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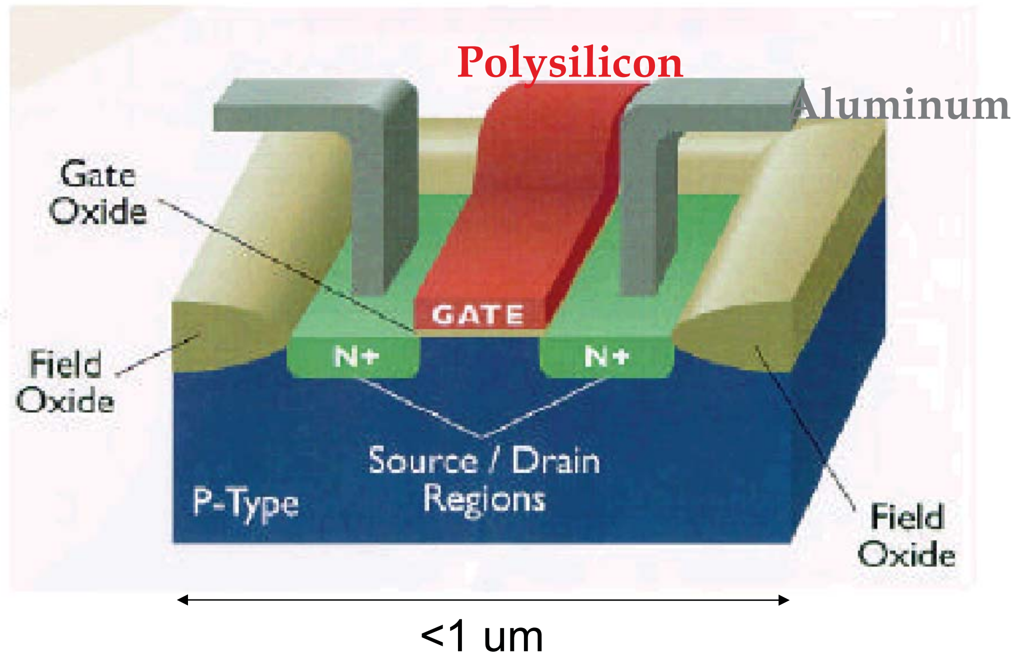
EECS 1 – More Moore and More than Moore

Fadi J. Kurdahi
EECS Dept., UC Irvine

MOORE'S LAW

The MOS Transistor



Building logic from Transistors

http://tams-www.informatik.uni-hamburg.de/applets/cmos/cmosdemo.html

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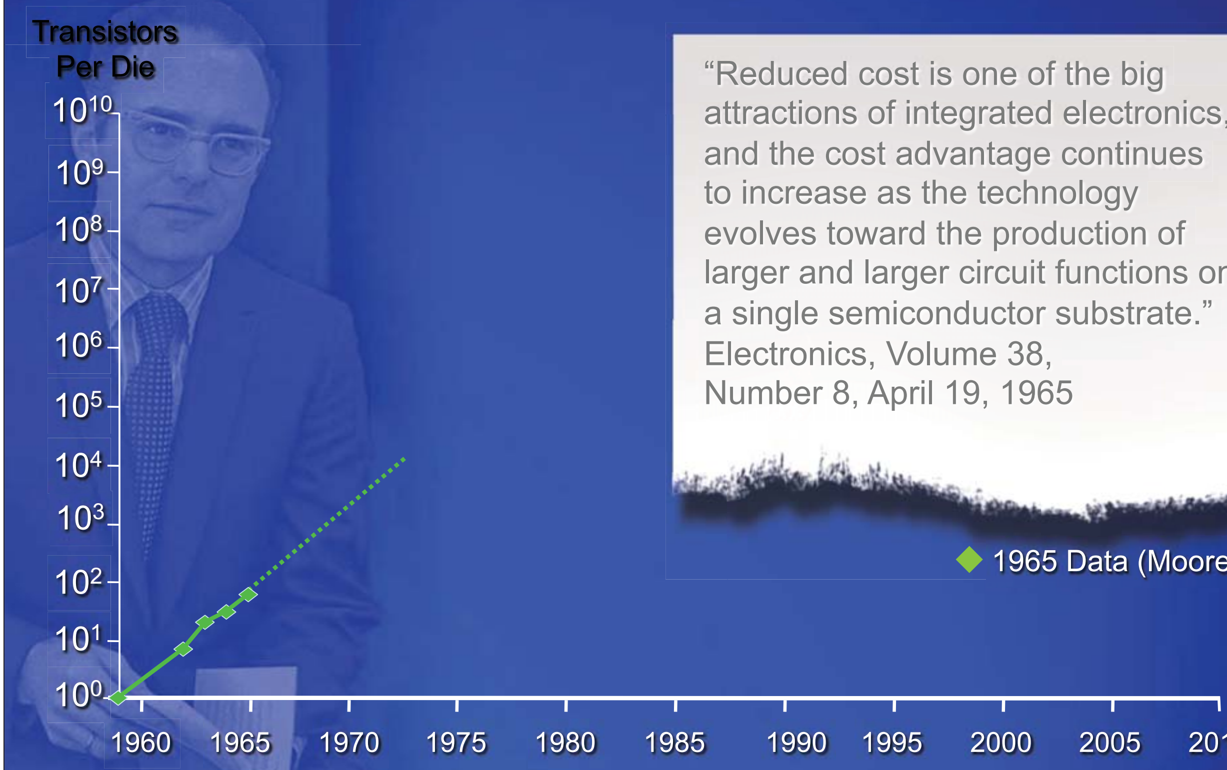
Moore's Law - 1965



"Reduced cost is one of the big attractions of integrated electronics, and the cost advantage continues to increase as the technology evolves toward the production of larger and larger circuit functions on a single semiconductor substrate."
Electronics, Volume 38, Number 8, April 19, 1965

[Ref: G. Moore, ISSCC 2004

Source: Intel

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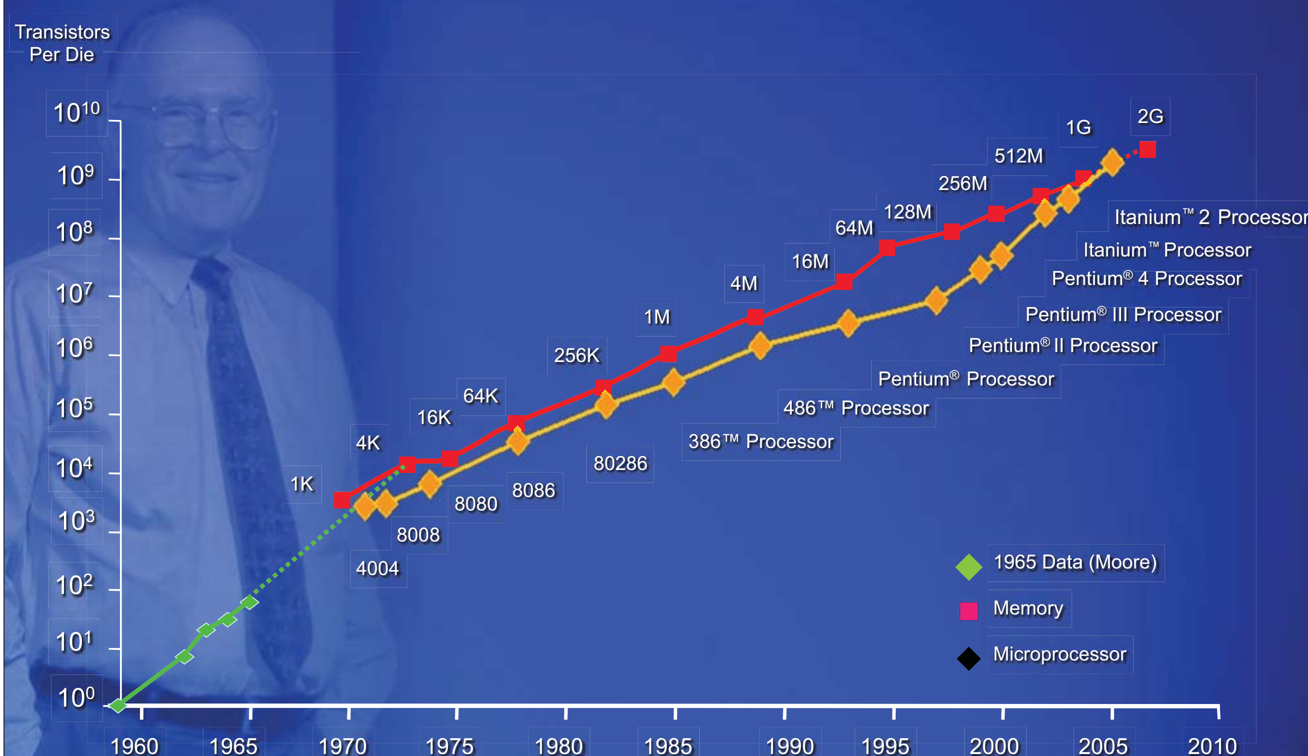
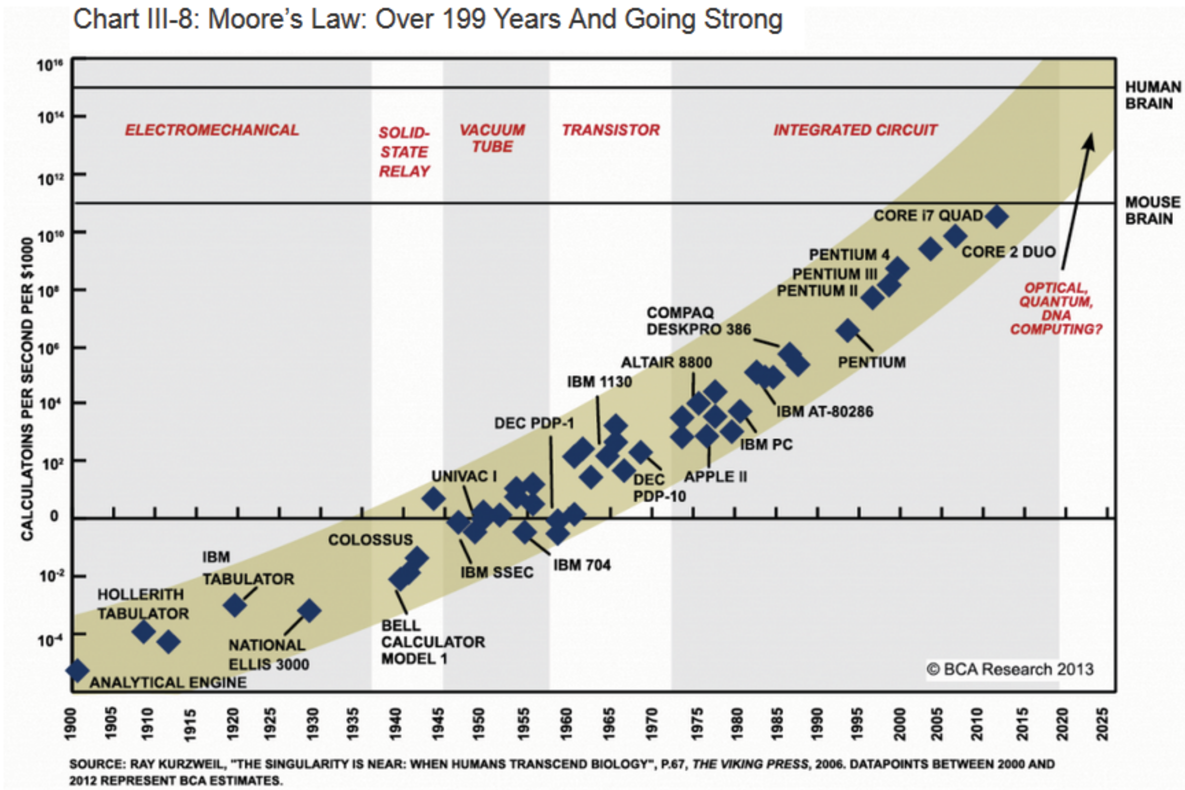
Moore's Law - 2005

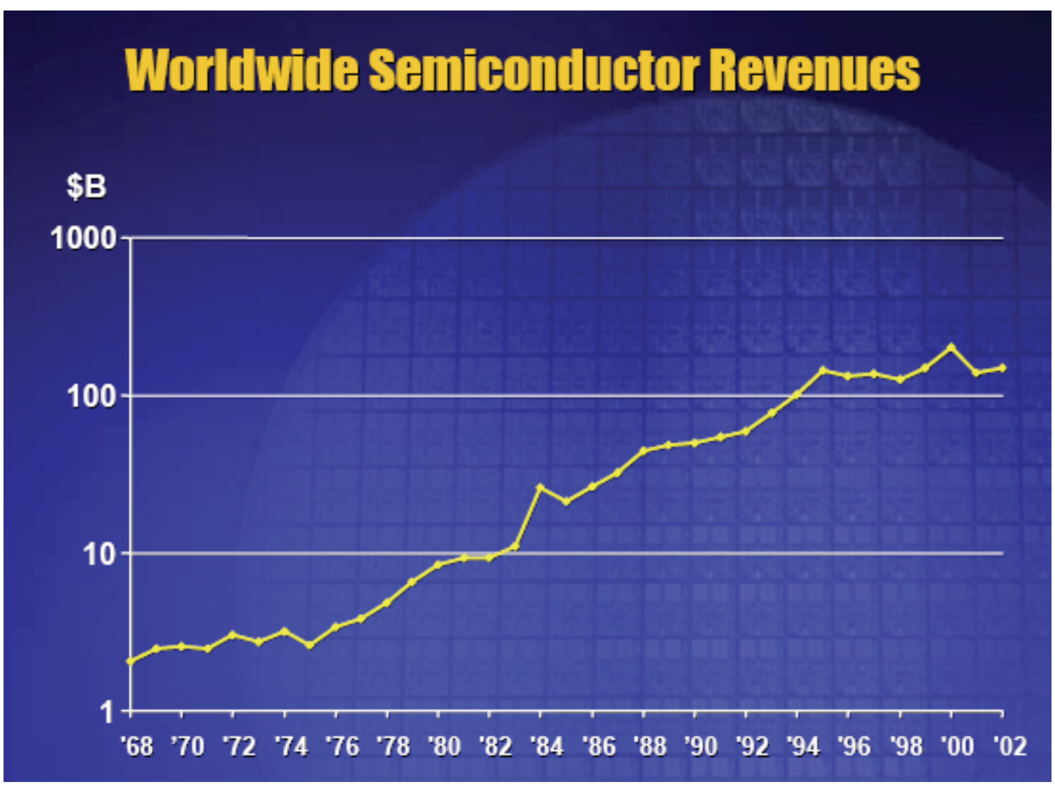


[Ref: G. Moore, ISSCC 2004

Source: Intel

Or is it longer?





[Ref: G. Moore, ISSCC 2004]

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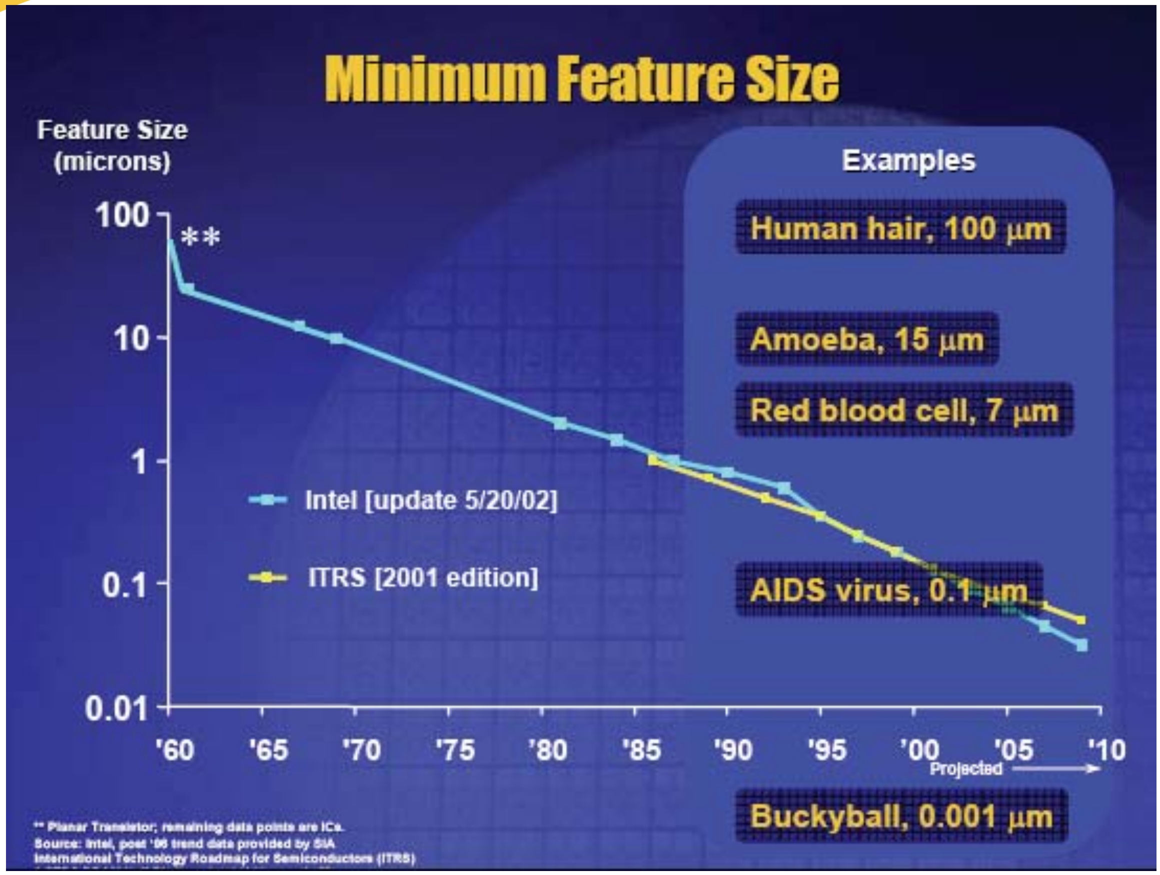
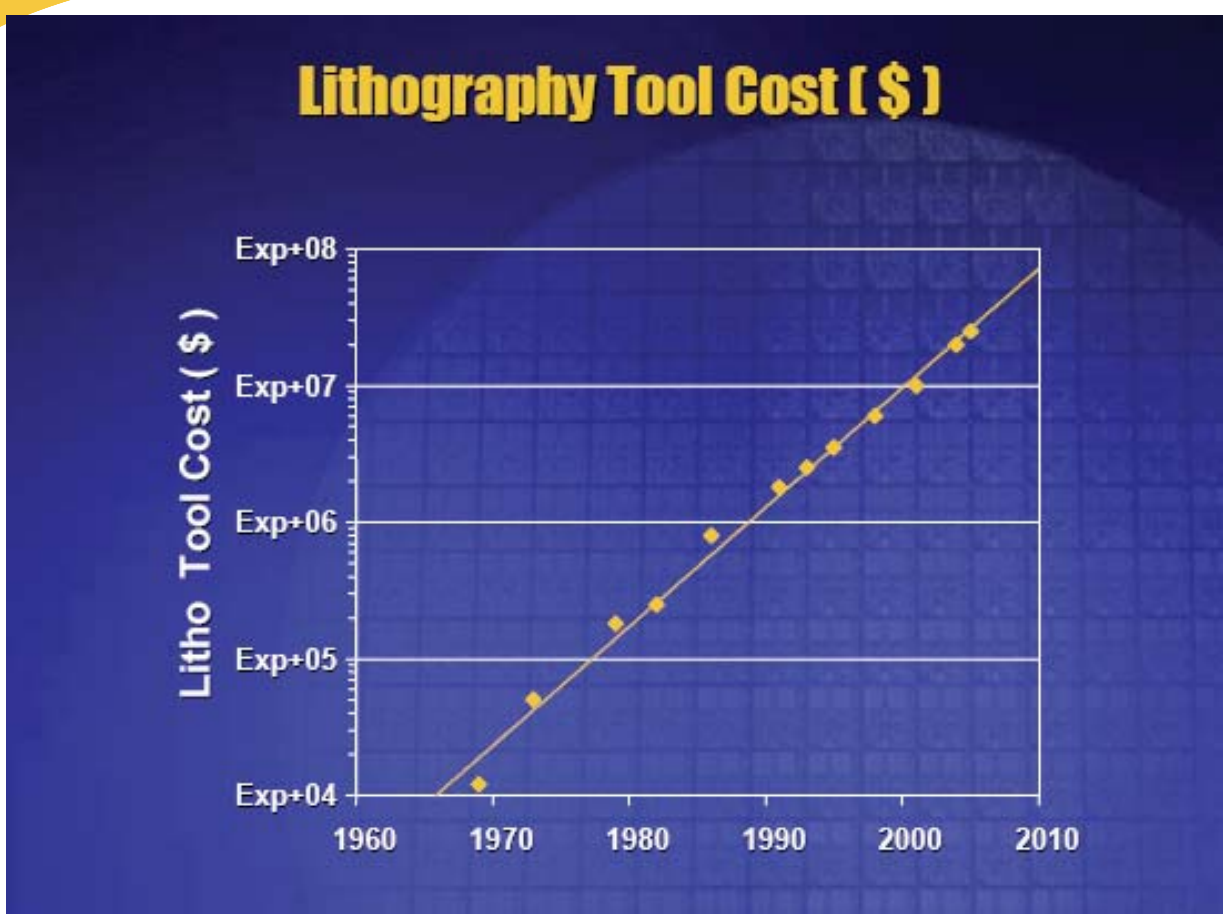
[Ref: G. Moore, ISSCC 2004

Electrical Engineering & Computer Science



[Ref: G. Moore, ISSCC 2004



[Ref: G. Moore, ISSCC 2004

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Processor Performance (MIPS)

[Ref: G. Moore, ISSCC 2004

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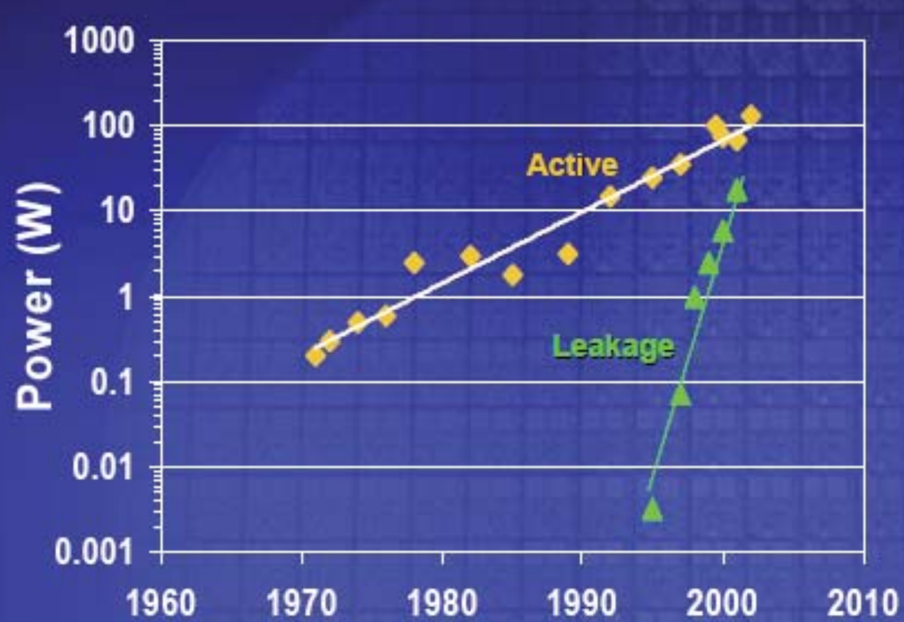
Processor Power (Watts) - Active & Leakage



[Ref: G. Moore, ISSCC 2004

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Summary

- Moore's law: Exponential Growth: 2x transistors/chip every 18-24 months
- Holding since 1965
  - More complex systems
  - Faster
  - Chips Cost less
- But:
  - Increasing fab costs
  - Higher power

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THE POWER CHALLENGE

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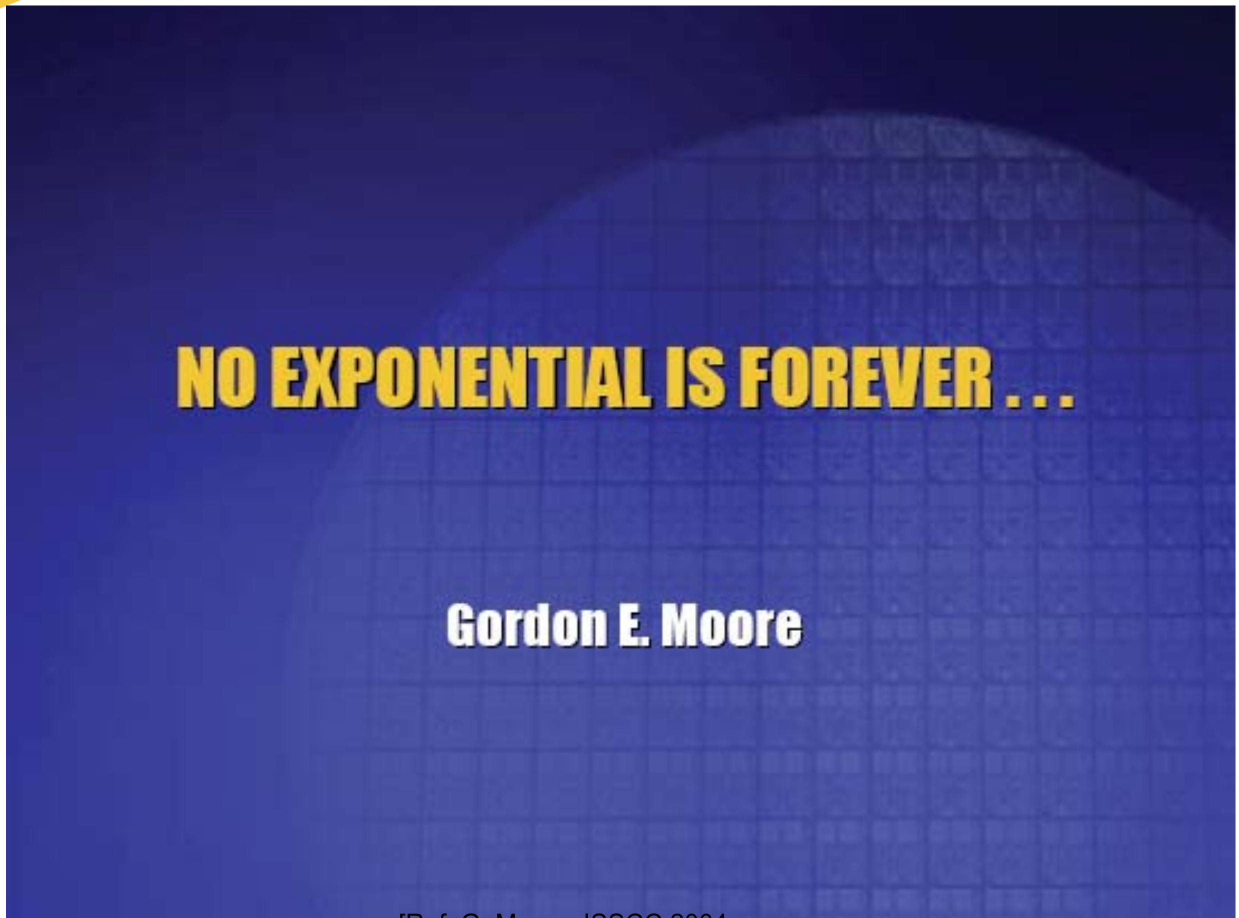
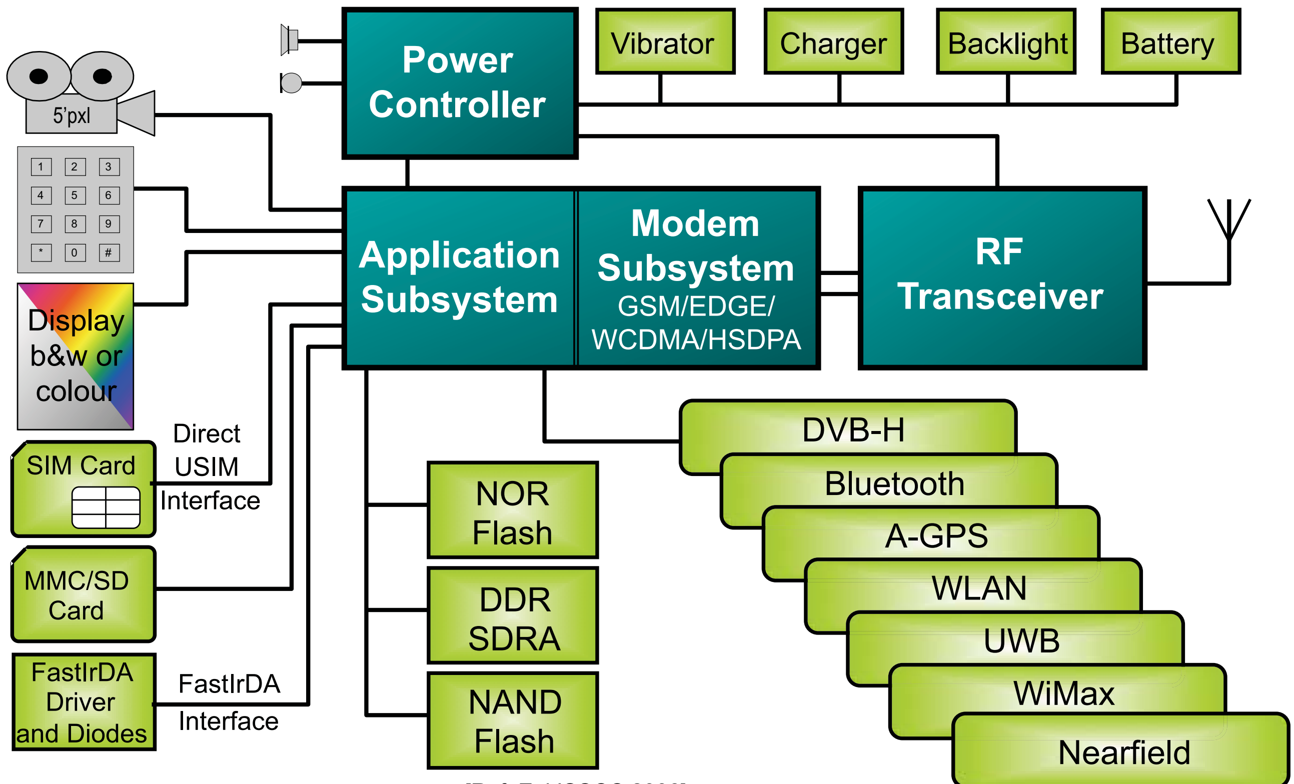


[Ref: G. Moore, ISSCC 2004

Diverse Products and Markets

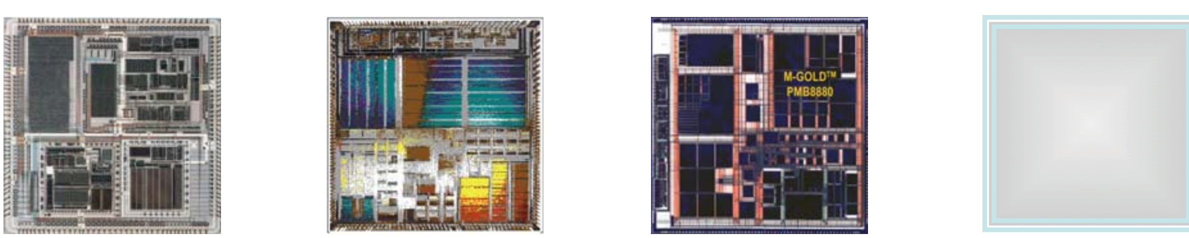
Future Mobile Phone Content



[Ref: Eul ISSCC 2006]

Moore's Law: Ever Increasing VLSI Power

GSM Modem	GSM, GPRS, EDGE Modem + Application	GSM+UMTS Modem	GSM, UMTS HSDPA, Bluetooth, WLAN, GPS, DVB-H
1µ CMOS 50k Tr.	0.25µ CMOS 11M Tr.	0.18µ CMOS 40M Tr.	nm CMOS 1B Tr.



0.1 — 1 — 10 GIPS

Mobile Pentium (~10W)

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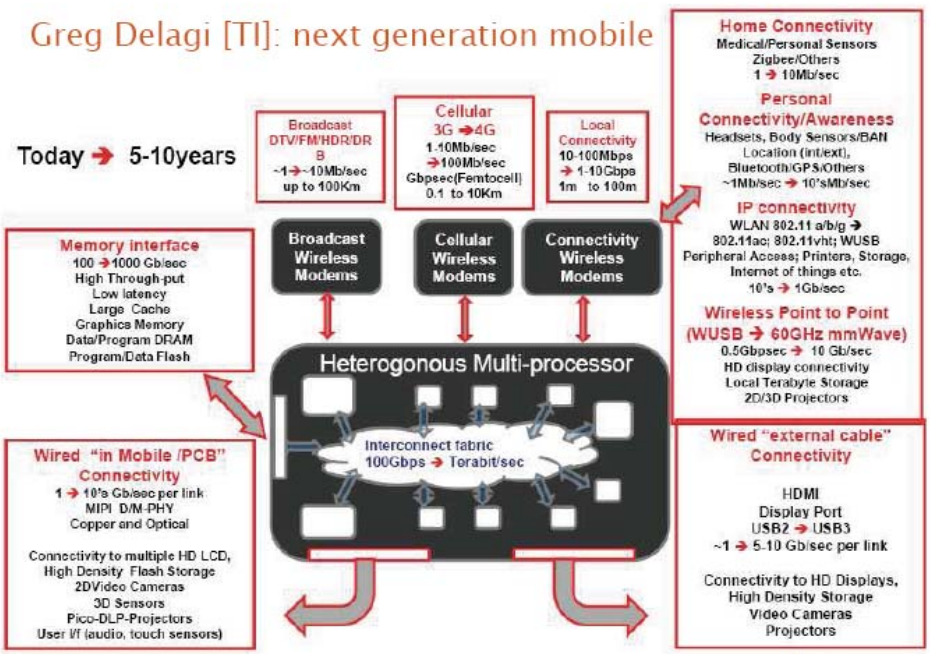
Systems-on-Chip (SoC)



[Ref: Delagi ISSCC 2010]

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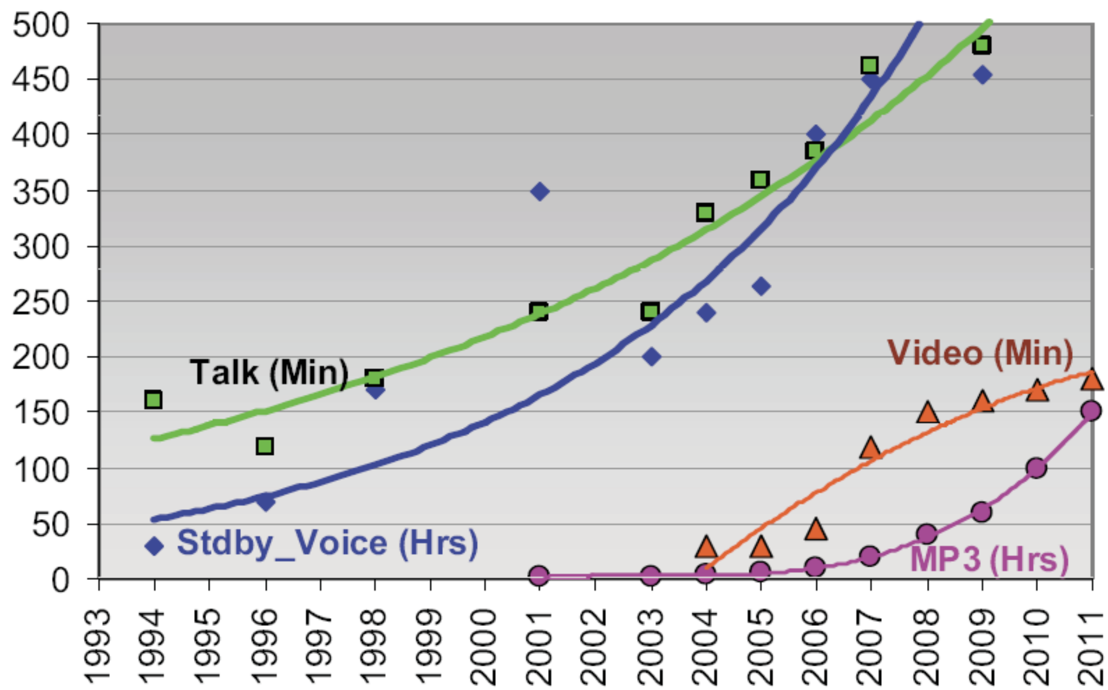
Increased Demand from Users



[Ref: Delagi ISSCC 2010]

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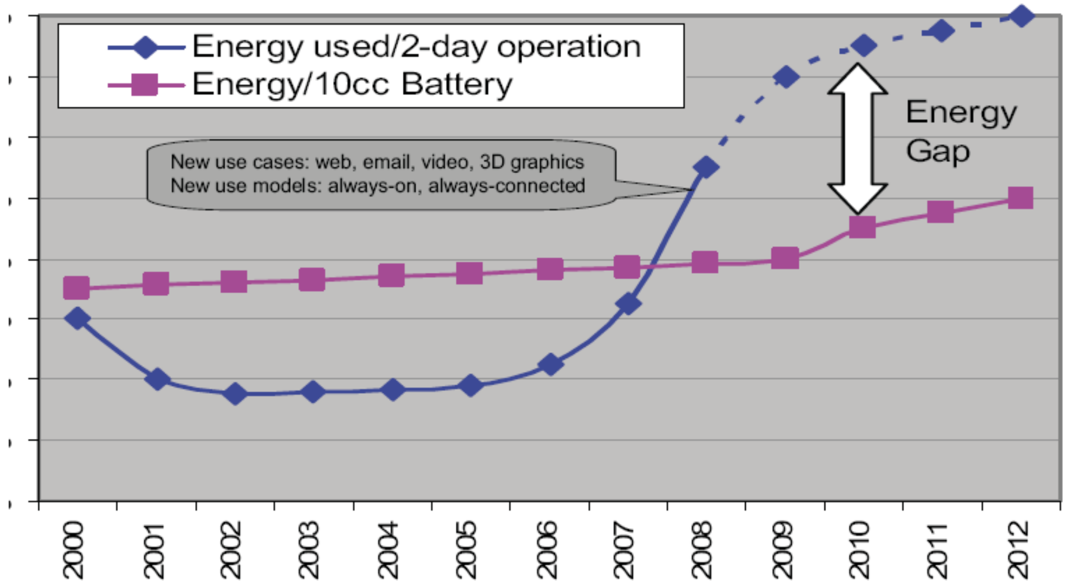
Energy Gap



[Ref: Delagi ISSCC 2010]

The Most Important Engineering Challenge of our time

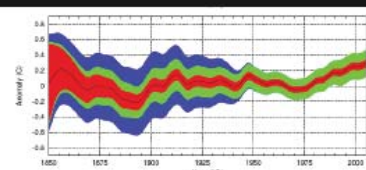
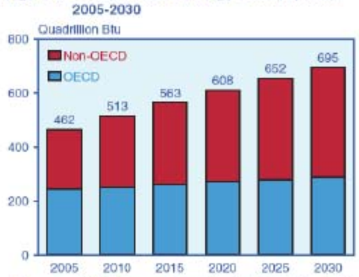


Figure 12: Global average of land and marine components of HadCRUT3. (°C); Land (top), Sea (middle) and difference (Land-Sea, bottom). The solid black line is the best estimate value, the red band gives the 95% uncertainty range caused by station, sampling and measurement errors; the green band adds the 95% error range due to limited coverage; and the blue band adds the 95% error range due to bias errors.

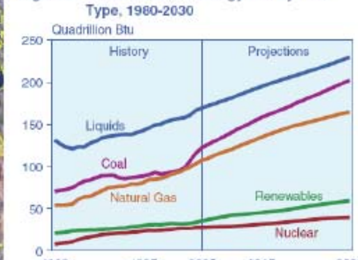
P Brohan, et. Al.
J. Geophysics 06

Figure 1. World Marketed Energy Consumption, 2005-2030



Sources: 2005: Energy Information Administration (EIA), *International Energy Annual 2005* (June-October 2007), web site www.eia.doe.gov/iea. Projections: EIA, World Energy Projections Plus (2008).

Figure 2. World Marketed Energy Use by Fuel Type, 1980-2030



Sources: 2005: Energy Information Administration (EIA), *International Energy Annual 2005* (June-October 2007), web site www.eia.doe.gov/iea. Projections: EIA, World Energy Projections Plus (2008).

ENERGY DENSITY COMPARISONS

Gasoline	9000 Wh/l	13,500 Wh/Kg
LNG	7216 Wh/l	12,100 Wh/Kg
Propane	6600 Wh/l	13,900 Wh/Kg
Ethanol	6100 WH/l	7,850 Wh/Kg
Liquid H2	2600 Wh/l	39,000* Wh/Kg
150 Bar H2	405 WH/l	39,000* Wh/Kg
Lithium	250 Wh/l	350 Wh/Kg
Flywheel	210 Wh/l	120 Wh/Kg
Liquid N2	65 Wh/l	55 Wh/Kg
Lead Acid	40 Wh/l	25 Wh/Kg
Compr Air	17 Wh/l	34 Wh/Kg
STP H2	2.7 Wh/l	39,000* Wh/Kg

* = uncontained

D. Lancaster,
Blatant Opportunist 02

cadence

3

[Ref: T. Vucurevich SAME 2008]

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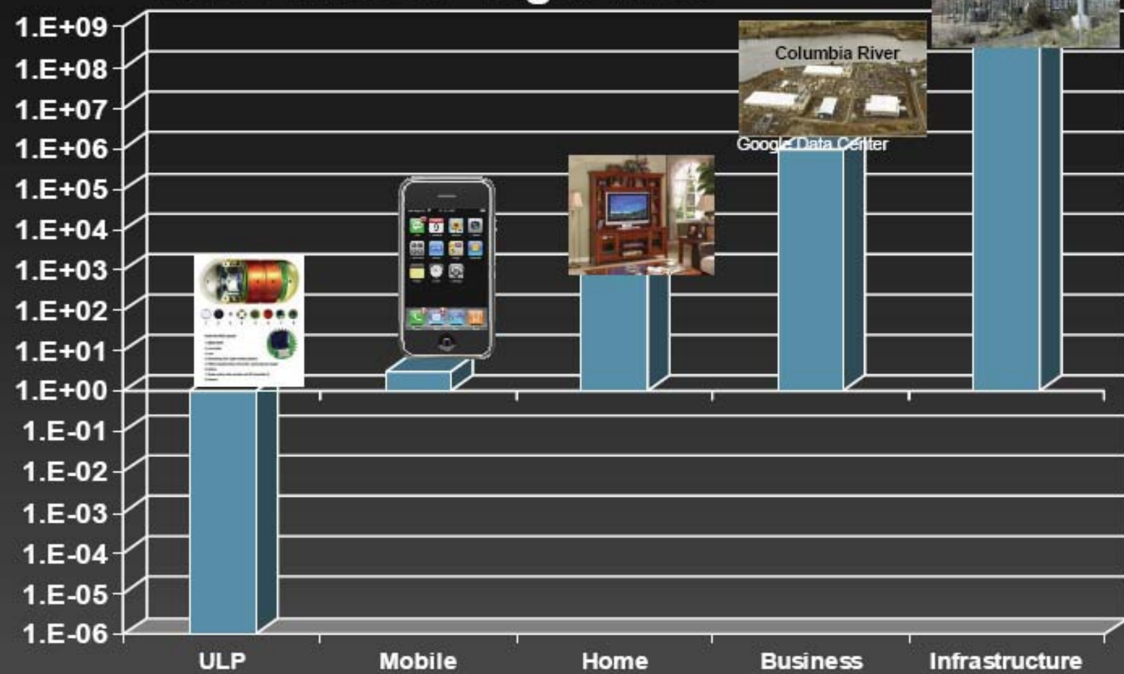
Electronic System Power: Microwatts to GigaWatts



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[Ref: T. Vucurevich SAME 2008]

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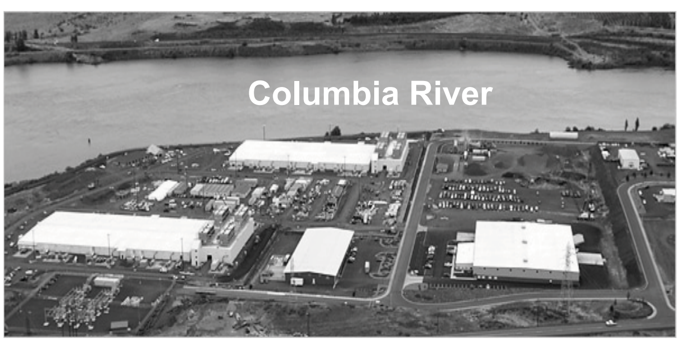
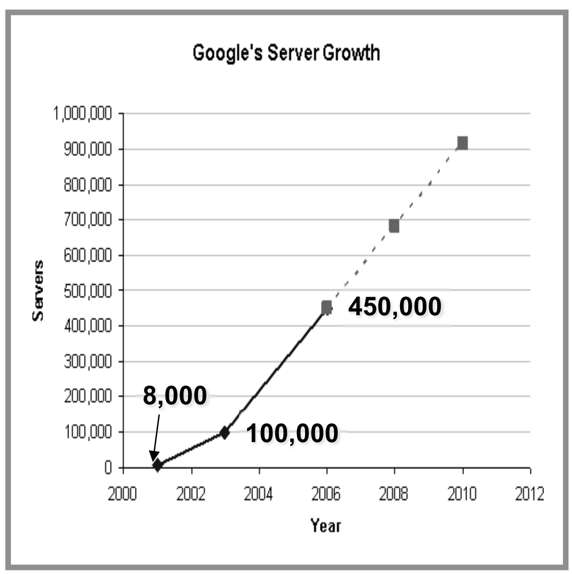
Power the Dominant Design Constraint (1)

Cost of large data centers solely determined by power bill …



Google Data Center, The Dalles, Oregon

NY Times, June 06



- 400 Millions of Personal Computers worldwide (Year 2000)
  - Assumed to consume 0.16 Tera (10^{12}) kWh per year
  - Equivalent to 26 nuclear power plants
- Over 1 Giga kWh per year just for cooling
  - Including manufacturing electricity

[Ref: Bar-Cohen et al., 2000]

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Power the Dominant Design Constraint

[Ref: R. Schmidt, ACEED'03]

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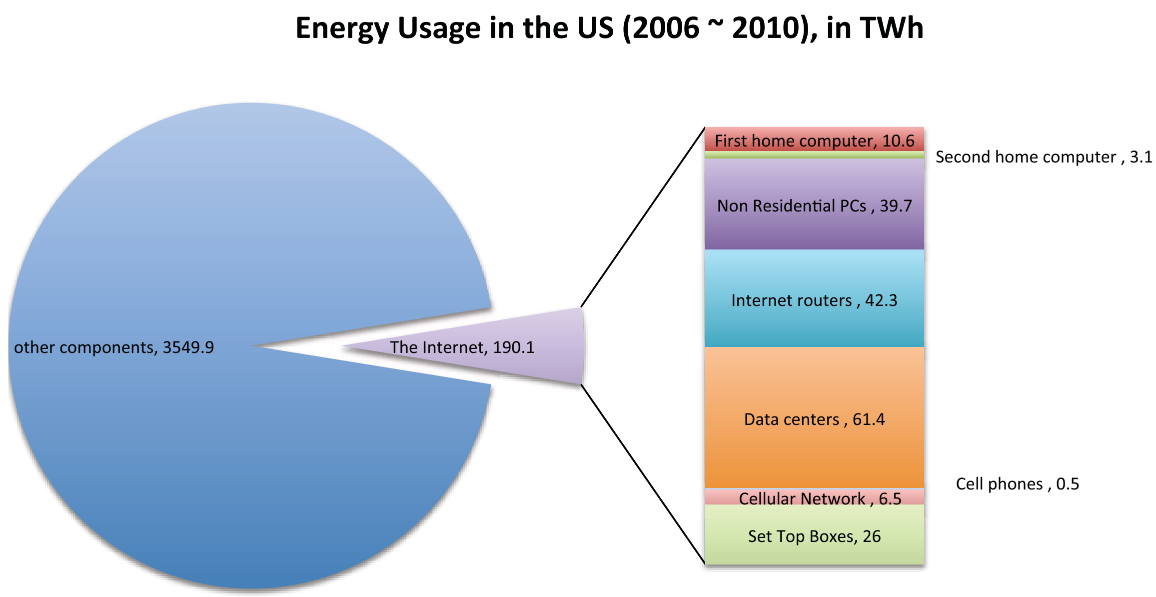
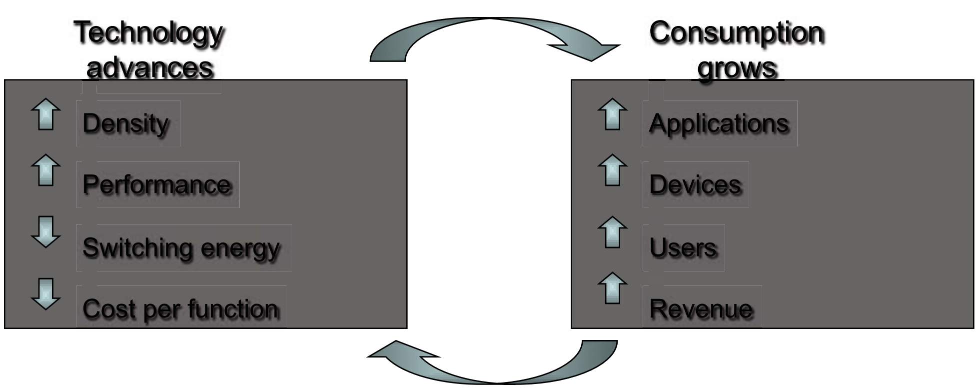
Data Centers Energy Usage

- U.S. Environmental Protection Agency (EPA) Report (August 2007):
  - Data centers consumed about 61 billion kWh in 2006,
    - 1.5 percent of total U.S. electricity consumption
    - Most U.S. data centers spend as much on energy costs as on hardware
    - Data center power/cooling costs increased 800% since 1996.
- NDRC Report (2013)
  - 91 billion kWh in 2013
    - 34 coal power (500MW) plants
    - 2x energy needed for NYC,
    - ~9-10x Lebanon's total electricity production
  - Projected 140 billion kWh in 2020
    - 50 coal power plants
    - ~ 150M metric tons CO_2

Where is the energy used?





APPLICATIONS GROWTH

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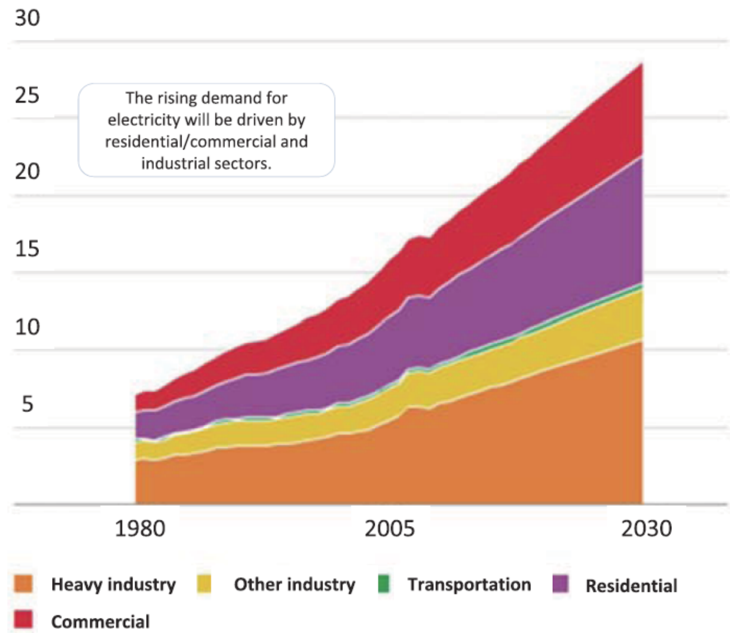
Energy Trends



Source: Papa ISSCC 2012

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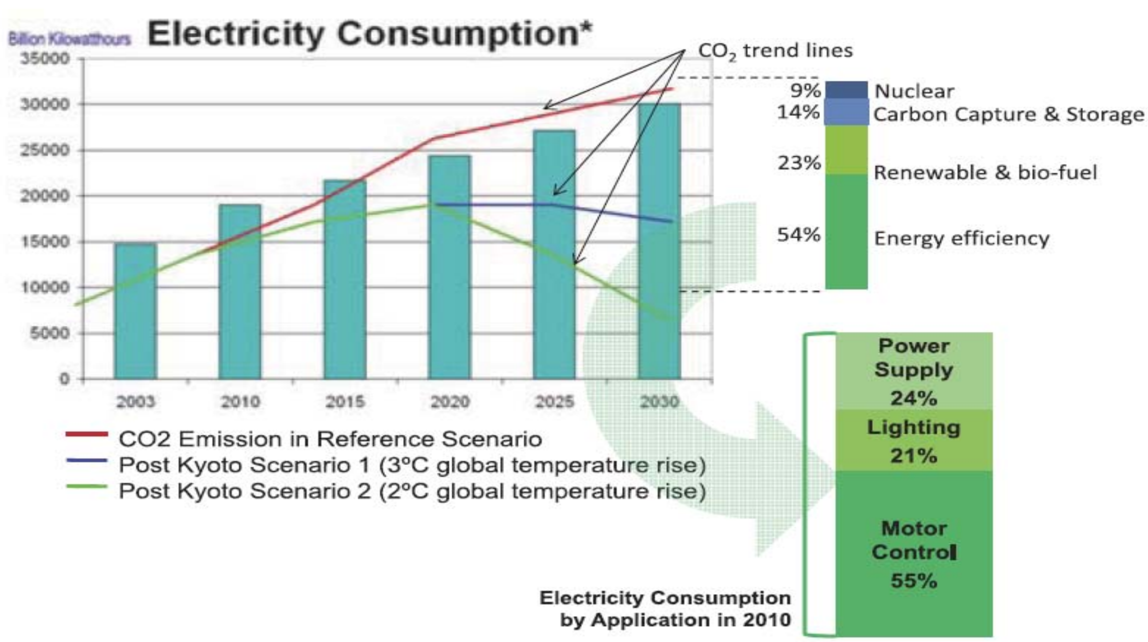
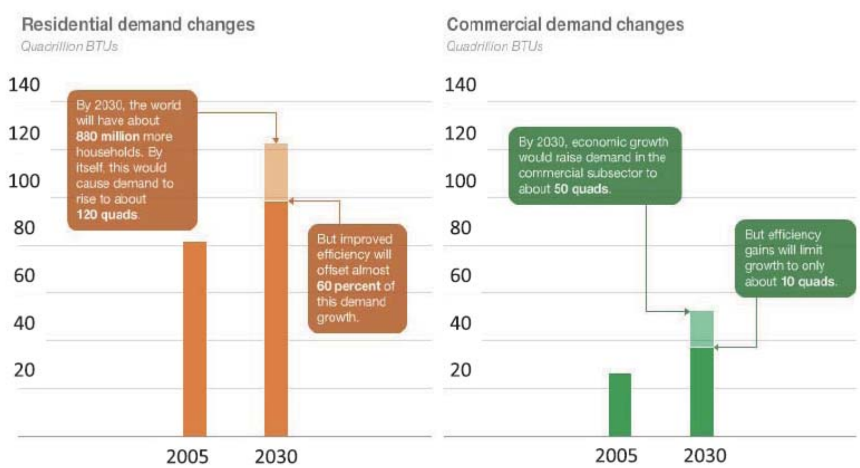
Impact of Energy Efficiency on CO2 Reduction



Source: Papa ISSCC 2012

Residential and Commercial Demand Forecast 2030.



Source: Papa ISSCC 2012

What is a Quad?

Why Worry about Power?

The Tongue-in-Cheek Answer

- Total Energy of Milky Way Galaxy: 10^{59} J
- Minimum switching energy for digital gate (1 electron@100 mV): $1.6\ 10^{-20}$ J (limited by thermal noise)

- Upper bound on number of digital operations: $6\ 10^{78}$
- Operations/year performed by 1 billion 100 MOPS computers: $3\ 10^{24}$
- Energy consumed in **180 years**, assuming a doubling of computational requirements every year (Moore's Law).

Summary

- Power challenge could be Moore's law Achilles' heel
- Microscopically:
  - Higher switching rates increase power density
  - Smaller dimensions increase leakage
  - Higher temperatures affect reliability, leakage
- Macroscopicaly:
  - Consumers expect more functionality (i.e. more power)
  - Cloud computing -> increased energy consumption @ server centers
  - Globally, Environmental, sustainable impacts

[Ref: G. Moore, ISSCC 2004]

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MORE THAN MOORE

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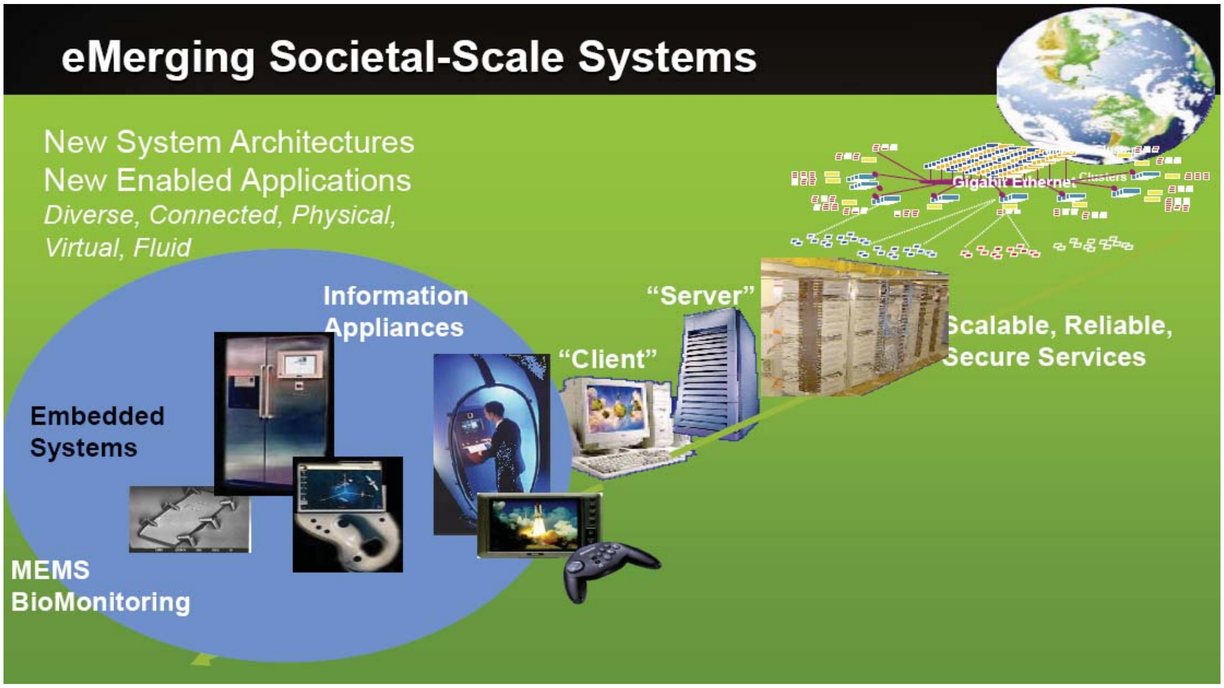


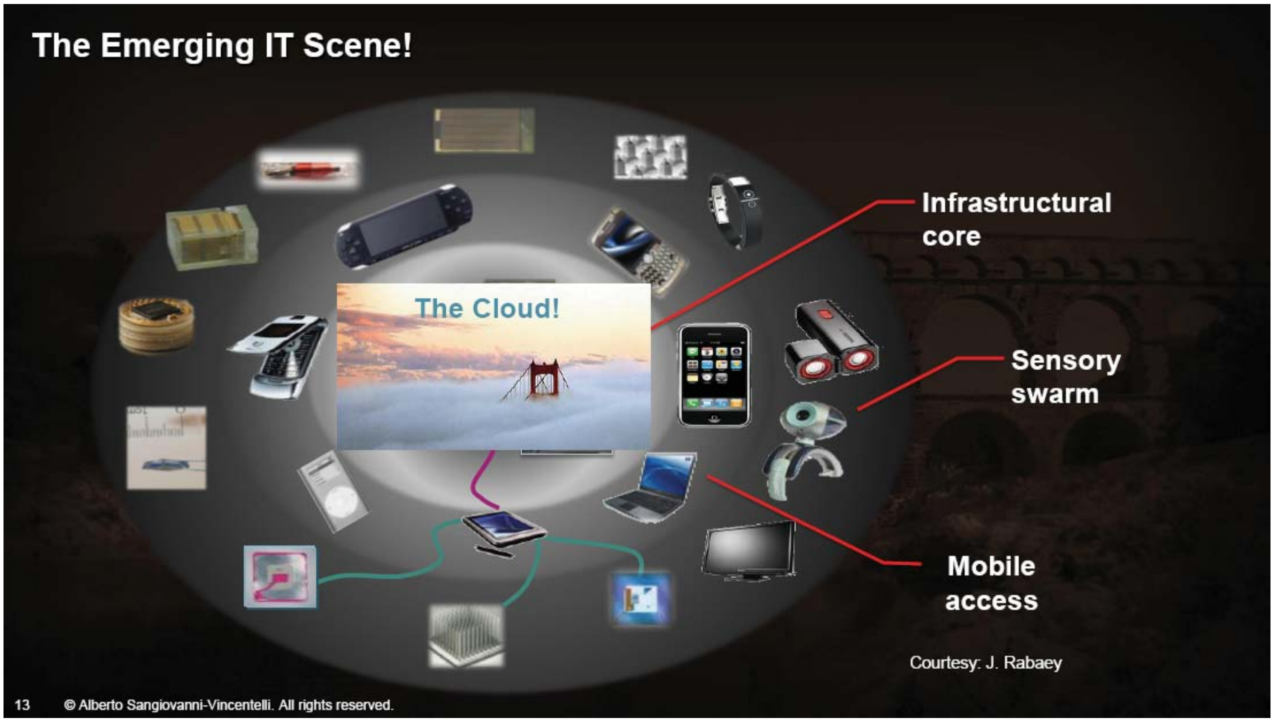
[Ref: Ed Lee et. al

Embedded Systems

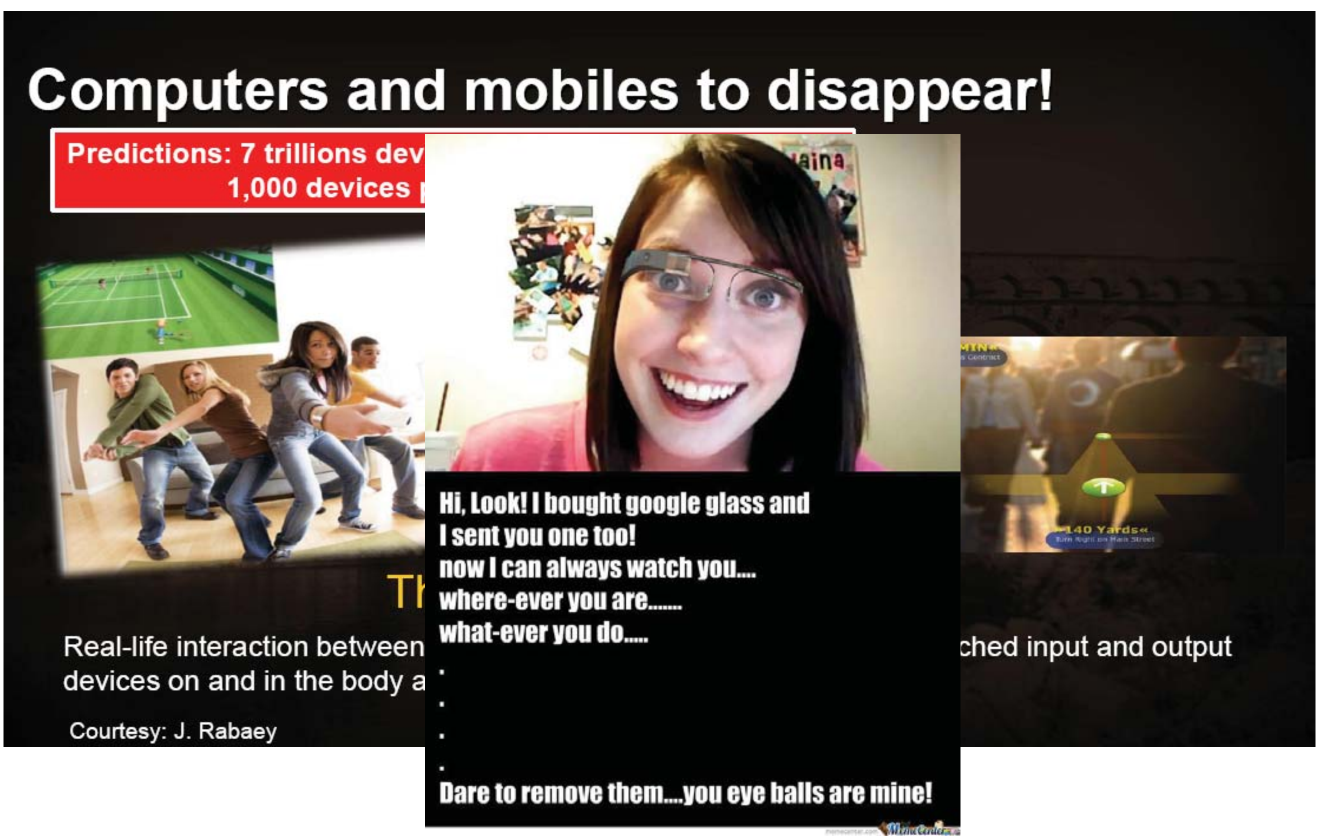
- Computational
  - but not first-and-foremost a computer
- Integral with physical processes
  - sensors, actuators
- Reactive
  - at the speed of the environment
- Heterogeneous
  - hardware/software, mixed architectures
- Networked
  - shared, adaptive

cellular phones

Source: Edward A. Lee



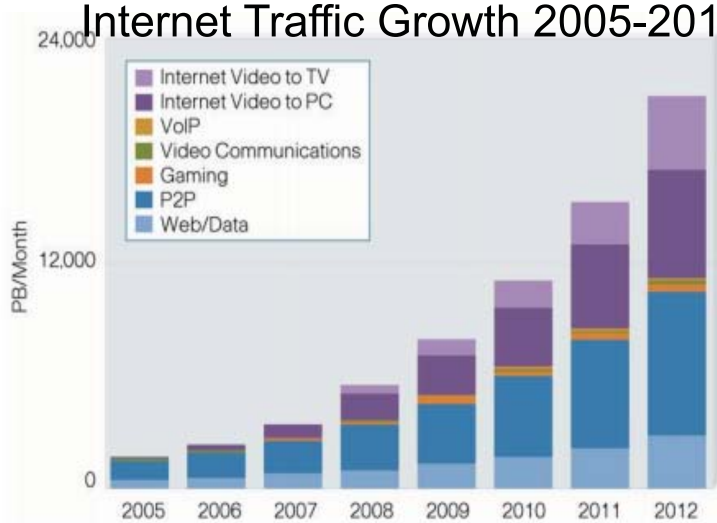
The Emerging IT Scene!
The Cloud!
Infrastructural core
Sensory swarm
Mobile access
Courtesy: J. Rabaey
13
© Alberto Sangiovanni-Vincentelli. All rights reserved.



Computers and mobiles to disappear!
Predictions: 7 trillions dev
1,000 devices p
Hi, Look! I bought google glass and
I sent you one too!
now I can always watch you....
where-ever you are.......
what-ever you do.....
Dare to remove them....you eye balls are mine!
Real-life interaction between
devices on and in the body a
ched input and output
Courtesy: J. Rabaey

Moore's Law has fueled a phenomenal growth in data traffic!

Internet Traffic Growth 2005-2012



Source: Cisco, 2008

What will drive the growth of the Cloud moving forward?

Trends to Watch (Cisco 2014)

- **Applications that might migrate from offline to online (cloud):** e.g. cloud gaming

- **Behavior that might migrate from broadcast to unicast**: Live TV over the Internet would carry a separate stream for each viewer.

- **New consumer behavior**: The adoption of UHD TV

- **Internet of Things**

How big will the cloud get?

Annual global IP traffic will pass the **zettabyte (1000 exabytes)** threshold by the end of 2016, and will reach **1.6 zettabytes** per year by 2018 (Cisco 2014)

Data inflation 2

Unit	Size	What it means
Bit (b)	1 or 0	Short for "binary digit", after the binary code (1 or 0) computers use to store and process data
Byte (B)	8 bits	Enough information to create an English letter or number in computer code. It is the basic unit of computing
Kilobyte (KB)	1,000, or 2^{10}, bytes	From "thousand" in Greek. One page of typed text is 2KB
Megabyte (MB)	1,000KB; 2^{20} bytes	From "large" in Greek. The complete works of Shakespeare total 5MB. A typical pop song is about 4MB
Gigabyte (GB)	1,000MB; 2^{30} bytes	From "giant" in Greek. A two-hour film can be compressed into 1-2GB
Terabyte (TB)	1,000GB; 2^{40} bytes	From "monster" in Greek. All the catalogued books in America's Library of Congress total 15TB
Petabyte (PB)	1,000TB; 2^{50} bytes	All letters delivered by America's postal service this year will amount to around 5PB. Google processes around 1PB every hour
Exabyte (EB)	1,000PB; 2^{60} bytes	Equivalent to 10 billion copies of *The Economist*
Zettabyte (ZB)	1,000EB; 2^{70} bytes	The total amount of information in existence this year is forecast to be around 1.2ZB
Yottabyte (YB)	1,000ZB; 2^{80} bytes	Currently too big to imagine

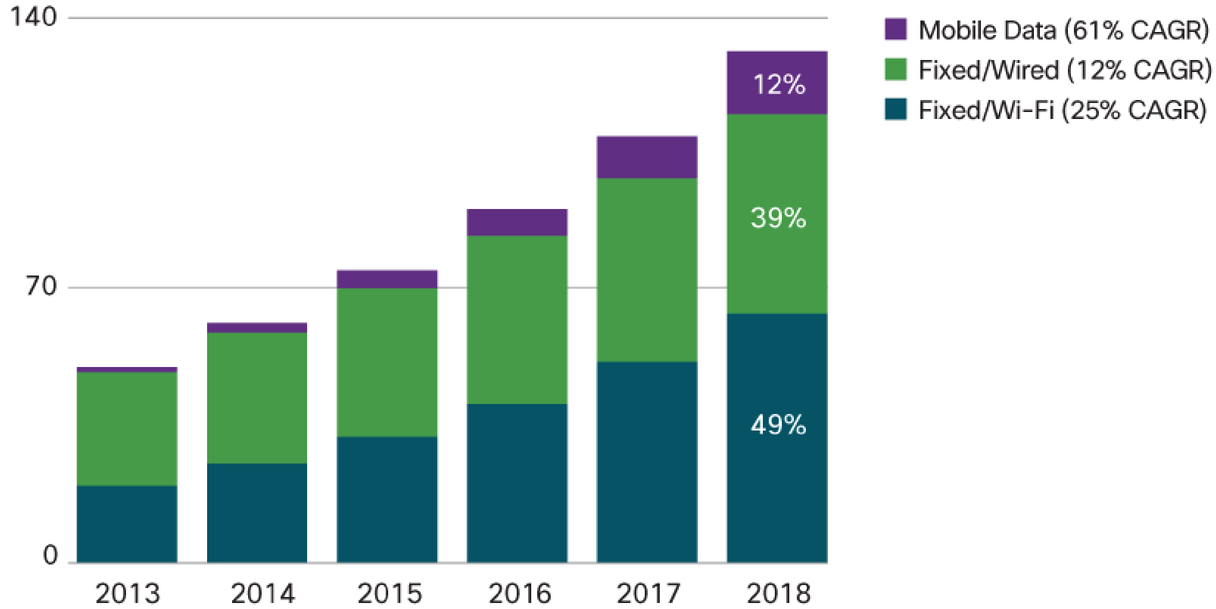
Source: *The Economist*

The prefixes are set by an intergovernmental group, the International Bureau of Weights and Measures. Yotta and Zetta were added in 1991; terms for larger amounts have yet to be established.

Video Dominates the Internet Traffic

The sum of all forms of IP video, which includes Internet video, IP VoD, video files exchanged through file sharing, video-streamed gaming, and videoconferencing, will continue to be in the range of 80 to 90 percent of total IP traffic. Globally, IP video traffic will account for 79 percent of traffic by 2018. (Cisco 2014)

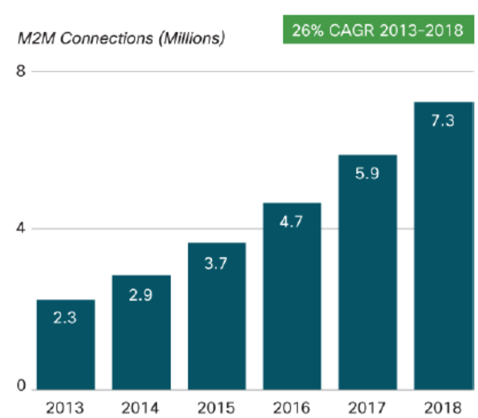
Most traffic will be over Wireless

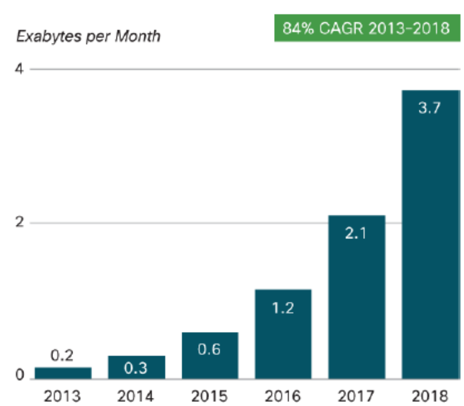


M2M Growth Drives the Reality of Internet of Everything

- Globally, M2M connections will grow *threefold*. ~ 1 M2M connection/person by 2018.
  - **video surveillance**,
  - smart meters,
  - smart cars,
  - asset and package tracking,
  - chipped pets and livestock,
  - digital health monitors.
- M2M IP traffic will grow *11-fold* (2.8% of global IP traffic).
- **The higher traffic growth than connections growth is due to more video applications** , that require higher bandwidth and lower latency**,** such as:
  - **video surveillance**
  - Telemedicine
  - smart car navigation.

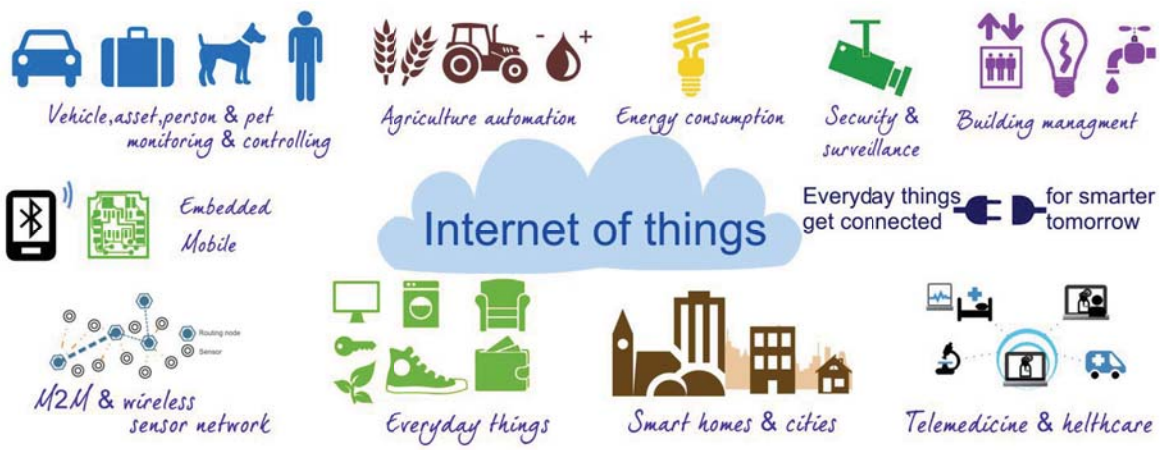
These applications are enabled by the Internet of Things



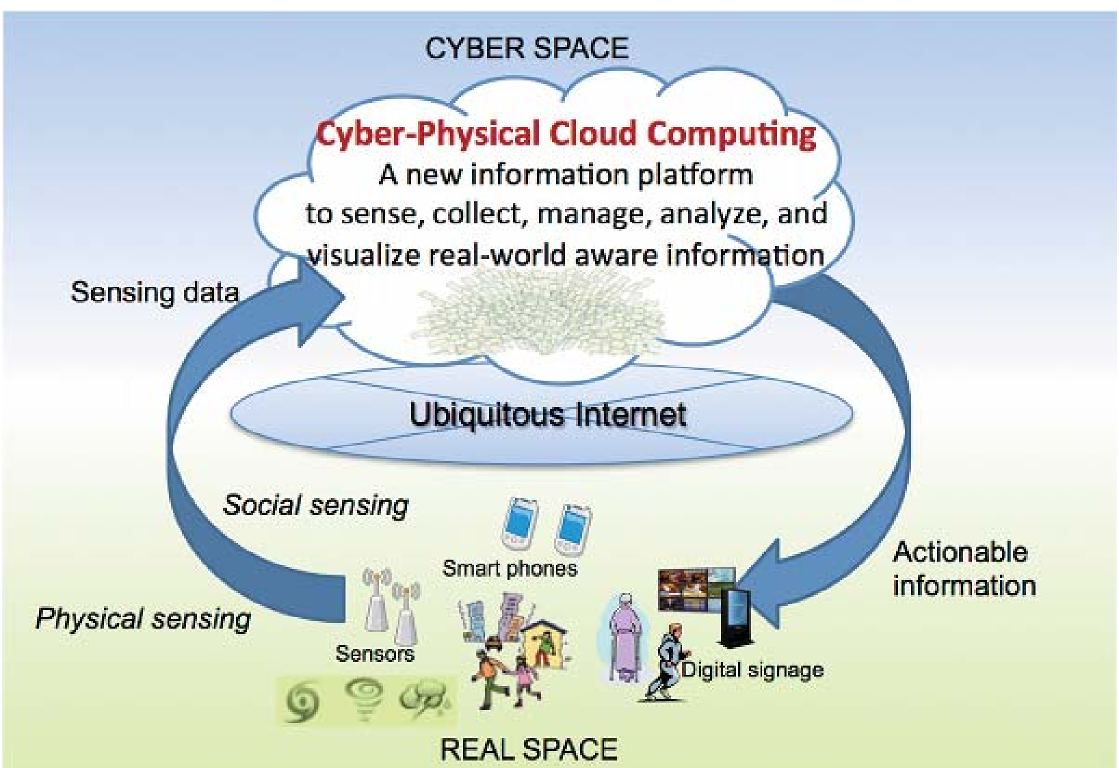


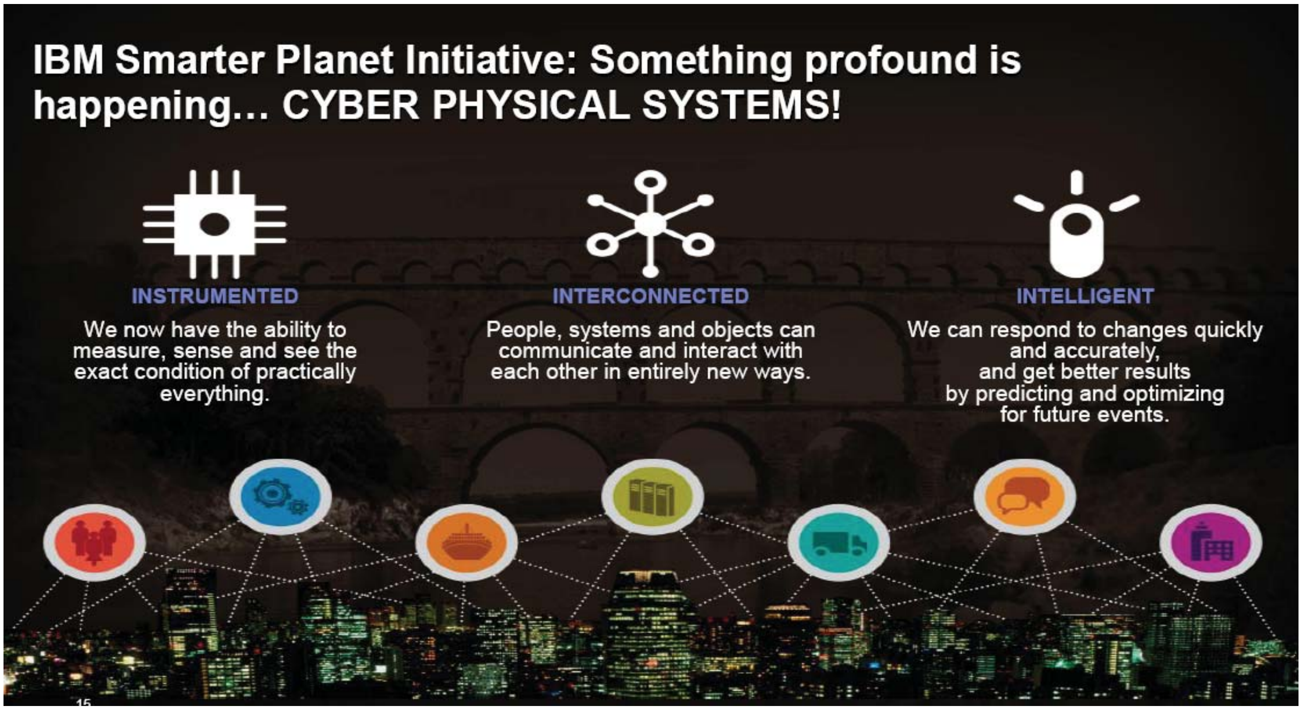
Source: Cisco VNI, 2014

Internet of Things



Cyber-Physical Systems: The Driver for IoT





[Ref: IBM 2010

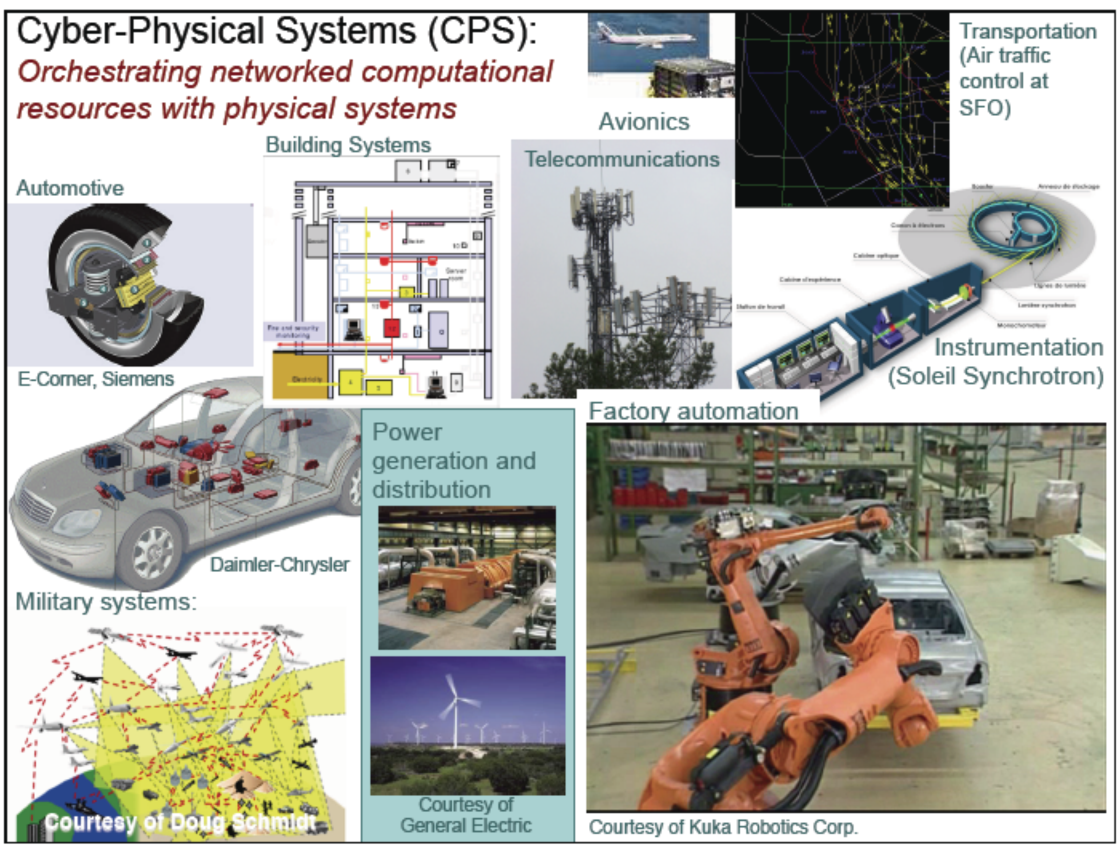
Vision 2025

- Integrated components will be approaching molecular limits and/or may cover complete walls
- Every object will be smart
- The Ensemble is the Function!
  - Function determined by availability of **sensing, actuation, connectivity, computation, storage and energy**
- Collaborating to present unifying experiences or to fulfill common goals

A humongous networked, distributed, adaptive, hierarchical control problem

[Ref: IBM 2010

[Ref: Ed Lee et. al



[Ref: Ed Lee et al

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IoT size estimates (2020)

Source	# IoT (B)	Economy ($T)	Data	comments
IDC	25	4	50 ZB?	
IBM	212 Installed/30B connected	8.9	3 ZB	excludes surveillance/ streaming data
CISCO	50	14.4	>1 ZB	
GE		10-15		
Intel	200	6.2		
HP	1000	2-6		by 2025
Goldman Sachs	28			

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Some Applications of CPS

- Manufacturing: smart production equipment, processes, automation, control, and networks; new product design
- Transportation: intelligent vehicles and traffic control, intelligent structures and pavements
- Infrastructure: smart utility grids and smart buildings/ structures
- Health Care: body area networks and assistive systems
- Emergency Response: detection and surveillance systems, communication networks, and emergency response equipment

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