Frontiers in Electronics Research

Tackling the Energy Challenge

Jan M. Rabaey

Donald O. Pederson Distinguished Prof.

University of California at Berkeley

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THE IT PLATFORM OF THE NEXT DECADE(S)

TRILLIONS OF CONNECTED DEVICES

[J. Rabaey, ASPDAC'08]

Today's Mobile: The Gateway to The Cloud

- Primary intent: interact with the Internet

Tomorrow's Mobile: The Bridge to the Swarm

"By 2020, a large fraction of us will be working in a virtual environment"
M. Macedonia,
Forterra Systems

Enabling immersive computing and augmented reality

Tomorrow's Mobile: The Bridge to the Swarm

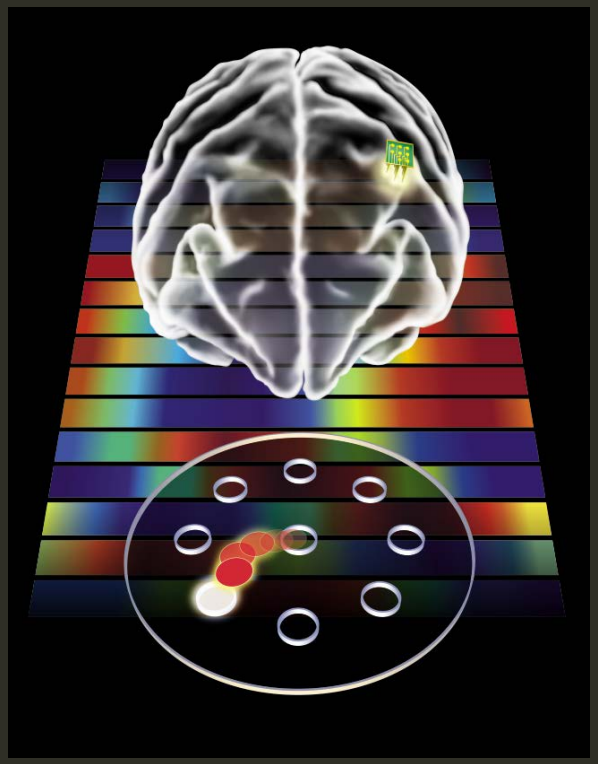





Linking the Cyber and the Physical Worlds: CyberPhysical Systems

[H. Gill, NSF 2008]

Tomorrow's Mobile: The Bridge to the Swarm



Creating new meaning to "bio-cyber interface"

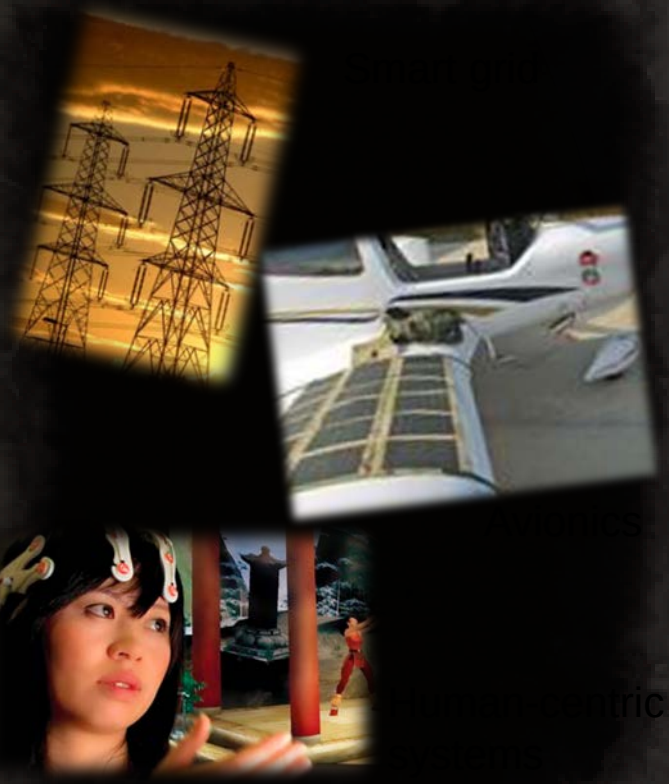
Example: Brain-Machine interfaces and body-area networks

What it Takes ...

- Seamless collaboration of huge numbers of distributed nodes – “the swarm”
- Huge communication challenges
  - Large numbers of multimedia data streams
  - Combined with critical sensing and control data
  - Varying degrees of availability, mobility, latency, reliability and privacy
- Tremendous computational power
  - Generating true real-time enhanced reality
  - Mostly provided by the “cloud” – but latency issues dictate locality
- Distributed storage
- All within limited energy budgets

It’s All About Energy

Energy among most compelling concern of distributed IT platform and its applications.



It’s All About Energy

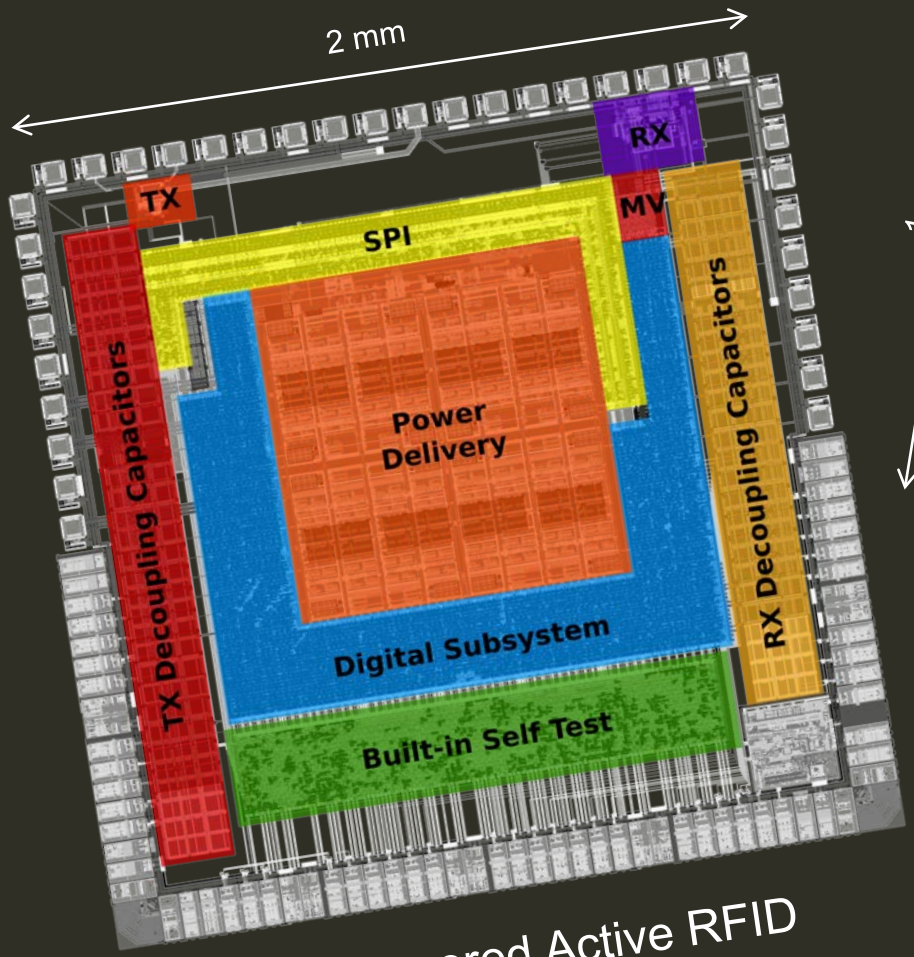
iPad

3.75V, 24.8 watt-hour battery
(150 g – 20% of the weight)

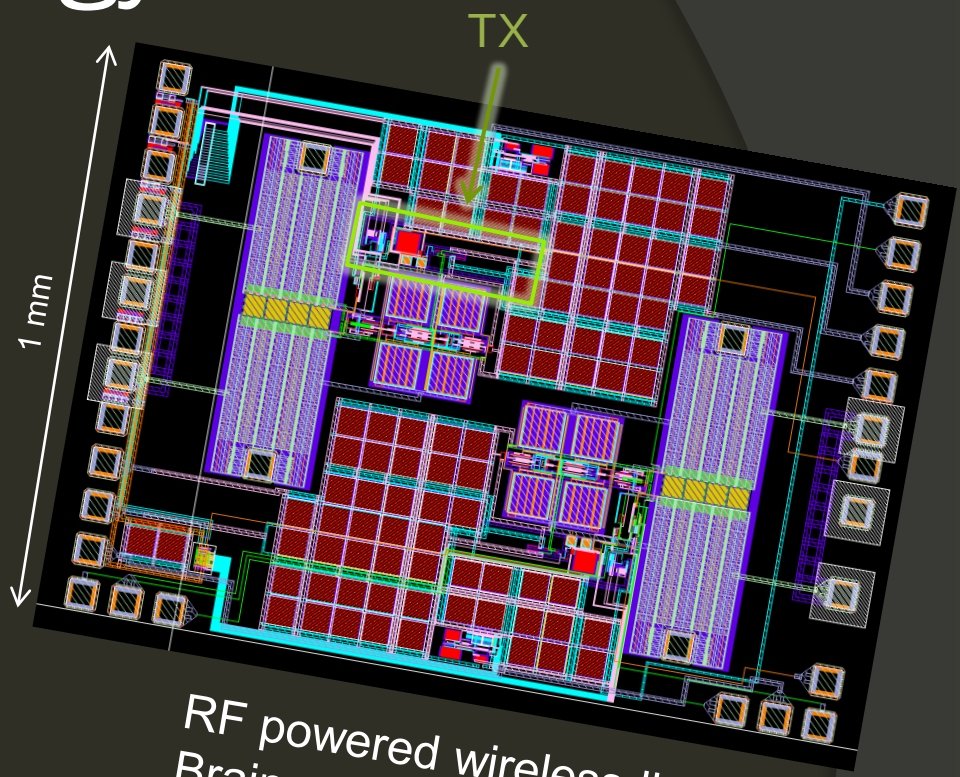
iPhone 3GS

3.7V, 4.51 watt-hour battery

It’s All About Energy



Light-powered Active RFID



RF powered wireless link for Brain-machine interfaces

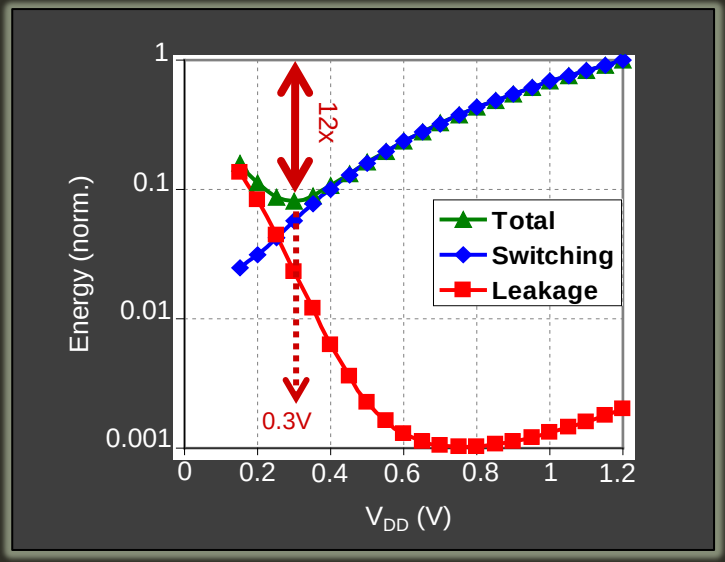
[Pictures Courtesy of BWRC]

Business as Usual Will Not Do

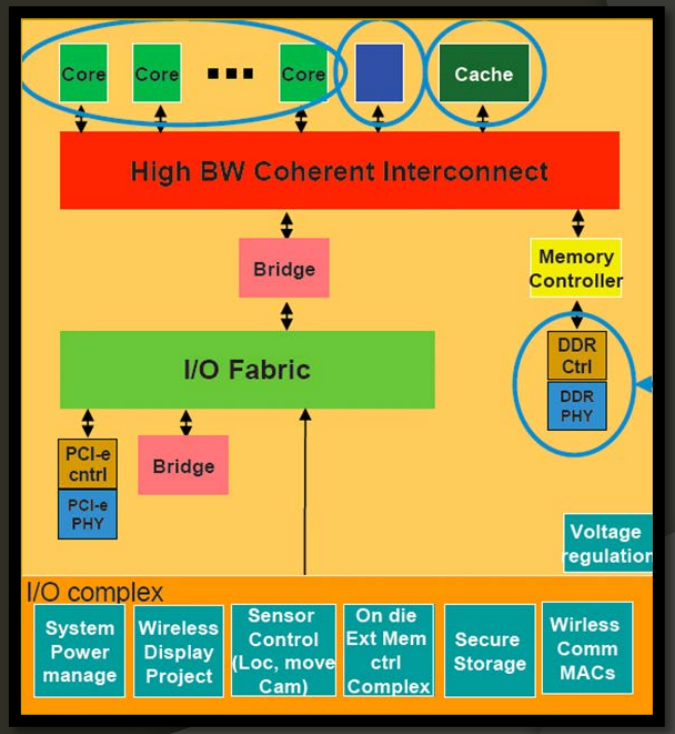
The mantra's of two decades of low-power design: slow, simple, many, dedicated, adaptive

While some opportunities are left, concepts now commonly exploited

The end of voltage and energy scaling !?



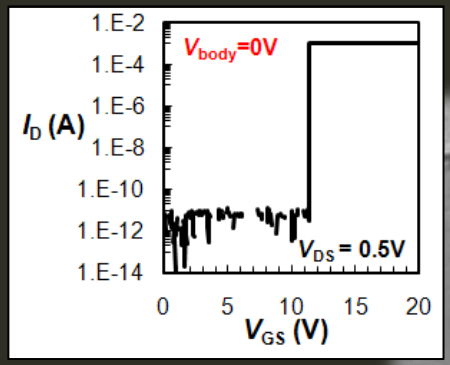
Unless novel devices are adapted soon …

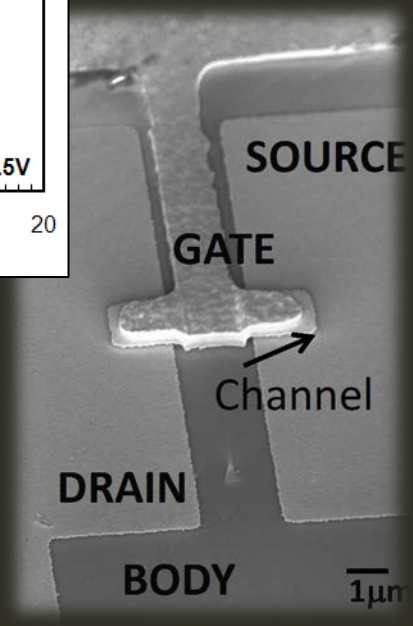


In Need of Novel Architectural Ideas

Some Promising Ideas …

Switching devices with steep on-off transition



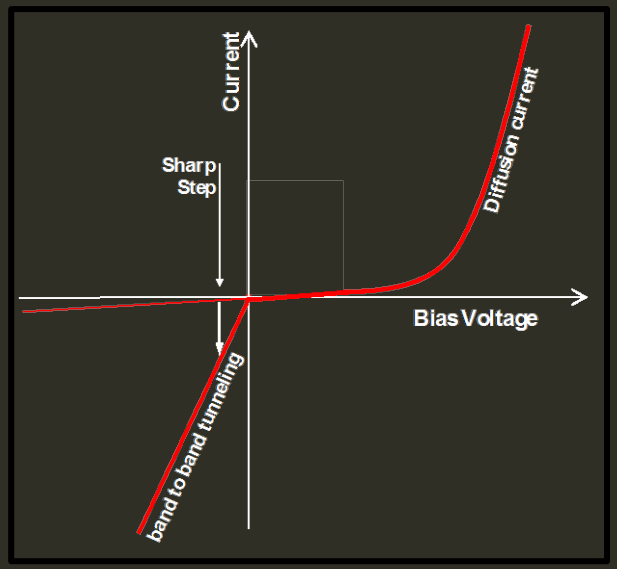


Example: NEMS relay logic (King, Alon, Stojanovic)

IEEE ELECTRON DEVICE LETTERS, VOL. 21, NO. 7, JULY 2000

Sb-Heterostructure Interband Backward Diodes

J. N. Schulman and D. H. Chow



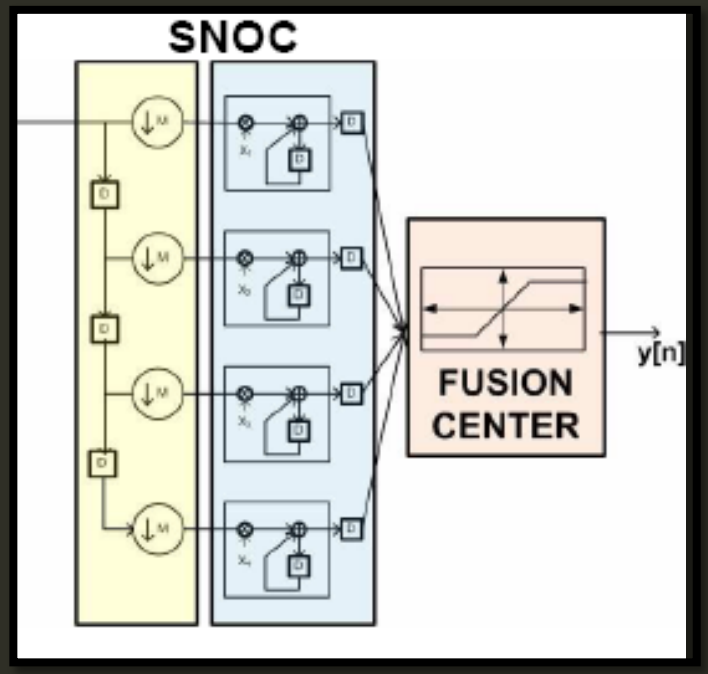
Switches that operate on mV transitions?

Other alternatives: Steep sub-VT such TFETs

[Source: E. Yablanovic]

Some Promising Ideas ...

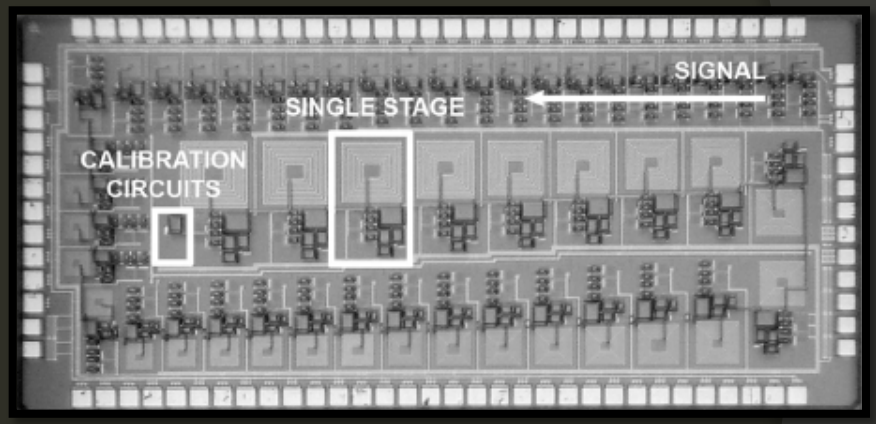
Statistical Computing



Non-deterministic computing allows errors to occur

[e.g. Sensor-Net on a Chip, Shanbhag]

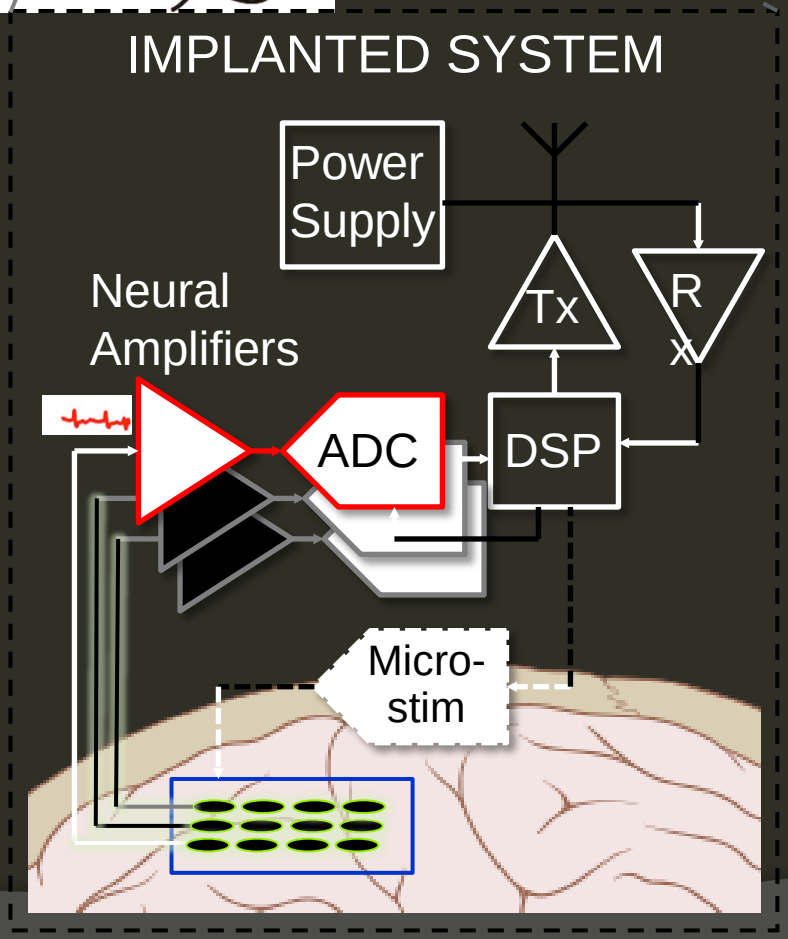
Accomplish functionality using low-resolution components

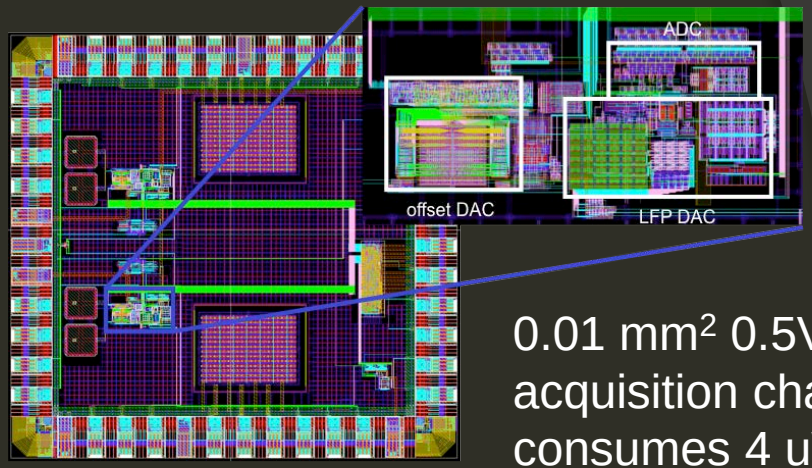


[E.g. Artificial Cochlea, Sharpeskar]

Bio-inspired Computing

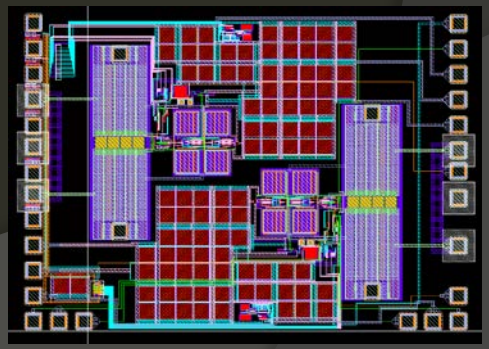
Example: Brain-Machine Interfaces





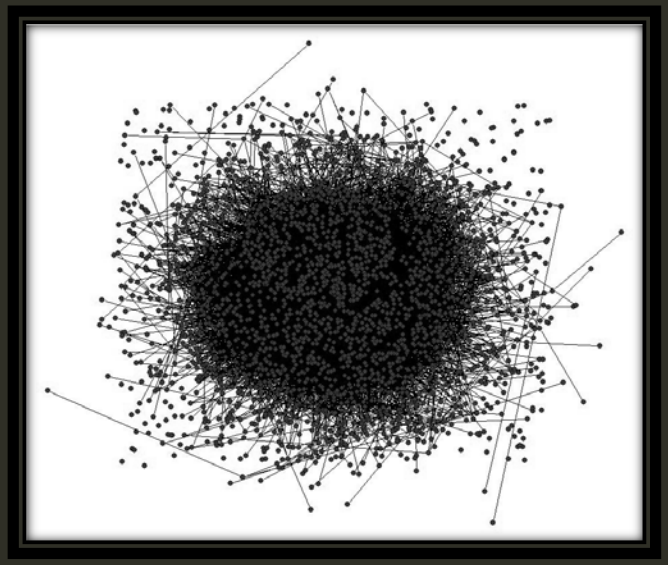
0.01 mm^2 0.5V data acquisition channel consumes 4 uW

1 mm^2 2 Mbits/sec data link delivers 8 uW of power



The Swarm/Cloud Opportunity

Moore's Law Revisited:
Scaling is in number of connected devices, no longer in number of transistors/chip



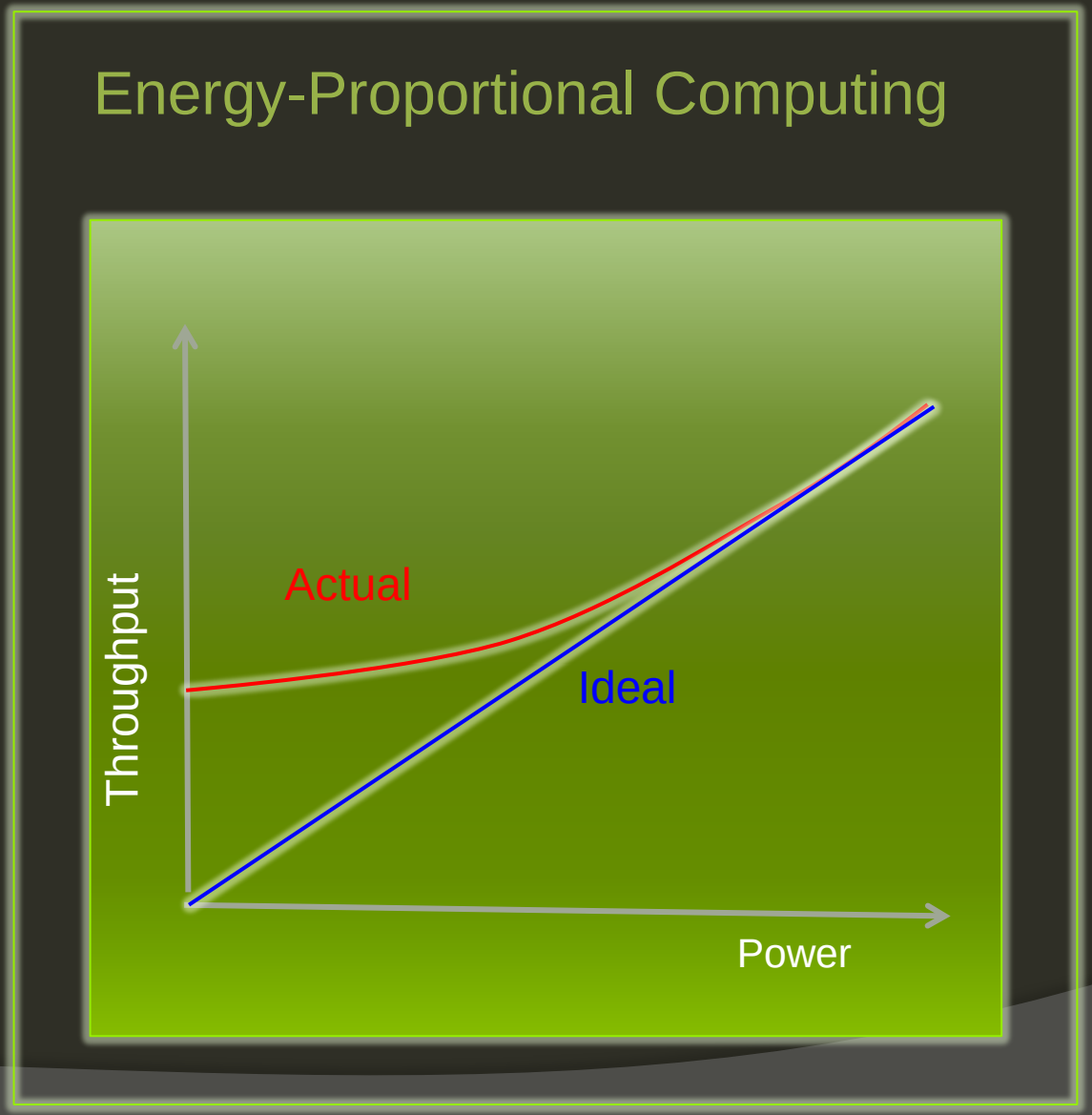
The functionality is in the swarm!
Resources can be dynamically provided based on availability

It's A Connected World

Time to Abandon the "Component"-Oriented Vision

[MuSyC 2009]

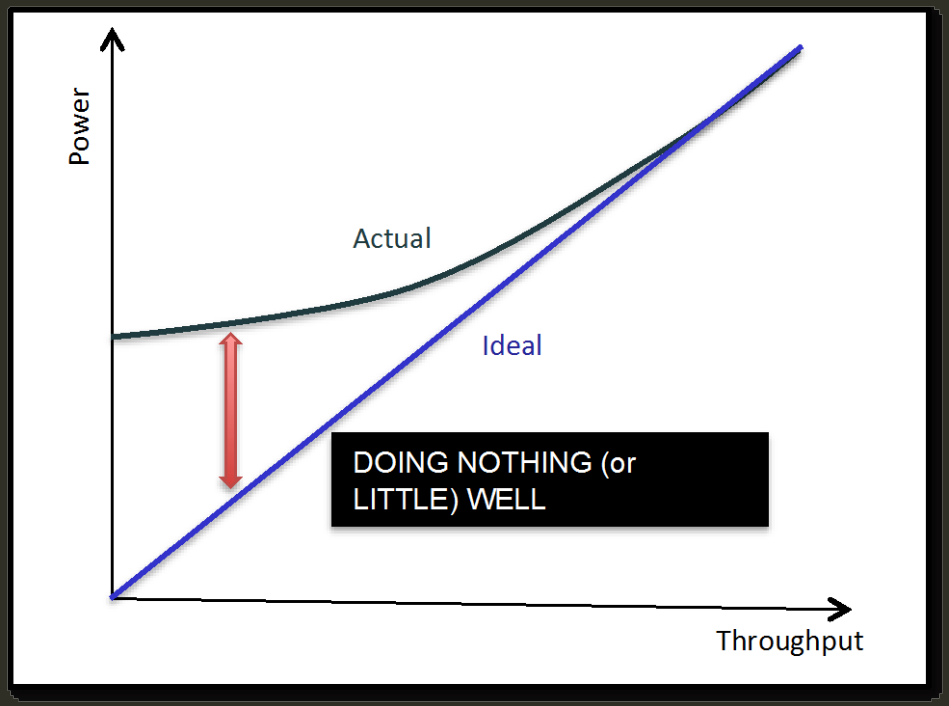
Opens New Opportunities



Energy-efficiency of most systems decreases under reduced loads

Courtesy:
L. Barroso, Google

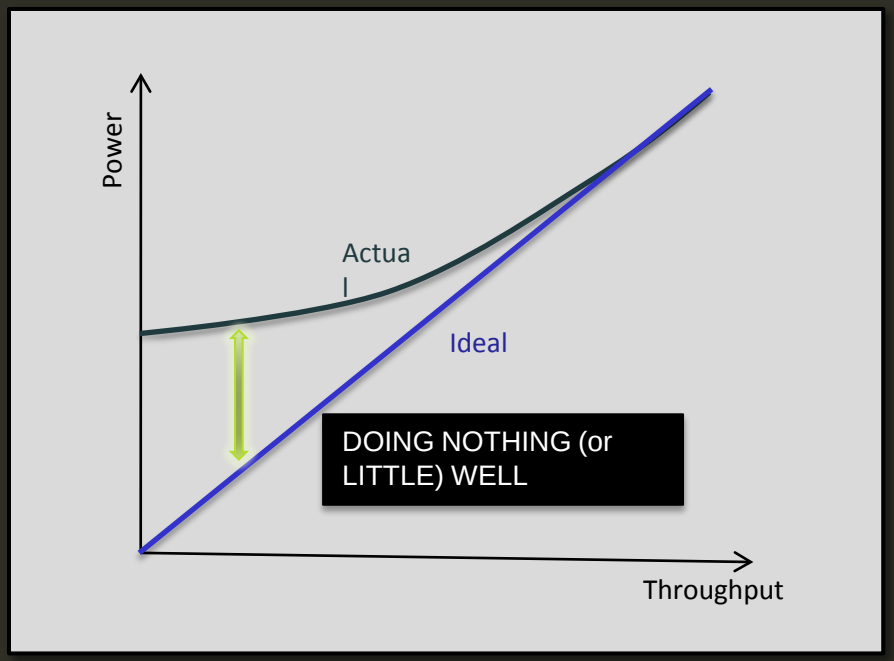
Computation and Energy



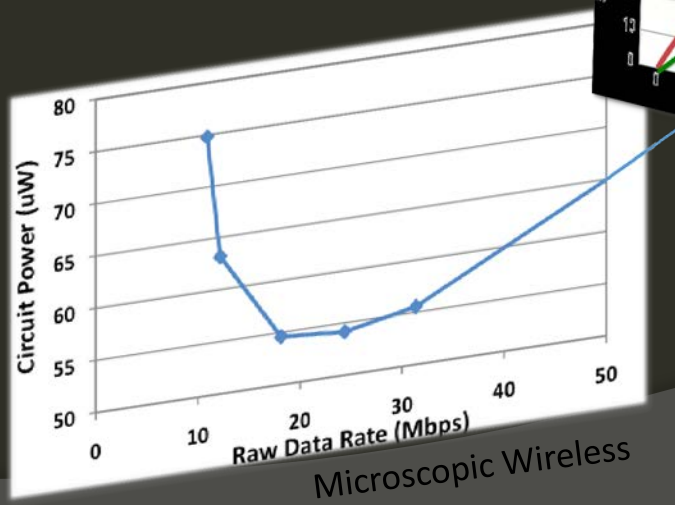
Energy efficiency of most systems degrades under reduced load conditions

[* Term coined by L. Barroso, Google]

A Generic Concept



- Conceive and Enable Systems that are Energy-Proportional over Large Throughput Range.
- Applies to **all aspects of the IT Platform!**

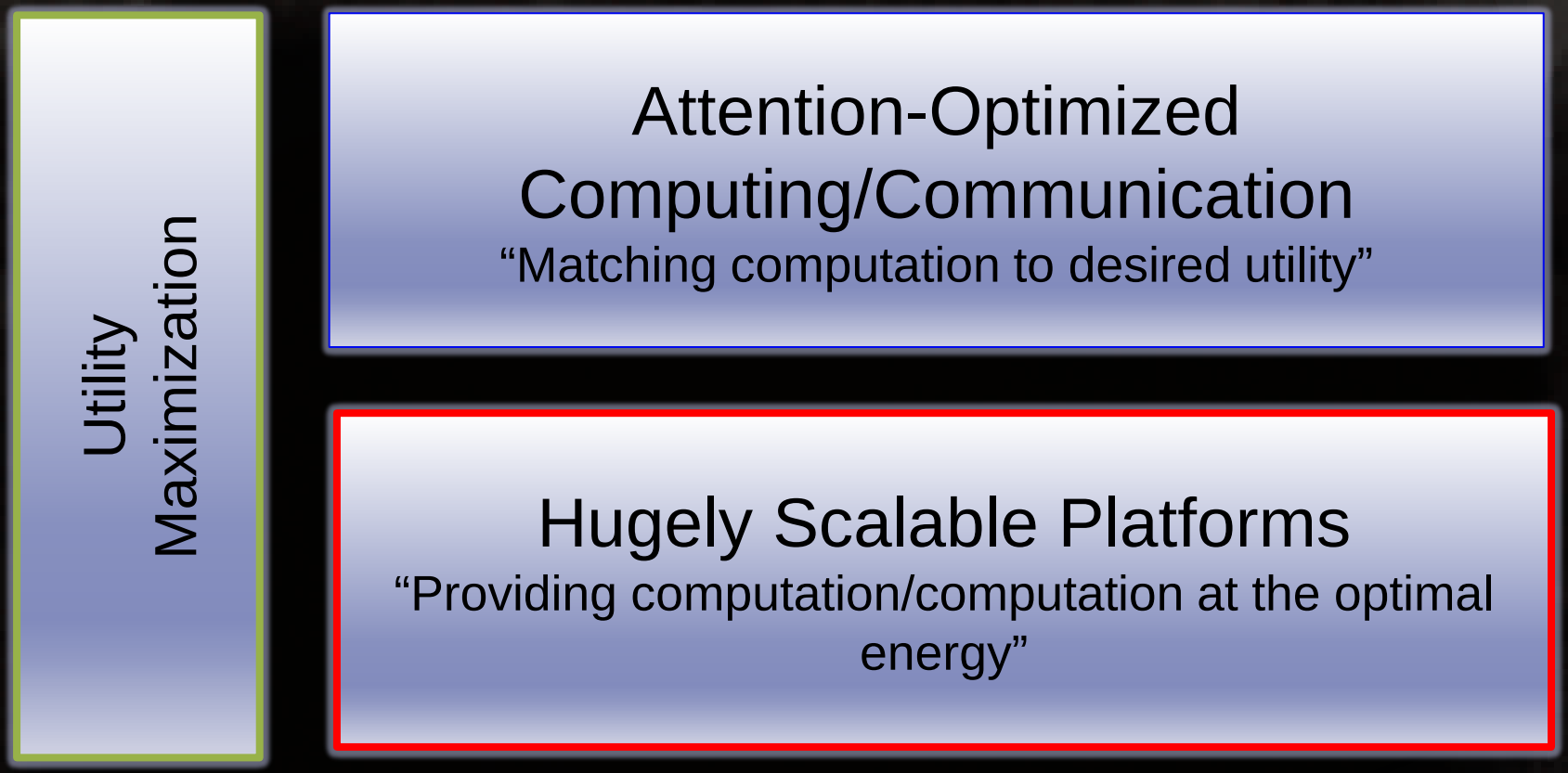


Microscopic Wireless

Data Centers

Not the case in today's systems (computing, storage, communication)

The Big Picture



[From: MuSyC FCRP Center]

The Cloud/Swarm Challenge

- Trade off computation and communication
- in light of limited energy, communication and, computational resources
- so that desired utility is reached
- under highly variable conditions and loads

Requires scalable distributed optimization strategy

The "Playground"

Distributed Resources

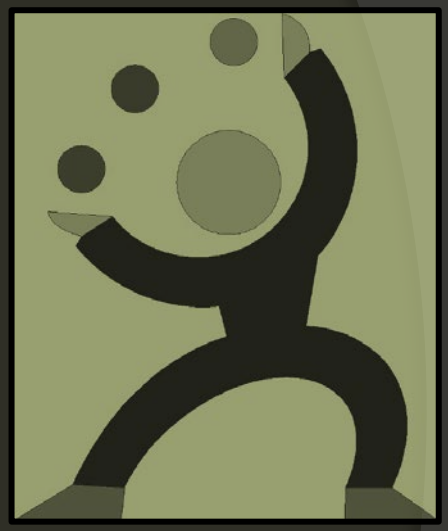
- Communication (Spectrum)
- Computation
- Sensing Actuation
- Storage
- Energy

The Swarm/Cloud Operating System -
Dynamically trading off resources

The Swarm/Cloud Services and Applications

Utility Maximization

"What matters in the end is the utility delivered to the user"



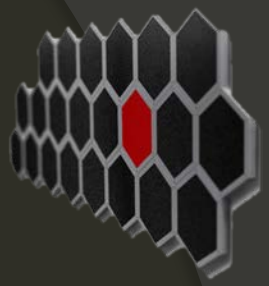
A continuously changing alignment
(environment, density, activity)

In Summary … The Laws of the Swarm (and the Cloud)

- In a connected world, functionality arises from connections of devices.
- Largest efficiency gain obtained by dynamically balancing available resources: computation, spectrum and energy.
- The dynamic nature of the environment, the needs and the resources dictate adaptive solutions.
- No one wins by being selfish. Cooperation and collaboration are a must.

The Electronics Perspective: Need for truly Scalable Platforms that are efficient over all possible workloads

Making it Happen: The Berkeley “Swarm Lab”



An experimental playground for the exploration and realization of innovative and disruptive swarm applications

Creation of the most advanced “swarm nodes”, exploring **post-Moore technologies and manufacturing strategies** combined with **ultra-low power implementation fabrics and architectures** for both computation, communication, storage, sensing and energy provision

Multi-disciplinary in nature, the lab combines researchers from diverse backgrounds covering the complete spectrum from application over integration to technology and materials.

Seeded by a major donation by Qualcomm, Inc