The science that drives modern computers.

COS 116, Spring 2010
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Changing face of manufacturing

1936
“Modern Times”

Late 20th century
Silicon wafer fabrication
20th century science and IT: a match made in heaven?

“These are the days of miracles and wonders.” – Paul Simon, Graceland

Main theme in this lecture:

Scientific Advances → Ability to control matter precisely → Amazing products/computers
Example of precise control of matter: Lasers

- Quantum mechanics (wave-particle duality, quantization of energy, etc.)
- Ability to create light of a single frequency ("laser")
Why lasers are so useful: Accurate focusing

- White light
  - Different colors focus at different points — "smudge"

- Laser
  - Focus at single point
Silicon Chip manufacturing

“A picture is worth a billion gates.”

Fact: Modern chips are manufactured using a process similar to photography
Timeline

Vacuum Tube Triode (1908)

Transistor 1947 (silicon, germanium)

Very Large Scale Integrated (VLSI) Circuits; 1970s-- (> 1,000 transistors per chip)

Intel Itanium (Tukwila) 2008: 2 billion transistors
Moore’s Law

Technology advances so that number of gates per square inch doubles every 18 months.

[Gordon Moore 1965]
Implementation of a gate in a modern chip

- **Semiconductor:**
  - not as good a conductor as metals, not as bad as wood
  - Example: silicon

- **Doped semiconductor:**
  - semiconductor with some (controlled) impurities: p-type, n-type

- **Switch:** p-n junction
Example: an AND gate
Chip Fabrication

Grow silicon ingots

Cut wafers and polish

Create mask

Coat wafer with light sensitive chemicals and project mask onto it

Coat with chemicals that remove parts unexposed to light

Repeat to add metal channels (wires) and insulation; many layers!
Aside: Lasik eye correction

Uses laser invented for chip fabrication
Chip Packaging

- Inside
- Outside
Life cycle of a microprocessor

Fact: Less than 1% of microprocessors sold are used in computers

Inside an iPod Remote
Why so few new CPU’s?

Cost of new design: $8 billion

☐ Profit: $100 / chip

☐ Need to sell 80 million to break even
Engineering tradeoffs

- Can run at twice the clock speed! (Why?)
- But: higher clock speeds → much more heat!
Even more precise control of matter

**Nanotechnology**: manufacture of objects (machines, robots, etc.) at the atomic or molecular level (1-100 nanometers)

“nanogear”

**Biocomputing**: Implementing computers via interactions of biological molecules.
Another example of control of matter: the changing data cable

- Serial cable: 115 kb/s
- USB cable: 480 Mb/s (USB 2.0)
- Fiber optic cable: 40 Gb/s
Total Internal Reflection

Porro Prism
How optical fibers work

- Glass fiber: 10-40 billion bits/s

“Total internal reflection”
Wave Division Multiplexing (WDM)

- Multiple (100 or so) data streams enter
- Fiber optic cable
- One beam with various frequencies mixed in
- Multiple data streams exit

- Transmission rates of trillion ("Tera") bits/s
Thoughts about the 20\textsuperscript{th} century

- What factors (historical, political, social) gave rise to this knowledge explosion?

- Will it continue in the future?

As we know,
There are known knowns.
There are things we know we know.
We also know
There are known unknowns.
That is to say
We know there are some things
We do not know.
But there are also unknown unknowns,
The ones we don’t know
We don’t know.

— D. Rumsfeld, Feb. 12, 2002
Are faster chips the answer to all problems in computing?

An Answer:
No!  Halting problem is undecidable!
What about this **decidable** problem?

\[(A + B + C) \cdot (\overline{D} + F + G) \cdot (\overline{A} + G + K) \cdot (\overline{B} + P + Z) \cdot (C + \overline{U} + \overline{X})\]

- Does it have a satisfying assignment?
- What if instead we had 100 variables?
- 1000 variables?

We resume the discussion of these questions in the next lecture (**P v NP**)…