Chapter 1

Introduction: Computer Abstractions and Technology

The Computer Revolution

- Progress in computer technology
  - Underpinned by domain-specific accelerators
- Makes novel applications feasible
  - Computers in automobiles
  - Cell phones
  - Human genome project
  - World Wide Web
  - Search Engines
- Computers are pervasive

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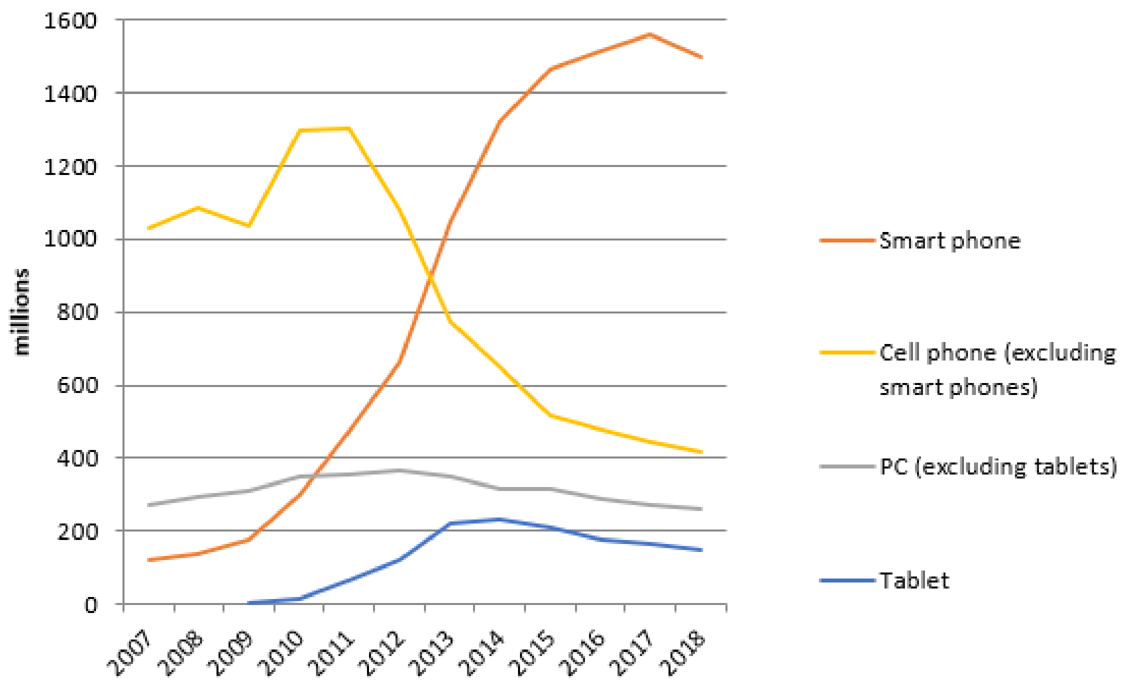
Classes of Computers

- Personal computers
  - General purpose, variety of software
  - Subject to cost/performance tradeoff
- Server computers
  - Network based
  - High capacity, performance, reliability
  - Range from small servers to building sized

Classes of Computers

- Supercomputers
  - Type of server
  - High-end scientific and engineering calculations
  - Highest capability but represent a small fraction of the overall computer market
- Embedded computers
  - Hidden as components of systems
  - Stringent power/performance/cost constraints

The PostPC Era



The number manufactured per year of tablets and smart phones, which reflect the PostPC era, versus personal computers and traditional cell phones. Smart phones represent the recent growth in the cell phone industry, and they passed PCs in 2011. Tablets are the fastest growing category, nearly doubling between 2011 and 2012. Recent PCs and traditional cell phone categories are relatively flat or declining.

The PostPC Era

- Personal Mobile Device (PMD)
  - Battery operated
  - Connects to the Internet
  - Hundreds of dollars
  - Smart phones, tablets, electronic glasses
- Cloud computing
  - Warehouse Scale Computers (WSC)
  - Software as a Service (SaaS)
  - Portion of software run on a PMD and a portion run in the Cloud
  - Amazon and Google

What You Will Learn

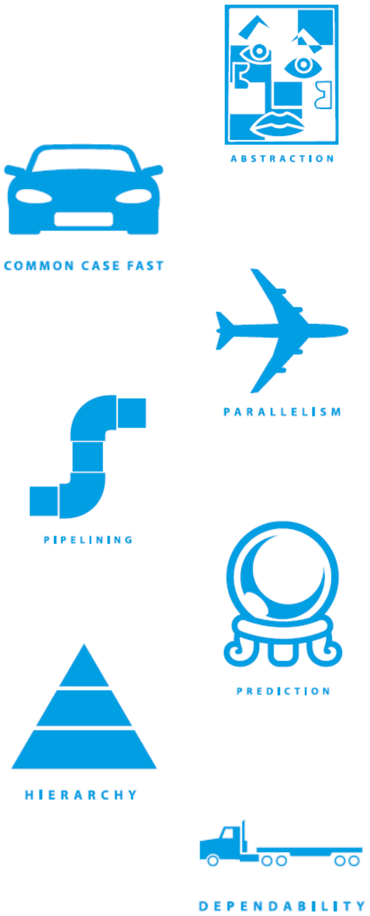
- How programs are translated into the machine language
  - And how the hardware executes them
- The hardware/software interface
- What determines program performance
  - And how it can be improved
- How hardware designers improve performance
- What is parallel processing

Understanding Performance

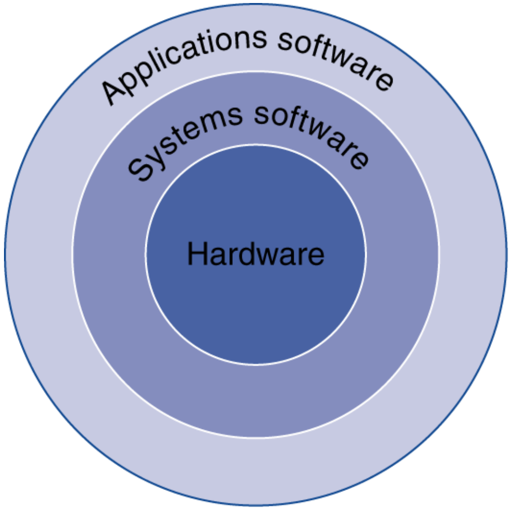
- Algorithm
  - Determines number of operations executed
- Programming language, compiler, architecture
  - Determine number of machine instructions executed per operation
- Processor and memory system
  - Determine how fast instructions are executed
- I/O system (including OS)
  - Determines how fast I/O operations are executed

Seven Great Ideas

- Use ***abstraction*** to simplify design
- Make the ***common case fast***
- Performance *via* ***parallelism***
- Performance *via* ***pipelining***
- Performance *via* ***prediction***
- ***Hierarchy*** of memories
- ***Dependability*** *via* redundancy



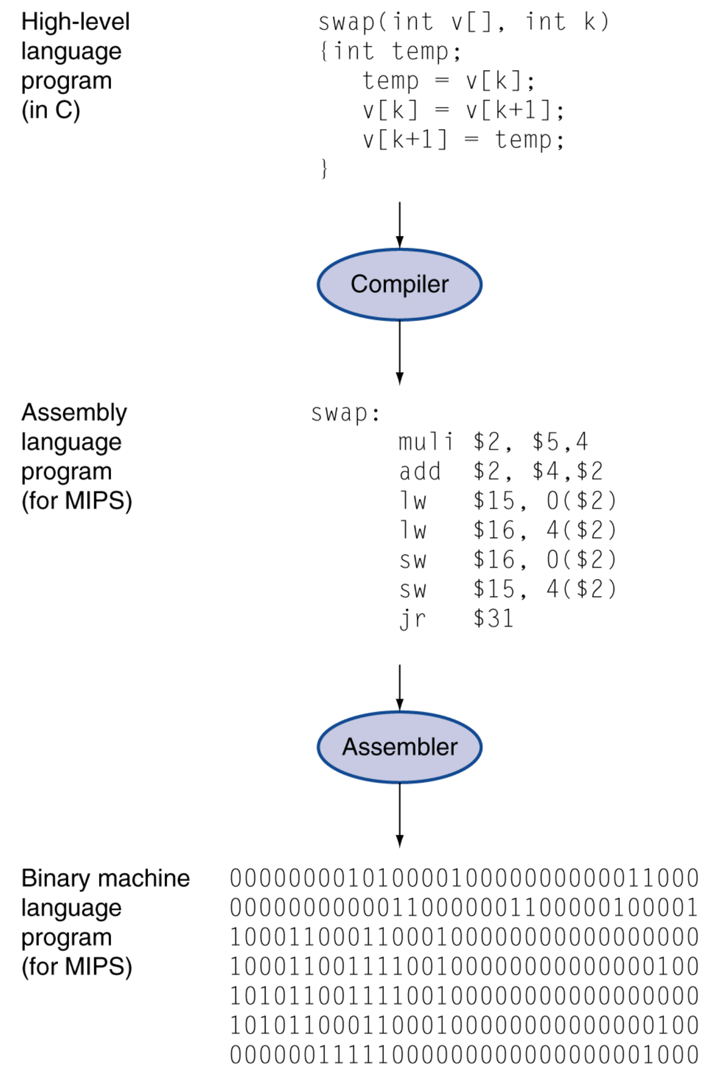
Below Your Program



- Application software
  - Written in high-level language
- System software
  - Compiler: translates HLL code to machine code
  - Operating System: service code
    - Handling input/output
    - Managing memory and storage
    - Scheduling tasks & sharing resources
- Hardware
  - Processor, memory, I/O controllers

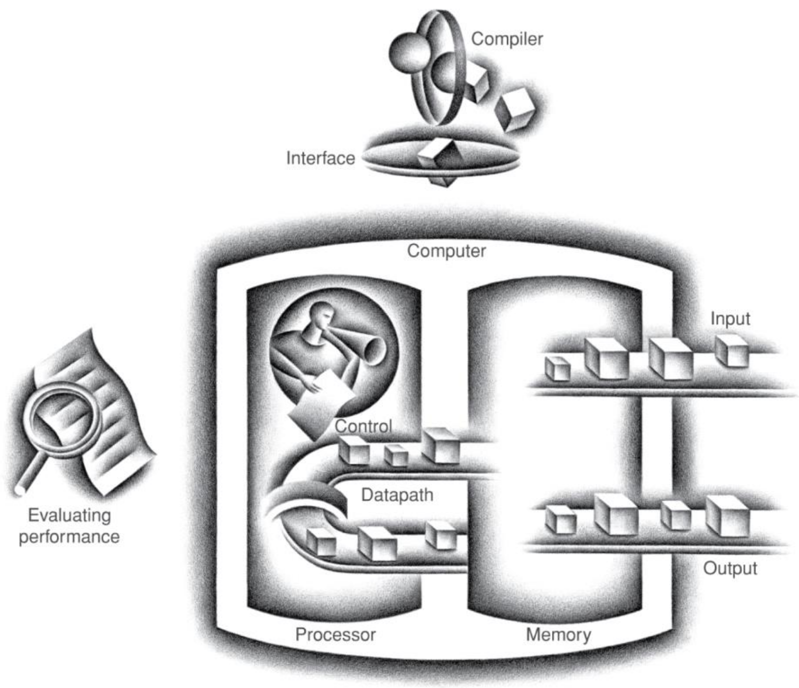
Levels of Program Code

- High-level language
  - Level of abstraction closer to problem domain
  - Provides for productivity and portability
- Assembly language
  - Textual representation of instructions
- Hardware representation
  - Binary digits (bits)
  - Encoded instructions and data



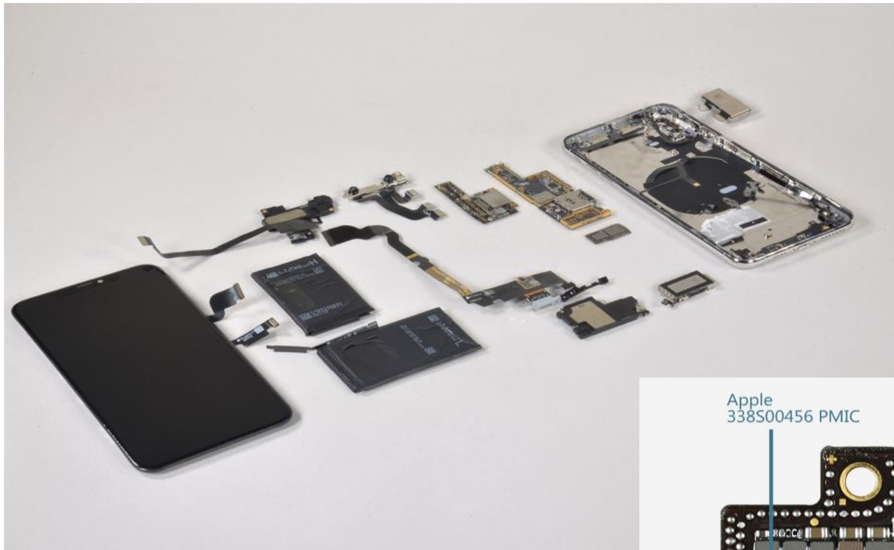
Components of a Computer

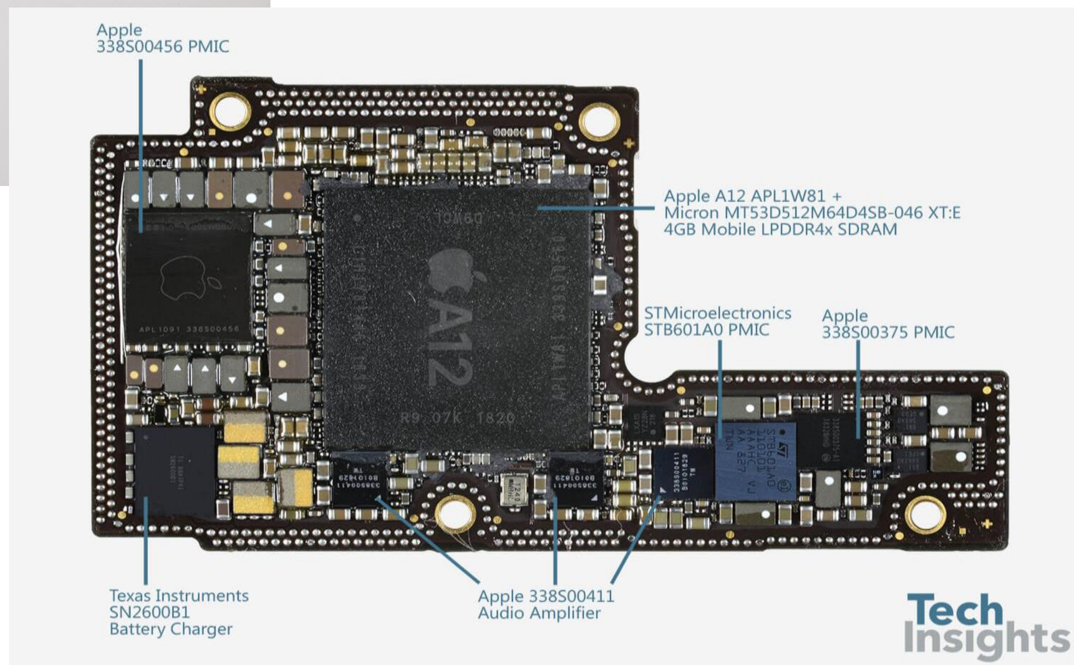
The BIG Picture



- Same components for all kinds of computer
  - Desktop, server, embedded
- Input/output includes
  - User-interface devices
    - Display, keyboard, mouse
  - Storage devices
    - Hard disk, CD/DVD, flash
  - Network adapters
    - For communicating with other computers

Opening the Box





Inside the Processor (CPU)

- Datapath: performs operations on data
- Control: sequences datapath, memory, ...
- Cache memory
  - Small fast SRAM memory for immediate access to data

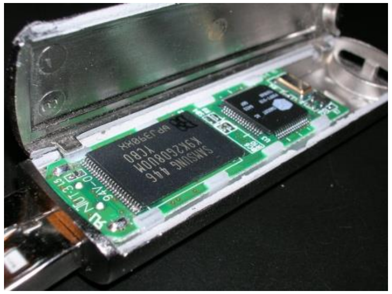
Abstractions

The BIG Picture

- Abstraction helps us deal with complexity
  - Hide lower-level detail
- Instruction set architecture (ISA)
  - The hardware/software interface
- Application binary interface
  - The ISA plus system software interface
- Implementation
  - The details underlying and interface

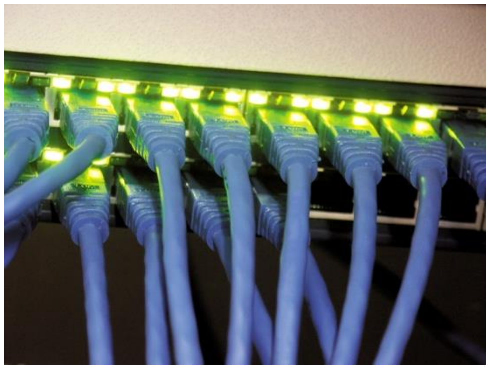
A Safe Place for Data

- Volatile main memory
  - Loses instructions and data when power off
- Non-volatile secondary memory
  - Magnetic disk
  - Flash memory
  - Optical disk (CDROM, DVD)



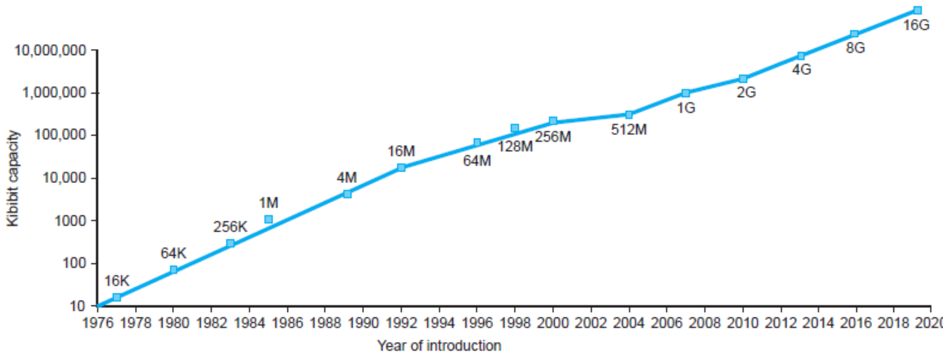
Networks

- Communication, resource sharing, nonlocal access
- Local area network (LAN): Ethernet
- Wide area network (WAN): the Internet
- Wireless network: WiFi, Bluetooth



Technology Trends

- Electronics technology continues to evolve
  - Increased capacity and performance
  - Reduced cost

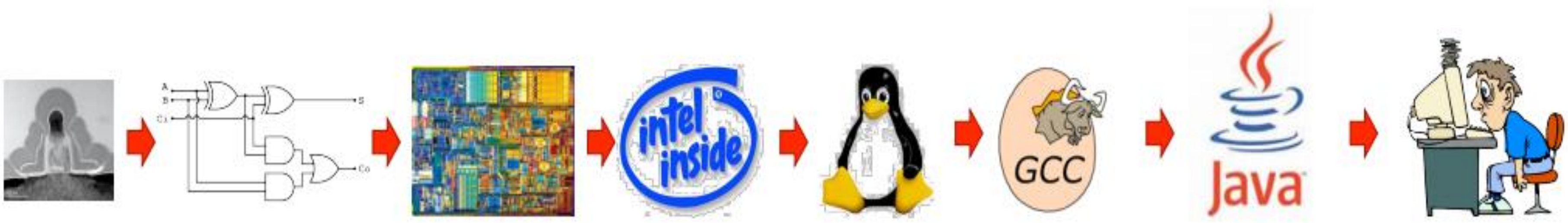


DRAM capacity

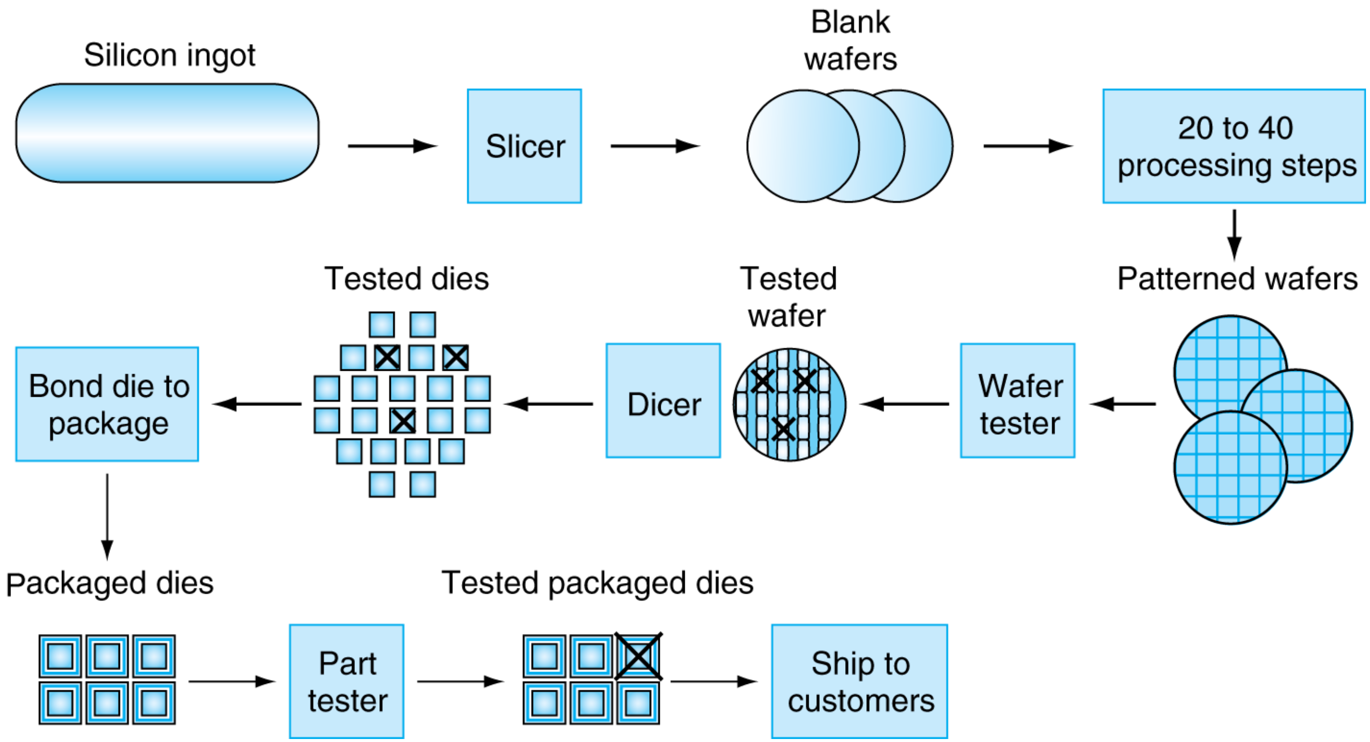
Year	Technology	Relative performance/cost
1951	Vacuum tube	1
1965	Transistor	35
1975	Integrated circuit (IC)	900
1995	Very large scale IC (VLSI)	2,400,000
2013	Ultra large scale IC	250,000,000,000

Semiconductor Technology

- Silicon: semiconductor
- Add materials to transform properties:
  - Conductors
  - Insulators
  - Switch

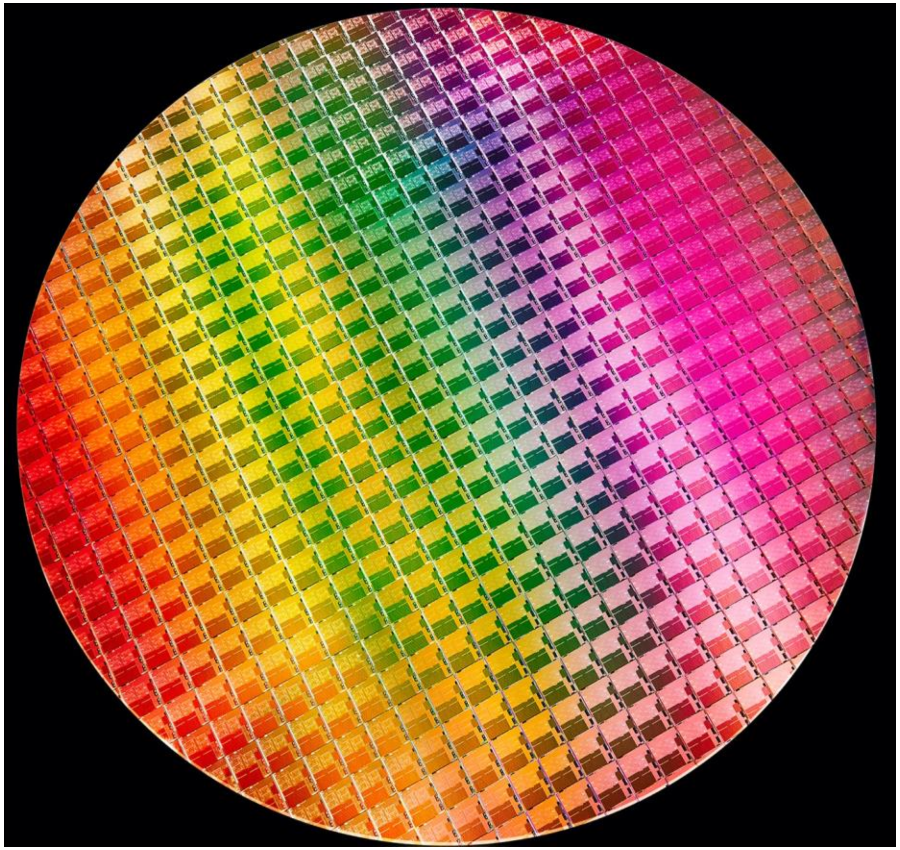


Manufacturing ICs



- Yield: proportion of working dies per wafer

Intel® Core 10th Gen



- 300mm wafer, 506 chips, 10nm technology
- Each chip is 11.4 x 10.7 mm

Integrated Circuit Cost

$$\text{Cost per die} = \frac{\text{Cost per wafer}}{\text{Dies per wafer} \times \text{Yield}}$$

$$\text{Dies per wafer} \approx \text{Wafer area} / \text{Die area}$$

$$\text{Yield} = \frac{1}{(1 + (\text{Defects per area} \times \text{Die area}/2))^2}$$

- Nonlinear relation to area and defect rate
  - Wafer cost and area are fixed
  - Defect rate determined by manufacturing process
  - Die area determined by architecture and circuit design

What Is Computer Architecture?

Computer Architecture: The science and art of designing, selecting, and interconnecting hardware components and designing the hardware/software interface to create a computing system that meets functional, performance, energy consumption, cost, and other specific goals.

What Is Computer Architecture?

Computer Architecture: The term ***architecture*** is used here to describe the attributes of a system as seen by the programmer, *i.e.*, the conceptual structure and functional behavior as distinct from the organization of the dataflow and controls, the logic design, and the physical implementation.

What Is Computer Architecture?

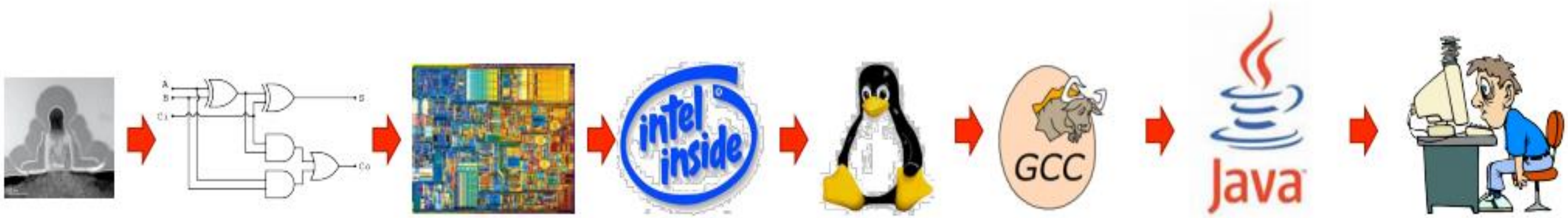
- Computer Architecture
  - Instruction Set Architecture & Computer Organization

- Instruction Set Architecture (ISA)
  - WHAT the computer does (logical view)

- Computer Organization
  - HOW the ISA is implemented (physical view)

Current State of Architecture

Since 1940



Current State of Architecture

Advance of Semiconductors: "Moore's Law"

Gordon Moore, Founder of Intel

- 1965: since the integrated circuit was invented, the number of transistors/inch^2 in these circuits roughly doubled every year; this trend would continue for the foreseeable future
- 1975: revised - circuit complexity doubles every 18 months

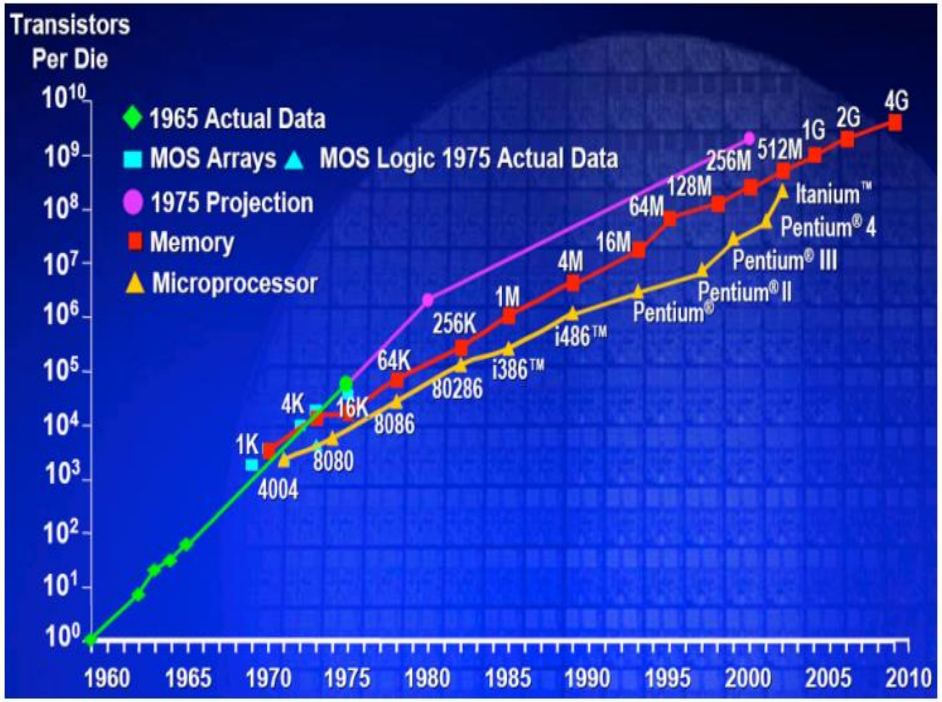


Image credit: http://download.intel.com/research/silicon/Gordon_Moore_ISSCC_021003.pdf

Current State of Architecture

Leveraging Moore's Law Trends

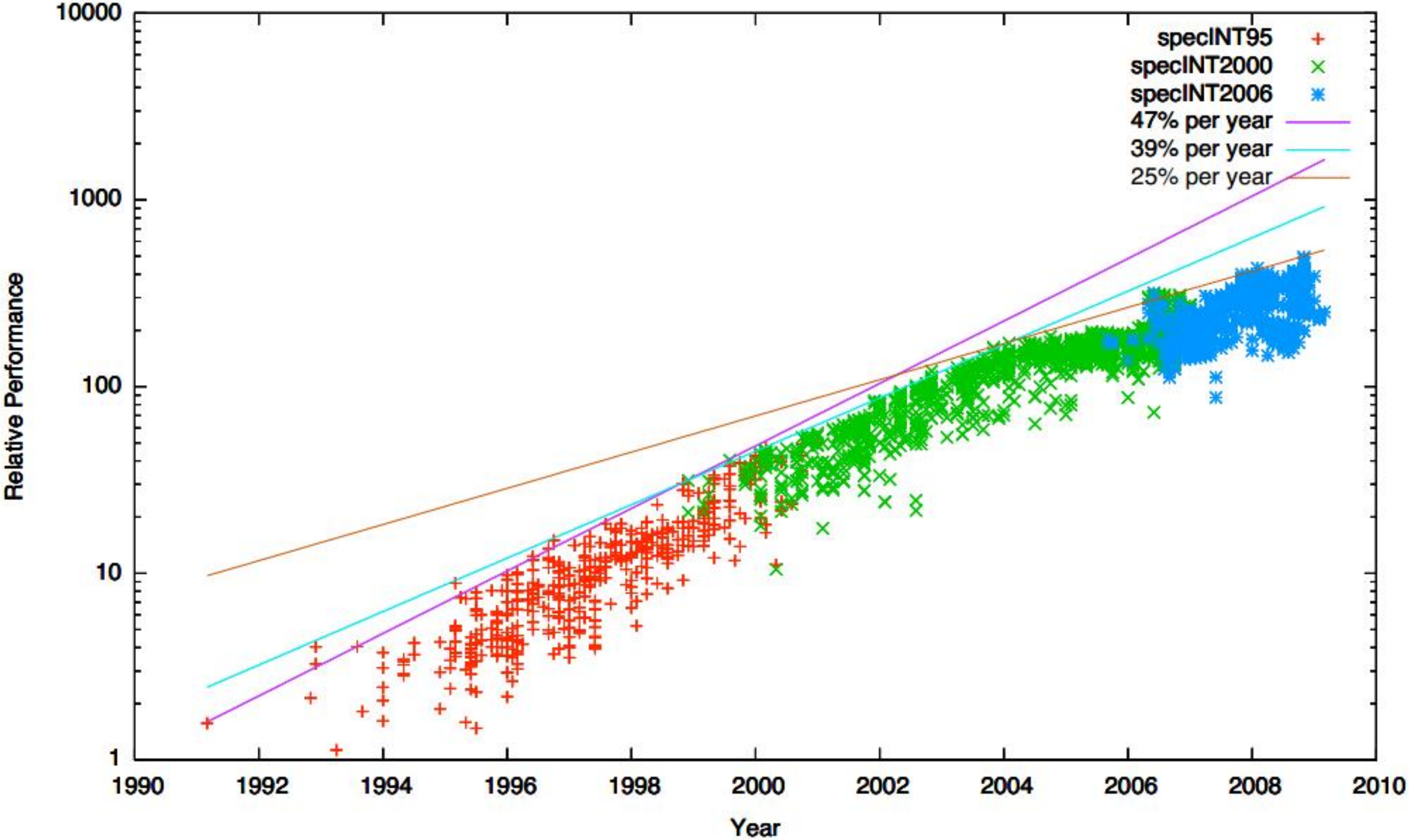
From increasing circuit density to performance:

- More transistors = ↑ opportunities for exploiting parallelism

The Importance of Architecture

- We design smarter and smarter processors
  - Process technology gives us about 20% performance improvement per year
  - Until 2004, performance grew at about 40% per year
- The gap is due to architecture! (and compilers)

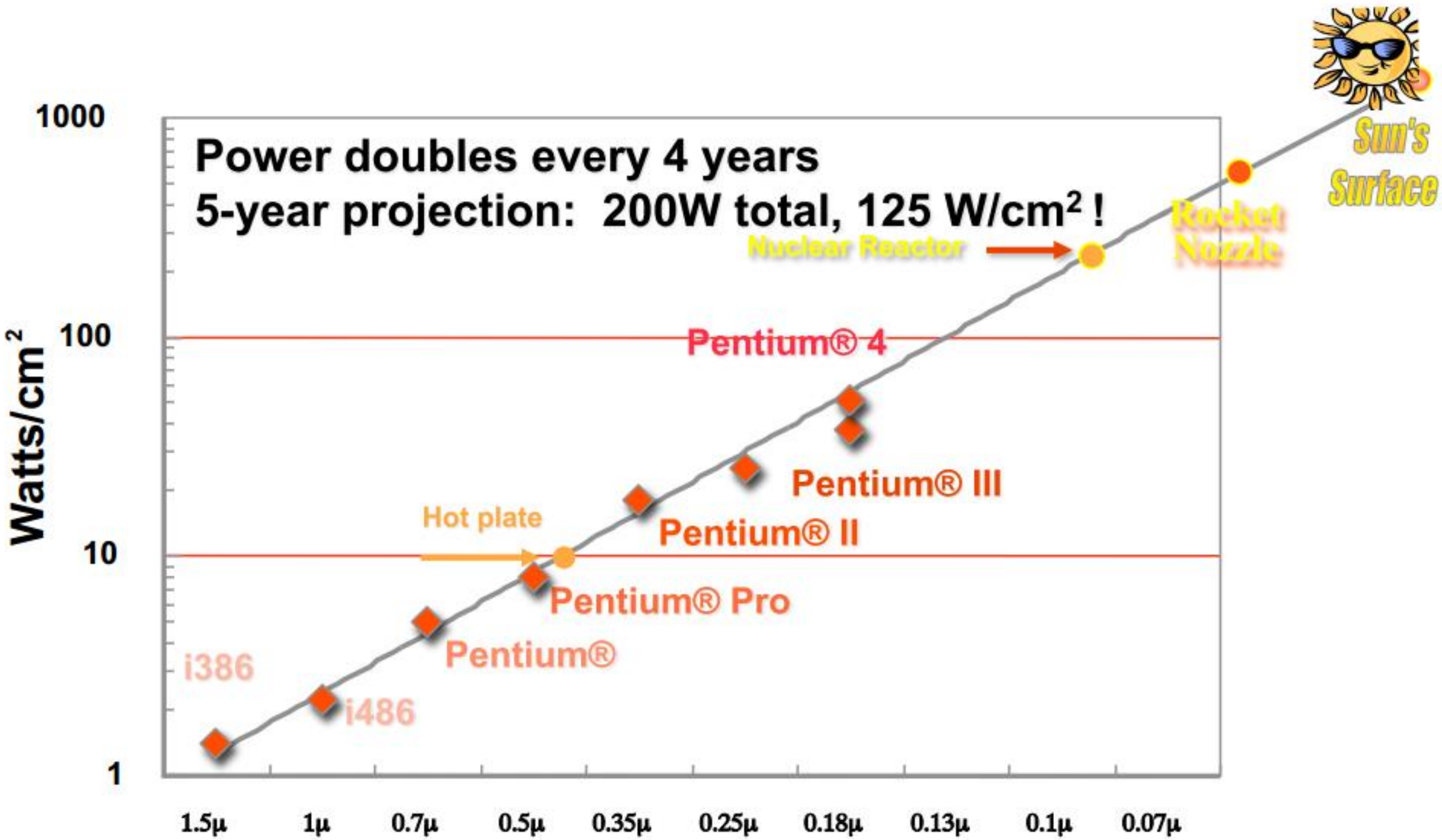
Computer Performance



Power

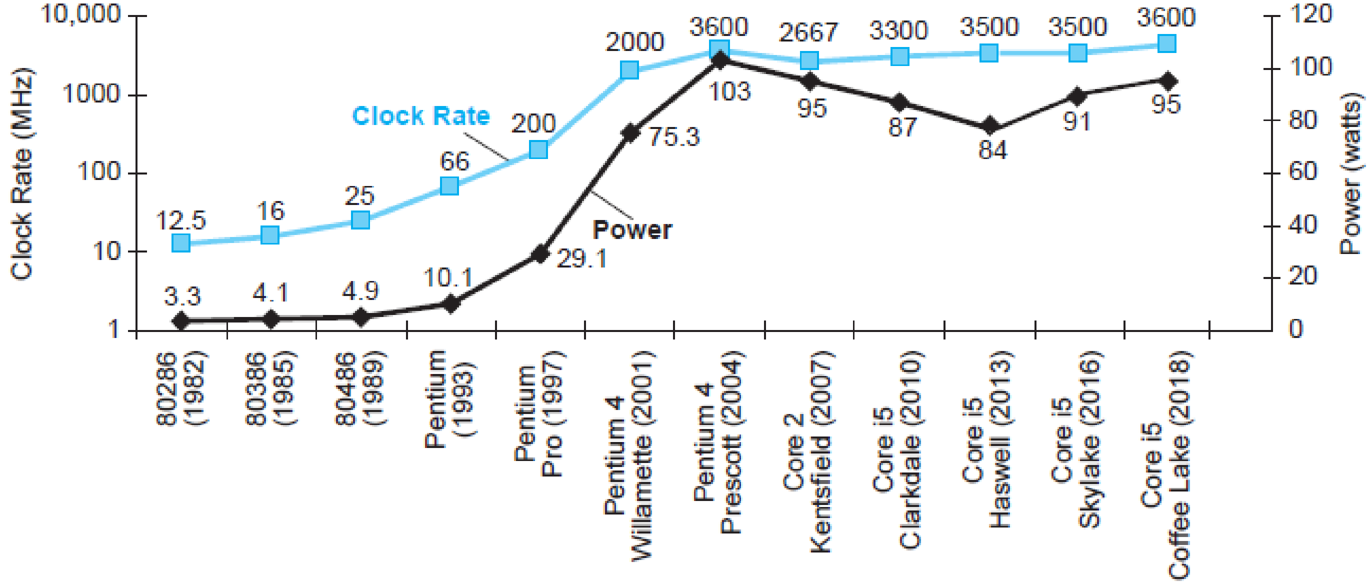
- **Clock speed** is the biggest contributor to power
  - Chip manufactures (Intel, esp.) pushed clock speeds very hard in the 90s and early 2000s.
  - Doubling the clock speed increases power by 2-8x
  - Clock speed scaling is essentially finished.

Power



From "New Microarchitecture Challenges in the Coming Generations of CMOS Process Technologies" – Fred Pollack, Intel Corp. Micro32 conference key note - 1999.

Power Trends



- In CMOS IC technology

$$\text{Power} = \text{Capacitive load} \times \text{Voltage}^2 \times \text{Frequency}$$

×30

5V → 1V

×1000

Reducing Power

- Suppose a new CPU has
  - 85% of capacitive load of old CPU
  - 15% voltage and 15% frequency reduction

$$\frac{P_{new}}{P_{old}} = \frac{C_{old} \times 0.85 \times (V_{old} \times 0.85)^2 \times F_{old} \times 0.85}{C_{old} \times V_{old}^{\,2} \times F_{old}} = 0.85^4 = 0.52$$

- The power wall
  - We can't reduce voltage further
  - We can't remove more heat
- How else can we improve performance?

Important Trends

- Historical contributions to performance:
  - Better processes (faster devices) ~20%
  - Better circuits/pipelines ~15%
  - Better organization/architecture ~15%

- In the future, bullet-2 will help little, and bullet-1 will eventually disappear!

	Pentium	P-Pro	P-II	P-III	P-4	Itanium	Montecito
Year	1993	95	97	99	2000	2002	2005
Transistors	3.1M	5.5M	7.5M	9.5M	42M	300M	1720M
Clock Speed	60M	200M	300M	500M	1500M	800M	1800M

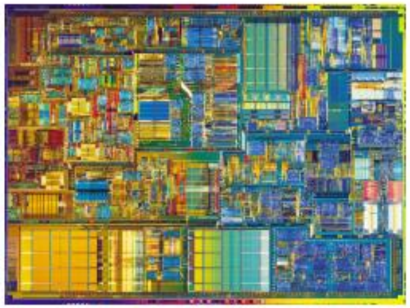
Moore's Law in action

At this point, adding transistors to a core yields little benefit

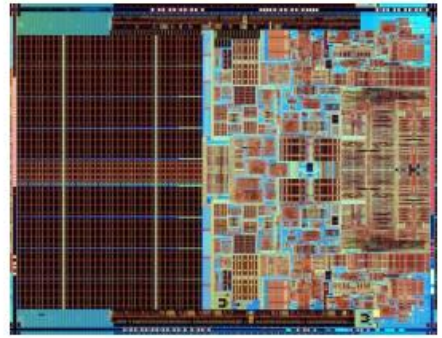
What's Next: Parallelism

- You probably own a multi-processor
- They provide some performance, but it's hard to Fully exploit (parallel programming !)

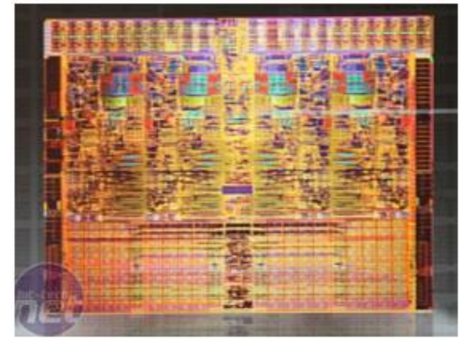
What's Next: Parallelism



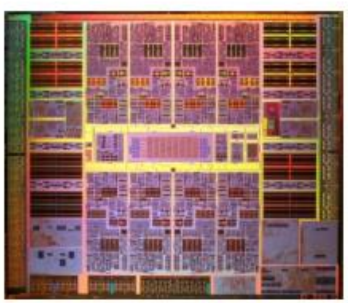
Intel P4
1 core



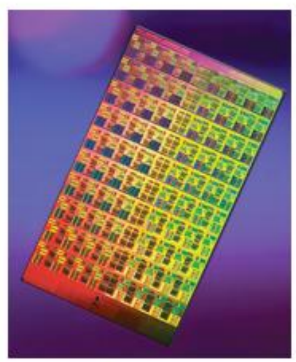
Intel Core 2 Duo
2 cores



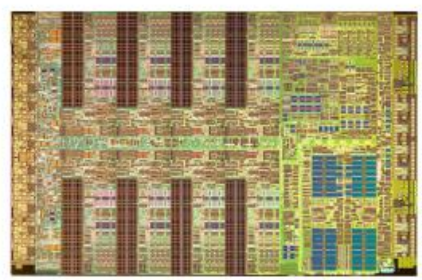
Intel Nahalem
4 cores



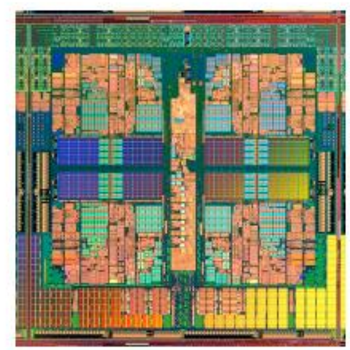
SPARC T1
8 cores



Intel Prototype
80 cores



Cell BE
8 + 1 cores



AMD Barcelona
4 cores