Past 25 Years and the Next 25 years of Electronics

Reality, Dreams, & Engineering in a Changing World

Cornell University

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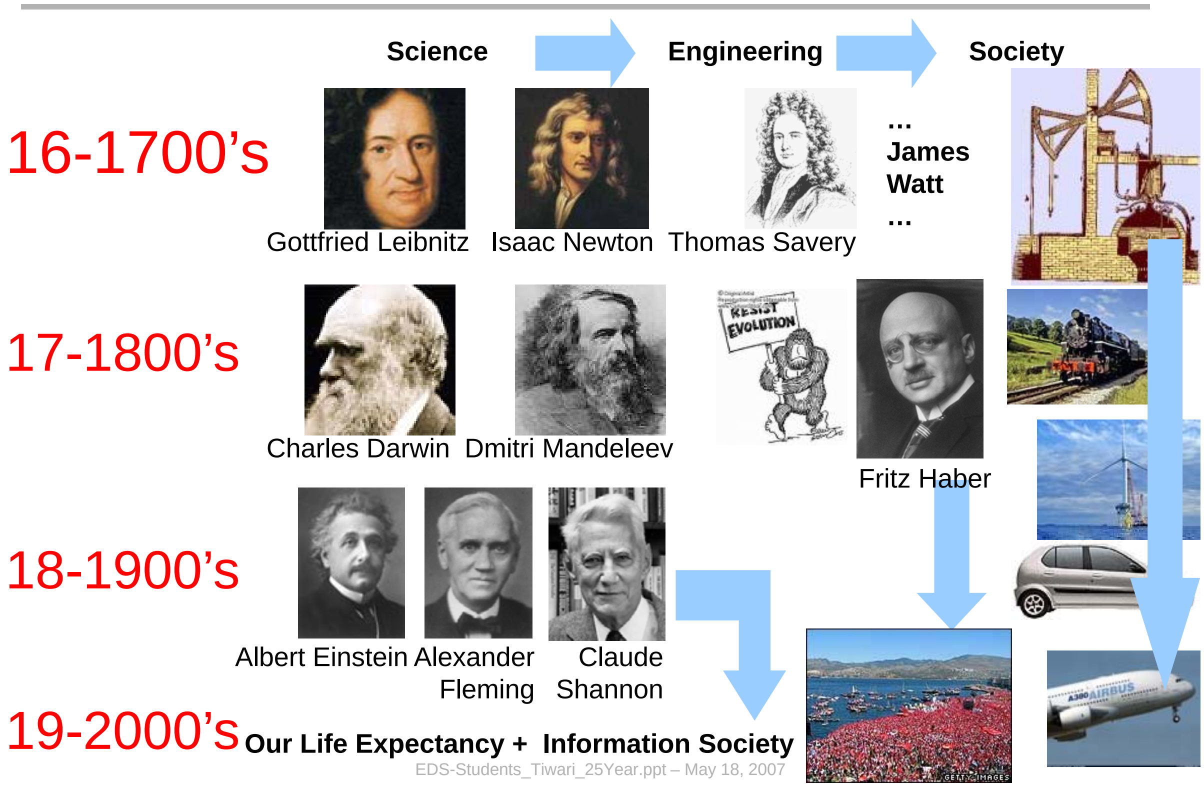
Science -> Engineering -> Society



Information Revolution

Burgundy color:
Where Electrosciences plays

Science

Correlated Electron States – 1980s
Scanning Tunneling Microscopy – 1980s
Single-electron effects – 1960s
Semiconductor Tunneling – 1950s
BCS Theory of Superconductivity – 1957
Electron Microscopy – 1930
Electronic States in Crystals – 1920
Wave Nature of the Electron – 1927
Quantum Mechanics – 1920s
X-Ray Diffraction – 1911
Magnetoresistance - 1856

Technology

Giant Magnetoresistance – 1990s
Single-electron and Quantum-Effect
Memories – 1990s
Quantum-Well Lasers – 1980s
Large Scale Computation – 1970s
Hetero-Semiconductor Laser – 1970s
Laser – 1960's
Integrated Circuit – 1950's
Transistor – 1947
Vacuum Tubes – 1910's
Telephony - 1876

Computing
Business and scientific computers, personal computers, optical and magnetic storage, liquid crystal displays

Communications
Information superhighway, cellular phones, satellite communications, high capacity fiber optic cables

Security
Advances in communications, command and control, sensors, weapon systems, mobile electronics

Energy
Photovoltaics, sensors, light-weight motors, high performance transformers

Transportation
Automotive electronics, sensors, avionics, air-traffic control

Entertainment
Consumer electronics

Medicine
Lasers, medical imaging, sensors

Based on National Academy Report

A Timeline

?

1964

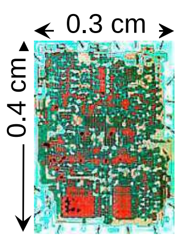
IBM 360

Semiconductors
Reliability

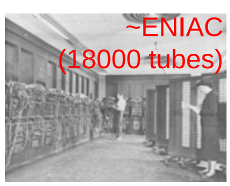
Programming:
Virtual machine and
common software

1971

Intel 4004



2300 Tx
10000 nm



Integration

1981

Micro/PC/Risc

Integration
System Compaction

Reduced Complexity
in Programming-
Hardware

Cellphones, iPods, …

Low power
Signal processing
Leverage from integration
Software-hardware optimization

Parallelized Supercomputers

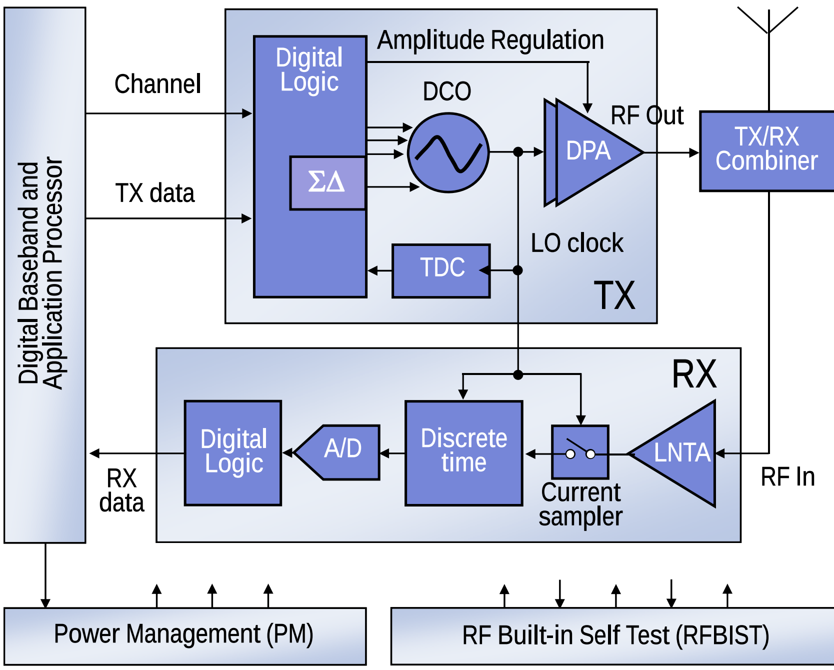
Multi-processor chips
Network switches
Reduced power-embedded memory

Integration

An Inflection Point
arising from
underlying science

Scales, Energies
& Small

Software Radios

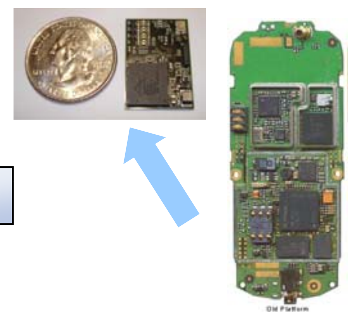


Global Context
0.2, 1.25, 2.5,5,
10, 15, 20MHz BW

450, 800, 900,
1800, 1900, 2100,
2500, 3400MHz
Transmission bands

GMSK, QPSK,
8-PSK, 16QAM,
64QAM Modulation

TDMA, FDMA,
CDMA, OFDMA,
IFDMA schemes



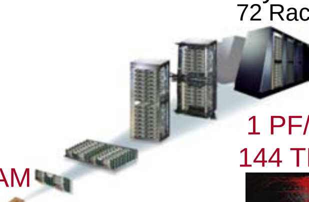
Source: TI

"Current Big Computing Models"

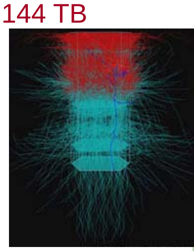
Boxed

BlueGene/P

Chip
4 processors
13.6 GF/s
8 MB EDRAM



System
72 Racks
1 PF/s
144 TB



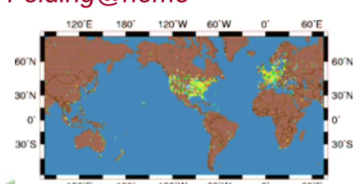
73,000 quad-core compute chips
Network: Torus(64x32x32; 6GB/s) & Tree (2GB/s)

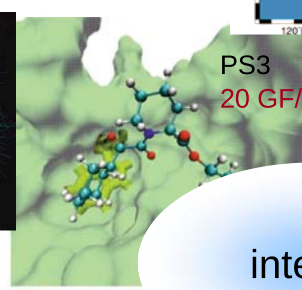
Performance/Watt and /sq.foot not /Processor
2.5 MW

73000 x 150x10^6 = ~10^13 transistors

Distributed

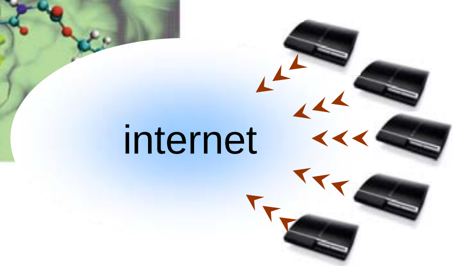
Folding@home





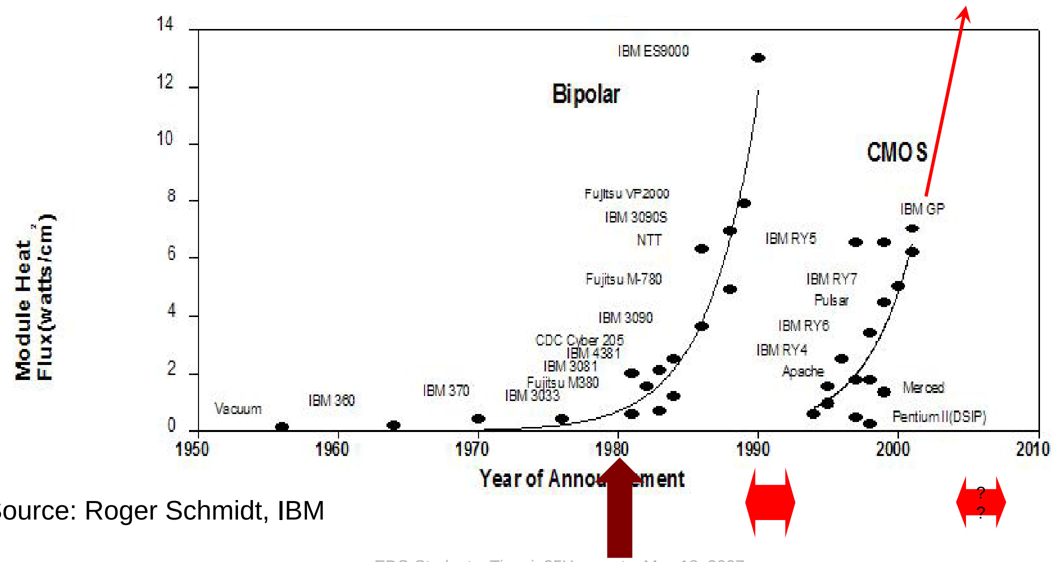
PS3
20 GF/s

1 PF/s
via 200,000 PS3's



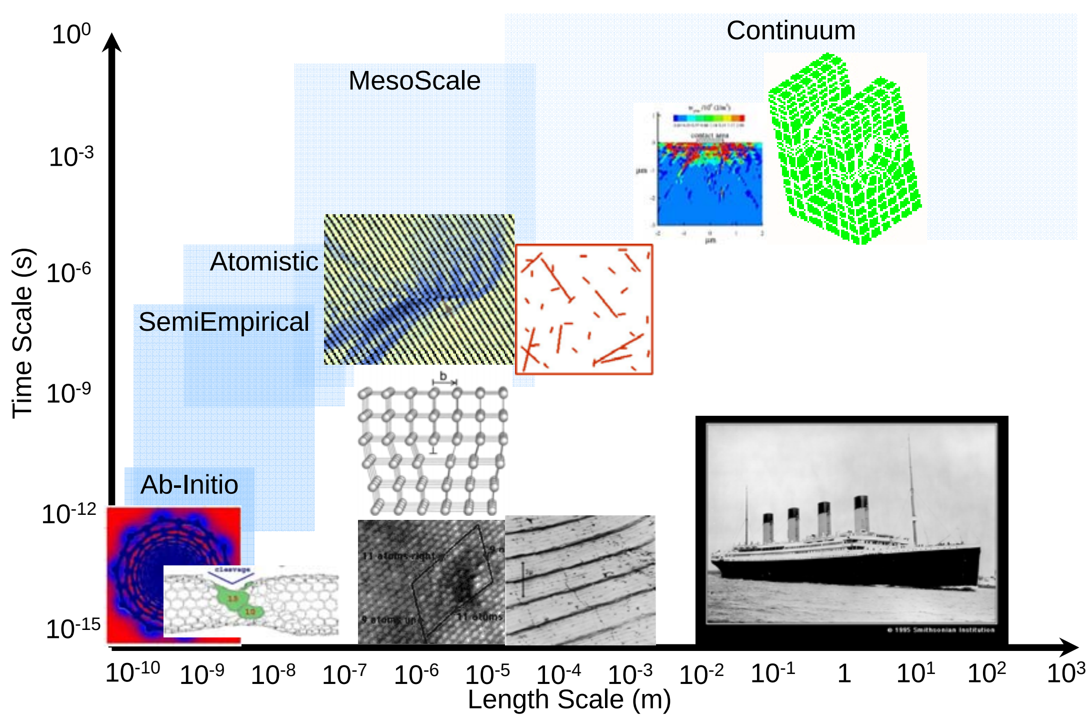
200,000 x 380 = ~76 MW
200,000 x 235x10^6 = ~4x10^13 transistors

Power & Energy in Computing



Source: Roger Schmidt, IBM

The Sinking of RMS Titanic!



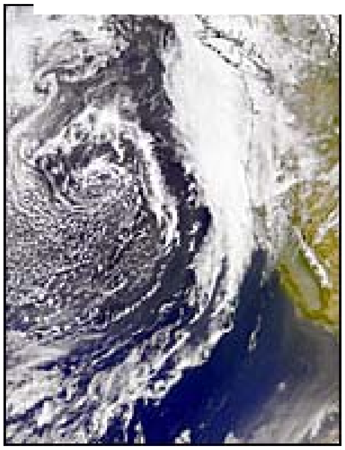
Connections of Scale

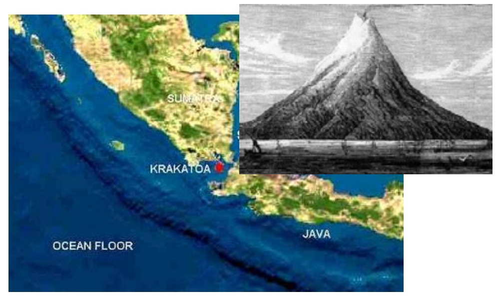
Sci/Tech > Environment
from the May 17, 2007 edition

Small particles' big impact on climate

Dust and soot from Asia create air pollution in California, but also temper global warming and may stymie hurricane formation. Scientists are taking a look.

By Peter N. Spotts | *Staff writer of The Christian Science Monitor*

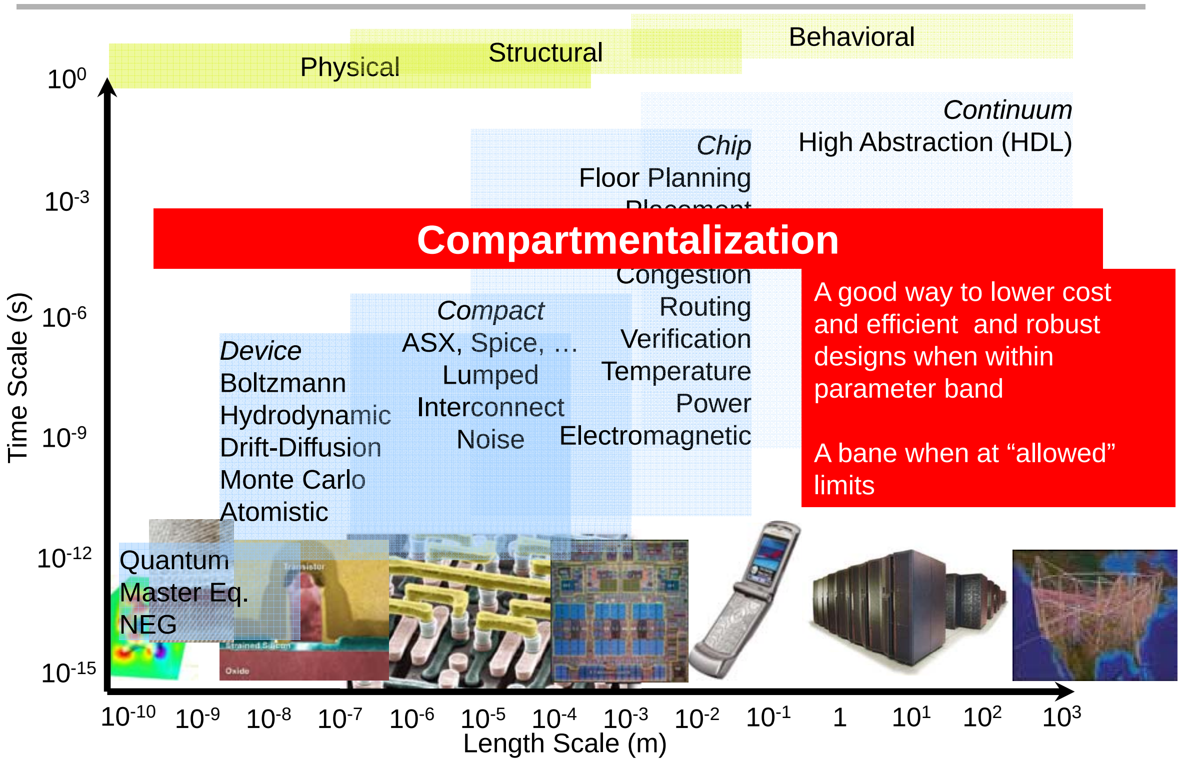




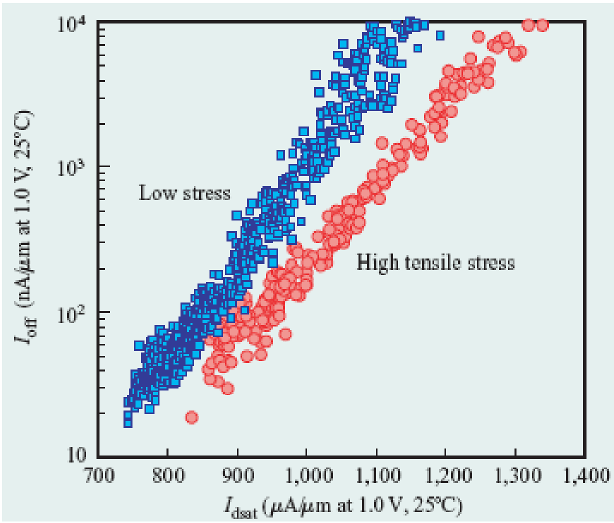
Krakatoa's Activity. Even a single major volcanic outburst adds so much dust to the atmosphere that it reduces the amount of sunlight reaching the earth's surface; the result can be a brief but noticeable cooling of global climate. After the eruption of Krakatoa in 1883, for instance, unusually cool weather was reported in many parts of the world for several years. The evidence is still preserved in the annual growth rings of old trees. Only recently, scientists at the University of Arizona's tree-ring laboratory discovered disturbed rings in California trees, dating back to 1884, that showed the trees had experienced a hard freeze that year. The scientists strongly suspect that the unusually cold California weather was linked to Krakatoa's eruption a year earlier.

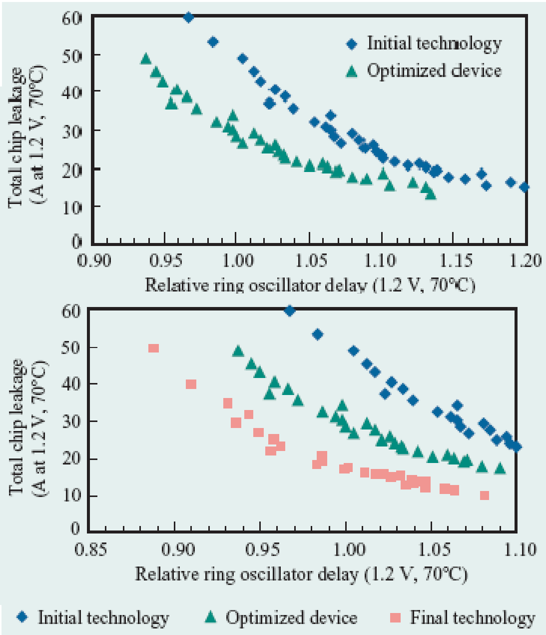
Traveling particles: 2001 NASA satellite image of dust arriving in California from Asian deserts. SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE

Electronics



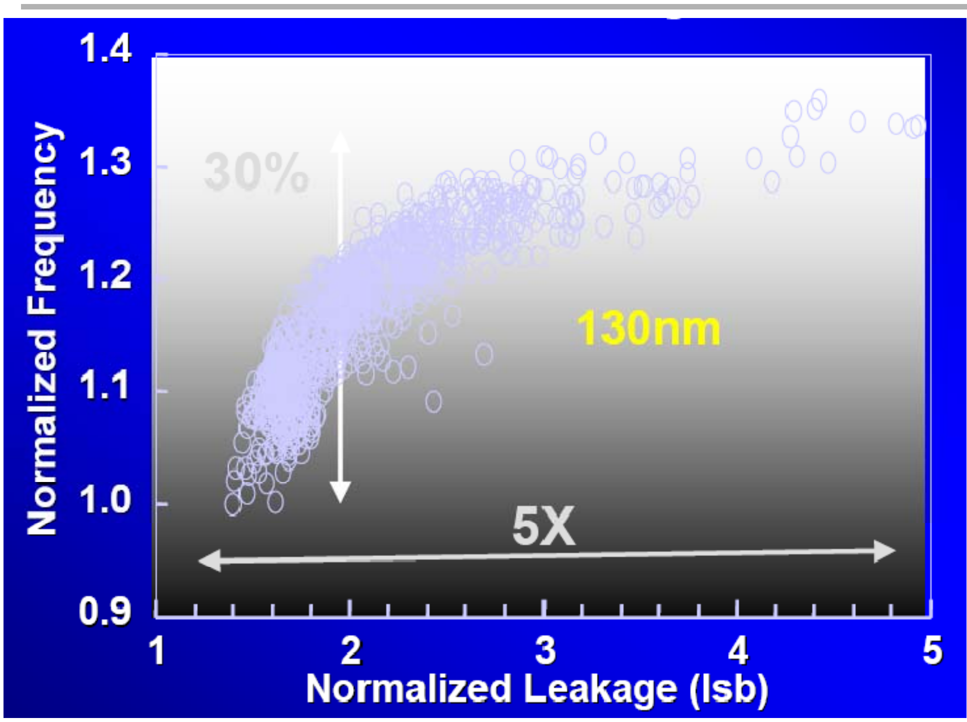
Nano-Scale in Computing





Source: Poindexter et al. IBM J R&D (2007)

Variability

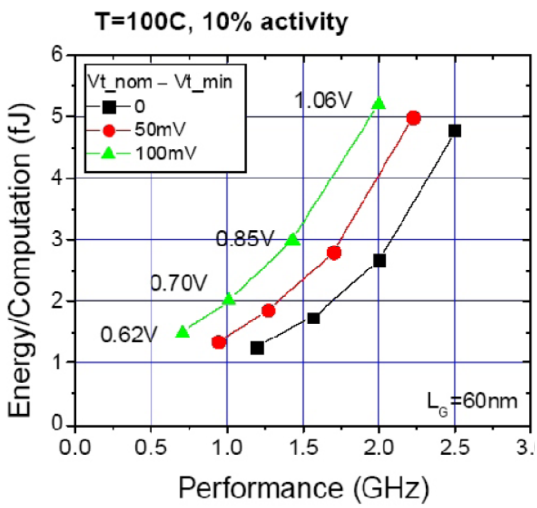


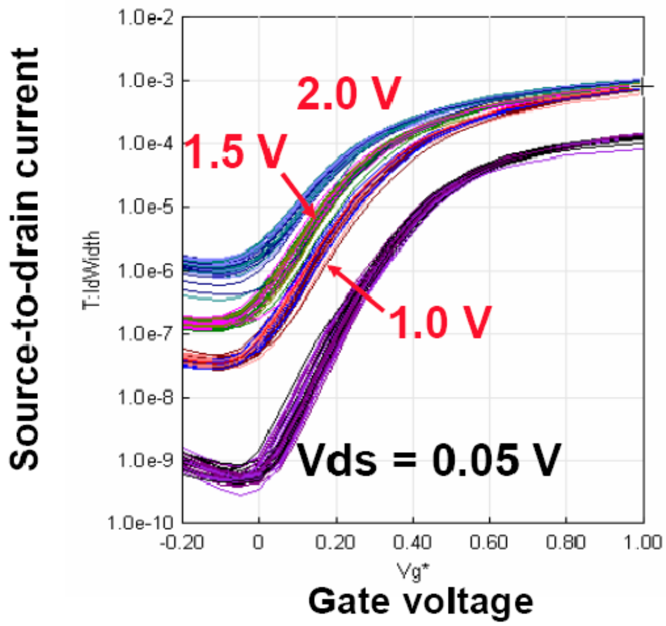
30% in frequency

5x in leakage

Borkar (2007)

Process Variability – Energy at Nanoscale





Source: Dennard (2005)

Stochastic Variance of Nanoscale

	10 nm	5 nm	3nm	1 nm
3D: Bandgap, Threshold, Junctions, Capacitances, …				
$\bar{n}$	~28,000	~3,500	~750	~28
$\sigma(n)/\bar{n}$	0.6%	1.7%	3.7%	19%
2D: Inversion Charge, Interface Defects, Contacts, …				
$\bar{n}$	920	230	83	9
$\sigma(n)/\bar{n}$	3.3%	6.6%	11%	33%
1D: Wire Resistance, Wire Defects, Molecular Contacts, …				
$\bar{n}$	30	15	9	3
$\sigma(n)/\bar{n}$	18%	26%	33%	57%

- Yield of chain: $Y = (1 - p_f)^m$ where p_f is failure property of each element

From DOE Reports

Edvard Munch

Nearly 13% of electricity is used for computers and peripherals

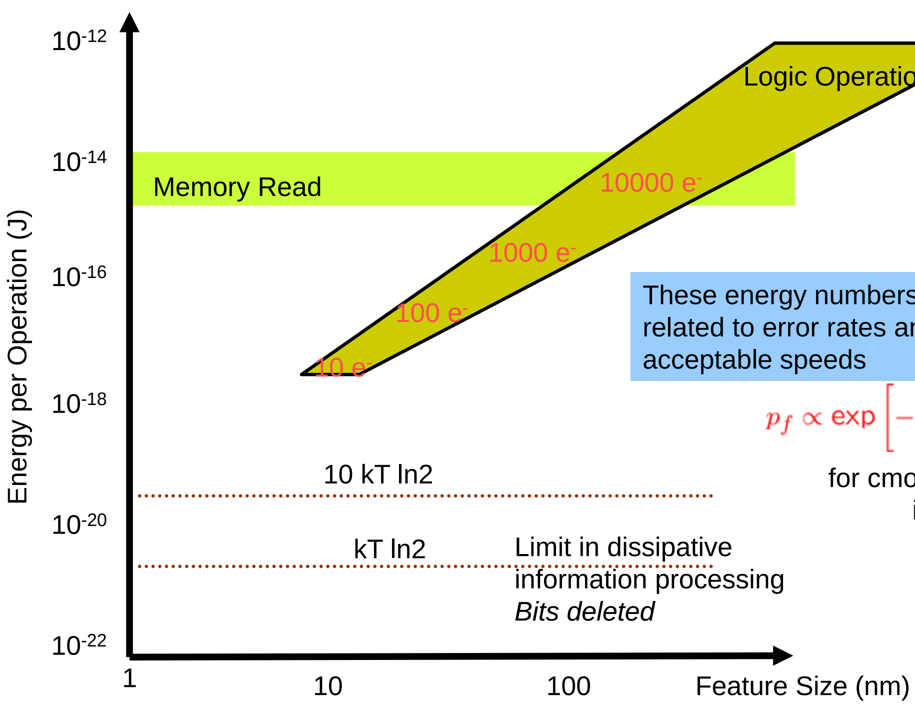
39% of primary energy input goes towards generating electricity

69% of this electrical energy is lost in transmission and inefficiencies

72% of this electrical energy is generated by greenhouse emission processes

We should care!
We are responsible.

Energy per Operation



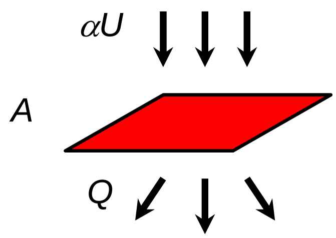
These energy numbers are related to error rates and acceptable speeds

$$p_f \propto \exp\left[-\frac{2V_{DD}}{\sigma(V_T)}\right]$$

for cmos static inverter

Energy: A Fundamental Constraint at Nanoscale

S. Tiwari et al., IEEE Conf. Em. Tech. (2006)



In any approach based on charge transport and change in electromagnetic fields
Power /Energy dissipation and heat removal set the fundamental constraints of system operation

$$\tau = \frac{\alpha U}{QA}$$

time constant; α: activity factor; U: energy per operation; A: x-section area of heat removal; Q: density of heat removal

Large collection of devices
Q = 100 W/cm^2
t ~ 5 ns

Individual devices
Q =10^5 W/cm^2
t ~ 5 ps

Error rates are related to energy
CMOS Inverter: *$p_f \sim \exp(-2V_{DD}/\sigma(V_T))$*
Synthesis: *variance ~ $\exp(-\Delta E/kT)$*
ΔE ~ 0.1 eV => $p_f \sim 2 \times 10^{-2}$

Minimum energy: U ~ 1000kT

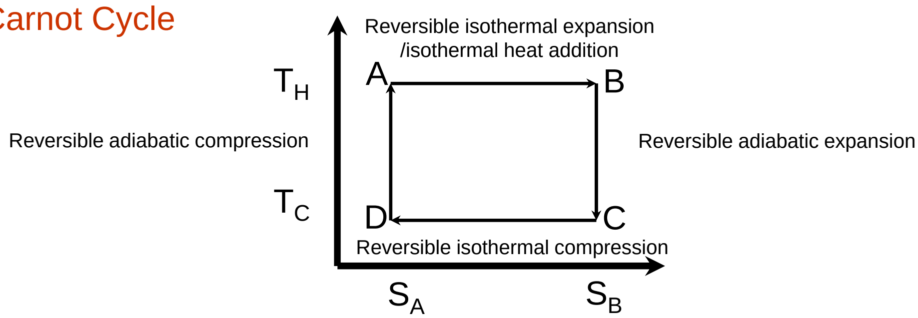
Energy/Power Dissipation

Complexity/Adaptation

Energy, Heat & Work

Gibbs Free Energy $\Delta G \equiv \Delta H - T\Delta S$ Entropy
Enthalpy

Carnot Cycle

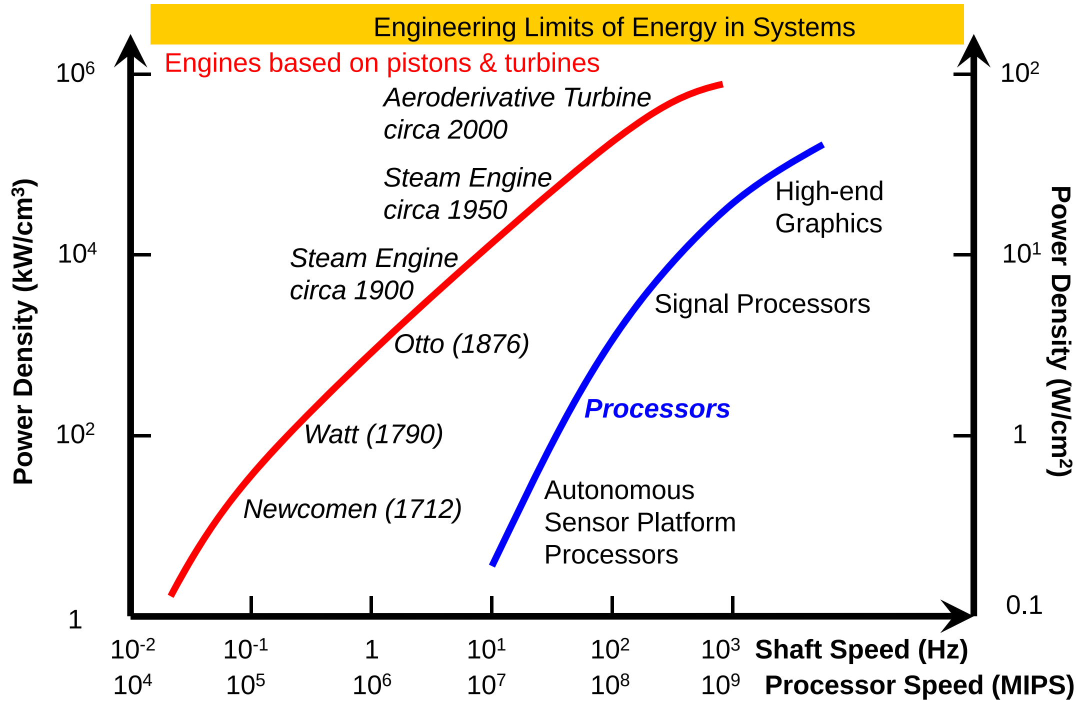


No engine operating between two heat reservoirs can be more efficient than a Carnot engine operating between the same reservoirs

Work Efficiency for Combustion Engine < 30% (typically ~25%)

Work Efficiency for Information Engine too has Constraints

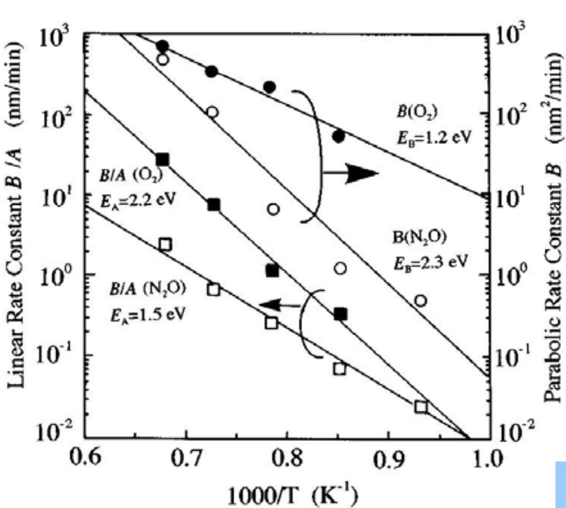
Power Densities



Source for engine data: P.W. Huber & M.P. Mills (2005)

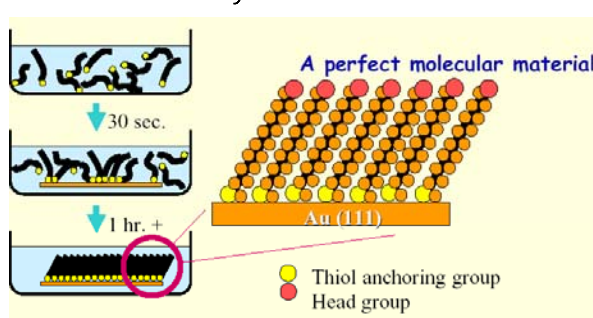
Energy Scales of Processing

Koyama et al. Self Assembly: Oxide Growth



ΔE = 1.5 to 2.5 eV (oxide growth)
ΔE > 2 eV for dopants used

Self Assembly: Molecular Nuzzo et al.



ΔE = 0.1 to 0.5 eV (self-assembly)

Vladiviroma et al.

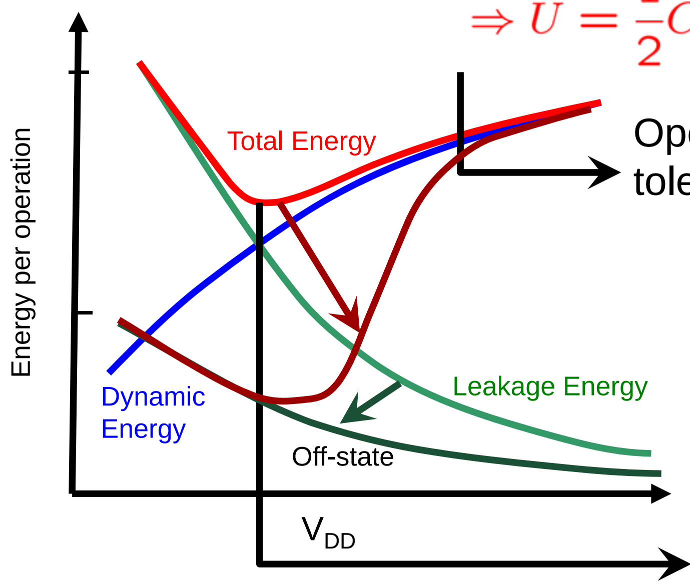
Probabilities proportional to *exp* $(-\Delta E/kT)$
Smaller activation energies lead to larger variance
Short range and long range order

Energy	*Error Rates*
0.1 eV	~2×10^{-2}
0.5 eV	~5×10^{-9}
1.5 eV	~1×10^{-26}

Energy Minimization by Low Voltage Operation

$$P = \frac{1}{2} C_s V_{DD}^2 \alpha f + I_{leak} V_{DD}$$

$$\Rightarrow U = \frac{1}{2} C_s V_{DD}^2 \alpha + I_{leak} V_{DD} \tau_{stage}$$



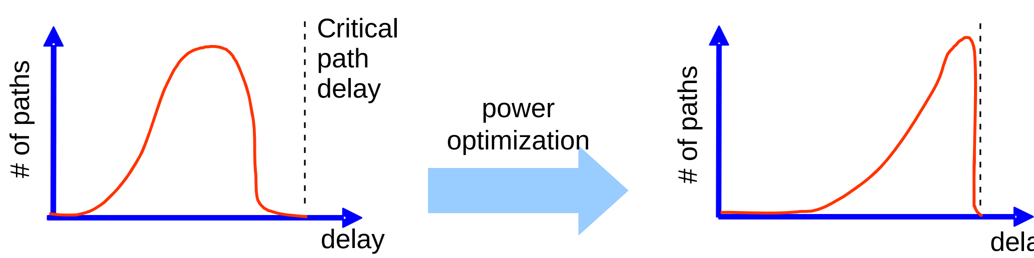
Operating point to assure tolerant operation

Energy consumption has a minimum higher than the minimum operating voltages

S. Hanson et al., IBM J. R&D, 2006

Power and Robustness Conflict

Always correct approach



and now add margins for errors

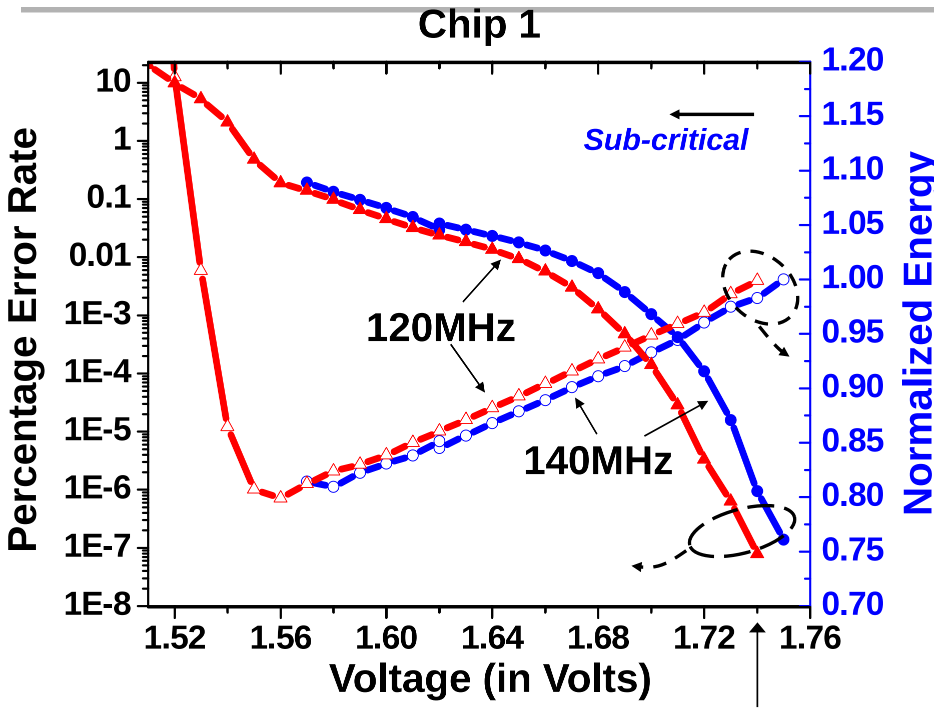
“Let fail and correct”

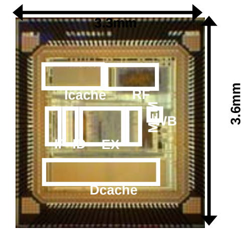
Tune circuit to point of failure, eliminate margins (slow/fast & local/global), tune algorithms that trigger error, apply error correction for uninterrupted operation

Upon failure, overwrite main latches with correct data from shadow latches that are designed to be always correct by conventional design

An example of adaptation
D. Blaauw (UMich)

Using New Design Approaches for Variability: RAZR



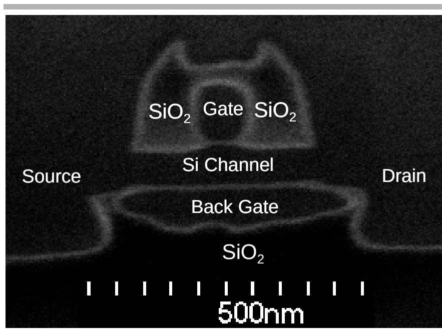


180 nm
1.6M Trx

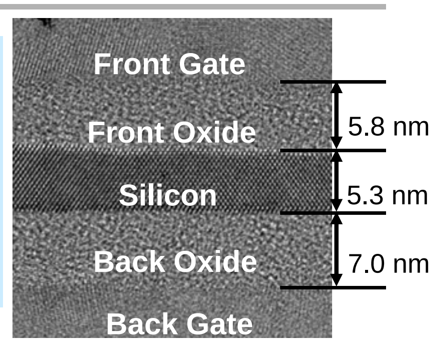
~50% energy reduction from margin-safe design

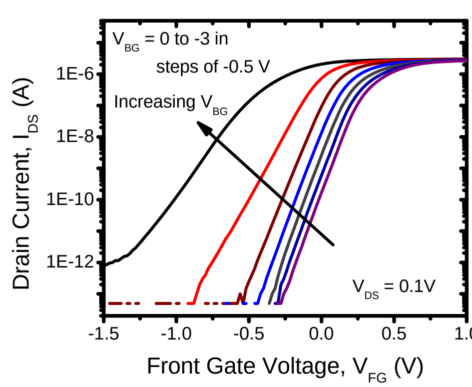
D. Blaauw (UMich)

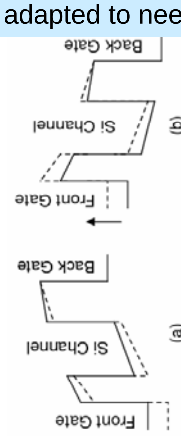
Adaptation

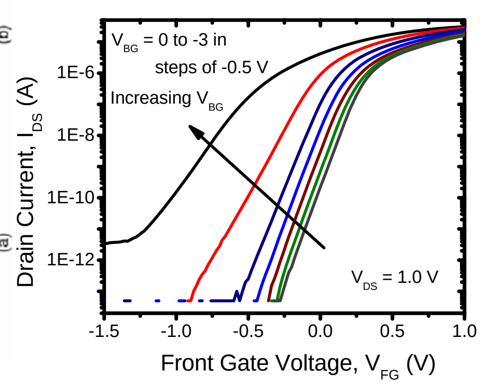


Self-aligned Back-Gate:
A structure where the threshold voltage can be changed so that the device, circuit & system can be adapted to needs.



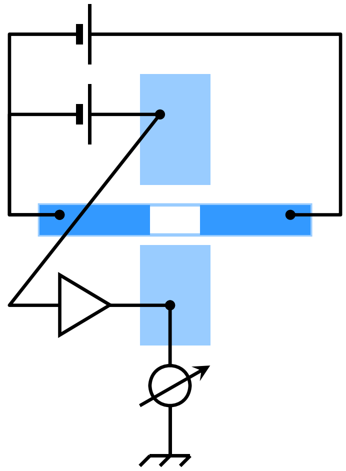


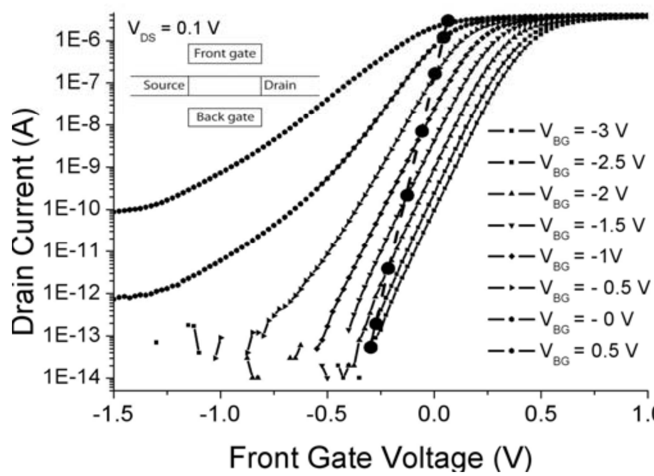




Sub-Threshold Swing

L~ 1 μm

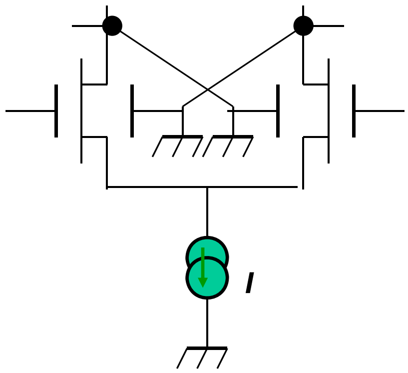




W. Chan et al., (2007)

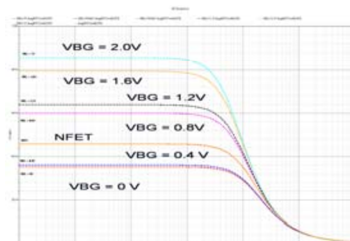
Analog: Dynamic Change in Transistor Strength

Larger gain and drive

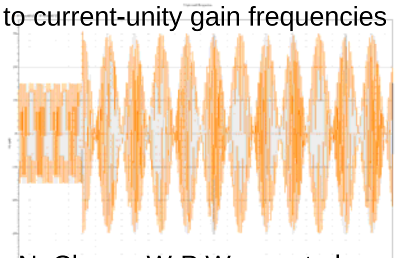


Useful in a variety of places where dynamic drive modulation provides faster response, higher dynamic range, larger bandwidth, and tunability.

High gain transimpedance amplifiers



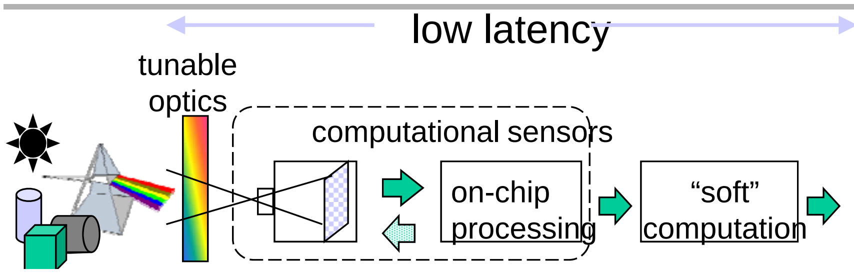
Mixers with spectrally purer output operating up to current-unity gain frequencies



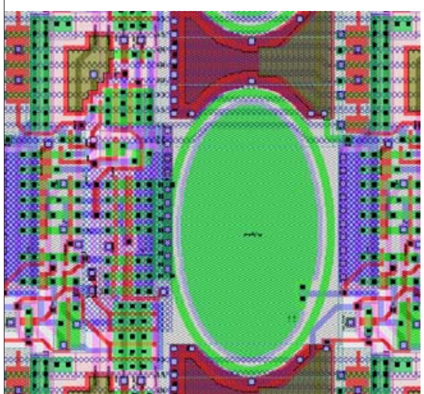
Large tuning range RO for PLLs

Source: N. Chang, W-P Wang, et al.

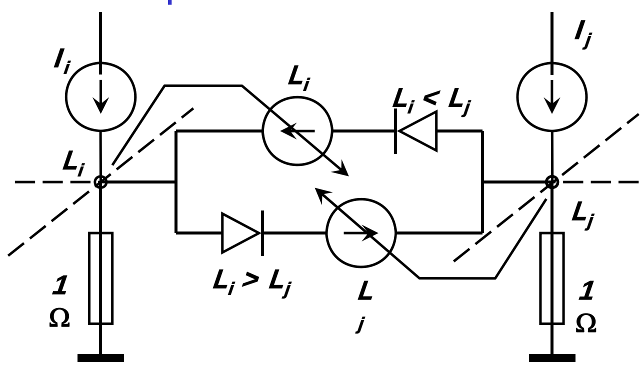
Adaptive Imagers



Vladimir Brajovic
Intrigue Technologies



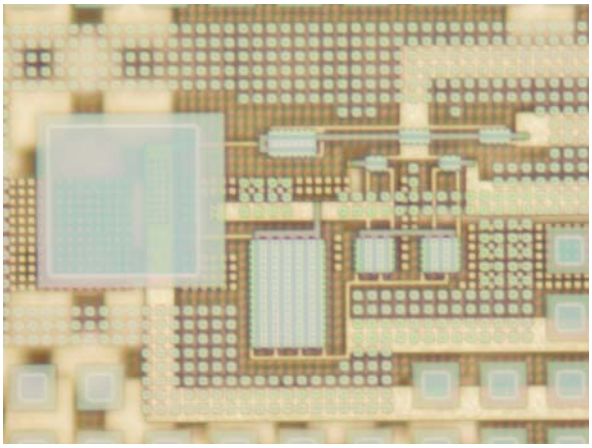
Adaptive Pixel-to-Pixel “Switch”

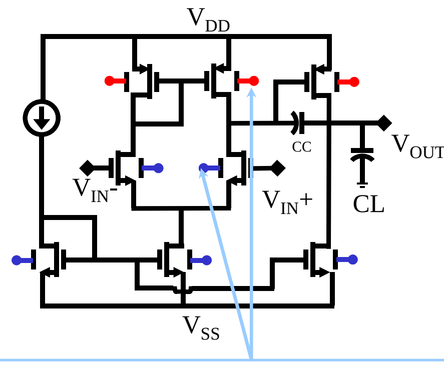


Vladimir Brajovic
Intrigue Technologies

Local gain, offset adaptive compensation

Geometric Leverage: Operational Amplifier

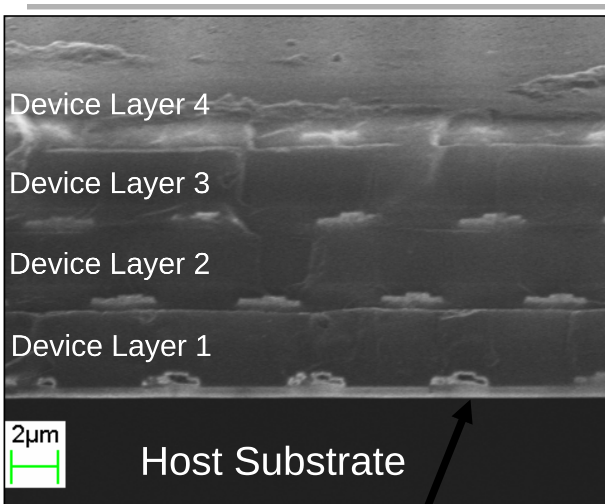


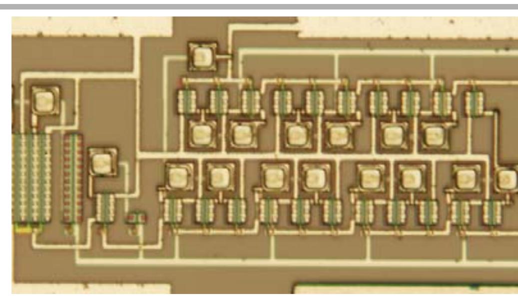


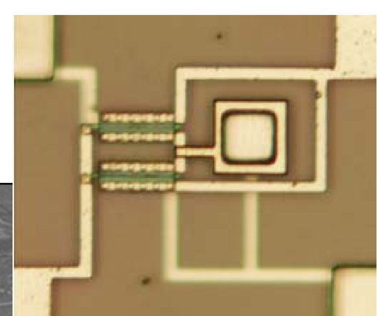
Supply	1.5V	0.6V
Gain (dB)	108.9	99.8
Gain Bandwidth (MHz)	32.1	29.5
Open-Loop Gain Voltage Gain (V/V)	4.3×10^4	3.9×10^4
Phase Margin (degrees)	84	89.8

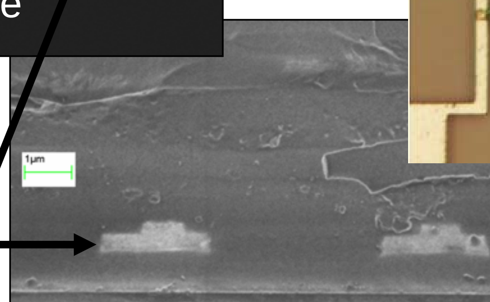
A. Kumar et al. (2006)

3D Integration (4 Device Planes)



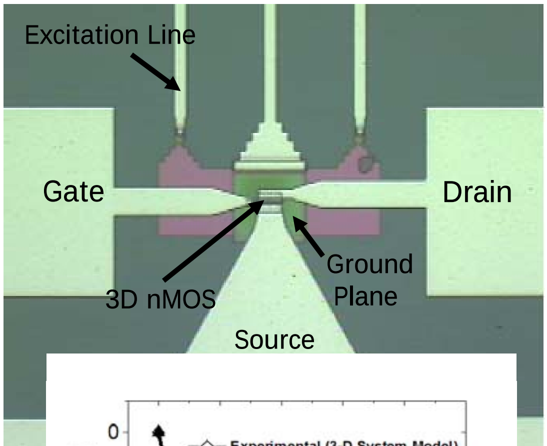


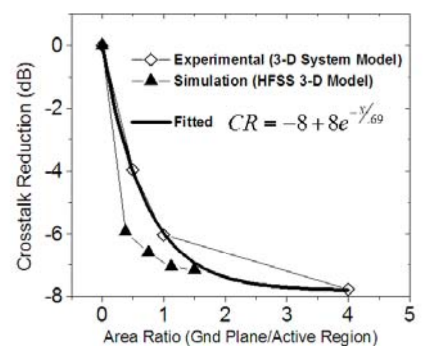


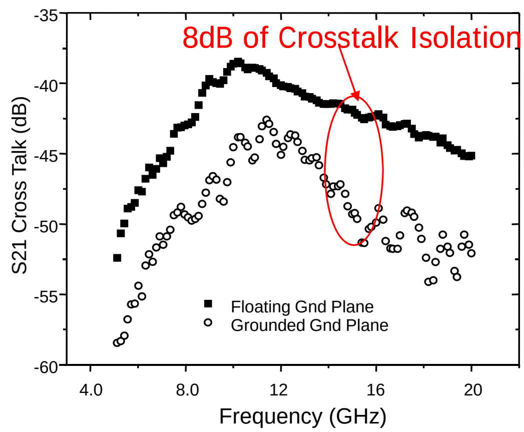


SOI Transistor Structure

Crosstalk Reduction using Ground Planes

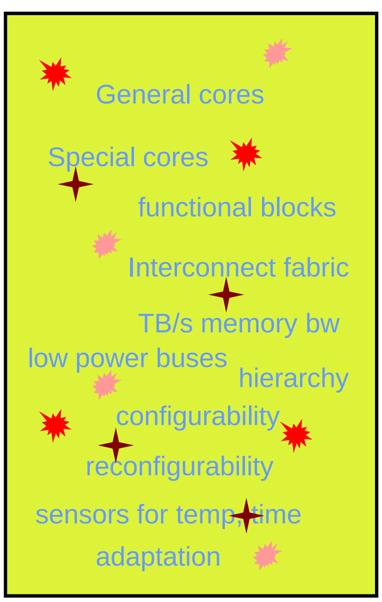






3D provides a very suitable platform for cross-talk reduction for mixed analog/digital designs

Source: S. K. Kim (2005)



Terascale integration capacity

Billions will be unusable due to variations

Many will fail in time

Intermittent failures

A desired performance at power and cost still needed

Dynamically self-test, detect errors, reconfigure, & adapt

Configurability: Hardware-Software Co-Design

Problem

Configurability as practiced in FPGAs has a high cost

For *FPGAs relative to ASICs for core logic (at 90 nm)*

Look-up table logic is 35x area and 3-5x slower
FPGAs consume ~14x dynamic power
Hard multipliers & dedicated memory reduce area and power but don't affect delay differences

Kuon & Rose, IEEE TCAD (2007)

One Answer

Coarse-grained configurable architectures

From processors: Predefined operators, Datapath + Control
& from FPGAs: Configurable interconnect and Control
Fast switch time for coarse grain, smaller area and power penalties

Environment of the Challenge

Power In: ~100 W/cm^2

Energy ⇔ Error Rates, S/N

10 nm F ⇔ 4×10^{13} F^2 in 2.5 inch □
& more in multilayer 3D

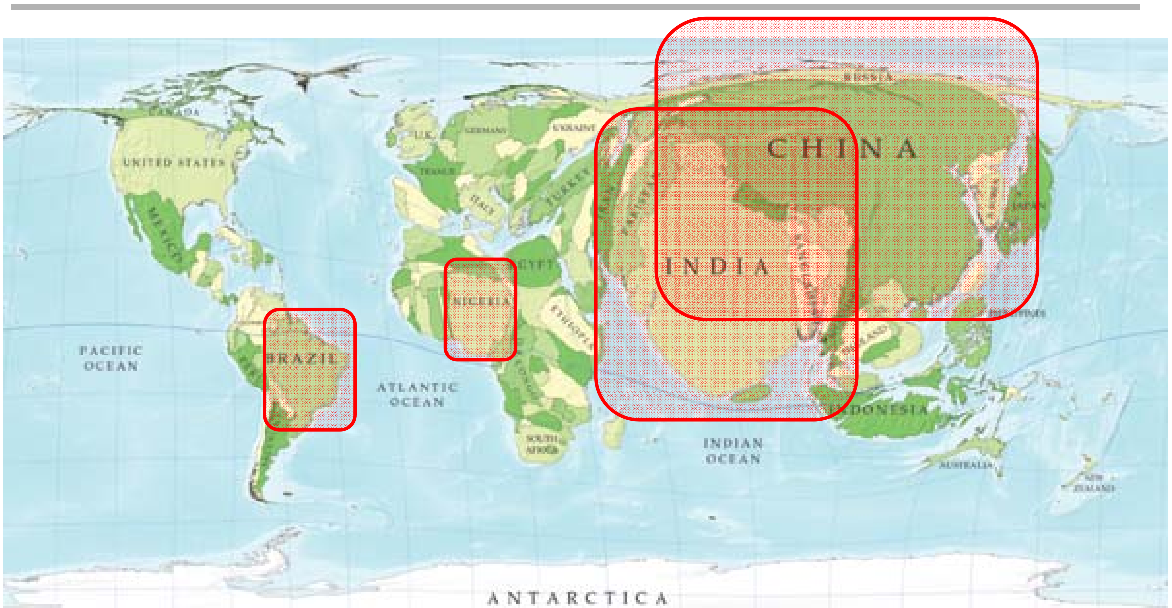
(reproducibility, resilience, robustness, routing, reconfiguration, …)

System-level Optimization
Hierarchy
Properties of Technology
Adaptation
Energy Partitioning
Network/Communication
Design Tools
Hardware-Software

So, the Biggest Problems

- Today's challenge: Power and Design
  - Adapt
  - Hardware-Software co-design
- Future challenge: Reliable Systems from Unreliable Components
  - Variations and reliability
  - Resiliency
- Cost
  - New technologies that are efficient at hardware-software co-design
  - Non-compartmentalized education and practice

World Map (normalized to population)

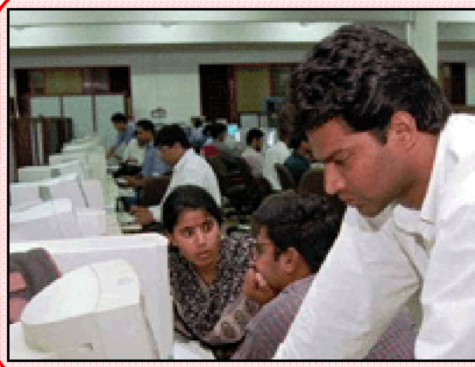


R. Webb, Nature 439, 800(2006)

The World is Not Flat

The old world

1620



The new world

Outsourcing

http://www.cnn.com/2007/US/05/10/outsourcing.news.ap/index.html

News site outsources local journ...

AMERICAN MORNING | SITUATION ROOM | LOU DOBBS TONIGHT | PAULA ZAHN NOW | LARRY KING LIVE | ANDERSON COOP

CNN.com

Member Center: Sign In | Register

SEARCH THE WEB CNN.COM SEARCH

Home World U.S. Weather Business Sports Analysis Politics Law Tech Science Health Entertainment Offbeat Travel Educa

U.S.

Tools: Save | Print | E-mail | Most Popular | [+] Feedback

News site outsources local journalism

POSTED: 9:03 p.m. EDT, May 10, 2007

James Macpherson, editor and publisher of the Web site pasadenanow.com, hired two local reporters -- based half a world away.

STORY HIGHLIGHTS

- Editor of California news site hired reporters based in India to cover local news
- Job ad was posted on craigslist.org
- Editor says reporters can watch local council meetings online
- James Macpherson's Web site gets about 45,000 unique readers per month

Adjust font size:

PASADENA, California (AP) -- The job posting was a head-scratcher: "We seek a newspaper journalist based in India to report on the city government and political scene of Pasadena, California, USA."

A reporter half a world away covering local street-light contracts and sewer repairs? A reporter who has never gotten closer to Pasadena than the telecast of the Rose Bowl parade?

Electronics used to be a technical business

Electronics is now jewelry



Artistic, Aesthetic, Cultural
Composition, movement, form, technique and material

Compact
Aesthetic
Entertaining
Utilitarian – Health & Environment - Distributed
Part of Culture

Simplicity:
hardware-software interaction leveraging large information processing capacity

Integration of tactile functions with intuitive interfaces:
physical interaction

Long use time:
battery-scale

Current Examples:
iPod: Clickwheel, audio, screen, storage, … and wireless with iphone
Cellphone: Wireless, screen, keyboard, camera …
Webcam and Endoscope Pill: Wireless, camera, …
Health Monitors: Wireless, temperature, blood pressure, heartbeat, camera, …

COMPACT
LOW COST
LOW POWER

Integration
Analog and Digital (Logic & Memory)
Sensors
Power Source
Human Interface Functions
Untethered Communications

Ultra low power memory, logic, analog elements holistically integrated

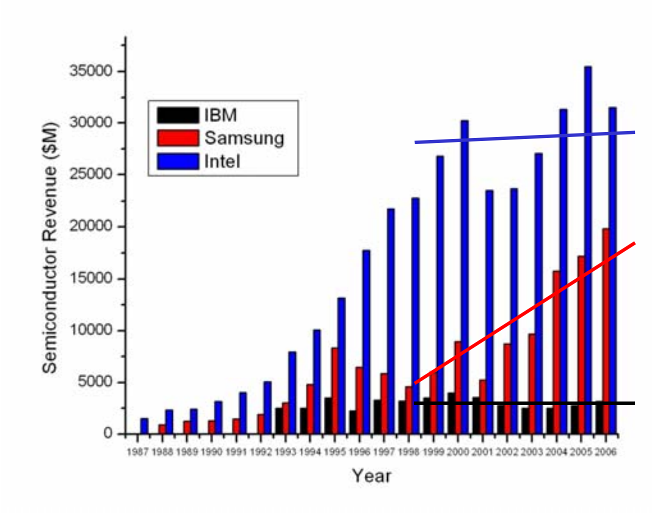
Sensors and sensor integration

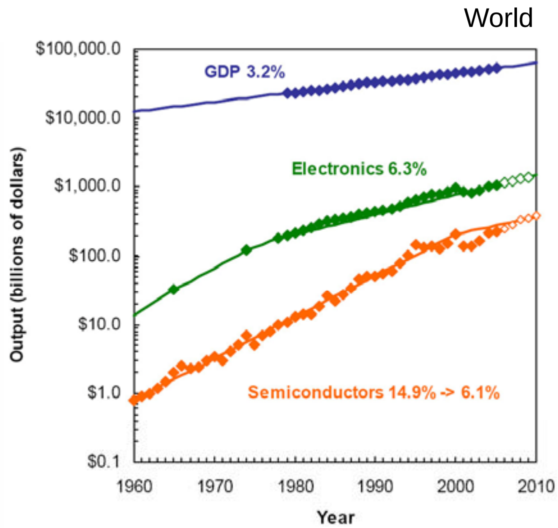
Low power wireless – passive and circuits with software control and/or digital/cognitive radio

FPGAs/PLDs with characteristics of ASICs

3D Integration
Ultra-low power devices, programmable and adaptive devices, universal memories, and devices that allow easier software-hardware coupling

Three Different Businesses





Source: IC Knowledge LLC

Electronics is not just Computing

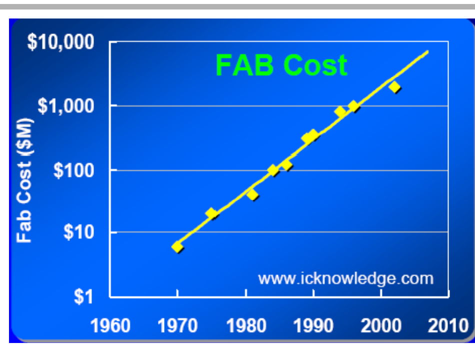
Computer and processor companies are stagnant/have low growth

Apple is not a computer company anymore

The growing businesses are in the "modern jewelry" and in taking care of a real need in human and family welfare and life

Semiconductors are the modern world's agribusiness
We can develop new "food"

Catch 22



Each fab = 500 employees + downstream employment
Currently 25 12" fabrication lines (mostly outside USA)

Employment
25x500 + 200x50 + AMAT+ TEL + LCD + …
~12500 + 10000 + 25% = 30,000
Fab Cost = 25x$3B = $75B
Semiconductor Revenue = $300B
Information Technology Revenue = $1T

There are about 200 major designs of IC's
Each design = 25-300 employees

No major world power can live without the communications, the information-based life-structure (entertainment, health, family life, …), and the military infrastructure to defend what countries are about

Semiconductors, and related core-disciplines of engineering are at the heart of this complex infrastructure and undertaking.
Countries can not live without it.

This is no different than our need for food and the agri-business in the societal context

It is here to stay!

From Prof. Les Eastman's Bulletin Board

Our futures almost certainly depend less on what Ronald Reagan and Walter Mondale say and do than on what is going on inside the head of some young Cornell graduate waiting for a plane in Pittsburgh.
Universal Press Syndicate

From the 1980's

This is more true now than ever

EDS-Students_Tiwari_25Year.ppt – May 18, 2007

The World is Not Flat

SATURDAY, JANUARY 18, 2003

THE TIMES OF INDIA

WORLD: THE UNITED STATES

Search in The Times of India Web Indian Sites GO Advanced search

Indiatimes > The Times of India > World > The United States > Article

Home

CLASSIFIEDS

IITs better than US institutes,

THE UNITED STA HEADLINES

But the moment of supreme irony comes when she interviews Infosys co-founder NR Narayana Murthy and asks him about his son's education.

Murthy: Well, my son, he wanted-probably wanted to do computer science at IIT. To do that, you have to be in the top 200 and he couldn't do that, so he went to Cornell instead.

Stahl: (awed voiceover amid footage of IIT students on campus): Think about that for a minute. A kid from India using an Ivy League university as a safety school. That's how smart these guys are.

Murthy: I do know cases where students who couldn't get into computer science at IIT, they have gotten scholarships at MIT, at Princeton, at Caltech.

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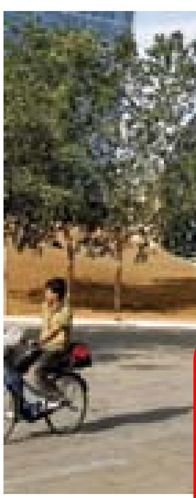
COMMENTS ON THIS ARTICLE

The Future and the Past

Software

Hardware

Software-Hardware



Information Week, A

Indiatimes| My Mail | Make TOI your home page | RSS

Updated: 21 May, 2007 1512hrs

Times of India

Home Cities India Indians Overseas World Business Sports Heal

HRD hopes to make $10 laptops a reality

4 May, 2007 | 0253 hrs IST | Akshaya Mukul/TIMES NEWS NETWORK

Print Save EMail Write to Editor

NEW DELHI: Having rejected Nicholas Negroponte's offer of $100 laptops for schoolchildren, HRD ministry's idea to make laptops at $10 is firmly taking shape with two designs already in and public sector undertaking Semiconductor Complex evincing interest to be a part of the project.

So far, the cost of one laptop, after factoring in labour charges, is coming to $47 but the ministry feels the price will come down dramatically considering the fact that the demand would be for one million laptops. "The cost is encouraging and we are hopeful it would come down to $10. We would also look into the possibility of some Indian company manufacturing the parts," an official said.

The two designs with the ministry are from a final year engineering student of Vellore Institute of Technology and a researcher from Indian Institute of Science, Bangalore. Due to reasons of Intellectual Property Rights being insisted by the two designers, the ministry is not parting with the design except giving out some of the major details.

Times of India, May 4, 2007

http://www.thehindubusinessline.com/2007/05/15/stories/2007051504520400.htm

ss Line

he Page - Hardware

-Tech - Overseas Investments

iwanese chip firm wants to set up fab unit in dia

omas K. Thomas

yanka Vyas

mmits $3 b in investment

w Delhi May 14 A Taiwanese-based chip manufacturing npany has expressed interest to set up a fab unit in India an investment of $3billion. The company has sent a letter the Communications Ministry expressing its interest said ior Government sources without revealing the name of the n.

s will be the third company to announce India-specific plans er the Government announced its semi-conductor policy to er fiscal incentives to companies setting up fab units in the intry.

...lier, Hindustan Semiconductor Manufacturing Corporation (HSMC) announced an alliance with Infineon Technologies of Germany to set up 2 chip manufacturing plants in India with an investment of $4 billion. SemIndia has also announced its plans to set up a fab unit.

Archives

Features

Investment World

The Hindu, May 15, 2007

Next 25 Years

Munson's hypothesis:

Students can do more than
- Traditional Homework
    - Standard Formulaic Laboratories
    - Math, Science and Technology

Primarily taught analysis

Engineering student education needs to match to the real world

Engineering education needs:

Creativity and innovation with In-Depth Knowledge

Analyze, Design, Build, Test

Teamwork and rolling leadership

Communications

Global real world learning

Societal needs and global good

A Narrow View

The Russians play Chess, plotting their moves with a strategy that looks decades into the future.

The Japanese play Go, systematically surrounding each technological territory with their pieces until they make it their own.

The Europeans play Bridge, kicking a lot under the table while presenting a smooth performance above its surface.

USA: We play Monopoly.

The world does not know how China and India play.

To the Student:

You will have to be a comprehensive problem solver by being the one who defines the problem.

You will have to learn to lead multidisciplinary teams of professionals, set agendas and foster innovation/cleverness.

You will have to have a global outlook and understand the cultures.

If you don't risk going too far, you'll never go far enough

EDS

Electronic Devices and Use

- Programmable and adaptive devices
- A new technology-architecture-software model for addressing energy
- Compact footprints
- Alternative phenomena where energy-time-information is manipulated differently – at low power, density and speed
- Configurable approaches to overcome design constraints (fast memories with logic to do logic at ASIC characteristics)
- Universal memories (information storage is ubiquitous)

Devices and technology that allow easier software-hardware coupling

A broader engineering learning that understands and uses learning across scales and has a global foundation

EDS-Students_Tiwari_25Year.ppt – May 18, 2007