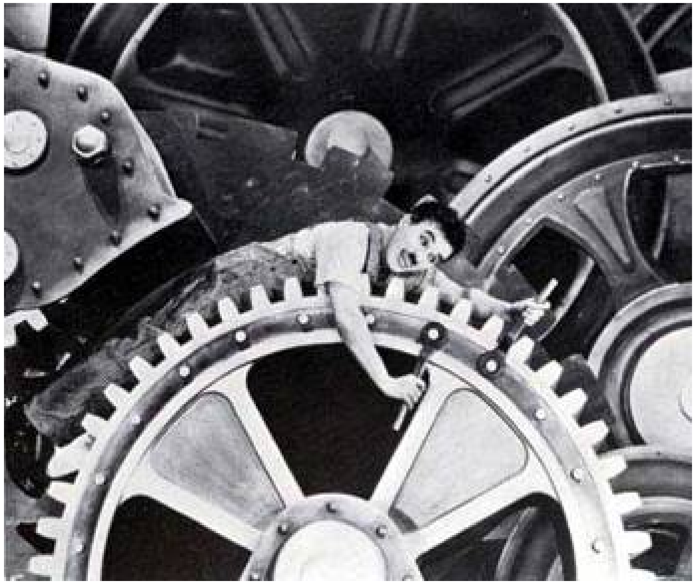
The science that drives modern computers.

COS 116
4/10/2006
Instructor: Sanjeev Arora

Changing face of manufacturing

1936



“Modern Times”

Late 20th century

Silicon wafer fabrication

20th century science and IT: a match made in heaven?

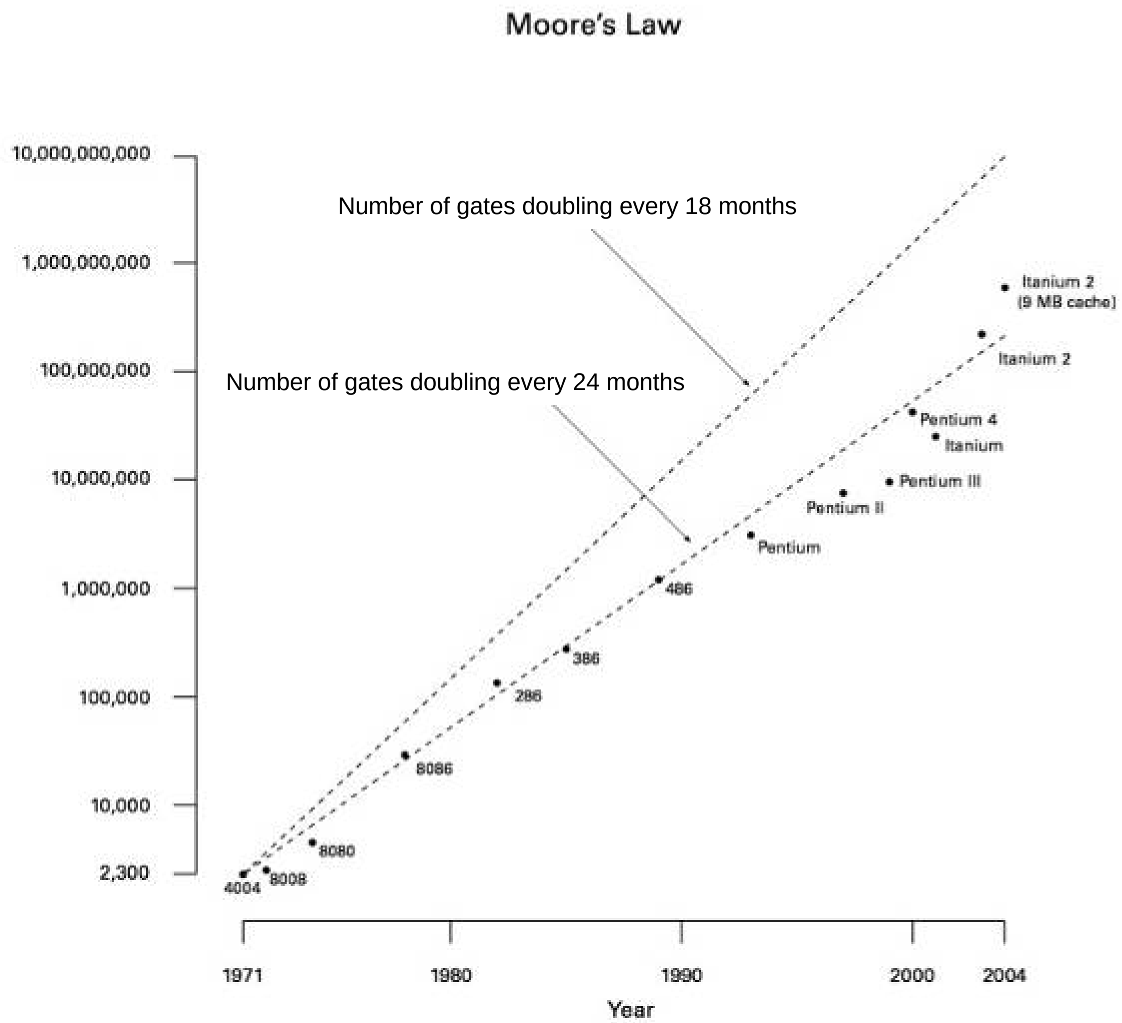
"These are the days of miracles and wonders." – Paul Simon, Graceland

Main theme in this lecture:

Scientific Advances → Ability to control matter precisely
→ Amazing products/computers

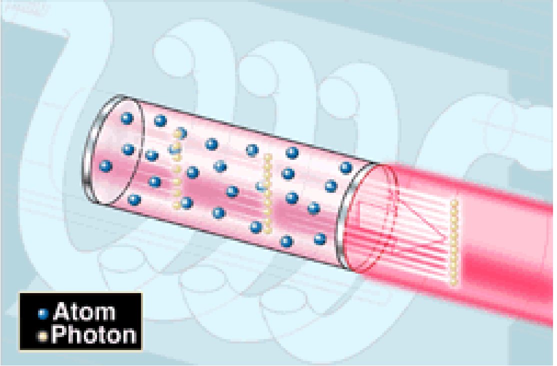
Moore’s Law

- [Gordon Moore 1965] Technology advances so that number of gates per square inch doubles every 18 months.



Example of precise control of matter: Lasers

- Quantum mechanics (wave-particle duality, quantization of energy, etc.)



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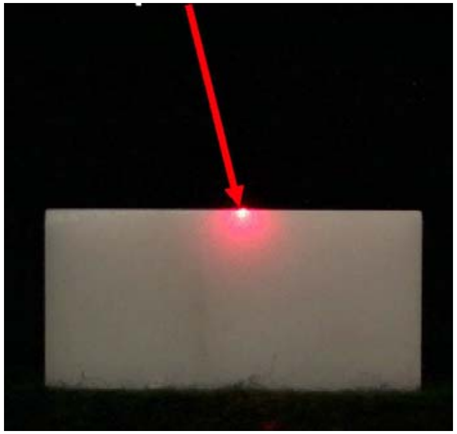
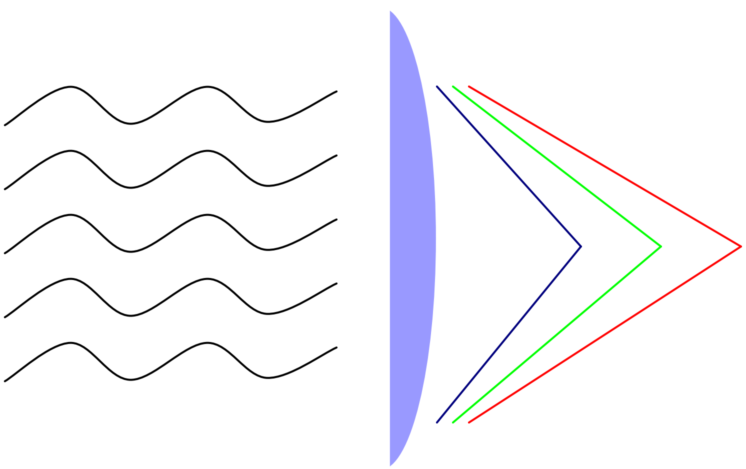
- Ability to produce light with a single frequency (“laser”)



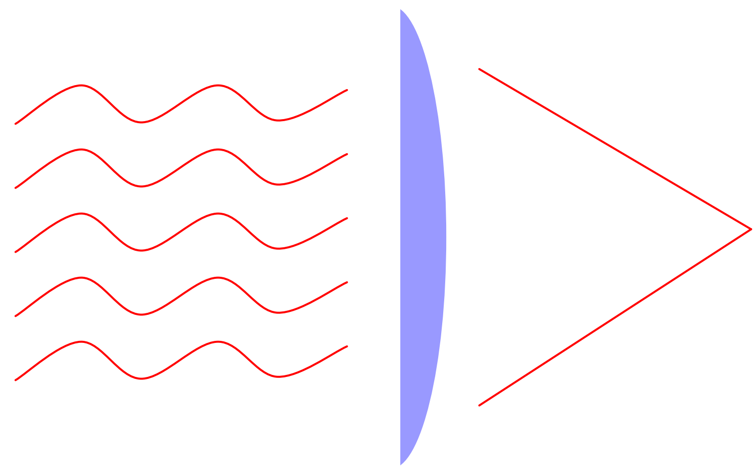
Why lasers are so useful: Accurate focusing

- White light



- Different colors focus at different points – “smudge”

- Laser



- Focus at single point

Silicon Chip manufacturing

"A picture is worth a billion gates."

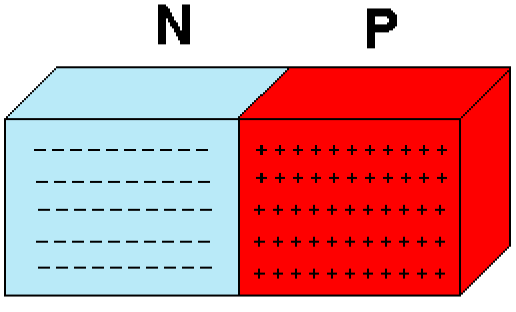
Fact: modern chips are manufactured using a process similar to photography

Implementation of a gate in a modern chip

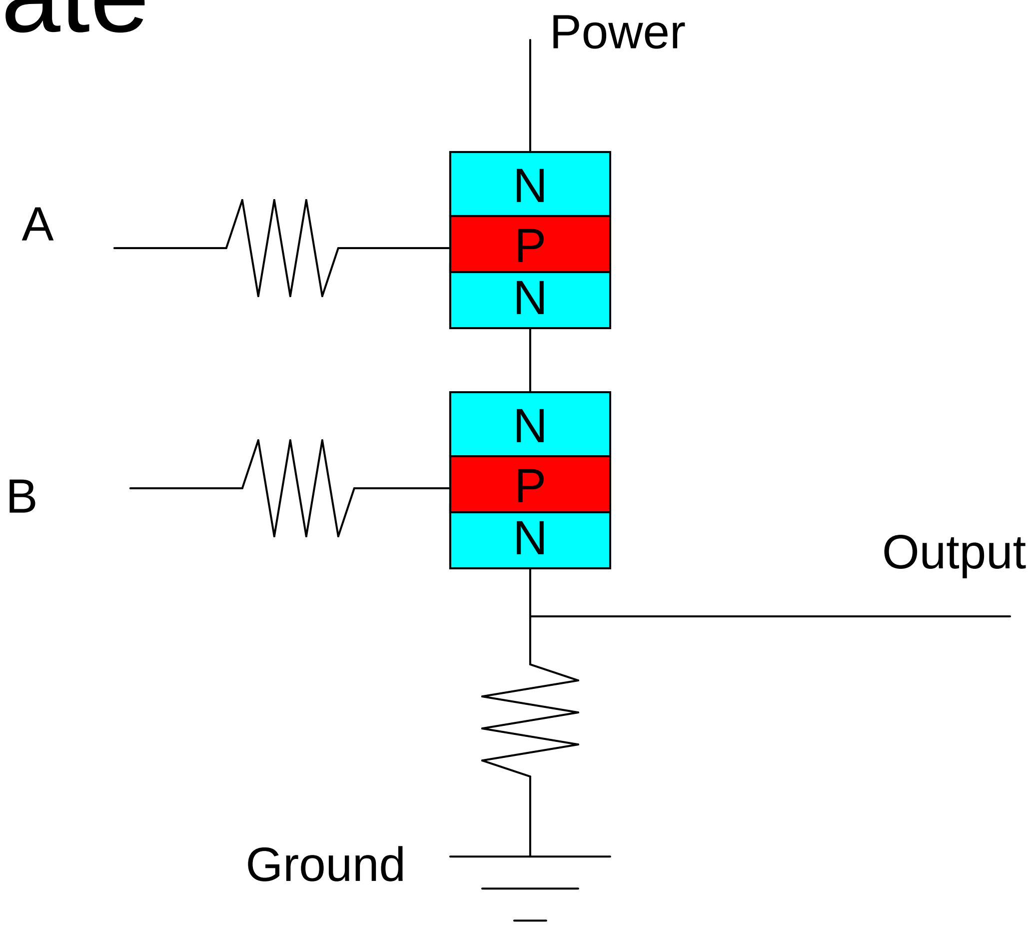
- Semiconductor: not as good a conductor as metals, not as bad as wood
  - Example: silicon

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

- Switch: p-n junction

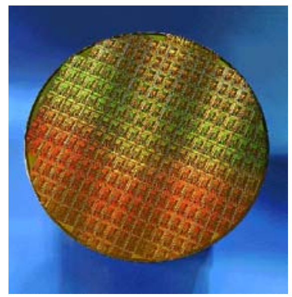


Example: Implementing an AND gate

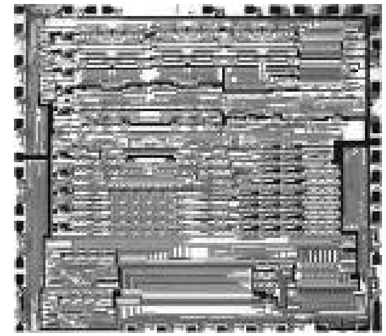


Chip Fabrication

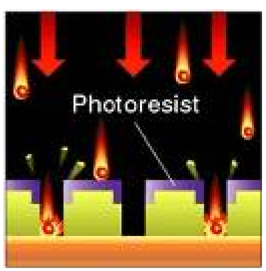
Grow silicon ingots



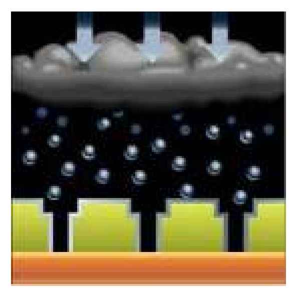
Cut wafers and polish



Create mask



Coat wafer with light sensitive chemicals and project mask onto it



Coat with chemicals that remove parts unexposed to light

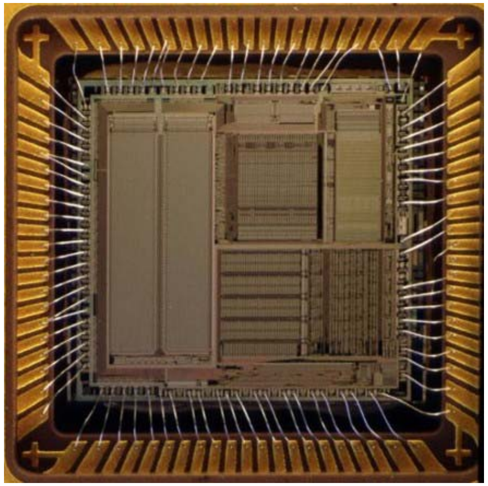
Repeat to add metal channels (wires) and insulation; many layers

Aside: Lasik eye correction

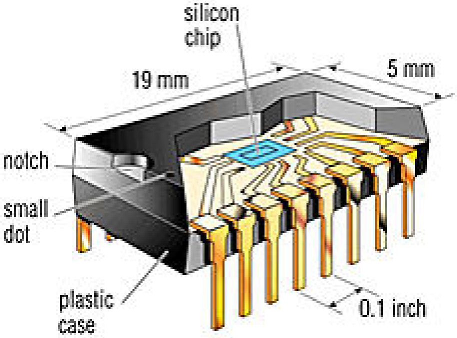
Uses laser that was invented for chip fabrication

Chip Packaging

- Inside



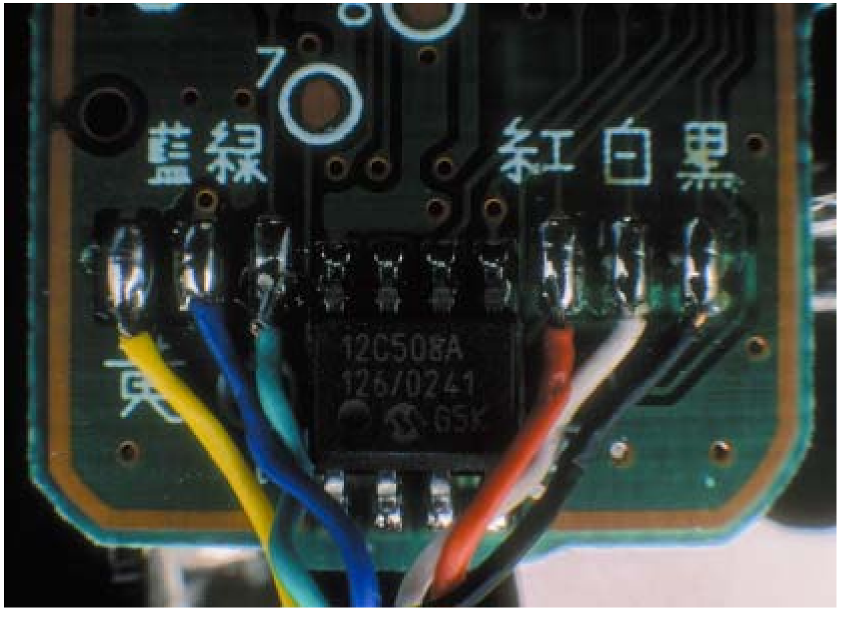
- Outside



Life cycle of a microprocessor

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

Inside an iPod Remote



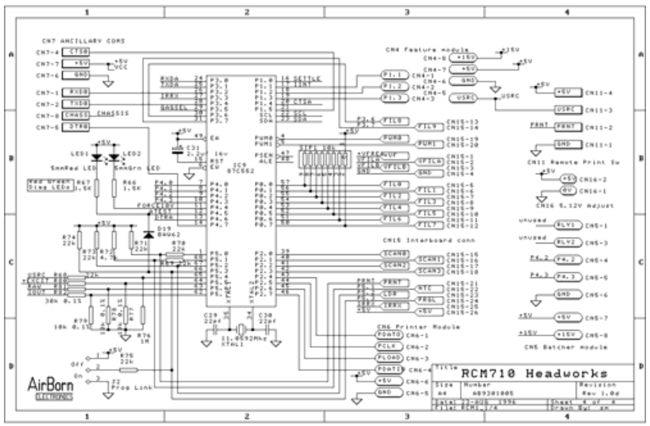
(see sheet being passed around)

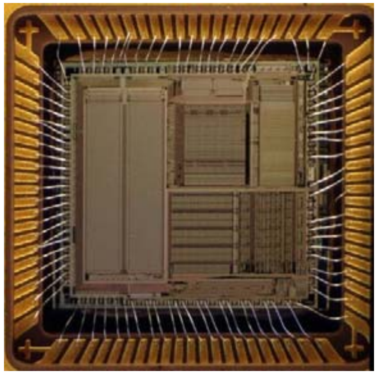
Why so few new CPU’s?

Cost of new design: $8 billion

- Profit: $100 / chip
- Need to sell 80 million to break even

Engineering tradeoffs





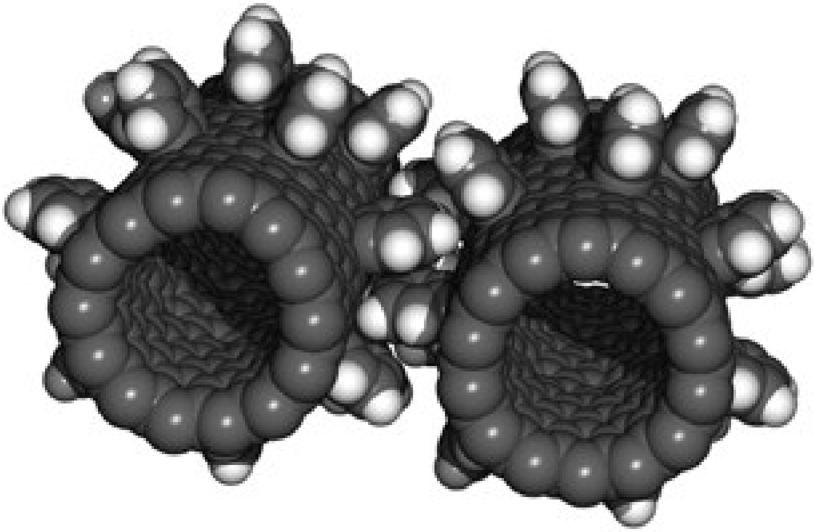
36 months later...

Half the size!

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

Even more precise control of matter: Nanotechnology

Technology to manufacture objects (machines, robots, etc.) at the atomic or molecular level (1-100 nanometers)



nanogear

Yet another example of control of matter: the changing data cable

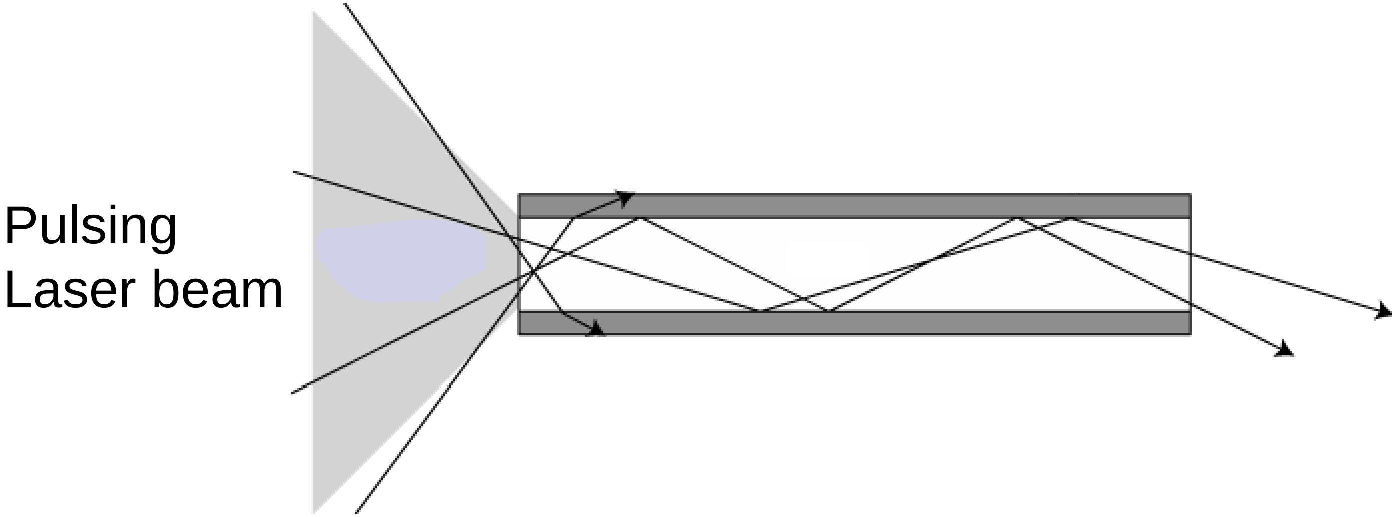
- Serial cable: 115 kb/s

- USB cable: 480 Mb/s (USB 2.0)

- Fiber optic cable: 40 Gb/s

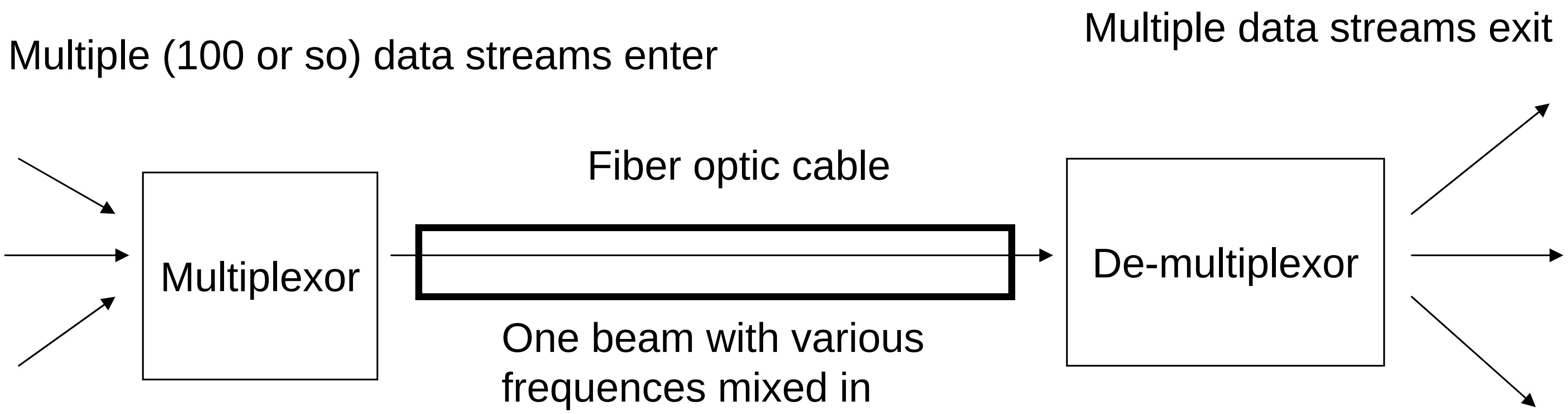
How optical fibers work

- Glass fiber: 10-40 billion bits/s



"Total internal reflection"

Wave Division Multiplexing (WDM)



- Transmission rates of trillion (“Tera”) bits/s

Thoughts about the 20th century

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

- Will it continue in the future?

What do we not know, and what do we not know we don't know? (D. Rumsfield)

Are faster chips the answer to all problems in computing?

An Answer: No! Halting problem is undecidable!

What about this <u>decidable</u> 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 this formula have a satisfying assignment?

- What if instead we had 100 variables?
- 1000 variables?

A week from today: The computational cost of automating serendipity

Discussion topic:

What is the difference between being creative and being able to appreciate creativity?

Next lecture (do not miss!)

How computation and computational models pervade biology.

“Bioinformatics.”