Rebooting Quantum Computing

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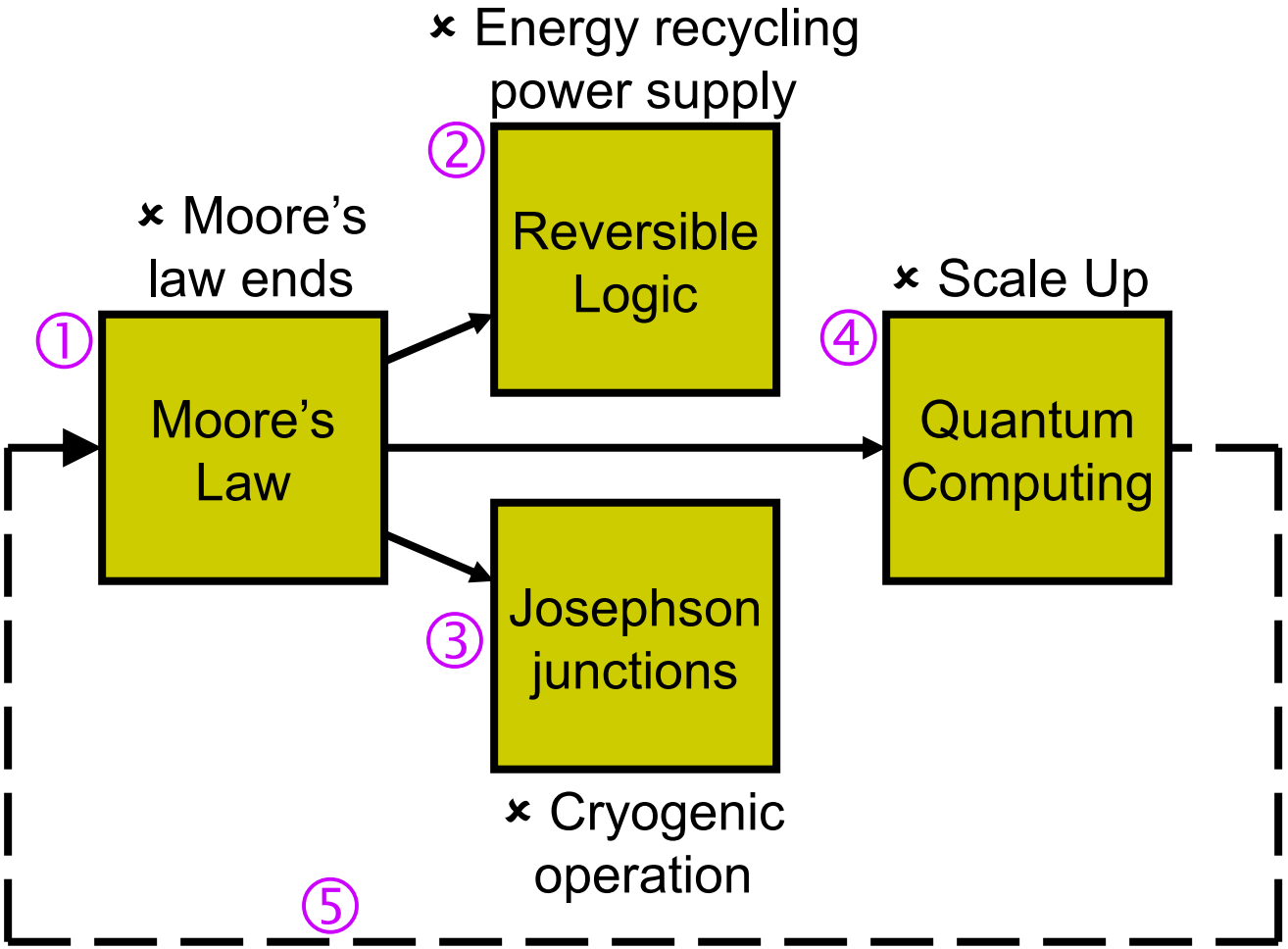
Technical Problem: Excessive Power Bill

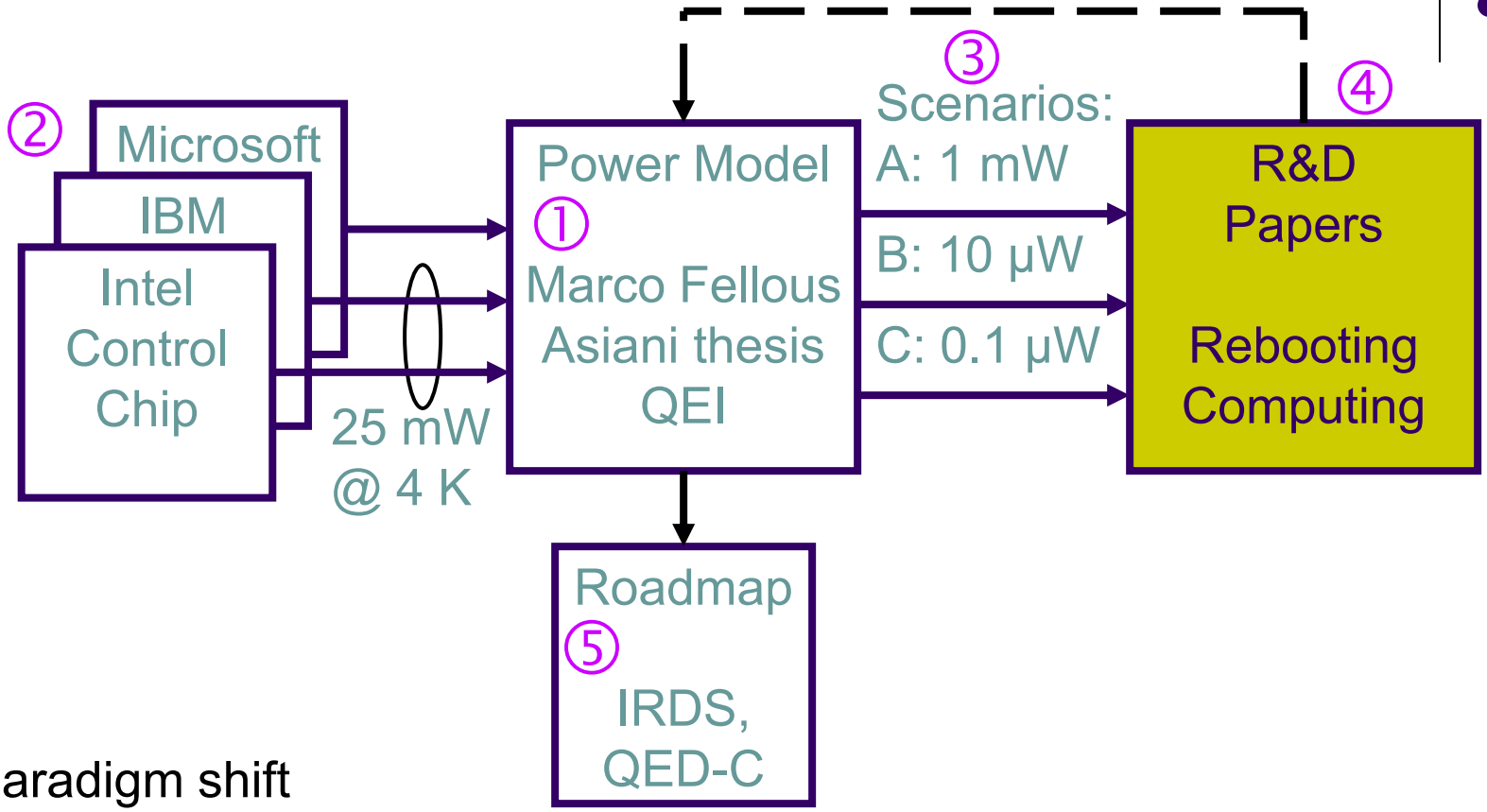
- Scale up of superconducting quantum computers is encountering technological challenges
  - Google's milestone 6 is a million qubits in a structure that looks bigger than 10 meters of A380 fuselage (possible hidden slide)
  - IBM's roadmap mentions "millions of qubits"
  - But more is needed: a well-known quantum factoring paper calls for 20 million raw qubits
- Problem 1: No technology can run a million cables into a cryostat
- Problem 2: Excessive power bill for cryo-CMOS controllers at 4 K
  - IBM and Intel have cryo-CMOS controllers at 25 mW/qubit 4 K
  - Multiplying by a million and then 200× cryocooler overhead gives 5 MW
  - At $1/watt-year,† the power bill will be $5M/year for a million qubits and $100M/year for 20 million qubits
- Rebooting Computing could hold conferences and publish results contributing to a solution

†12¢/kWH × 8766 hrs/year → $1.05/W-year

Rebooting Computing Becomes an Infinite Loop



Details of the Second Reboot



Paradigm shift

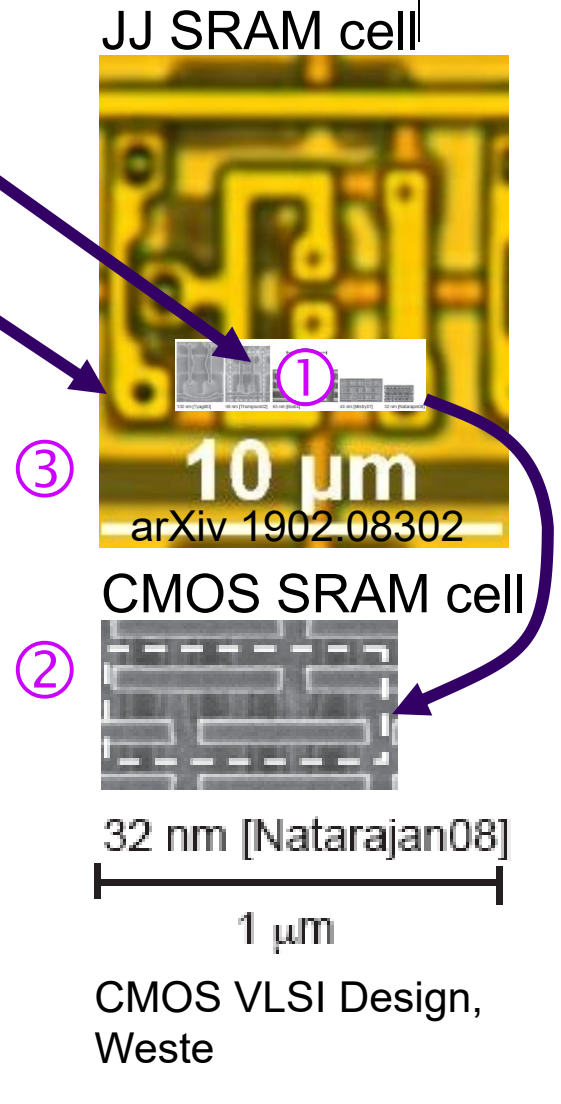
- Previously, physics informed engineers of the temperatures
- In future, temperatures will be selected by an optimization algorithm

Hybrids and Technology Teamwork

- Rebooting computing was organized like a horse race
  - Horses were named New Switch, Reversible, SFQ, … (see hidden slide)
  - Horse with best performance parameters, get research funding by reduction in budget for the losing horses; teaming would not help
- Different approach in production (Smartphones)
  - Horses are CMOS, DRAM, Flash, RF, etc.
  - Smartphone manufacturer wants a team of horses that can expand the total money supply
- Quantum computers now have a goal, so Rebooting Computing could use the teaming approach

Example: Semiconductor-Superconductor Hybrid

- Horse 1: You can make a transistor chip
  - And people have done this
  - For detail, see ②; transistor are small
- Horse 2: You can then evaporatively deposit JJ/SFQ circuits
  - Would not look like this; layers reversed
- However, there is a size disparity
  - CMOS excels on density (size)
  - JJ/SFQ circuits are intrinsically fast and low power
- Can we use these horses in a team?

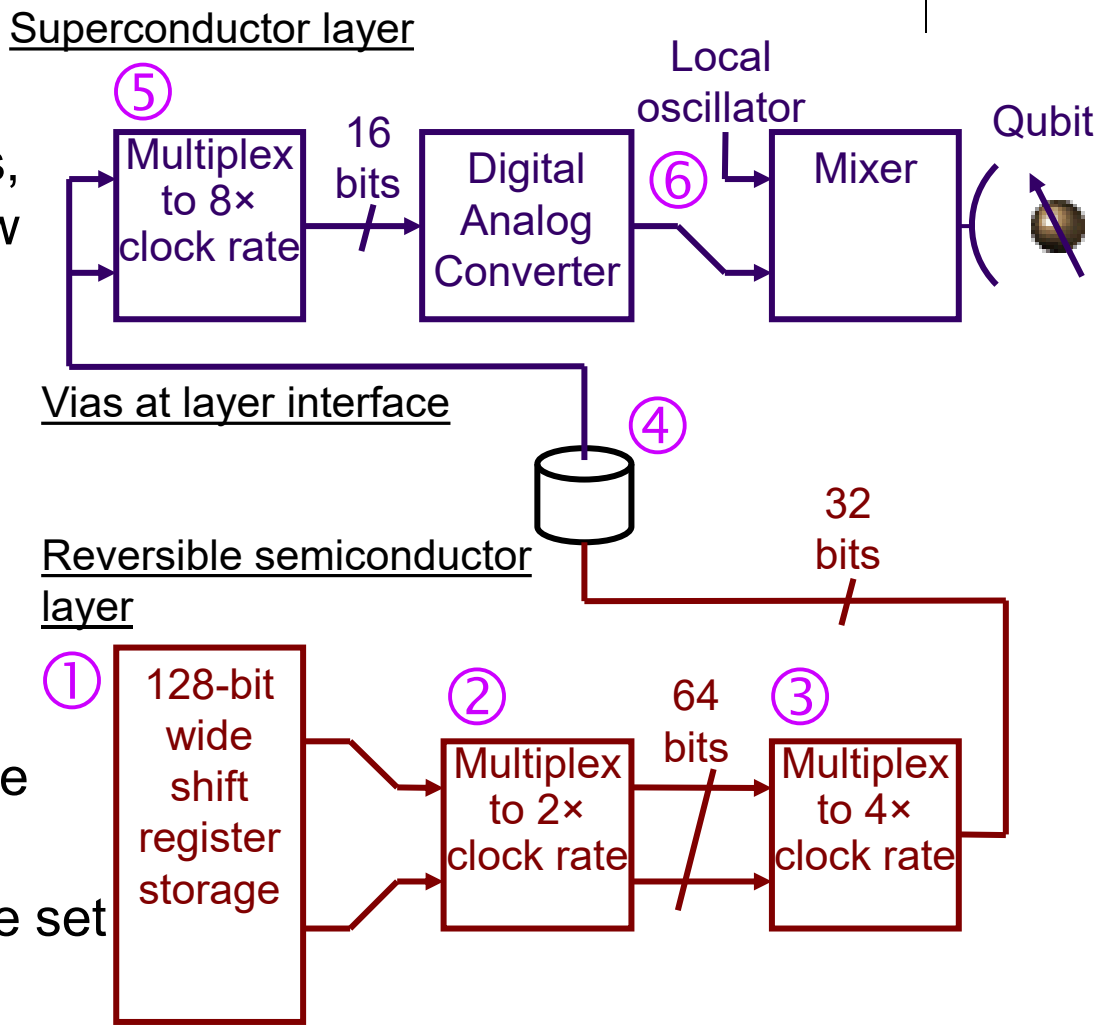


CMOS VLSI Design, Weste

Semi- Superconductor Hybrid for Waveform Playback

Design concept

- Store data in transistors, which are small but slow
- Process data in JJs, which have low dissipation even at high speed
- Benefit: do not need single technology to be best at everything
- Cost: Need to design the interface
- But will need a complete set functions



Quantum Roadmap

We now have a basis for an ITRS/IRDS-like roadmap

- Start with 25 mW/qubit and use framework to quantify how much each advance reduces the power of a quantum computer

Description	2022	2025	2030	2035	units
General factors					
Cryo-CMOS baseline power/qubit at 4 K	25 ①	25	25	25	mW
Cooling overhead to 4 K, large scale	200	200	200	200	W/W
Cryo-CMOS (not including this work)					
Process technology factor					
Example: 22FFL to GAA 3 nm			5 ②	5	×
Design optimization factor					
DAC, DSP improvements			10 ③	10	×
Rearchitect				5	×
Power per qubit @ 4 K	25,000	25,000	500	100	µW
Million qubit control system power	5,000	5,000	100	20	kW
Reversible logic (addon for this work)					
Circuit improvement over cryo-CMOS	1	25 ④	50	100	×
Power per qubit @ 4 K	25,000	1,000	10	1	µW
Million-qubit control system power	5,000	200	2	0.2 ⑤	kW

Summary

Technical material in this talk

- There is now a quantitative basis for roadmaps and benchmarks
  - Power prediction framework: Marco Fellous Asiani's thesis
  - Qubit controller chips: Intel, IBM, Microsoft; SeeQC
  - Quantum computers of growing size: Google, IBM, etc.
  - Source of new component technologies
    - Zettaflops, Hypres (us)
    - Rebooting Computing

Potential follow on activity

- IEEE has could support brainstorm type activity, which could be ICRC
- The prediction framework could become the basis of a roadmap like ITRS/IRDS
- Benchmarks could be created for subfunctions
  - Chip area and dissipation for the hybrid waveform playback using a reference waveform

Leave Behinds and Additional Information

The submitted paper and this PowerPoint (with hidden slides and references) are posted at

https://www.zettaflops.org/ICRC-22

It is a WordPress site, so you can go to zettaflops.org and use the site's navigation

Zettaflops, LLC and Hypres have applicable technology