Post Exascale/Post-Moore's Law

John Shalf

End of Moore's Law 2024?

- **Moore's Law is economic theory that underpins our current electronics industry**
  - 2x more parts each gen. for same price, or same amount for 2x lower price
  - Notice that it says nothing about CMOS!!!

- **End is near?**
  - Si Atomic radius is 0.1
  - Need large dopant atom population to have reasonable distribution
  - 3nm it gets hard to avoid quantum mechanical effects
  - Colwell prediction 3nm as last node in 2024 (HotChips2013)
  - ***Tech scaling underpins HPC performance improvements and the impetus to "replace" old machines that pays for HPC.***

- **SEMATEC Response**
  - We could go to 0.1nm *(just insert money)*
  - But if that doesn't cause you to buy more lithography machines, we'll do something else
  - 3D layers, new materials, cheaper machines…
  - From $4B Fab to MakerBot for Silicon? ***(Anton for everyone!)***

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Computing Beyond the End of Moore's Law: Alternatives for Sustaining Supercomputing Performance Improvements Despite Approaching Limits in Semiconductor Microelectronic Technology

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iARPA/IDA Report (background)

- **Taxonomy**
  - Classical digital: (e.g. Jack's Laptop)
  - Quantum
  - Neuromorphic
  - Analog

- **IDA/iARPA Conclusion**
  - Invest in extending reach of computing to new areas where digital is not efficient by studying Quantum, Neuromorphic, and Analog
  - But don't forget that you need digital (it offers a kind of computation that is not well replicated alternatives)

Post Moore's Law

- **Focus of OSTP report is Digital Electronics**
  - Reports on Neuromorphic, Quantum from others

- **How can we preserve/extend performance/cost-effectiveness of Digital Electronics?**
  - **New Materials/Better Switch:** (new transistor)
  - **Circuits** (up to 2x according to Bill D.)
  - **Lower the cost data movement**: photonics, superconducting, lower voltage
  - **Architecture**: non-von or other (like Thomas says)
  - **Packaging/Integration** (3DI): limited by power

Properties of a Digital Tech Replacement

(what does a CMOS replacement look like?)

Shekhar Borkar, Jeff Bokor input

- **Gain**: Less energy to go in to switching than what is being switched
- **Noise Immunity** how far above kT, how susceptable to stochastic state change
- **Scalability** improve with each generation for economic model
- **Manufacturability** Carbon nanotubes as an example

CMOS replacement: Replace or embrace?

- **Spintronics embedded in CMOS**
  - no-power when not accessed)
  - Single-clock-cycle powerdown
- **Carbon Nanotube modulators for high-speed low-voltage data movement over long-haul wires.**
  - Nanotubes more sensitive
  - don't have to do inefficient reamplificaiton stages at endpoints that eat in to the power advantage.
- **Micromechanical relays**
  - (yes relays).
  - Interesting properties when you shrink
  - Integrate better with Silicon photonics than electronics (piezo effect to change ring resonance is stronger than electrical effect).