Why Multi-core?

Based on slides from Katherine Yelick
http://www.cs.berkeley.edu/~yelick/

Technology Trends: Microprocessor Capacity
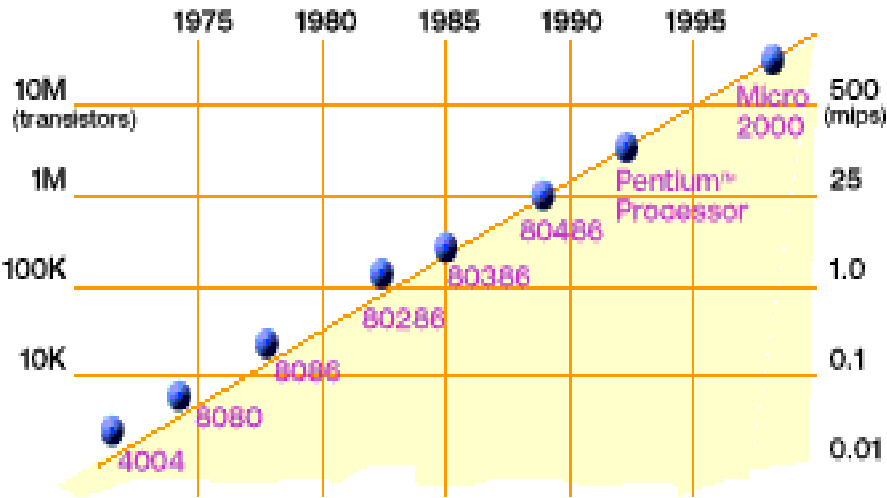
2X transistors/Chip Every 1.5 years

Called "Moore's Law"

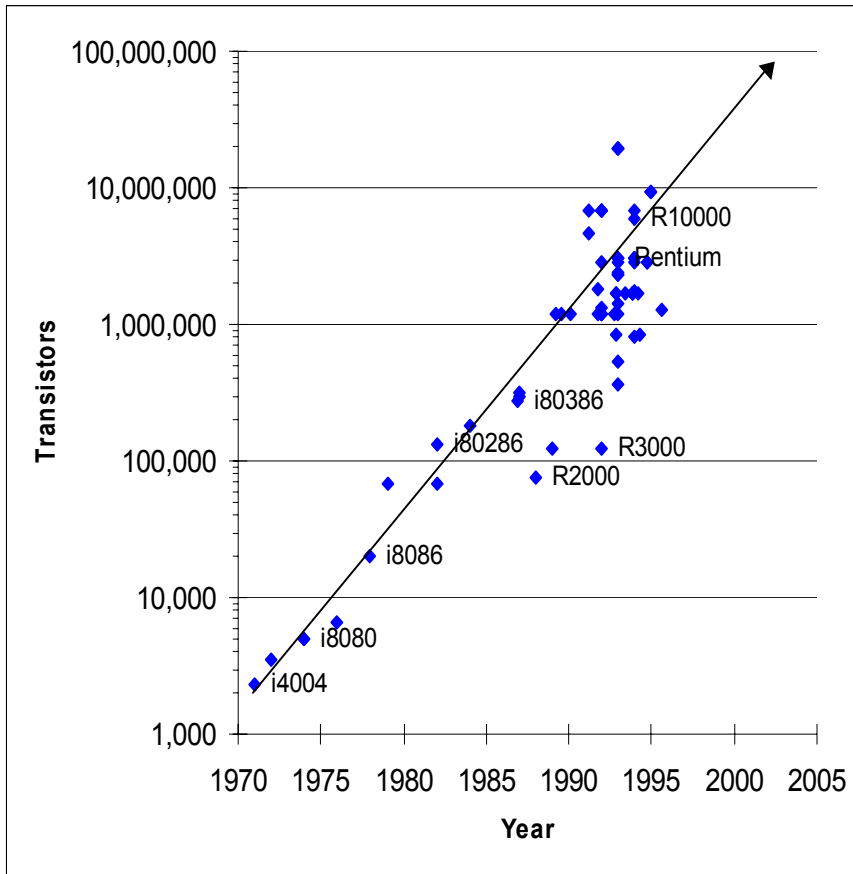**Microprocessors have become smaller, denser, and more powerful.**
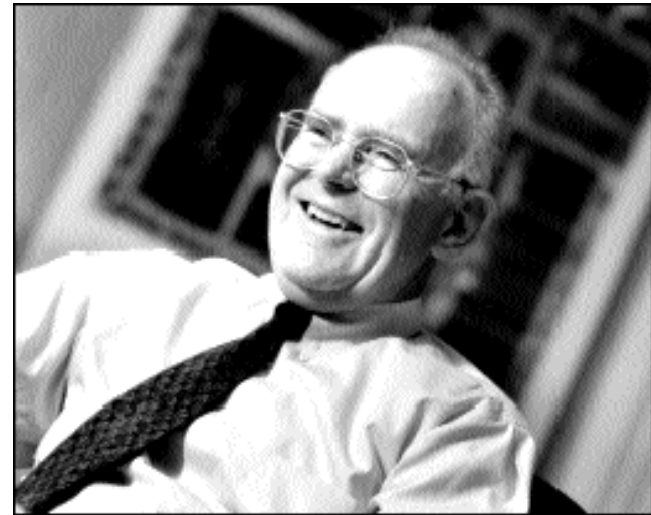
Gordon Moore (co-founder of Intel) predicted in 1965 that the transistor density of semiconductor chips would double roughly every 18 months.
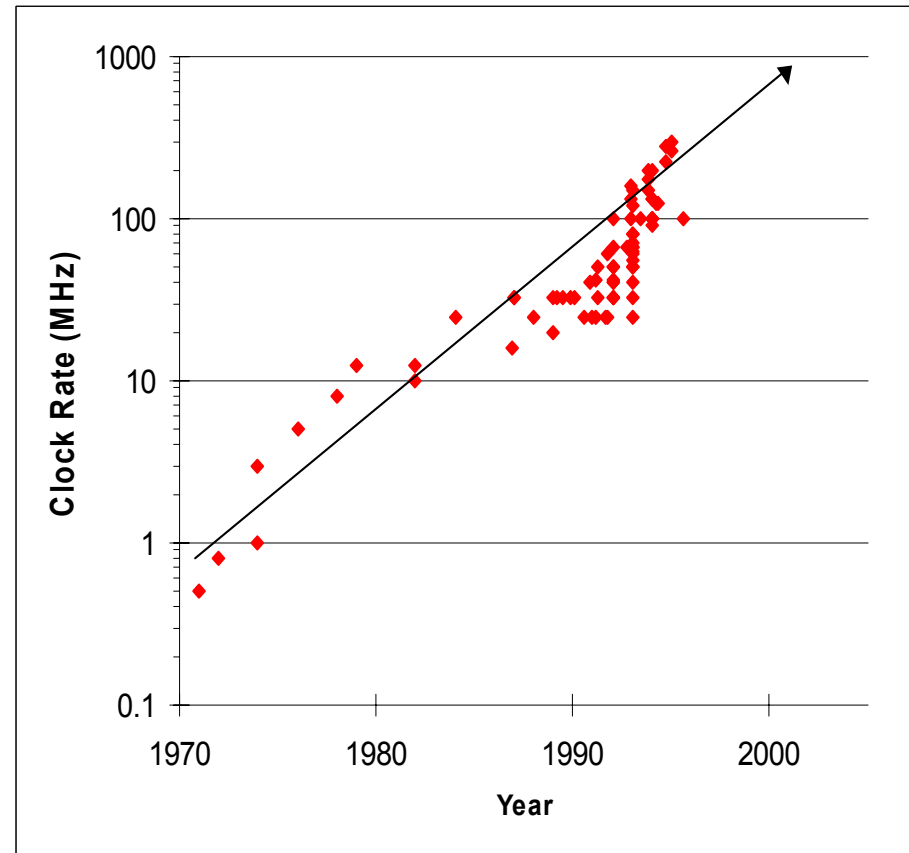
Slide source: Jack Dongarra

Microprocessor Transistors and Clock Rate

Growth in transistors per chip
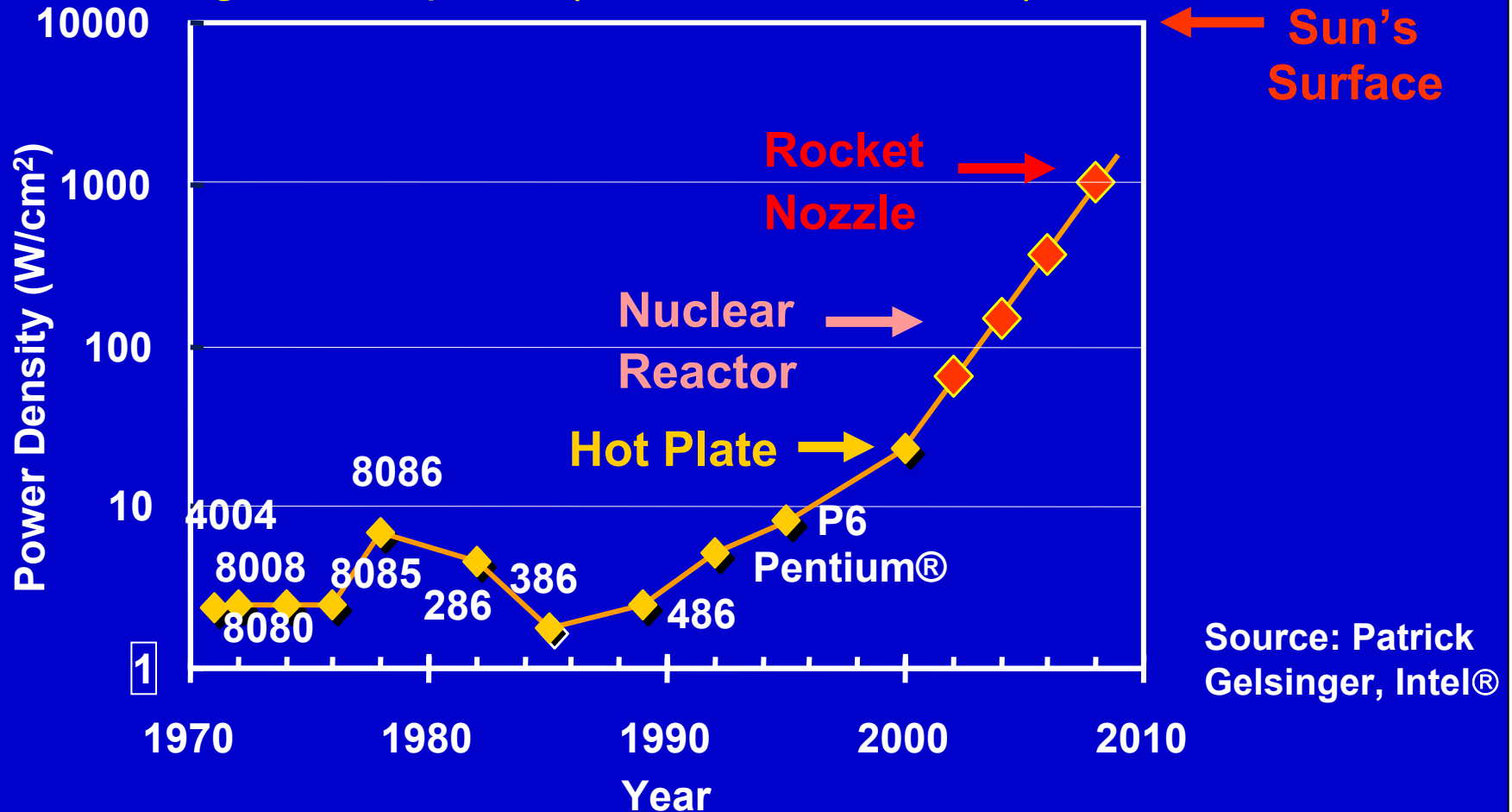
Increase in clock rate

Why bother with multicore? Just wait a year or two…

Limit #1: Power density

Can soon put more transistors on a chip than can afford to turn on.

-- Patterson '07

Scaling clock speed (business as usual) will not work

Source: Patrick Gelsinger, Intel®

Parallelism Saves Power

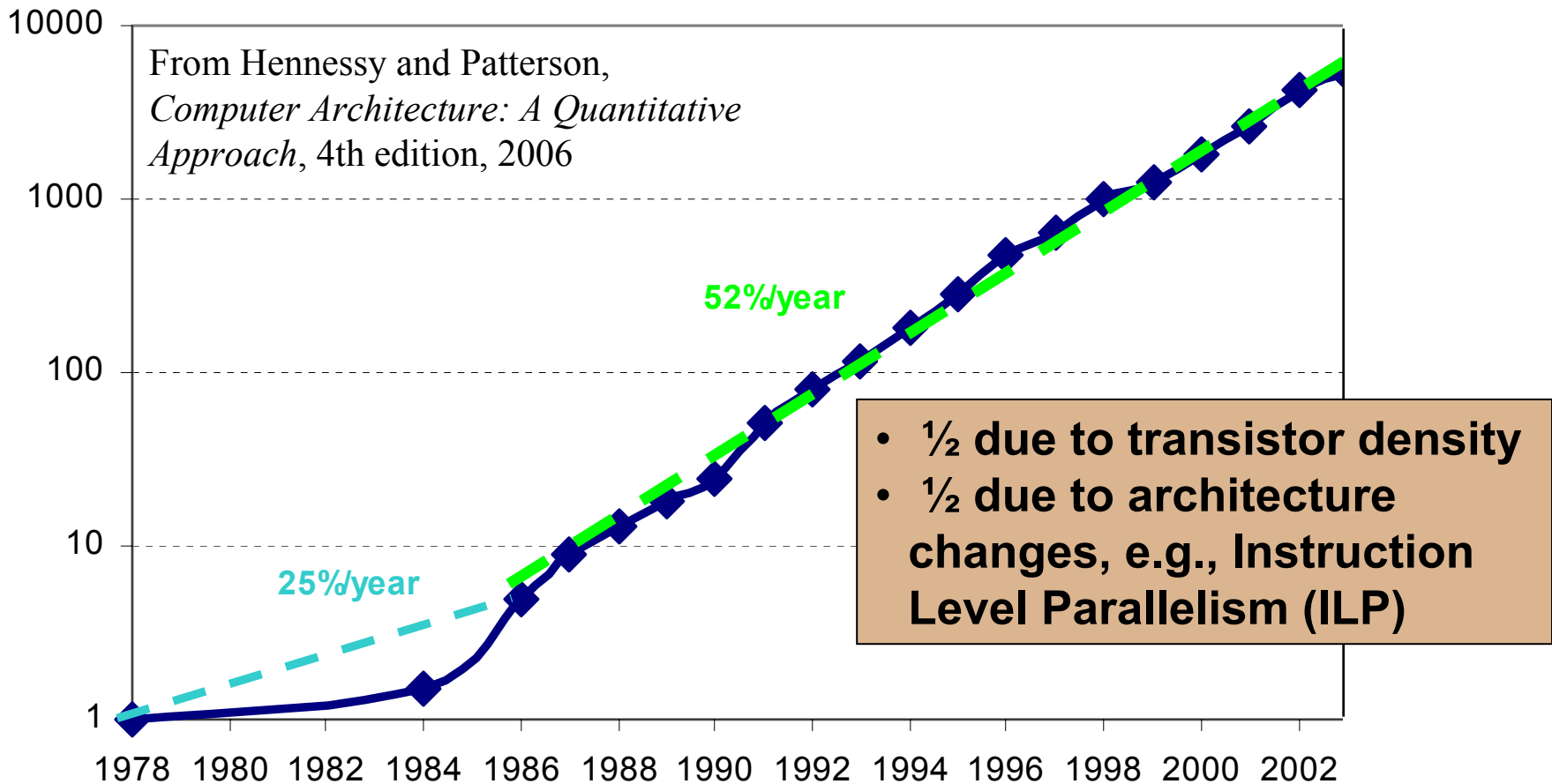- Exploit explicit parallelism for reducing power

$$1$$

Capacitance   Voltage   Frequency

- **Using additional cores**
  - Increase density (= more transistors = more capacitance)
  - Can increase cores (2x) and performance (2x)
  - Or increase cores (2x), but decrease frequency (1/2): same performance at ¼ the power

- **Additional benefits**
  - Small/simple cores → more predictable performance

Limit #2: Hidden Parallelism Tapped Out

Application performance was increasing by 52% per year as measured by the SpecInt benchmarks here

From Hennessy and Patterson,
Computer Architecture: A Quantitative Approach, 4th edition, 2006

52%/year

25%/year

- ½ due to transistor density
- ½ due to architecture changes, e.g., Instruction Level Parallelism (ILP)

Limit #2: Hidden Parallelism Tapped Out

- **Superscalar (SS) designs were the state of the art; many forms of parallelism not visible to programmer**
  - **multiple instruction issue**
  - **dynamic scheduling: hardware discovers parallelism between instructions**
  - **speculative execution: look past predicted branches**
  - **non-blocking caches: multiple outstanding memory ops**

- **Unfortunately, these sources have been used up**

Limit #3: Chip Yield

Manufacturing costs and yield problems limit use of density
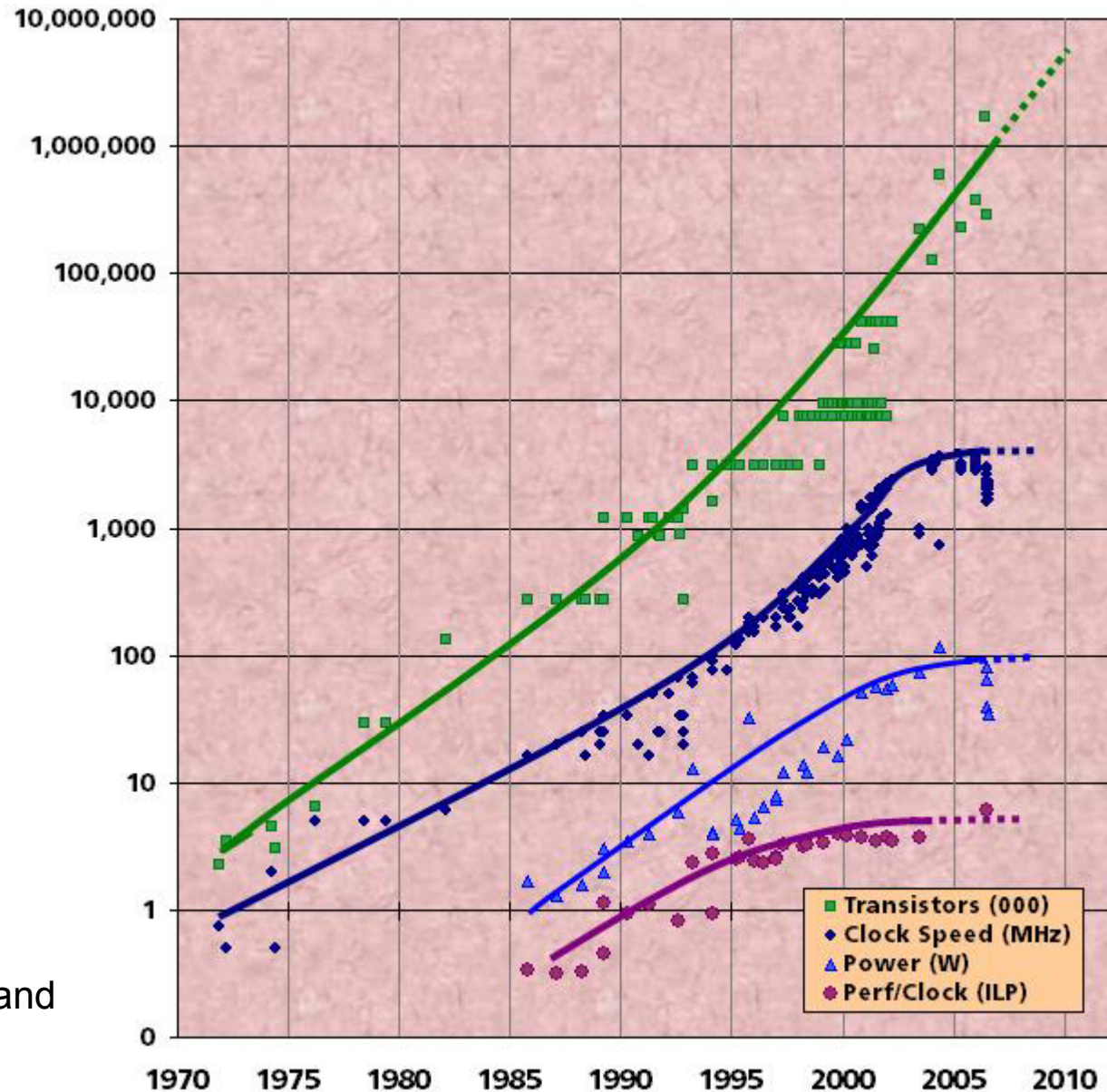
Cost of semiconductor factories in millions of 1995 dollars
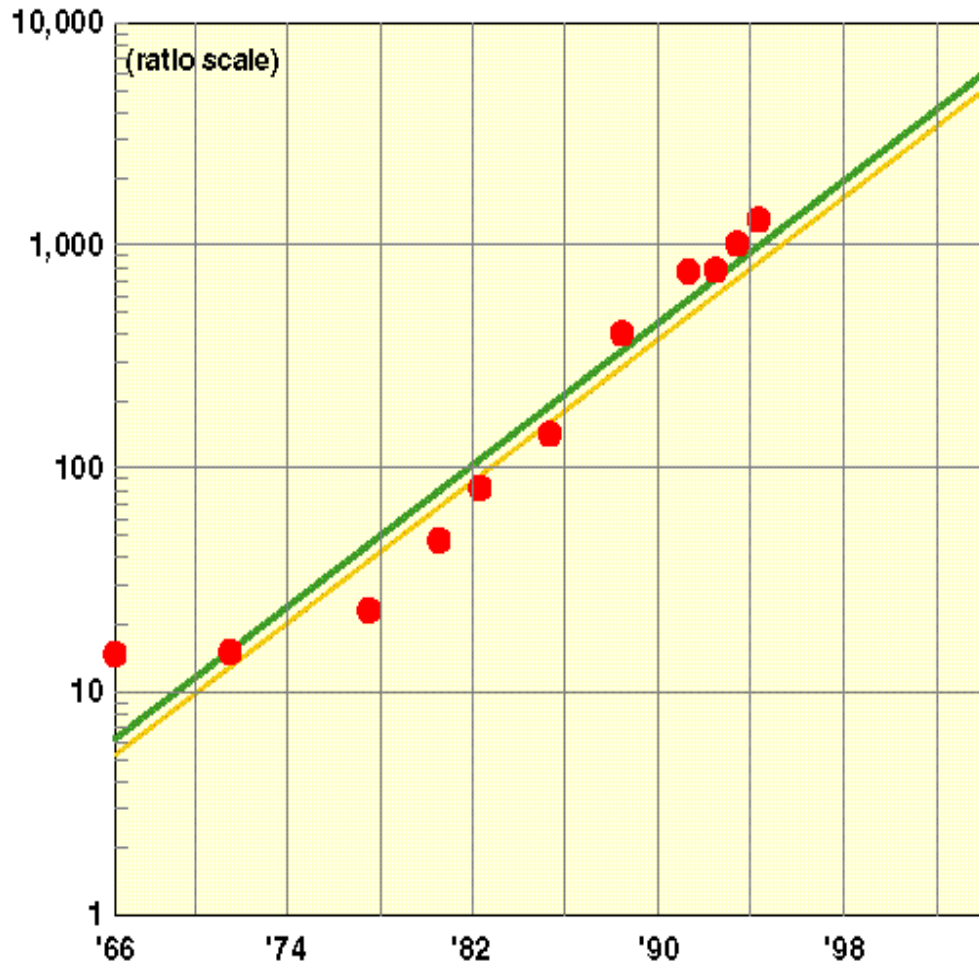
- **Moore's (Rock's) 2nd law: fabrication costs go up**
- **Yield (% usable chips) drops**

- **Parallelism can help**
  - **More smaller, simpler processors are easier to design and validate**
  - **Can use partially working chips:**
  - **E.g., Cell processor (PS3) is sold with 7 out of 8 "on" to improve yield**

Revolution is Happening Now

- Chip density is continuing increase ~2x every 2 years
  - Clock speed is not
  - Number of processor cores may double instead
- There is little or no hidden parallelism to be found
- Parallelism must be exposed to and managed by software

Source: Intel, Microsoft (Sutter) and Stanford (Olukotun, Hammond)

10,000,000

1,000,000

100,000

10,000

1,000

100

10

1

0

1970   1975   1980   1985   1990   1995   2000   2005   2010

- ■ Transistors (000)
- ♦ Clock Speed (MHz)
- ▲ Power (W)
- ● Perf/Clock (ILP)

Multicore in Products

- "We are dedicating all of our future product development to multicore designs. … This is a sea change in computing"

  Paul Otellini, President, Intel (2005)

- All microprocessor companies switch to MP (2X CPUs / 2 yrs)
  ⇒ Procrastination penalized: 2X sequential perf. / 5 yrs

Manufacturer/Year	AMD/'05	Intel/'06	IBM/'04	Sun/'07
Processors/chip	2	2	2	8
Threads/Processor	1	2	2	16
Threads/chip	2	4	4	128

And at the same time,
- The STI Cell processor (PS3) has 8 cores
- The latest NVidia Graphics Processing Unit (GPU) has 128 cores
- Intel has demonstrated an 80-core research chip