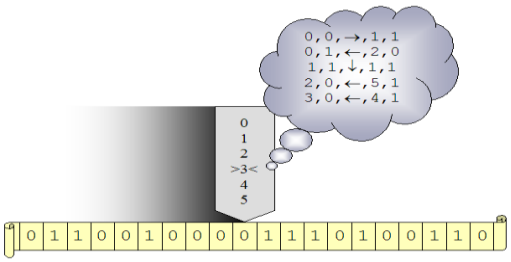
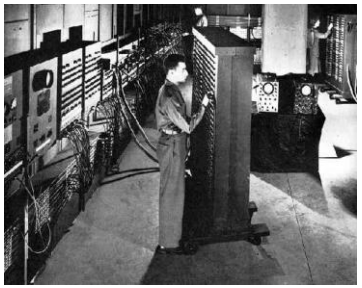
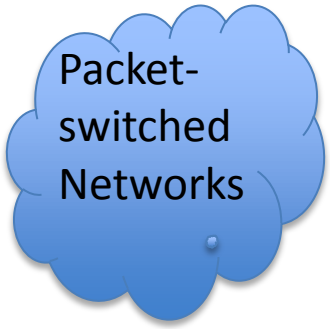
Disclaimer: Opinions are those of the speaker & do not represent official positions of NSF or RPI, unless noted.

A car for a buck?

- 1935 Alan Turing's abstract notion of a machine
- 1946 ENIAC, the first general-purpose Turing-complete electronic computer unveiled at the UPenn in 1946
  - [30x50 foot, 30 tons, 18,000 vacuum tubes, 5,000 additions/second]
- Today's laptops
  - 2.5 lbs, 1 B instructions/sec, $1,000.
- Staggering improvement, unprecedented in other industries (see cars!!)







Credit: Apple, Inc.

1935 1946 1960s~70s 2009

Progress in ‘Wireless’ (RF) -- evolution

- 1830s, Faraday, a physicist/chemist, experiments discovering induction/magnetism.
- 1864, Maxwell, “A dynamical theory of electromagnetic field,” dubbed Maxwell’s equations, considered the “second great unification in physics” after Newton’s.
- 1880, [Bell & Tainter, patented the photophone, a telephone that conducted audio conversations wirelessly over modulated light beams (not RF, so LoS needed).]
- 1888, Hertz, demonstrated the theory of EM waves showing how one can produce and detect EM waves. (Earlier work by Hughes, Edison, others).
- 1895-1897, Marconi, demonstrated how EM can be used to build a wireless telegraphy system. (Nobel prize in 1907).
- 0G (1920s~1940s, Cars, Ships, 2nd world war)
- ALOHAnet, 1970, star wireless (evolved to Ethernet & WiFi)
- ARPANET, ~1970, NSFNet ~1975, split MILNET~1983, Internet commercialization 90s
- 1G: 1980s, Analog, e.g AMPS in USA
- 2G: 1990s, Digital, CDMA
- 3G: 2000s, Digital, EVDO RevA, HSDPA, HSPA+,3GPP
- 4G: 2010s: Digital, 3GPP LTE, MIMO, OFDM, DCA, maybe WiMax as well

Drivers of Innovation

Society

7A's
Anytime
Anywhere
Affordable
Access to
Anything by
Anyone
Authorized.

Science

- (How) can we build complex systems simply?
- What is intelligence?
- What is information?
- What is computable?
- P = NP?

Technology

- By 2011, 22 percent of the Earth's population will surf the Internet regularly. Currently, 1.1 billion people enjoy regular access to the Web [JupiterResearch].

Progress in Wireless – challenges of an (unintended) Revolution

- 3G was first launched in Japan in 2001 by DoCoMo
  - Now, 88.7% of subscribers have Mobile Internet Access! [ref. DoCoMo]
  - Packet traffic: 9 times increase from 2003 to 2008! [ref. DoCoMo]
- A Phone is a Computer is a Sensor

Customers Angered as iPhones Overload AT&T

By JENNA WORTHAM
Published: September 2, 2009

Slim and sleek as it is, the iPhone is really the Hummer of cellphones.

Enlarge This Image

Michael Appleton for The New York Times
AT&T monitors its network from its operations center in Bedminster, N.J.
More Photos »

It's a data guzzler. Owners use them like minicomputers, which they are, and use them a lot. Not only do iPhone owners download applications, stream music and videos and browse the Web at higher rates than the average smartphone user, but the average iPhone owner can also use 10 times the network capacity used by the smartphone user.

The rise - and fall - of research disciplines

- In the past, there were no disciplines, e.g.
  - Galileo (~1600s): a physicist, mathematician, astronomer & philosopher
  - Maxwell (~1800s): theoretical physicist & mathematician.
- Rise of disciplines
  - The first Department of Computer Science in the U.S. was established at Purdue University in October 1962 (cs.purdue/history)
    - CS is “the study of the theoretical foundations of information and computation, and of practical techniques for their implementation and application in computer systems”
    - a significant amount of computer science does not involve the study of computers themselves!! →”computing science”
    - programming languages, algorithms and data structures, computation & complexity, human-computer interaction, etc.

Imprisoned by our own abstractions: Tear down the walls!

- Disciplines defined by abstractions.
- For decades, communities made strides within their own comfort zones, neglecting others. e.g.:
  - Information Theory vs circuit design or distributed systems
  - Control Theory vs networking
  - CS protocol design vs wireless channel
- The Internet serves as the stirring pot for most contributions.
- Rise of the word “multidisciplinary” – still ways to go…

Future: Old New and New New Challenges

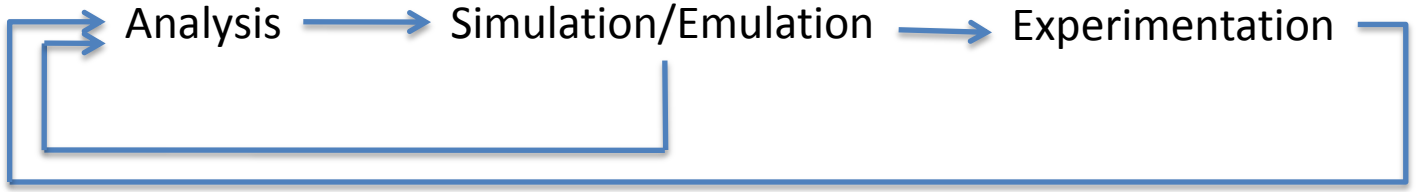
- Hard problems remain hard, and press harder:

  ("everything old is new again" -- the Old New Problems)

  - Dynamic channel assignment and spectrum access → Cognitive Radio, FCC Whitespace licensing. Note: how to certify a device? Broadband ranking of US?
  - Can we build a secure system from unreliable components → Trustworthy Computing and Networks.
  - P=NP? → everywhere.
  - Measurement science → repeatable experiments, validation, GENI, ORBIT, etc.
  - Economics and Game Theory → Economics, policies, pricing, Internet neutrality
  - Social networks and Milgrams experiment→Facebook, Myspace, Twitter, counter-terrorism, privacy
  - Feedback control over unreliable links → Cyberphysical systems

  (plus new new problems)

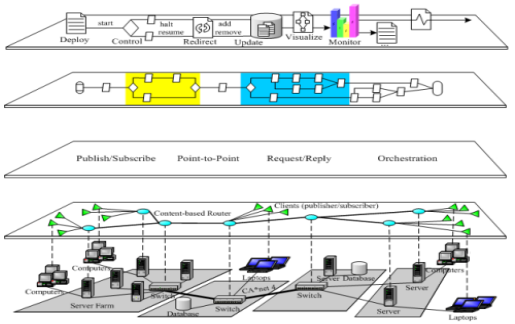
  - sensors, cooperation, ad-hoc, networking in GHz spectrum, cellular evolution/femtocells, etc.



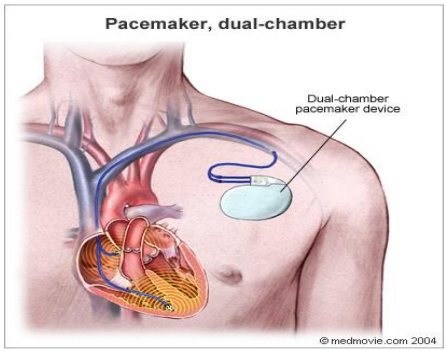
Opportunities Abound!

- Understanding the new things:
  - the space between the physical and the virtual:
  - social networks
  - cloud computing
  - data centers
  - data to knowledge
- Leveraging technology drivers
  - Computing and storage improvements induce changes in architecture and interactions
  - Software defined radio
  - Last mile vs last inch problems: it's what's on the card!
  - De-emphasizing wireless
  - Future architectures
- Networks and Computing of atypical computers:
  - Nano-bio networks
  - Replace parts of a brain by an artificial network?
  - Quantum computing and networks (will we care about NP?)
- How to invent better abstractions
- How to do better experimental work:
  - "*The most successful experimental work is one that renders itself useless*"
  - Aligning abstraction and reality (or theory and practice)
- Tackling problems between disciplines

No more easy problems, but plenty of hard ones ☺

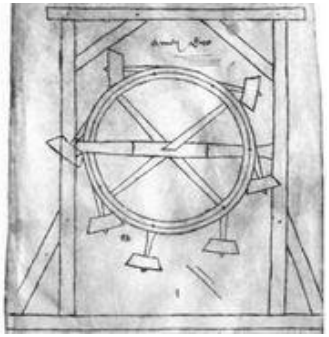


Credit Middleware Systems Research Group

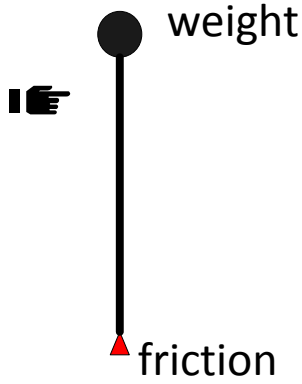


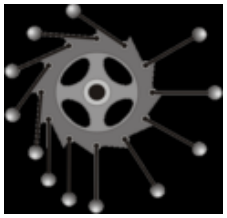
pacemaker

smart bridges

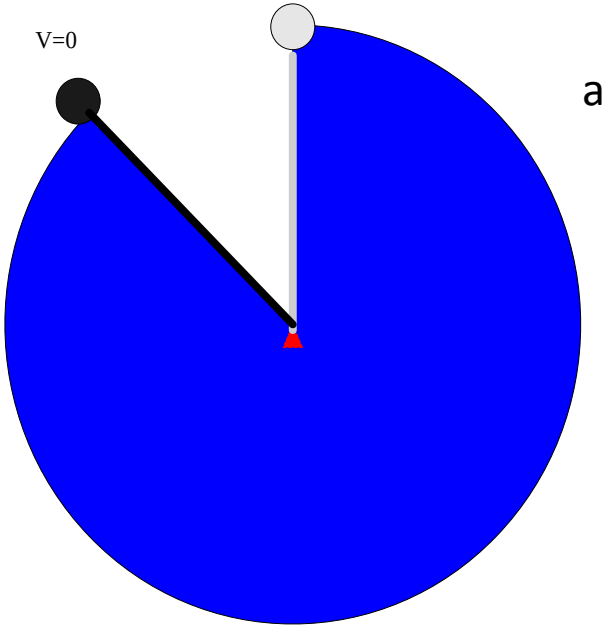


"Villard de Honnecourt", around year 1230



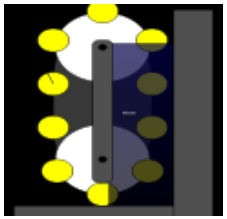


"Overbalanced Wheel"



air resistance

Actual system, "water screw" 1618



"Float Belt"

"Capillary Bowl"

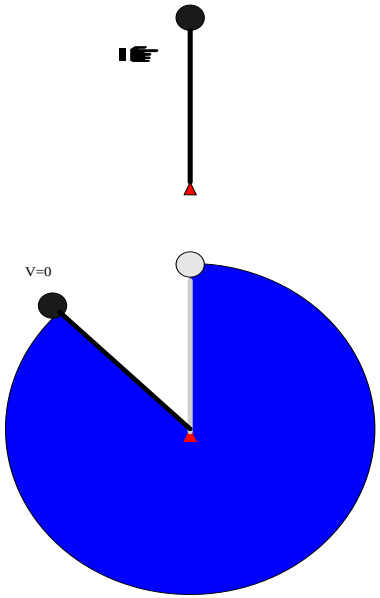
The quest for a *Perpetual Motion* Machine (before mid 19th century)

The outcome: The three laws of thermodynamics

- Research on efficient machines tries to design a `perpetual-motion' machine that runs continuously off its own exhaust.

- Mid 19th century: the three laws of thermodynamics.

- Which also proved that it is impossible to design such a machine!



Opportunities for Opportunistic Paradigm

- Internet access in rural areas (classic scenario for papers)
- I think wireless researchers need to think architecturally, e.g. like Andrew's position on cell phone.
- Be aware of the trends that will change the world
    - National priority applications:
        - Smart GRID
        - Healthcare
        - Broadband (and this is not just for the developing countries – how high does the US rank in broadband? Not even top 20)
        - Transportation
    - Future Internet …
- Real science challenges: mobility models, data dissemination, security, cooperation
    - I think these are definitely challenges, and we don't know much about such dynamic networks. Eg Ellen's paper on dominating sets, or my own paper around random walk in time-graphs

Opportunities for Opportunistic Paradigm

- Incentives for cooperation – Owning your problem (V. Bahl)
- 'Mobility' at different abstractions (pls call it dynamism)
- How to achieve cognition – opportunistic communication in cognitive networks
- Opportunistic communication in dynamic spectrum context (exploit white space opportunities) – by the way, this is an area that has just started.
- Not an academic exercise:
  - Opportunistic mechanisms have been used in deployed 3G networks
- ad hoc networks meets cellular networks: cellular are by far the largest carriers of traffic. However, 4G LTE networks: small cells, dense deployment and dynamic scheduling.
- Opportunistic services
- Opportunistic paradigm and CLOUD COMPUTING!
- Software Defined Radio (tied cognitive wireless networks and dynamic spectrum access)
- Software Defined Networks (egOpenFlow) for configuring routers on the fly
- Cognitive networks in general. Maybe an equivalent breaking of the lock by cellular vendors will appear so that the consumers get a say.

Need to LIBERATE this paradigm and concur new grounds into other types of networks, scenarios, and other INNOVATIVE ABSTRACTIONS, not just the mobile to mobile scenario.