Lecture 2
Moore’s Law

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Reading:
Chapter 1, Fabrication Engineering at the Micro- and Nanoscale, 4th edition, Campbell

Moore’s Law
“Doubling every 1 – 2 years”

1000000000
100000000
10000000
1000000
100000
10000
1000
100
10
1

Components per chip


Feature size + die size + device cleverness

A Note on “Small”

Patterns printed with lithography to make transistors are as small as 25 nm today, and still getting smaller!

Human Hair
~70 micron

Red Blood Cell
~7 micron

Retrovirus
~70 nanometer

Red Light Wavelength
~700 nanometer


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Two Versions of Moore’s Law

- **Moore’s Law 1.0**: scaling up
  - Doubling the number of transistors every 1–2 years
  - More powerful chip for the same price
- **Moore’s Law 2.0**: scaling down
  - Shrinking transistor area lowers the cost of a transistor by about 30%/year
  - Same chip for lower price
- Both versions enable many new applications
- Results in a large increase in chip volumes

Problems with Dennard Scaling

- Voltage has always shrunk more slowly (~1/λ)
- Voltage essentially stopped shrinking 10 years ago
  - Thermal noise (kT/q = 25 mV at room temperature)
  - Subthreshold leakage current
- Power is at a wall, dominates shrink issues
- Clock speed is stuck – we can’t make our transistors faster
- Today, shrinking a transistor makes it worse

Dennard + Moore Today

- The only benefits of shrinking a transistor today are more functions/chip and/or lower cost/function
- Moore’s Law cost: despite rising fab, equipment and material costs, and increasing process complexity, the cost/cm² of finished silicon has remained about constant (or risen only slowly) over the years.
  - Result: lower cost per transistor each year

Moore’s Law 3.0

- **Moore’s Law 1.0**: Scaling up
  - Only applies to Flash and supercomputers today
- **Moore’s Law 2.0**: Scaling down
  - Higher costs are putting this version in danger
- **Moore’s Law 3.0**: Scaling Out (Innovation through Integration)
  - New materials (e.g., HkMG)
  - 3D integration
  - Silicon photonics
  - Memory on microprocessor
  - Smart sensors and actuators, MEMS
  - More… (More than Moore)

Conclusions

- All three versions of Moore’s Law have always been present
  - A shift in emphasis over time
- The Golden Days of Moore + Dennard are over
- Moore’s Law is primarily an economic law
  - It is getting harder to keep costs down, putting the future of Moore’s Law in danger
- Moore’s Law 3.0 is the most exciting version yet

Lecture 2: What have we learned?

- What are the three versions of Moore’s Law?
- What is Dennard scaling?
- Why does Dennard scaling no longer work?
- What are the consequences of the end of Dennard scaling?