Towards Nanowatt Computing

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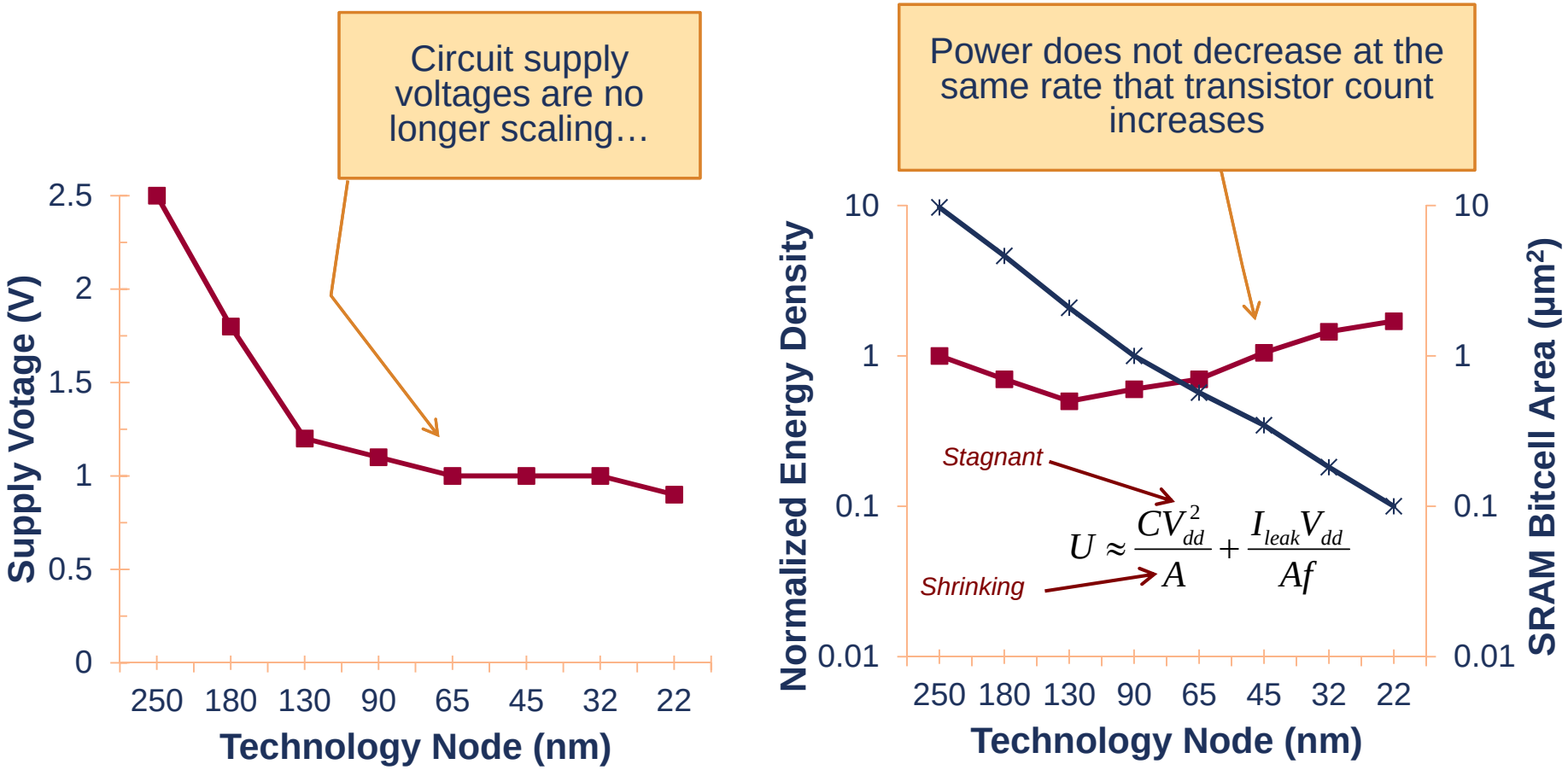
What I Learned from Chenming

- 1st meeting: If you want a job…
- Biggest thing: Research is fun!
  - Bucking the MS – PhD trend in late 90s
- What to spend time on…
  - New ideas vs. thesis
- How to run group meetings
  - Divide and conquer, get students engaged in others projects
- Not every project is the FinFET (but hopefully some are!)
- Empower your students, early and often
  - Proposal writing, reviewing journal submissions, internships
- Balance between hands-on and hands-off
  - Ex: Track papers out the door
- How to name a softball team:
  - Hot Electrons →
- And much more!

Modern Computing Landscape

- Cloud
  - Social networking, Google Docs
- Mobile
  - Smart phones, tablets
- Sea of sensors
  - Ubiquitous computing
  - The next explosion

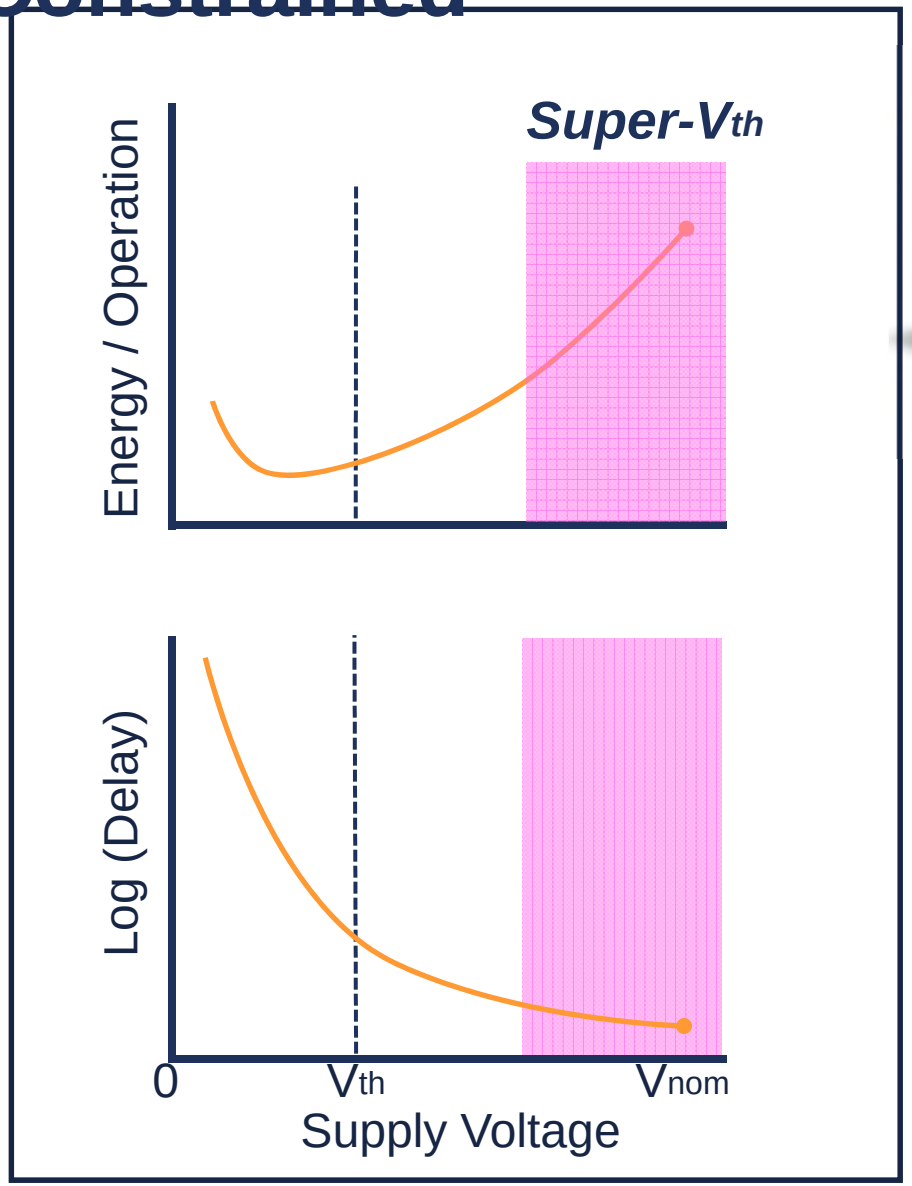
The Power Problem

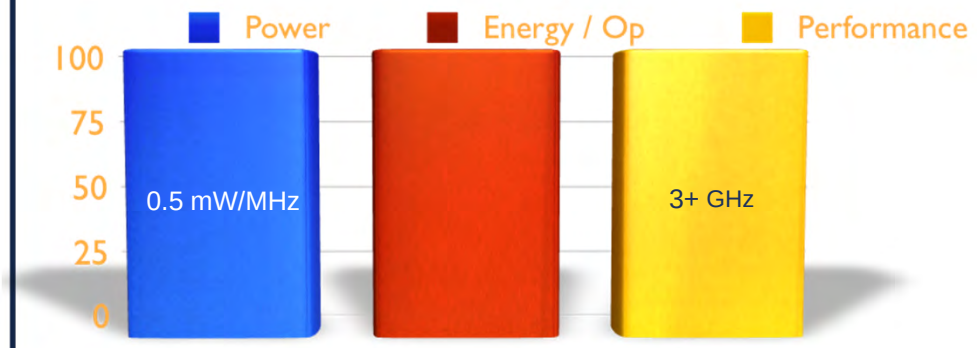


The emerging dilemma:

More and more gates can fit on a die,
but we can not turn them all on!

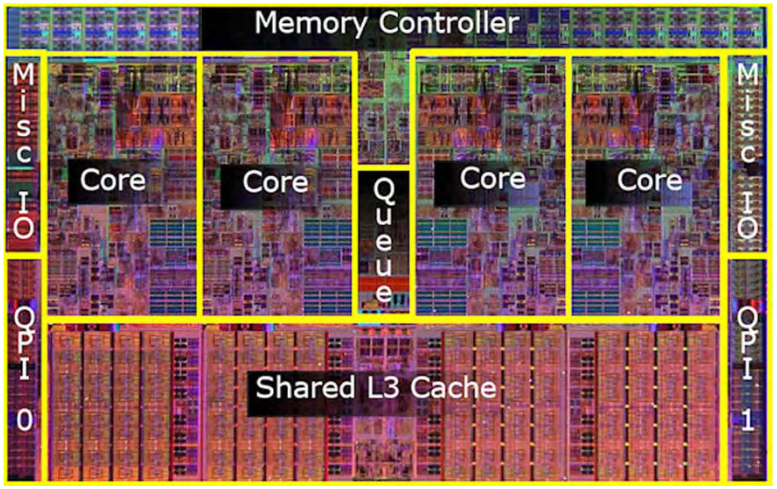
Today: Max Vdd, High Performance, Power Constrained





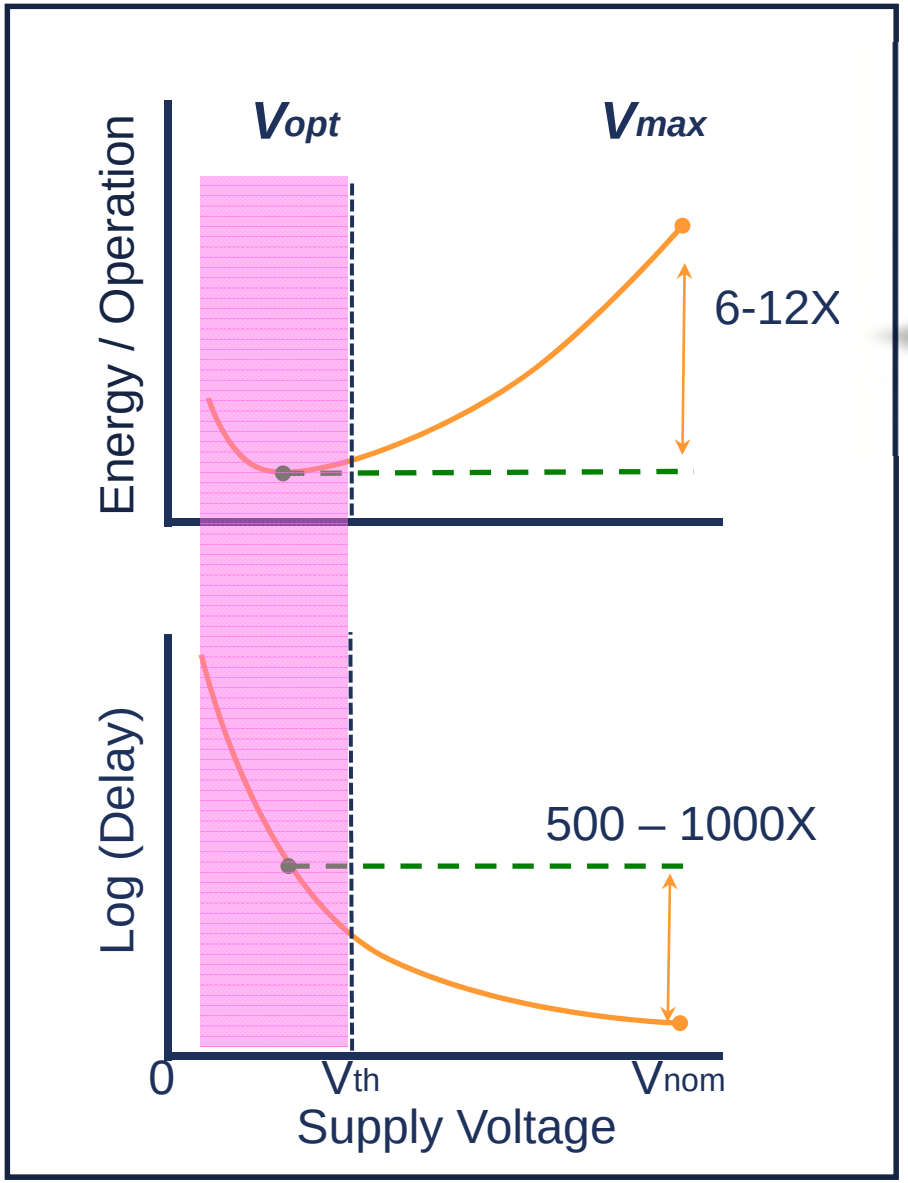
Normalized Power, Energy, & Performance

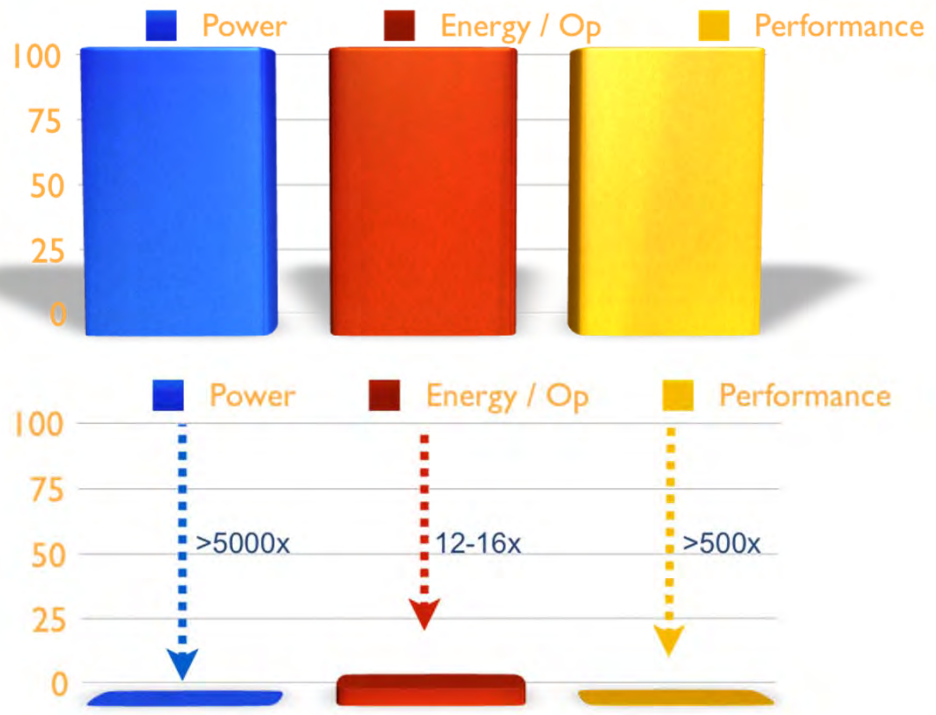
Energy per operation is the key metric for efficiency. Goal: same performance, lower energy per operation



Core i7

Optimal Energy Operation

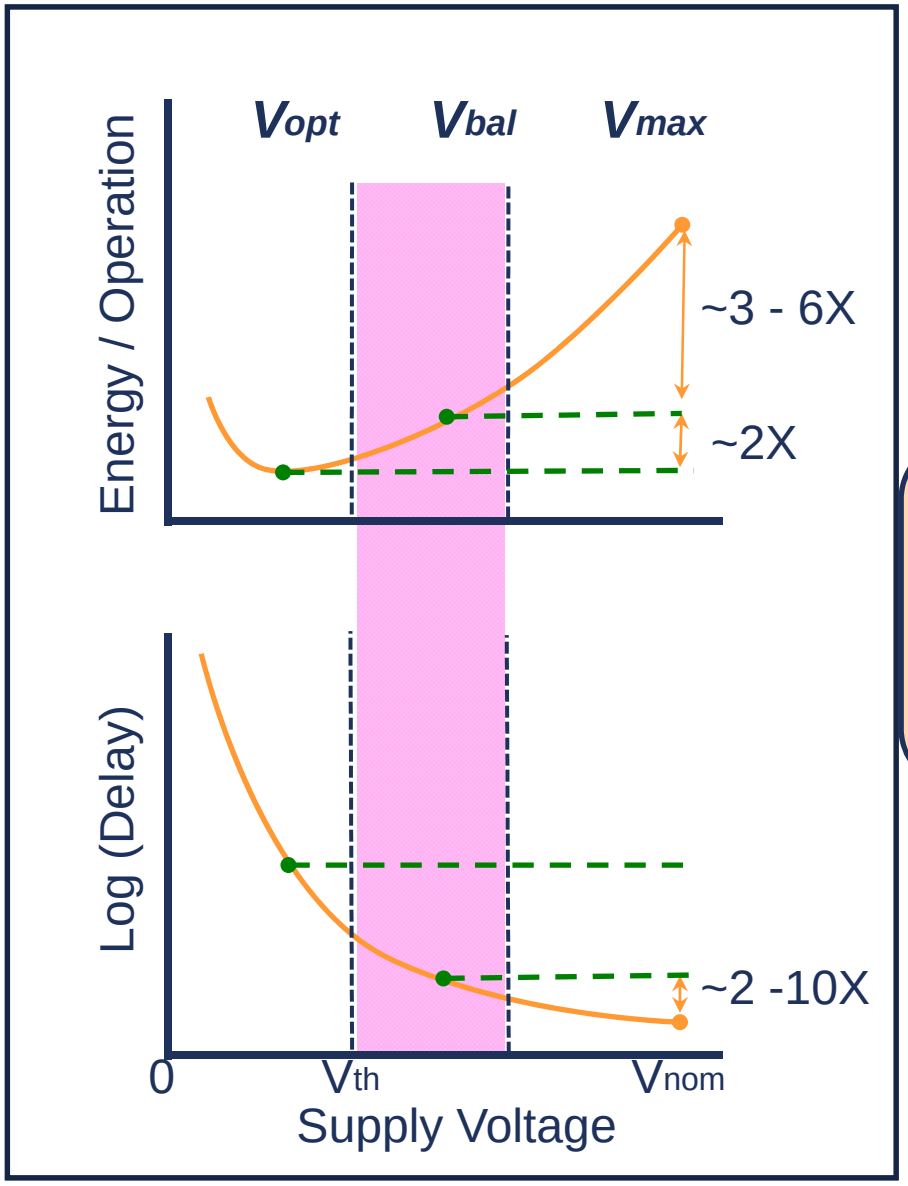


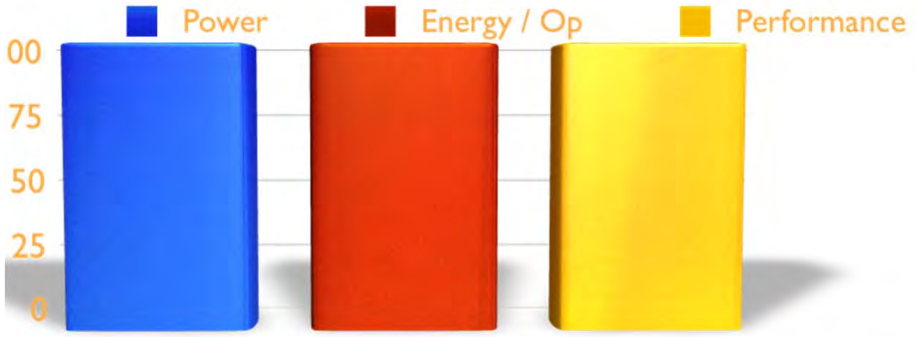


Operating in sub-threshold gives huge power gains at expense of performance →

OK for sensors but not for general purpose computing!

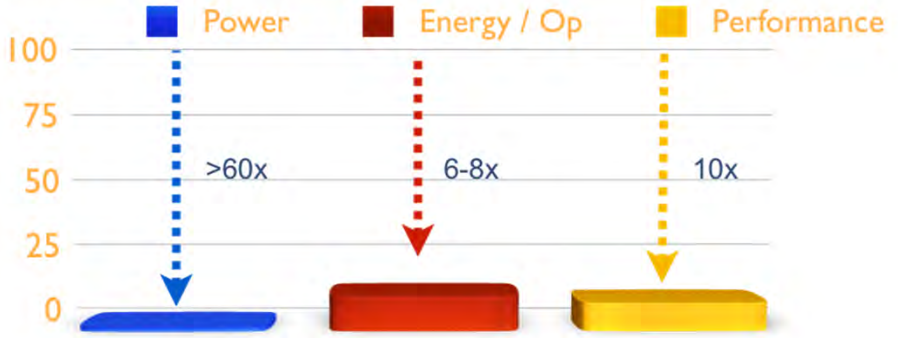
Near-Threshold Computing





Near-Threshold Computing (NTC):

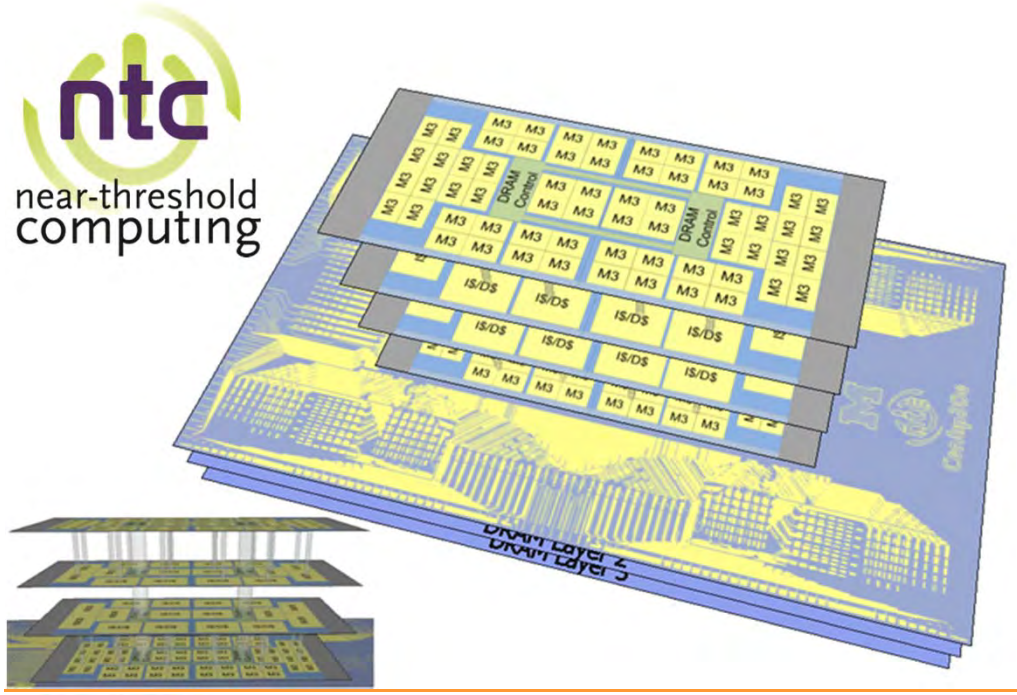
- *50+X power reduction*
- *5+X energy reduction*

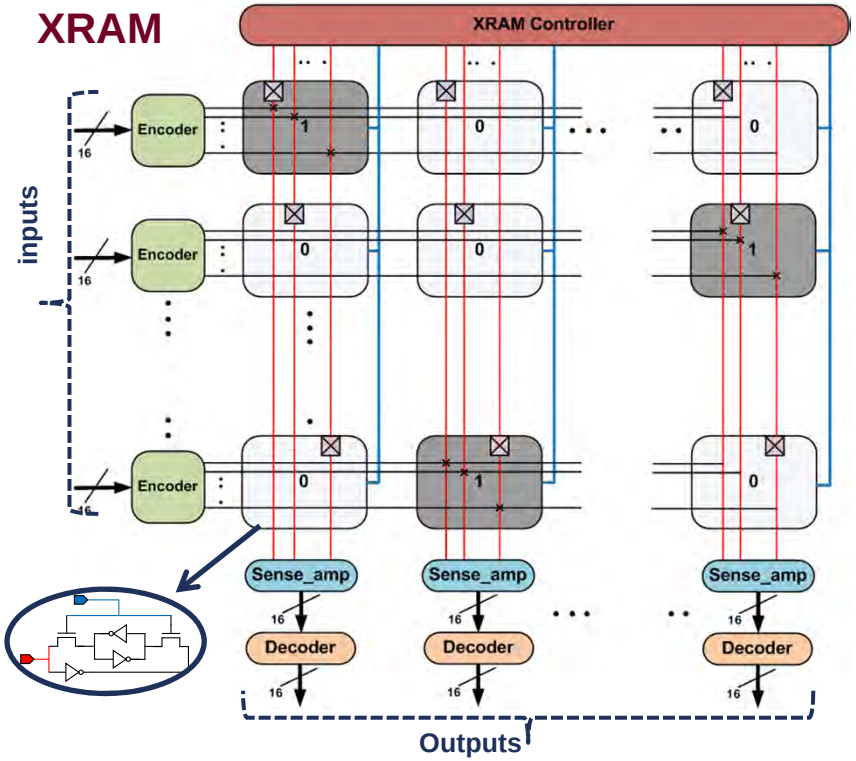


NTC in the Cloud

- Centip3De, 7-layer 128-core system with stacked DRAM
- 4 GOPS/W general purpose in 130LP

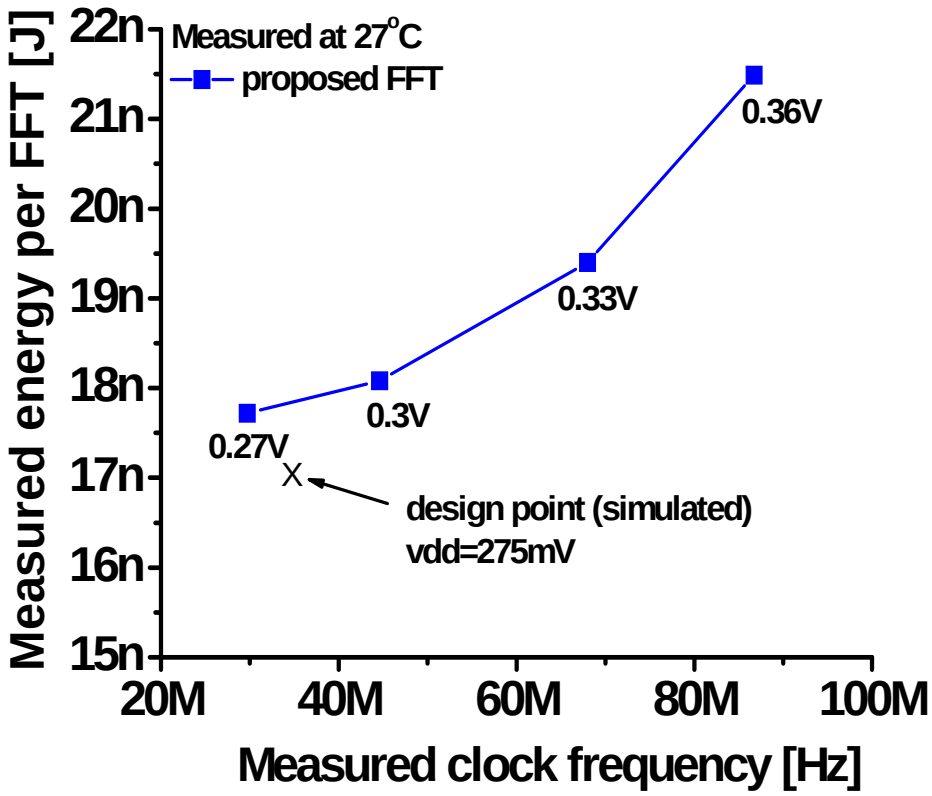
- XRAM: SRAM-inspired crossbar for many-core processors
  - 7.4Tb/s/W @ 0.6V



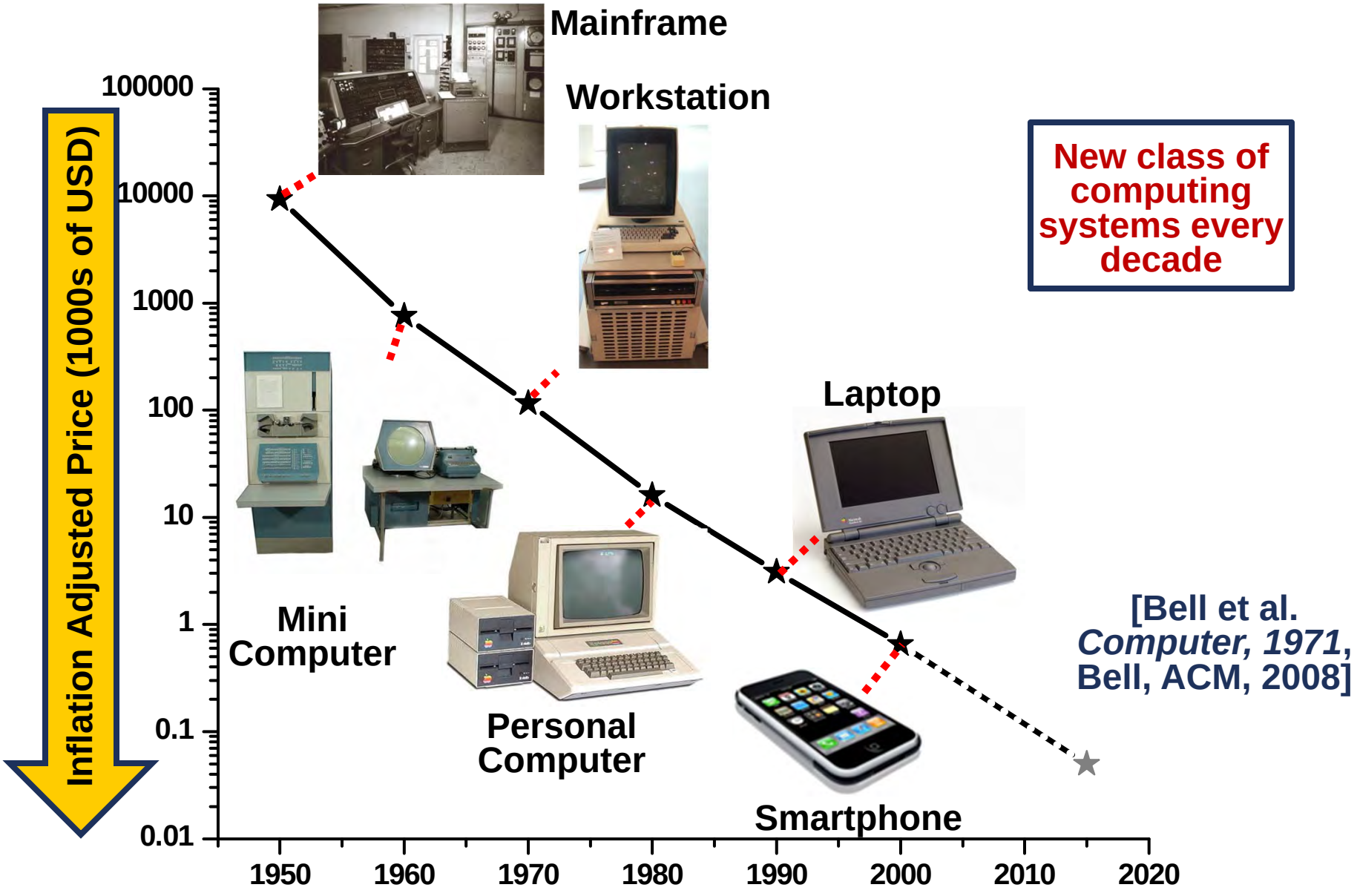


NTC in Mobile Multimedia

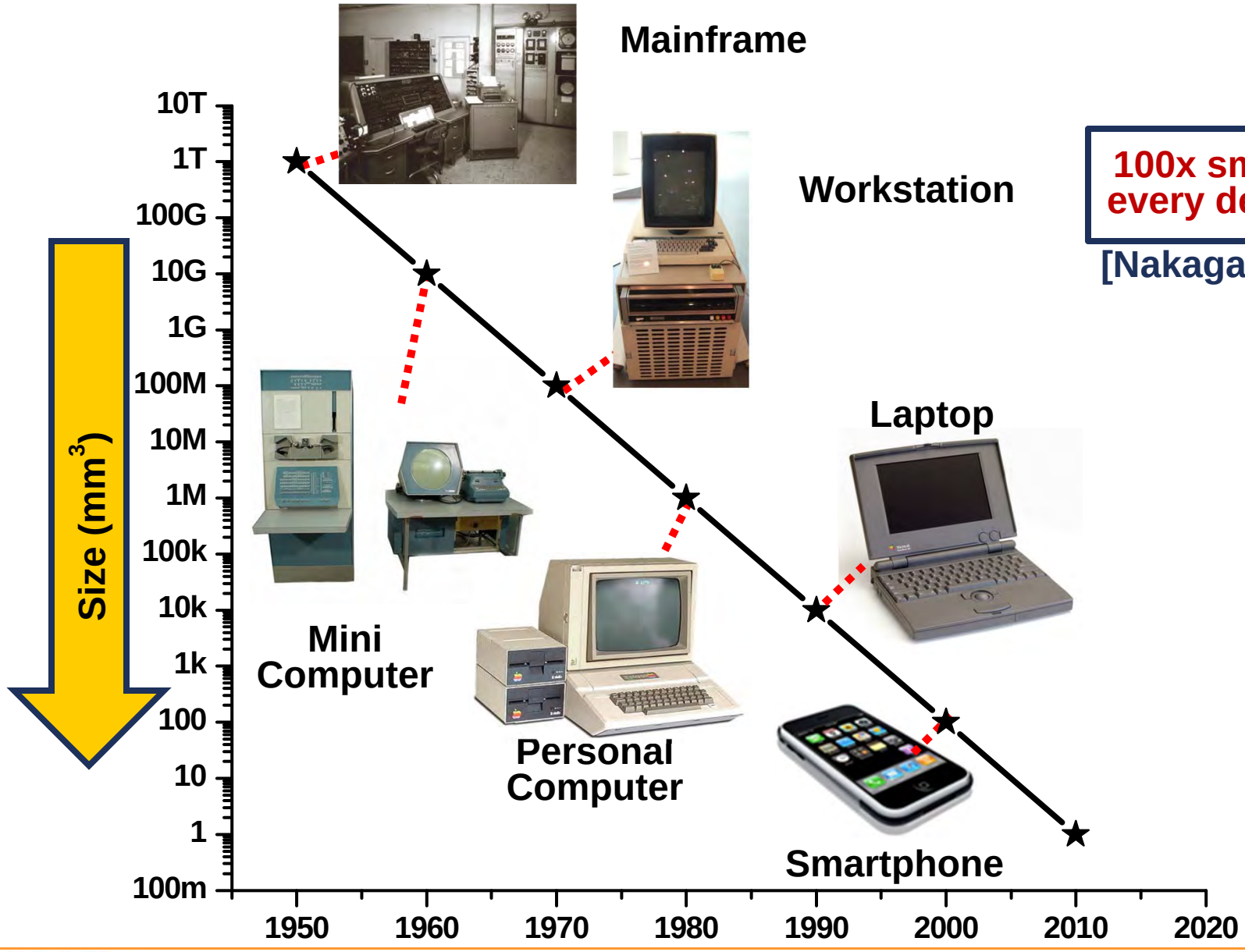
- FFT accelerator with record energy efficiency
  - 15-18nJ/FFT @ 240MS/s
- Aggressive pipelining used to drive down Vopt and Emin
- Minimize leaky memory through algorithm-circuit co-design
- Heavy Intel research in this area also (NTV)
- **BUT the largest opportunity lies elsewhere…**



Bell's Law


Mainframe
Workstation
Laptop
Mini Computer
Personal Computer
Smartphone
Inflation Adjusted Price (1000s of USD)
100000
10000
1000
100
10
1
0.1
0.01
1950
1960
1970
1980
1990
2000
2010
2020
New class of computing systems every decade
[Bell et al. Computer, 1971, Bell, ACM, 2008]

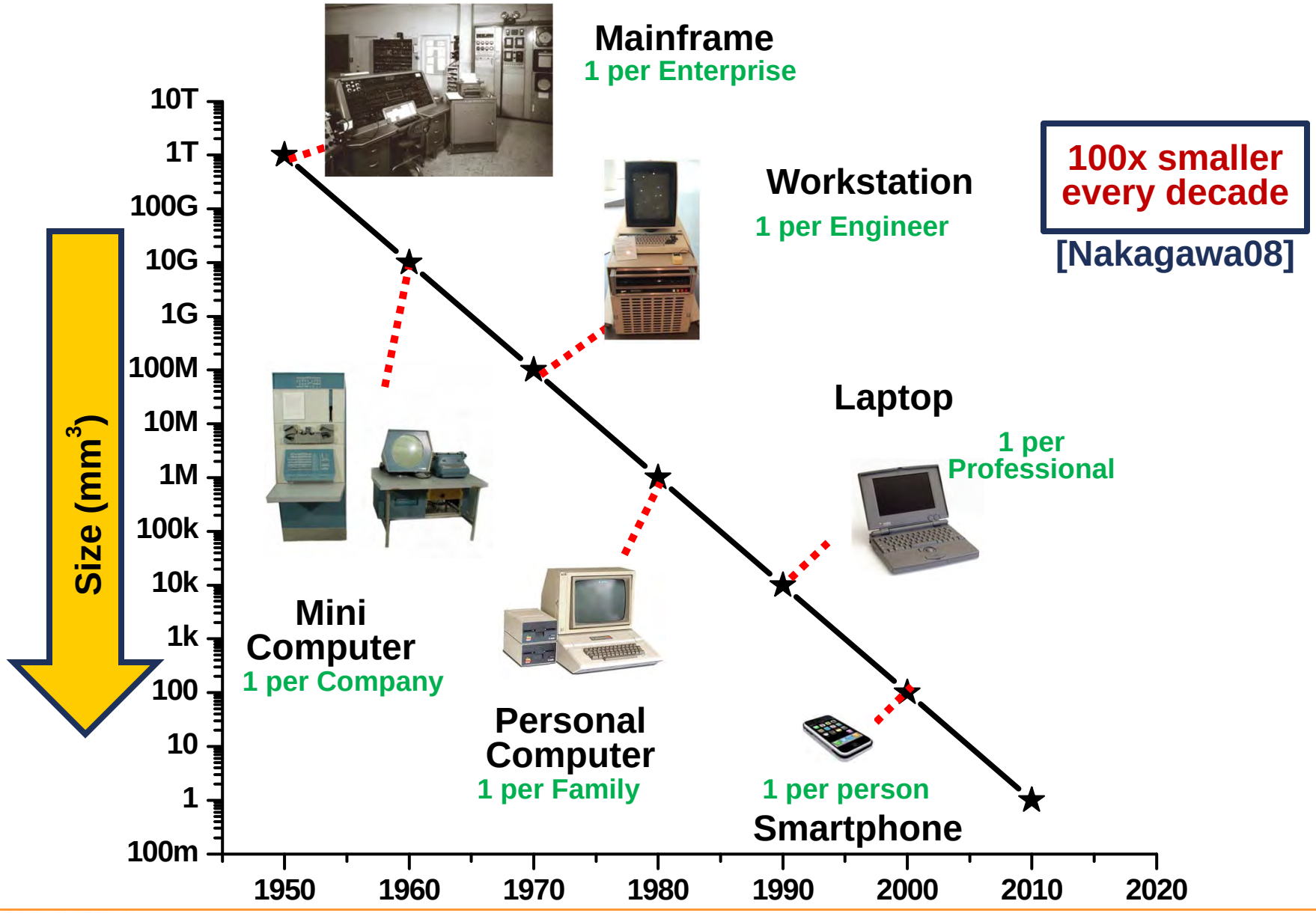
Bell's Law – Corollary



100x smaller every decade

[Nakagawa08]

Bell's Law – Production Volume



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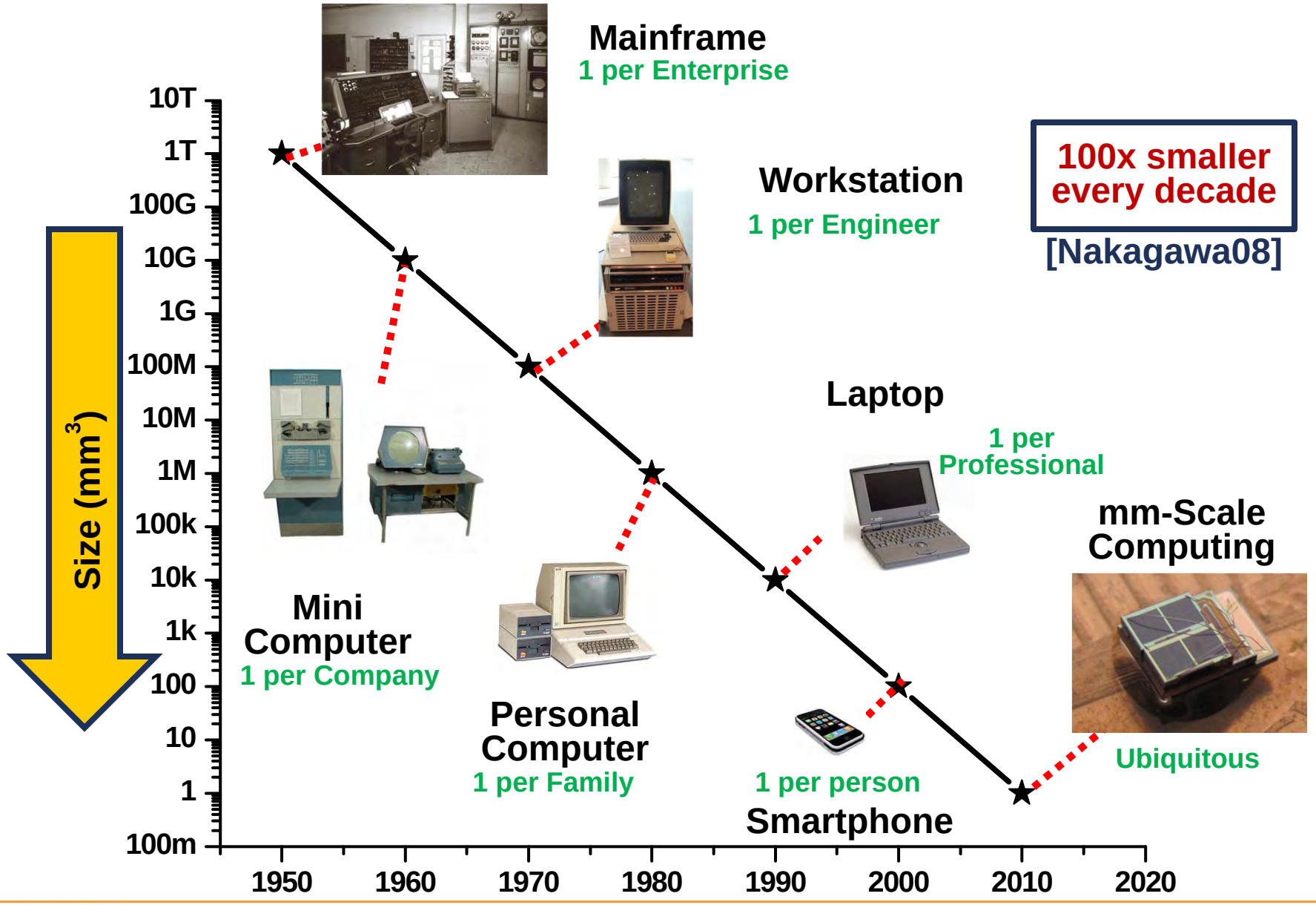
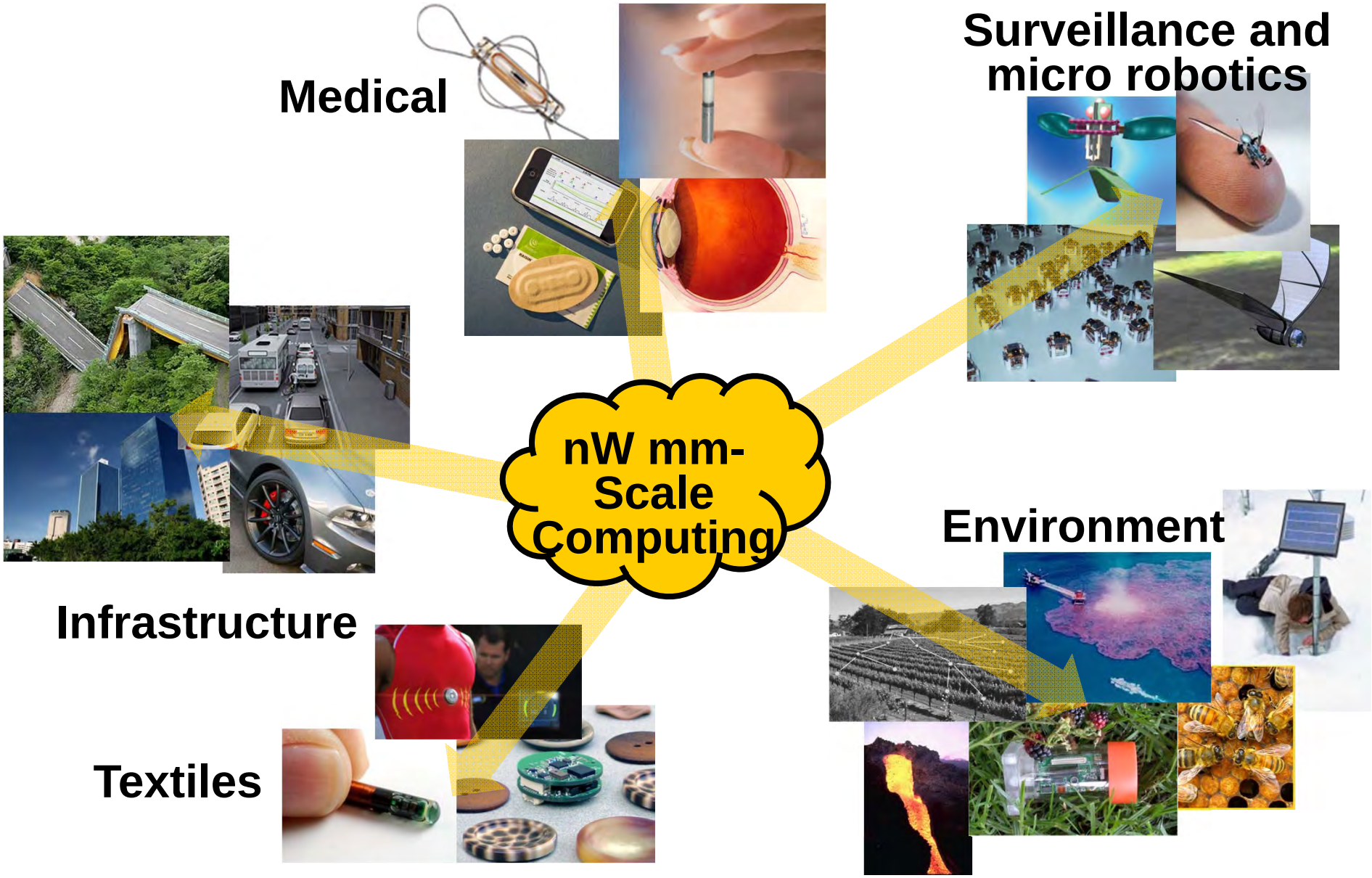


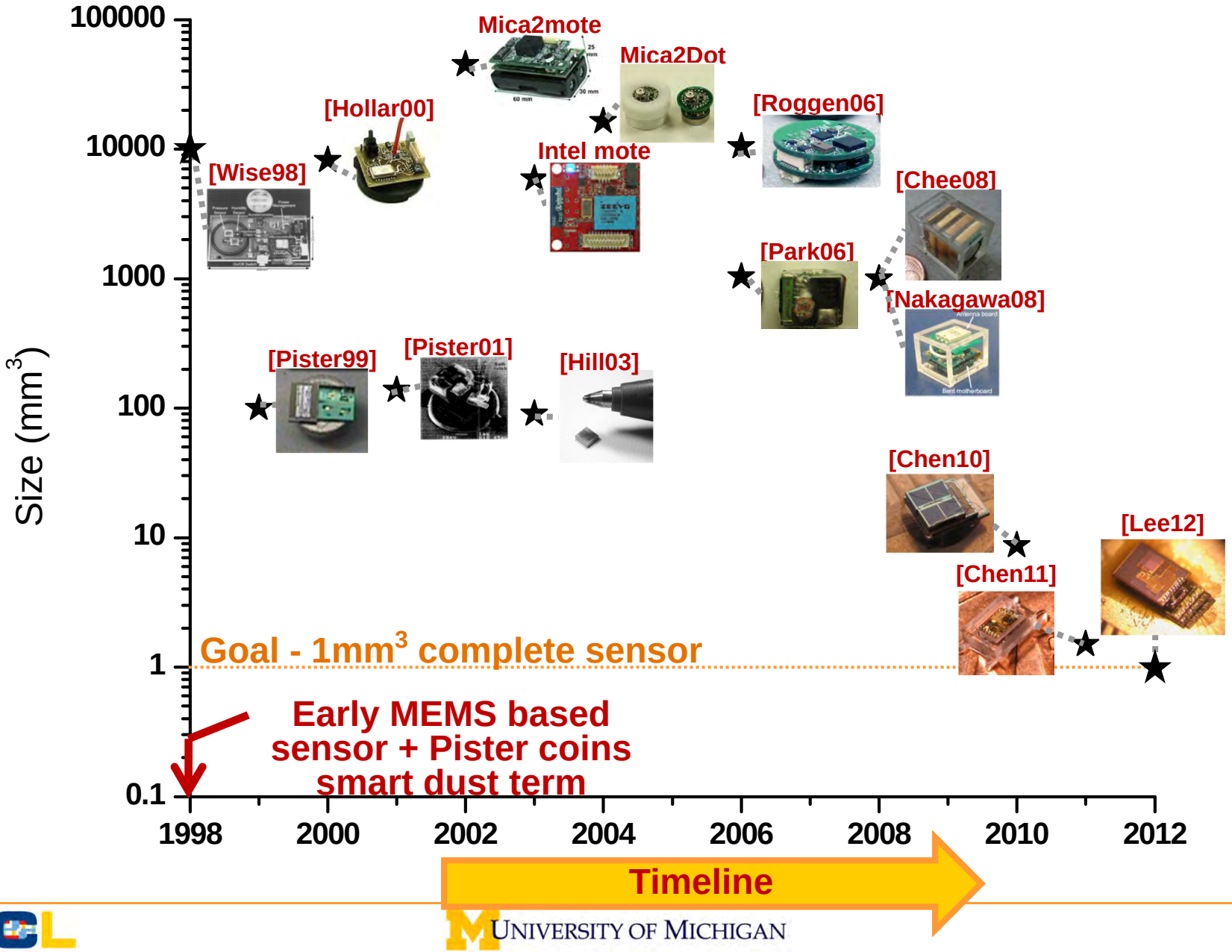
The Opportunity & Challenge

- **Tiny nearly invisible computing devices** will revolutionize health care, security, infrastructure and environmental monitoring
- Very hard to achieve
  - Size vs. lifetime
- We are close to delivering on this vision
  - What are the **killer apps**?
  - **How small** can we make them?

nW mm-Computing: Application Areas

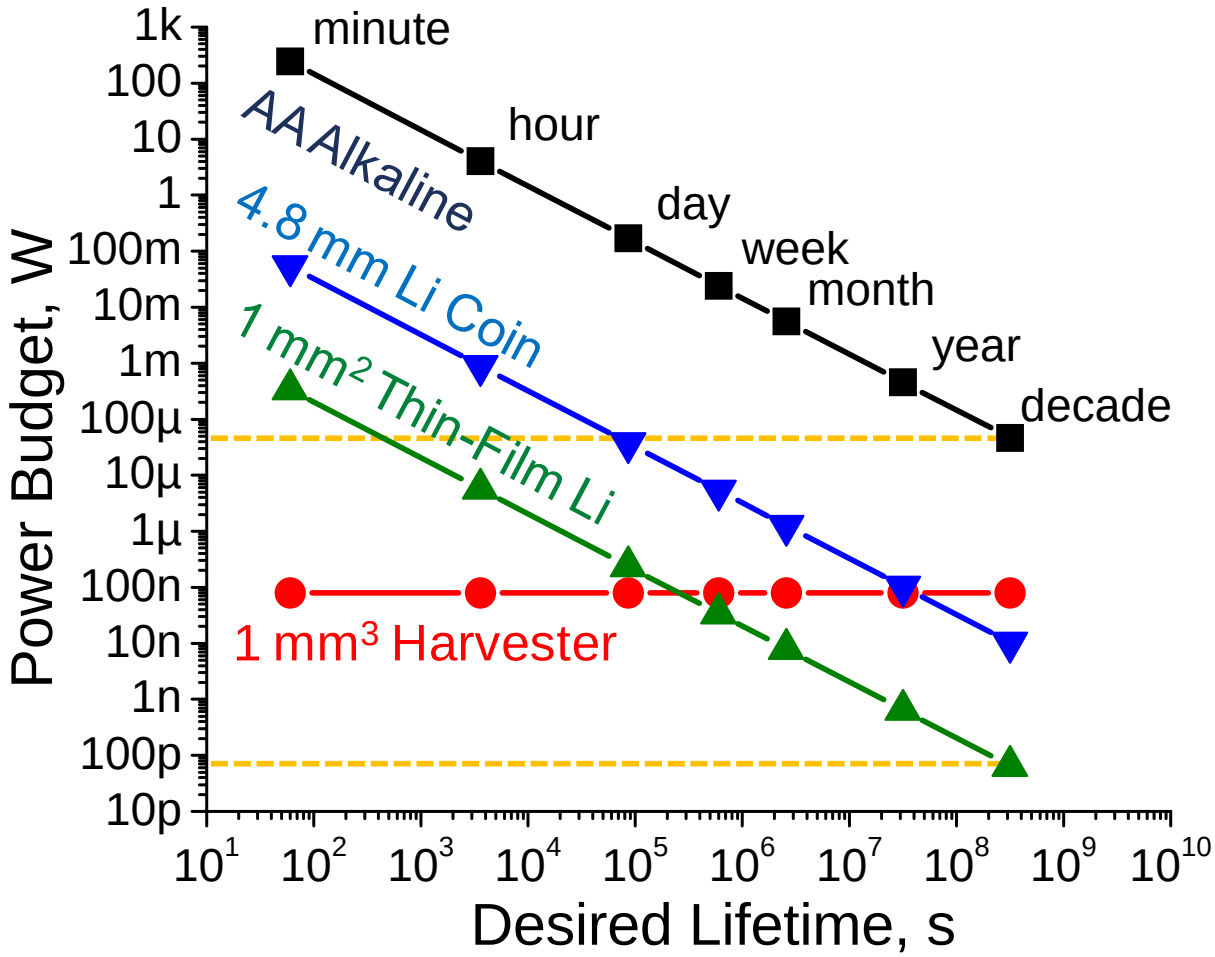


Where Are We Now?



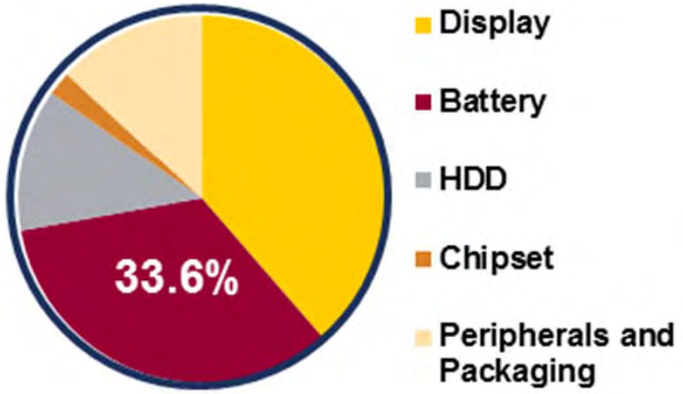
Why aren't we further along?

- Long device lifetime vs. small form factor
- The 3 most important things in miniaturization
- Circuits just are not there yet

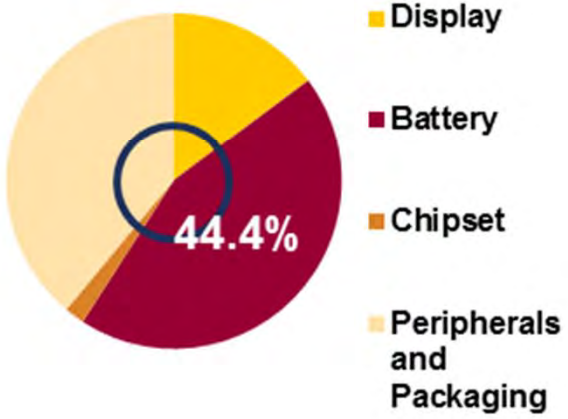


Reducing Size

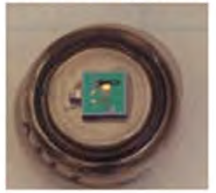
Laptop – 24,500cm^3

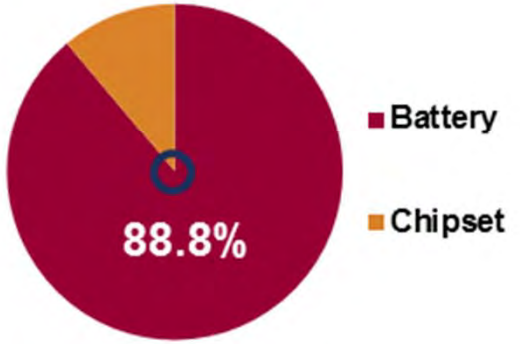


Smartphone – 63cm^3



Micro-mote – 63mm^3 [Pister2000]

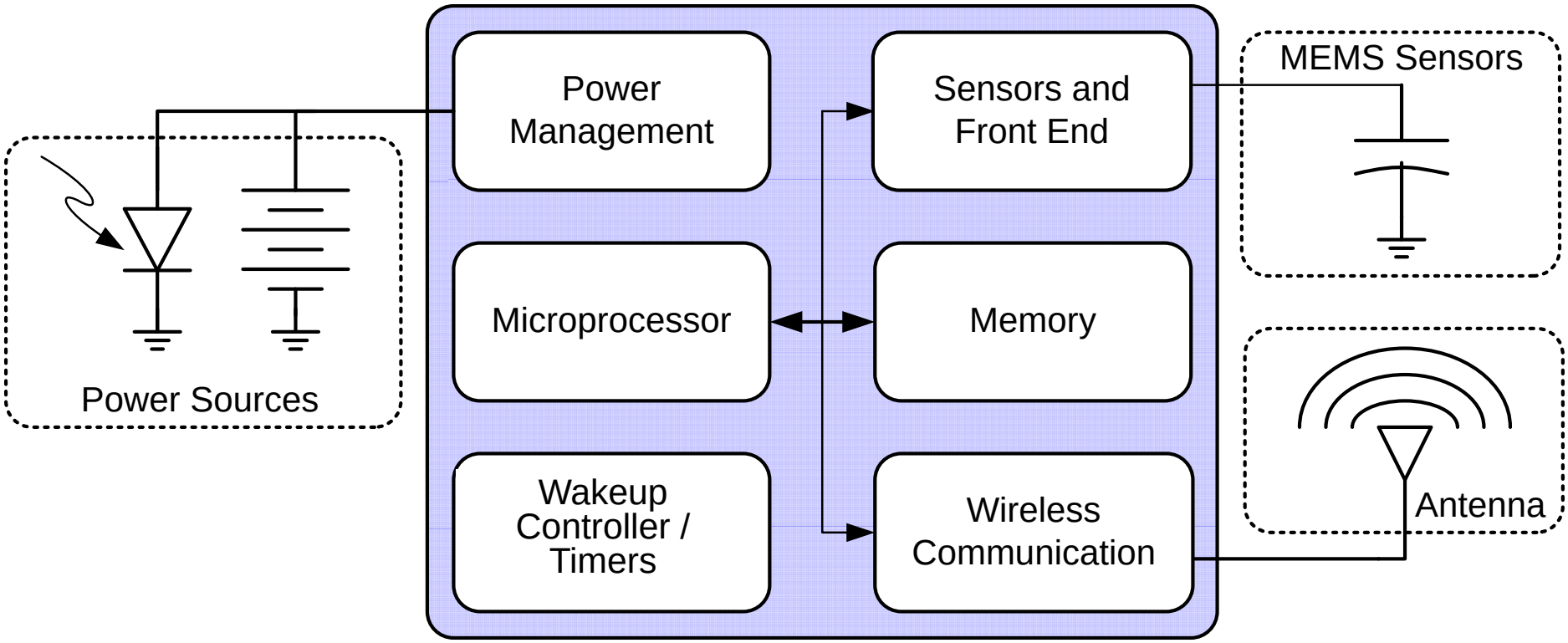




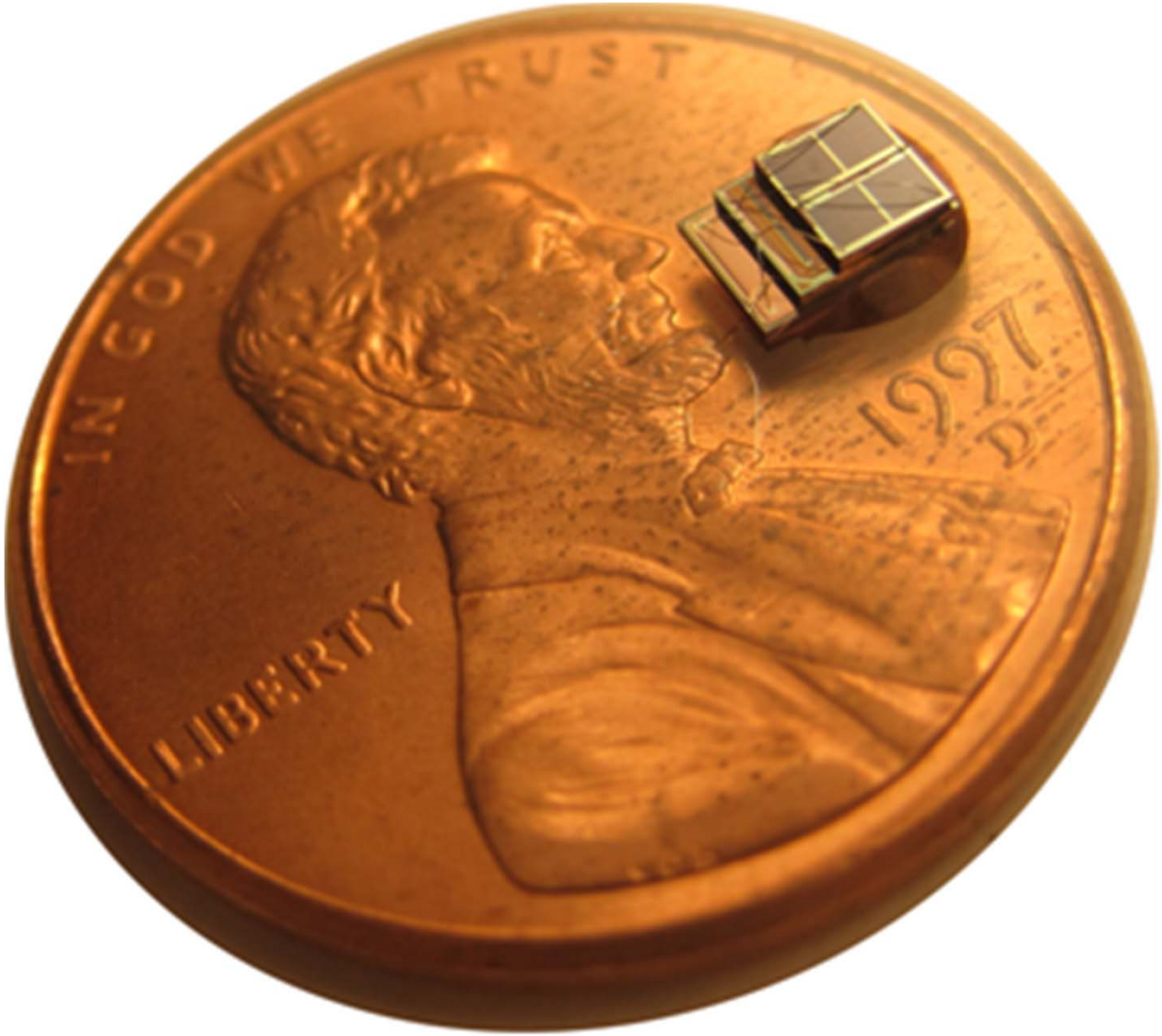
- Solving the battery size bottleneck:
  1. Improve battery capacity
  2. Energy harvesting
  3. Reduce power draw

mm³: How Do We Get There?

- Microsystem functions include sensing, processing, storage, and transmission
- All components must be re-examined to fit within power envelope defined by power sources and power management

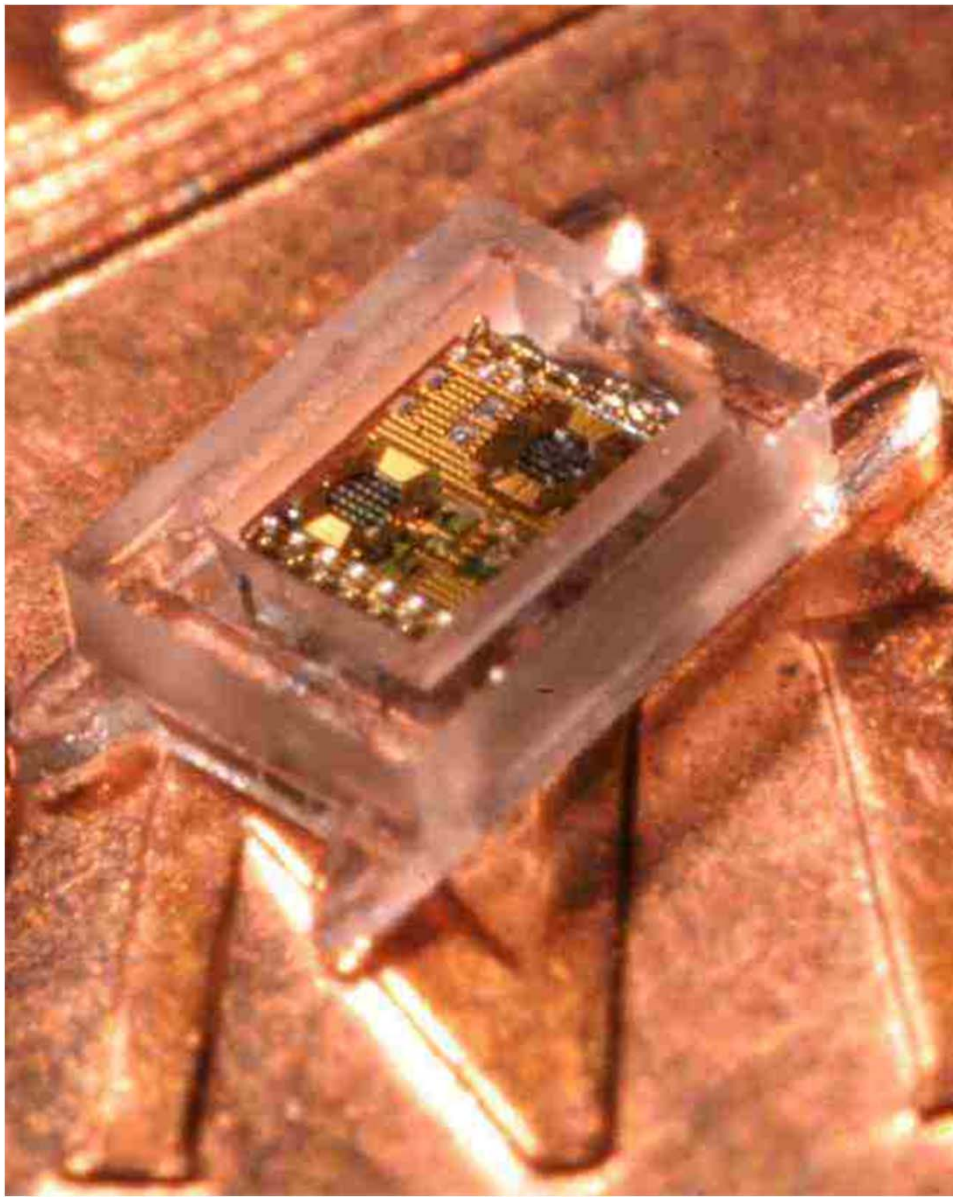


Building Systems in Academia

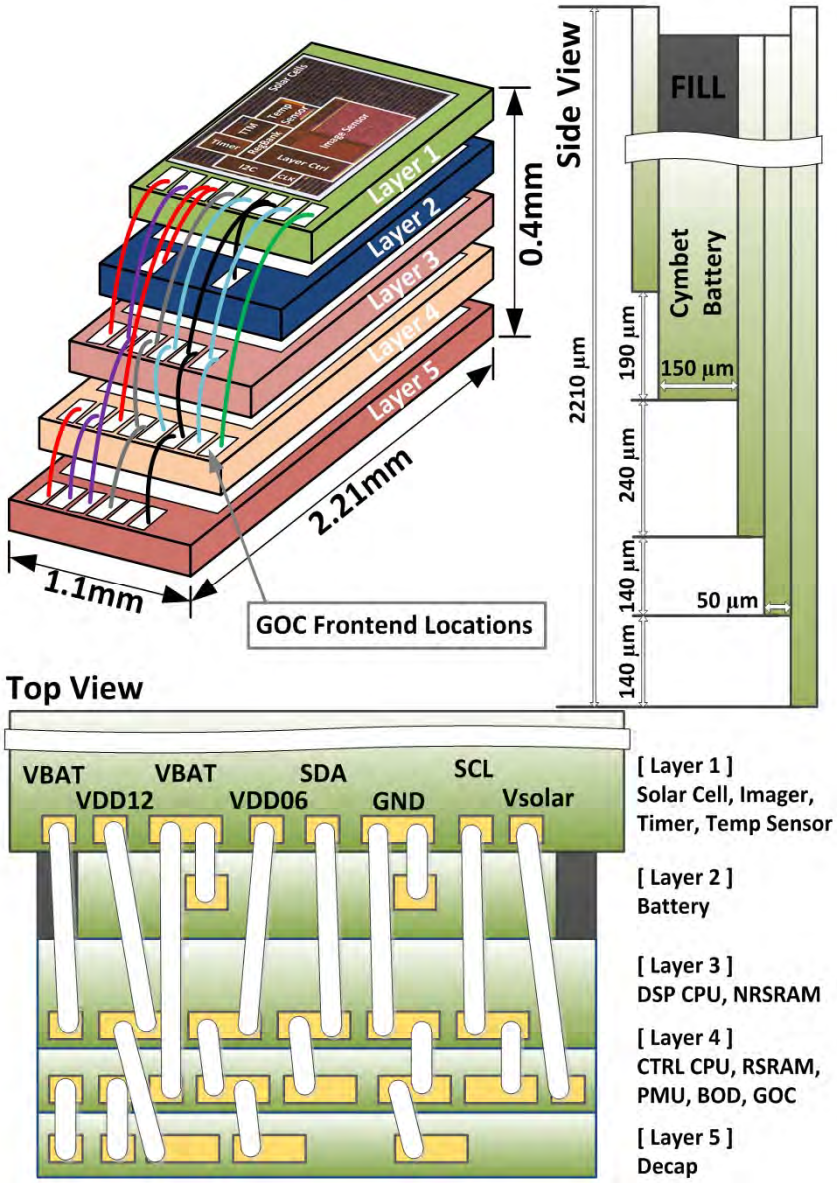


A 1.5mm^3 Wireless Microsystem

- Continuous intraocular pressure monitoring
- Wireless communication
- Energy-autonomy
- Device components
  - Solar cell
  - Wireless transceiver
  - Cap to digital converter
  - Processor and memory
  - Power delivery
  - Thin-film Li battery
  - MEMS capacitive sensor
  - Biocompatible housing

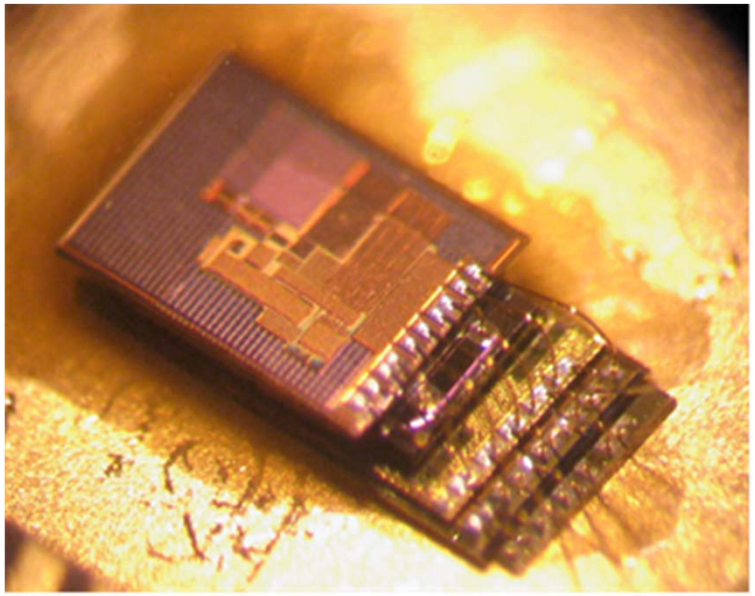


M³ : Michigan Micro-Mote



A 1mm³ general sensing platform

- *Modular* die-stacked structure
- I²C inter-layer communication
- 1 Thin film Li battery – 150µm
- 4 IC layers
  - Thinned (50µm)
  - 3 different technologies (65/130/180nm)



Conclusions

- Applications of mm-scale nanowatt computing are endless and often unimaginable today
  - But first the hardware must get there (it finally is)
  - **The nanowatt challenge!**
- Power minimization is paramount
  - Few nW avg power
  - 1-10m comm range
  - ~Indefinite lifetime
  - Re-think sensor system from bottom up