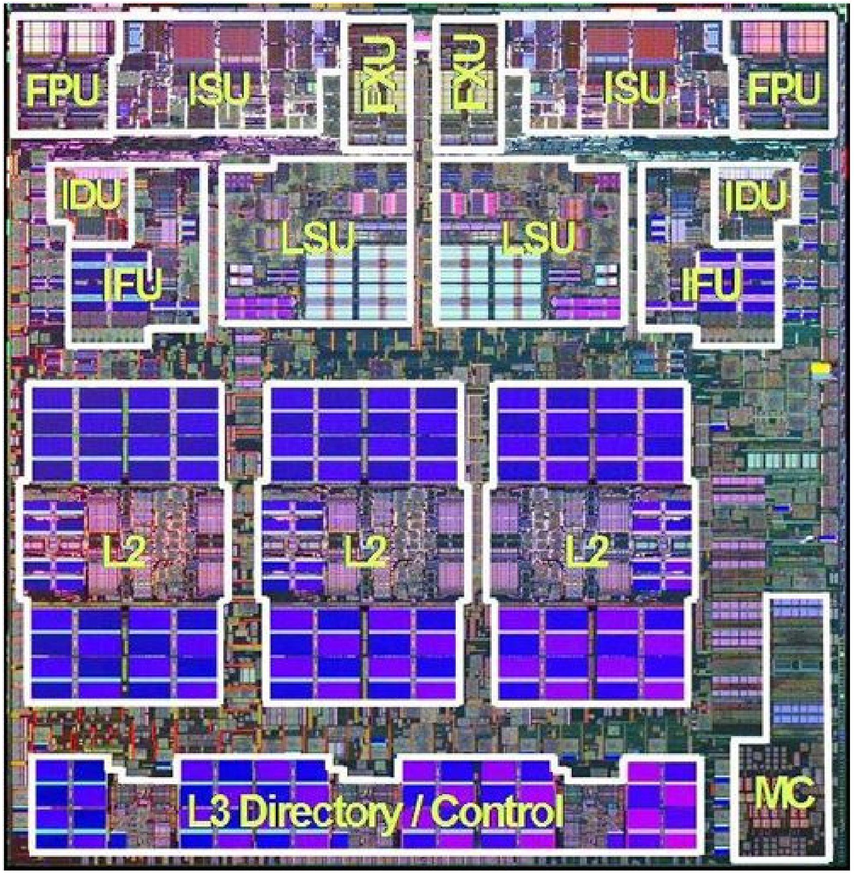
18-200

Introduction to Computer Hardware Area

or

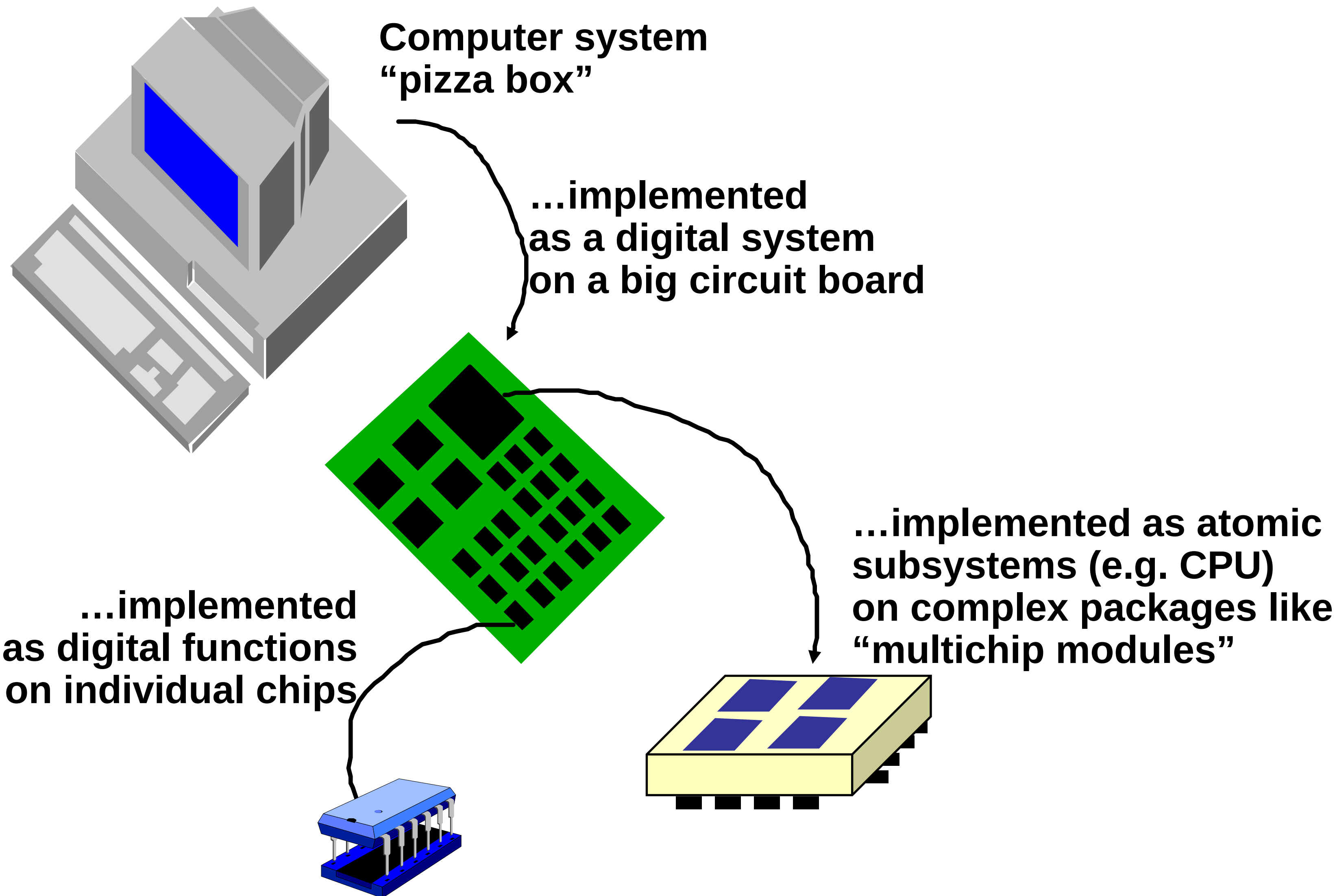
What to do with all these transistors



IBM POWER5
Chip Multiprocessor

Fall 2006
Prof. Babak Falsafi

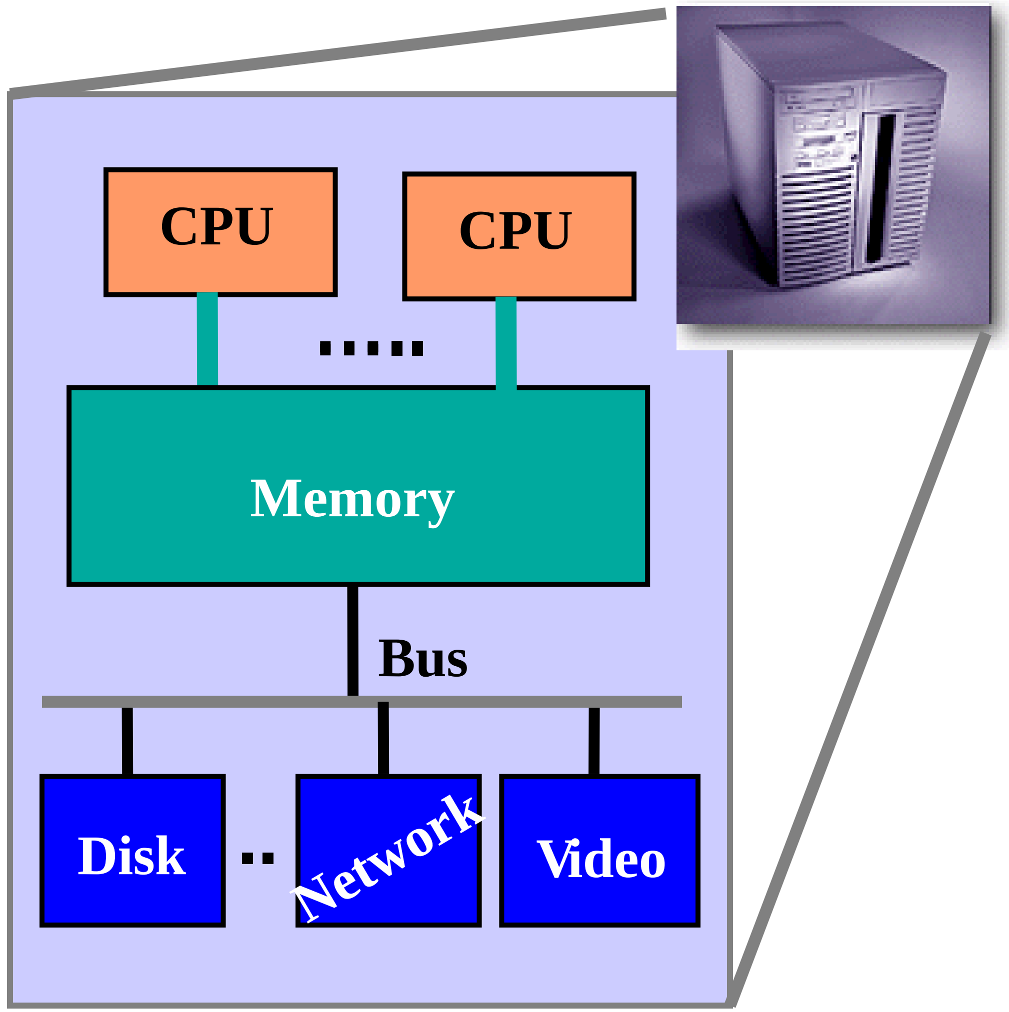
Computers are Digital Systems



What's Inside a Computer

- Processor(s), Microprocessor(s), or CPU(s)
- Memory subsystem
- I/O subsystem
  - network, disk drives, keyboard, mouse, etc.

- You learn what goes on inside in 18-447
- You learn how they work in 15-213



What is Computer Architecture?

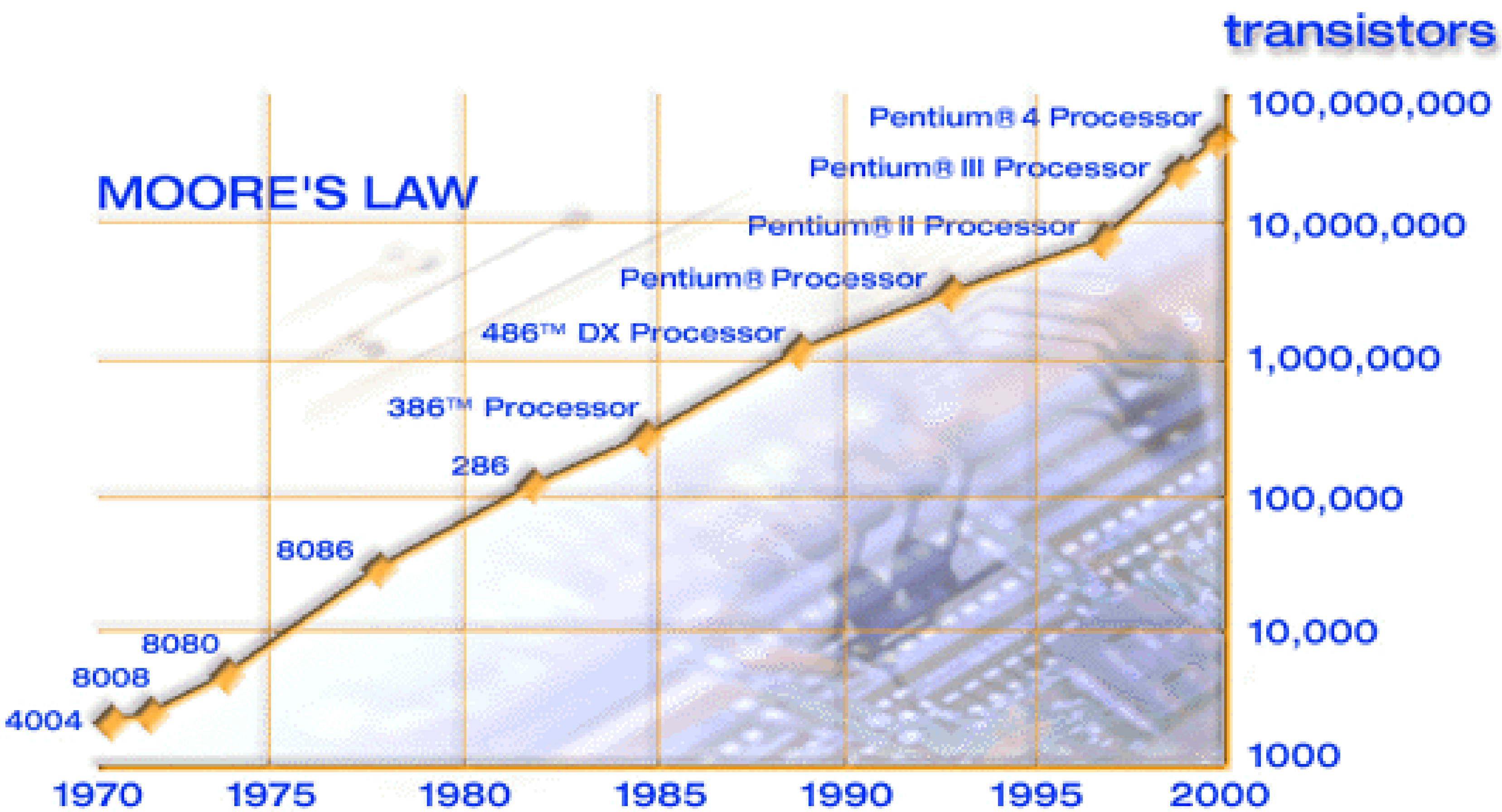
- The science and art of selecting and interconnecting hardware components to create a computer that meets functional, performance and cost goals.

Selection process evolves because

- Technology changes

→ Enables new applications

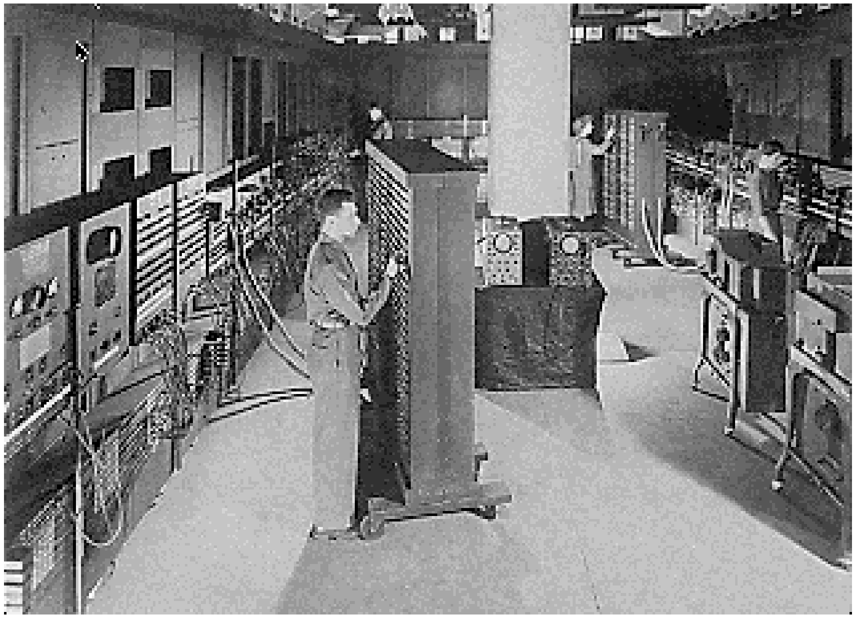
Why Study Computer Hardware?

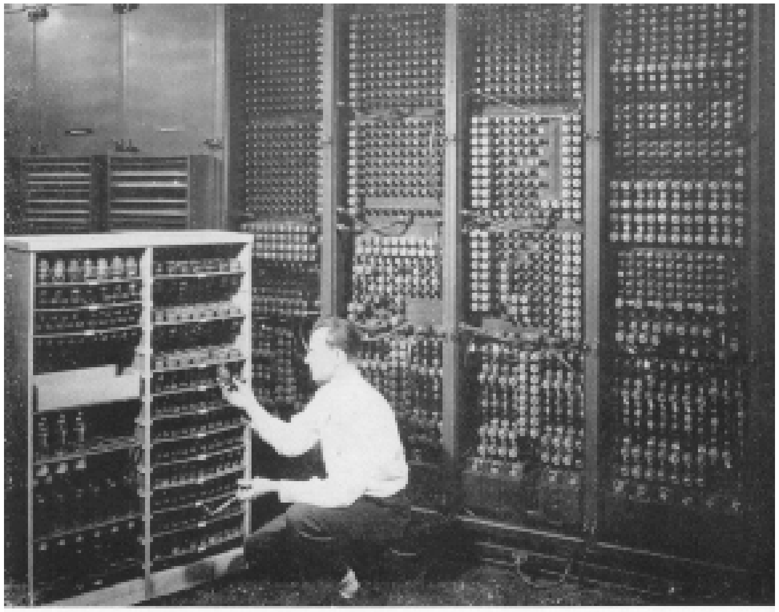


http://www.intel.com/research/silicon/mooreslaw.htm

A Historical Perspective

- In the beginning…Eniac

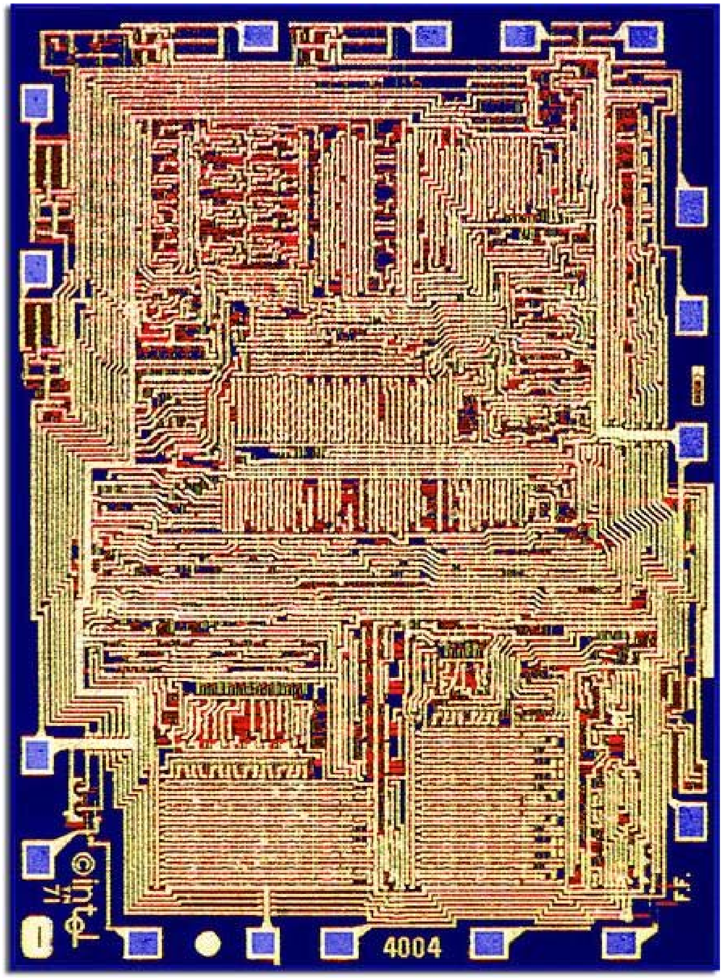




Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

5,000 additions in one second

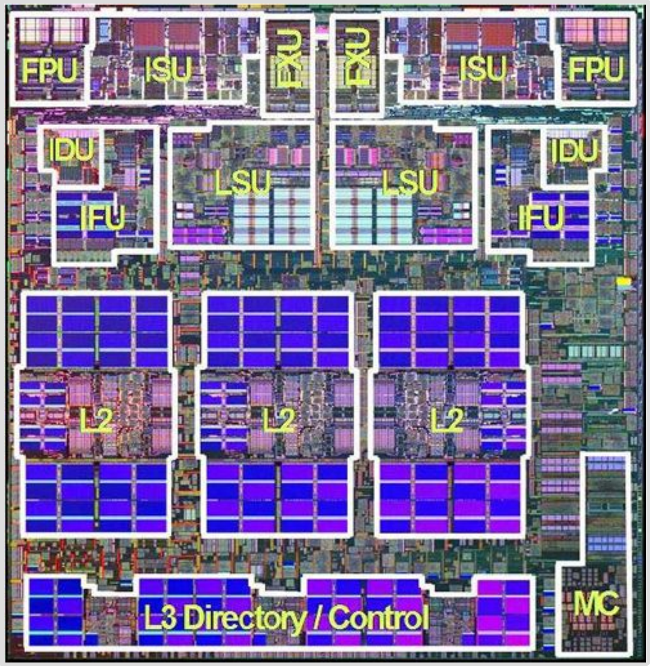
Intel 4004, circa 1971



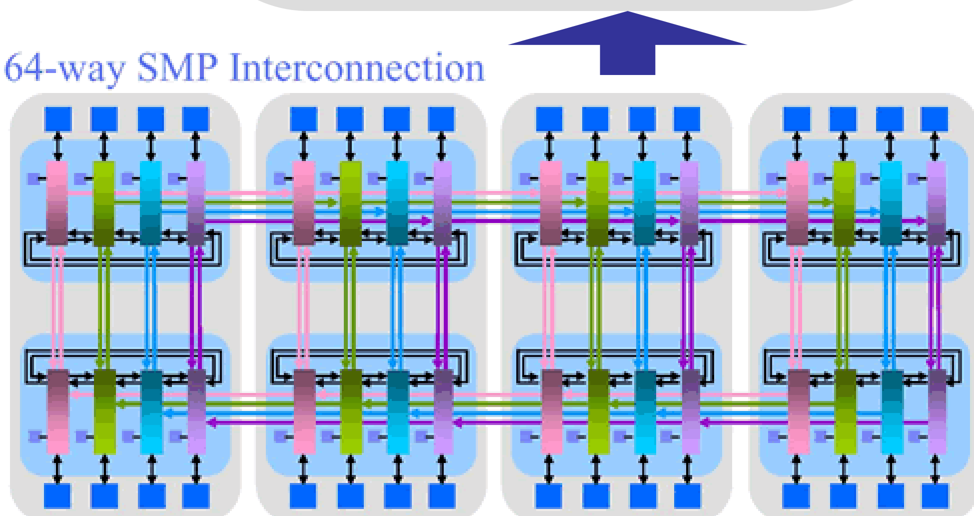
- **The first single chip CPU**
  - 4-bit processor for a calculator.
  - 1K data memory
  - 4K program memory
  - 2,300 transistors
  - 16-pin DIP package
  - 740kHz (eight clock cycles per CPU cycle of 10.8 microseconds)
  - ~100K additions per second

IBM POWER5, circa 2006

POWER5 Chip



Power5 System



- **Performance leader**
  - Two 64-bit processors
    - Four threads
  - 2 MByte in cache!!
  - 276 million transistor
  - 2 GHz, issues up to 10 instructions per cycle
  - ~20 billion additions/second

In ~30 years, about 200,000 fold growth in chip performance!

Processor Performance

"Unmatched by any other industry"

[John Crawford, Intel Fellow, 1993]

Doubling every 18 months (1982-1996): total of 800X

- Cars travel at 44,000 MPH; get 16,000 miles/gal.
- Air travel: L.A. to N.Y. in 22 seconds (MACH 800)

Doubling every 24 months (1970-1996): total of 9,000X

- Cars travel at 600,000 MPH; get 150,000 miles/gal.
- Air travel: L.A. to N.Y. in 2 seconds (MACH 9,000)

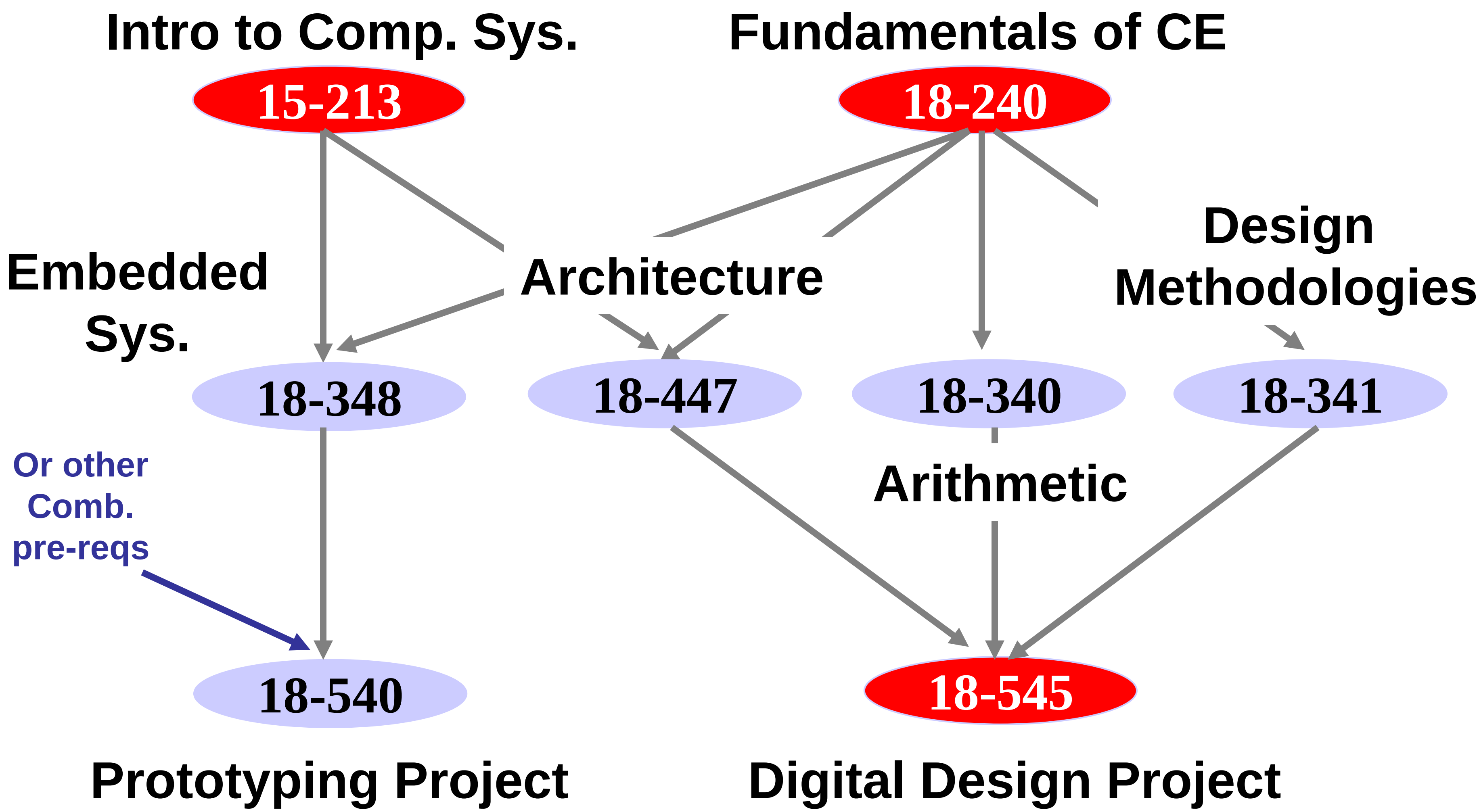
Exponential effect

[source: Shen et al., lecture notes 18-447/18-741]

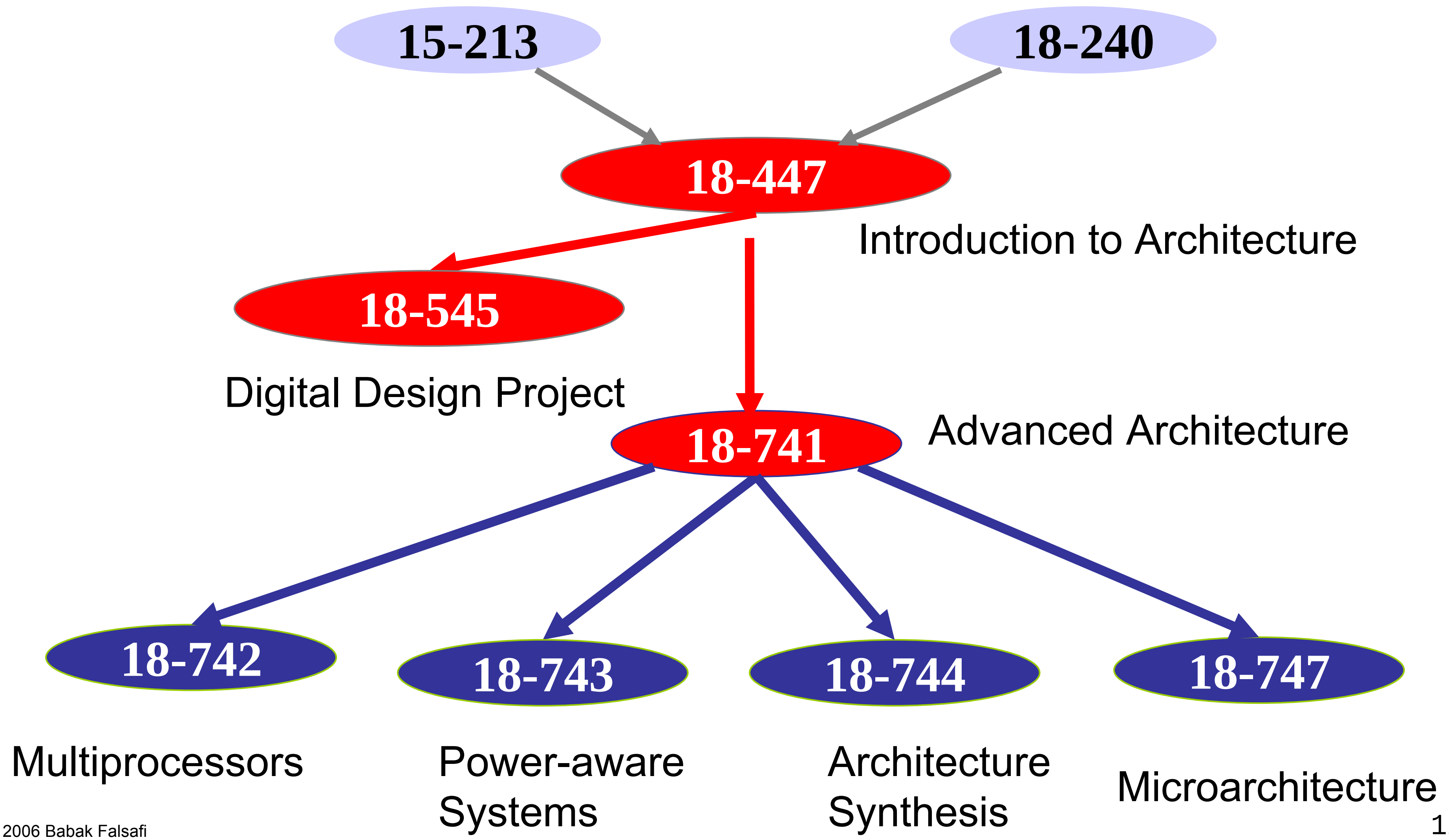
Where is Computer Hardware?

- Right now...
  - Supercomputers, desktops, laptops, handhelds
  - DVD players, CD players, Cell phones, iPods
  - Cars (many per car)
  - Modems, network cards
  - Toasters, microwave ovens, fridges
- Soon...
  - Your clothing, your glasses, your jewelry...
  - *Everywhere*

Computer Hardware Curriculum



Computer Architecture Curriculum



Related Courses

Computer systems:

- Must know OS (15-410), Compiler (15-411)
- Good to know Networks (18-345, 15-441), Security (18-487) and Databases (15-415)

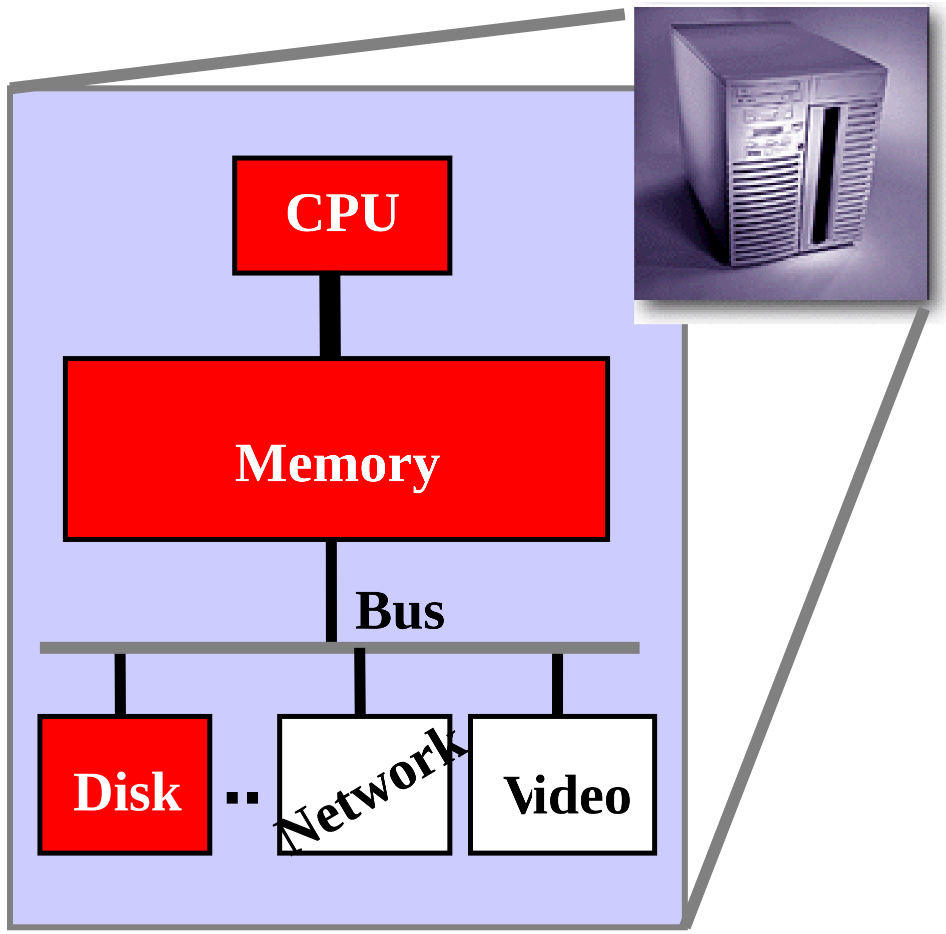
Circuits: Digital circuits (18-322)

18-447: Introduction to Computer Architecture

Designing the guts
- Processor, Memory, Buses, I/O,…
- OS hardware support
- E.g., what goes in a PlayStation
- Machine language design
- Performance evaluation

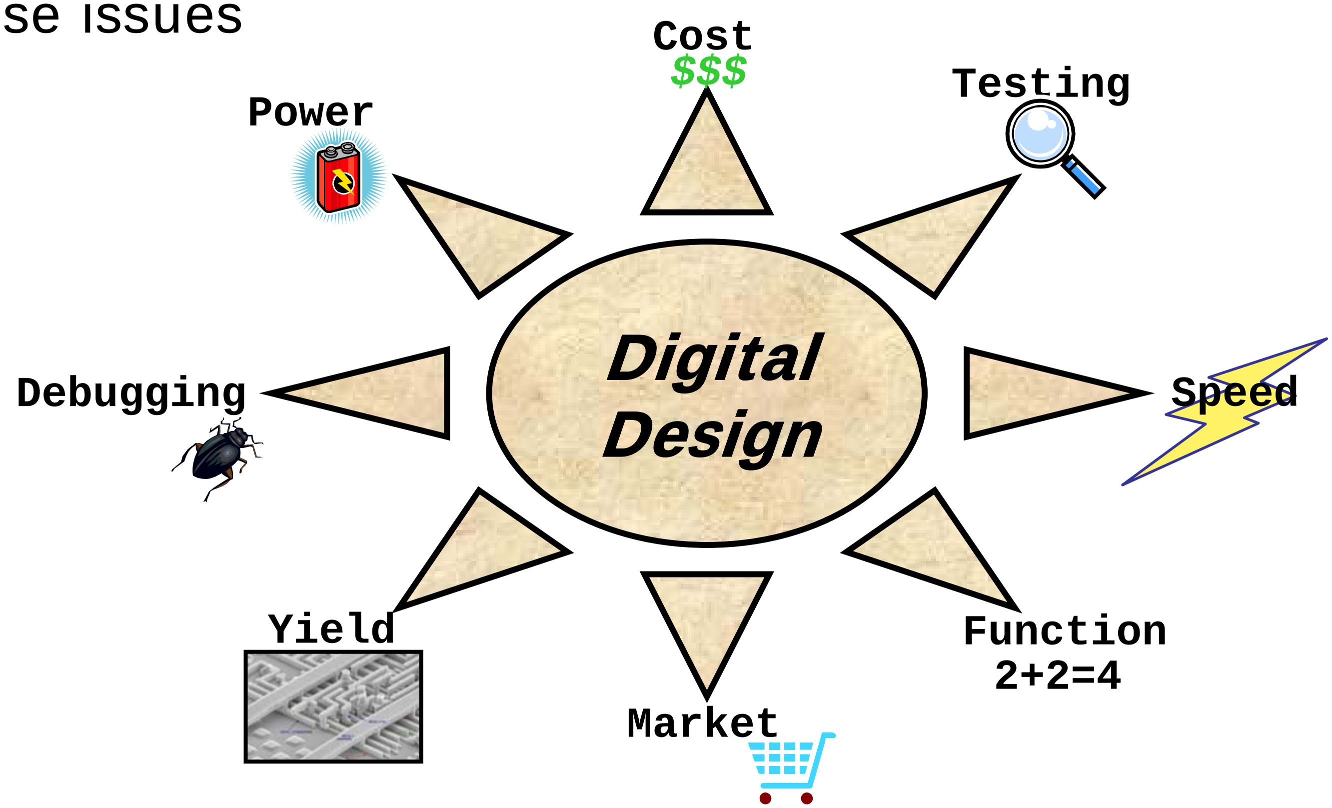
Nutshell:
- How to build HW for the 15-213 stuff

Mother of all Verilog projects



18-340: Digital Computation

- 340 is about the design of digital circuits for computation:
  - Adders, multipliers, dividers, and floating point units
- As a designer, you not only have to create the desired function, you have to satisfy other constraints
- In 18-340, you learn how to systematically deal with all of these issues



18-341: Logic Design Using Simulation, Synthesis, and Verification Techniques

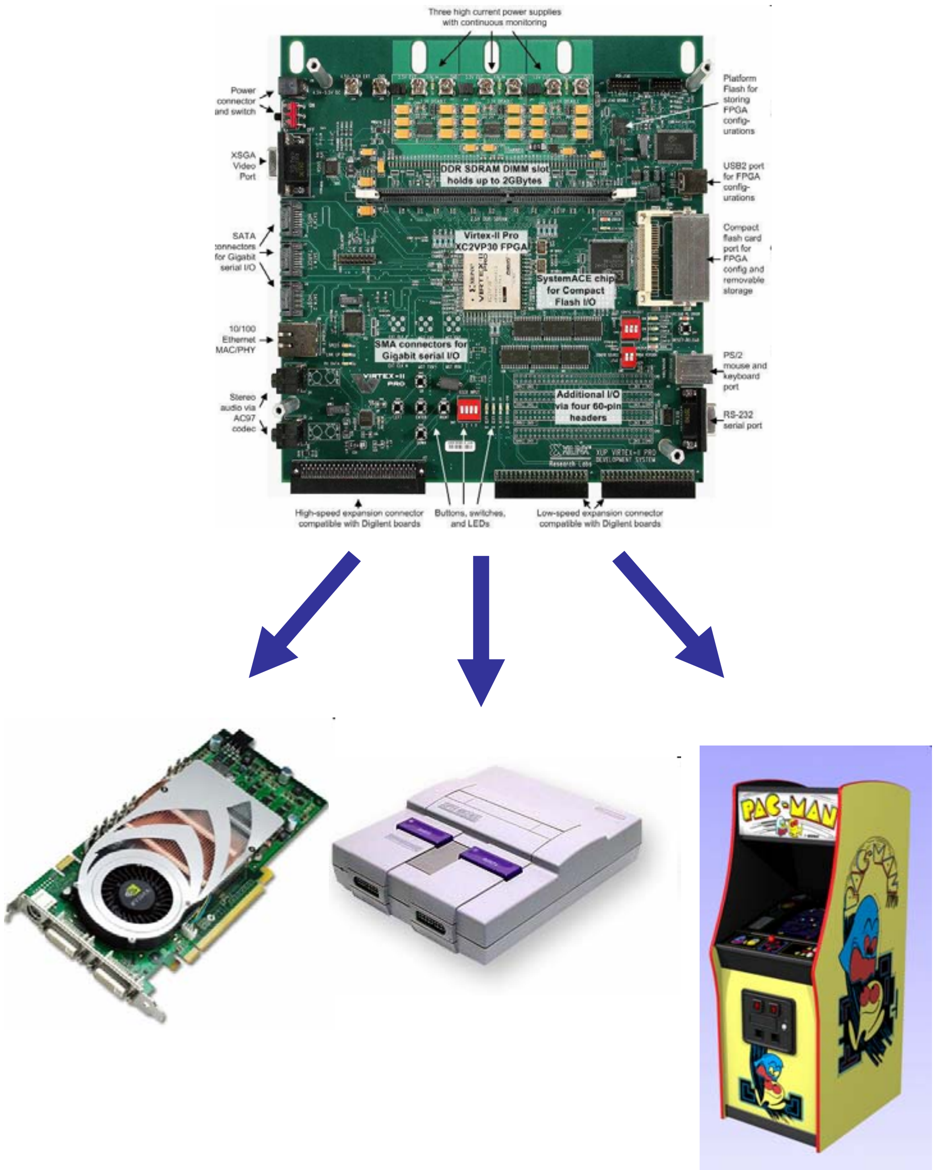
Abstract: **This course is a study of the techniques of designing the register-transfer and logic levels of complex digital systems using simulation, synthesis, and verification tools. This course teaches how to model such a system and how to synthesize an implementation from the model. Just as important is how to determine if the model is correct in the first place, and if the implementation also meets constraints – thus topics of assertion-based verification and testbench writing are included. Design examples are of interfaces (e.g., busses and memories).**

Why? **This course is good background for courses such as 18-545, 527, 525, 447, 744, 760 which tie into Verilog-based IC design. Pre-req: 18-240**

Threads of the course

- Modern modeling, simulation, synthesis, and verification tools
  - What they can and can't do for you
- The design of interface systems — physical layer
  - Bus and memory systems — used as design examples
- Concurrent FSMs
  - Synchronization (clocking) techniques, distributed systems
- Fault models, debugging, testing, testbenches, assertions
  - What can go wrong, …and did it?

18-545: Digital Design Project



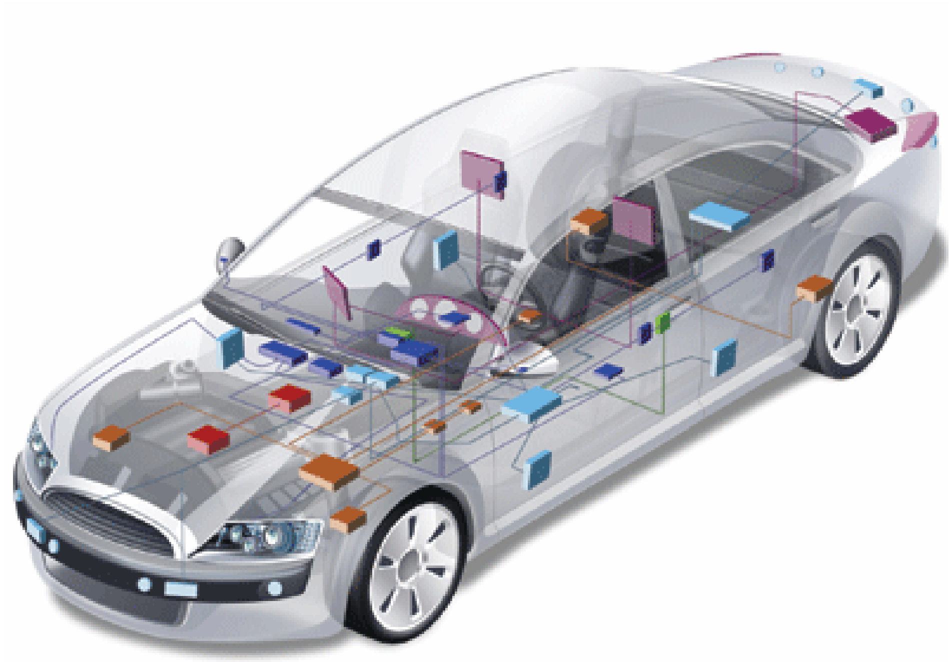
- Digital system capstone
  - Design/build a sizable digital system
  - Work in teams of 4
  - FPGA-based build platform
  - HDL-level and above
- Example projects
  - Video game ← this year's
  - MP3 player
  - Chess playing system

18-348 Embedded System Engineering

- Junior-level course with significant project content
  - Emphasis on small microcontrollers most of the CPUs sold worldwide using Freescale MC9S12C32 (a "CPU12" 16-bit micro)

- Core topic areas:
  - Microcontroller hardware
  - Assembly language
  - Embedded C
  - Optimization & coding hacks
  - Serial Communciations
  - Counters/Timers
  - Analog I/O
  - Interrupts
  - Concurrency
  - Low-Level Real Time op.
  - Debug & Test

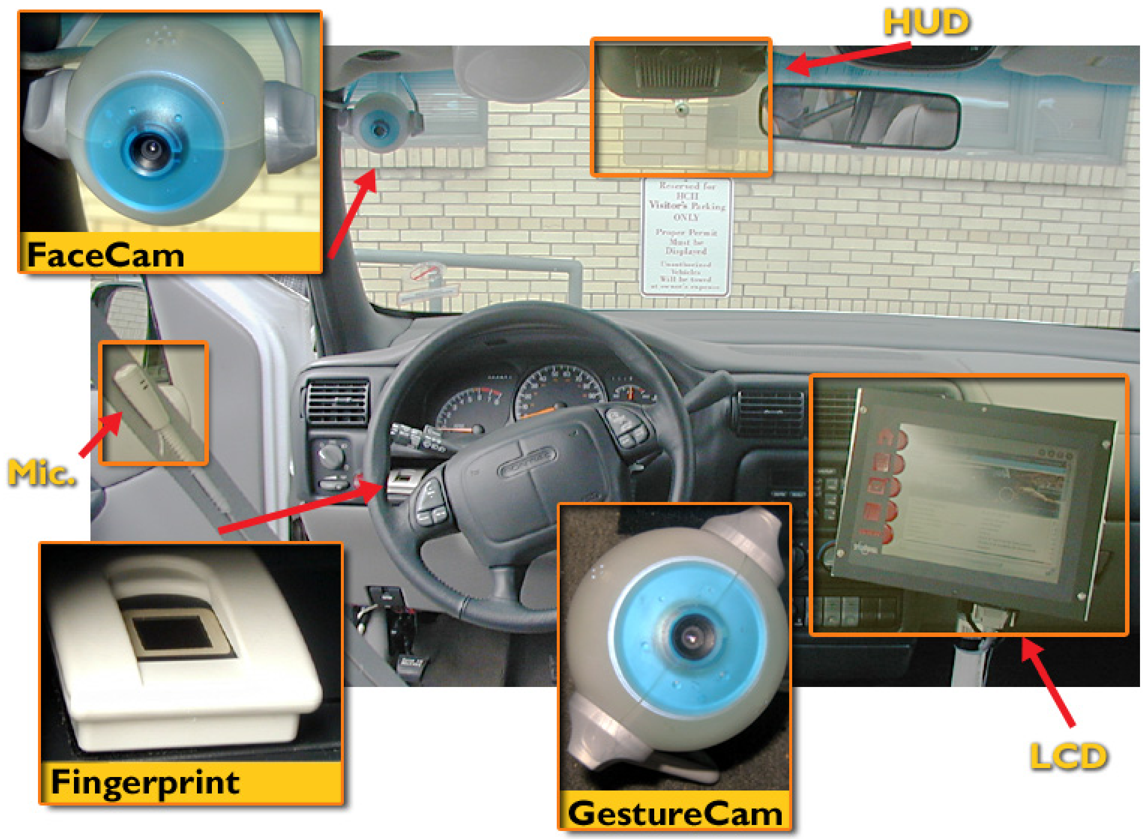
Automotive body control computers [Prengler05]



18-540: Rapid Prototyping of Computer Systems

Prototype for client

- Embedded HW/SW
- Real facilities
- Build small, embedded circuit boards with CPUs, mem, sensors, and wireless, SW services, and user interaction interfaces.



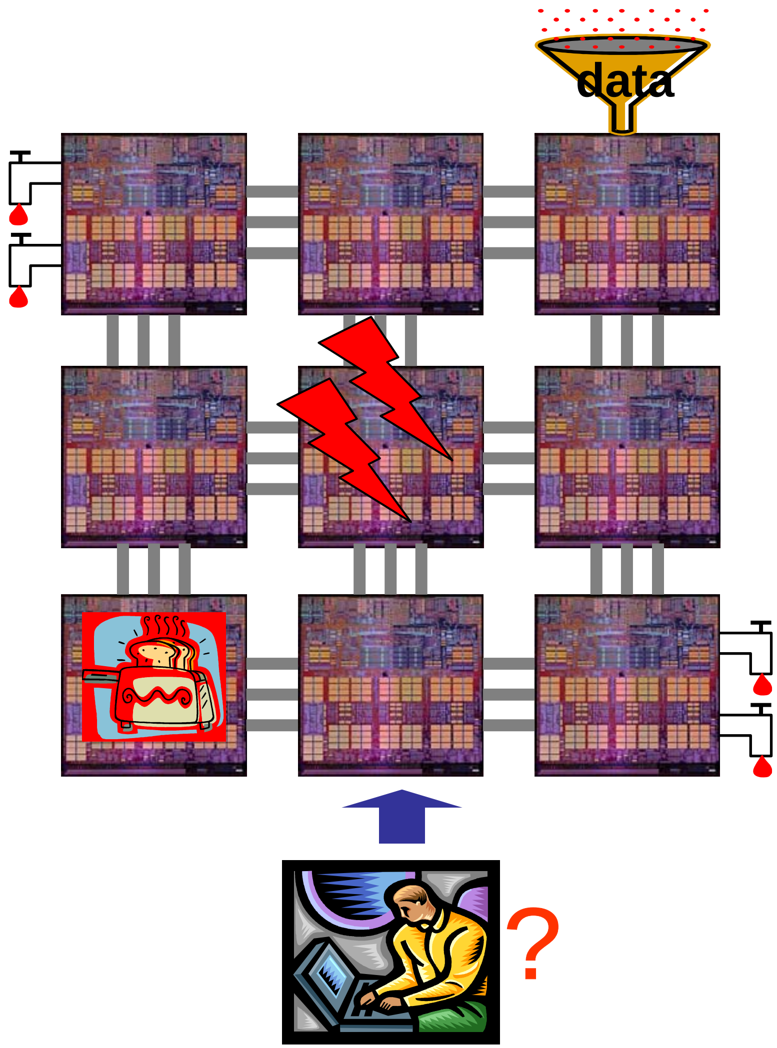
GM/CMU Companion driver interface system

What is "Hot" in Chip Design?

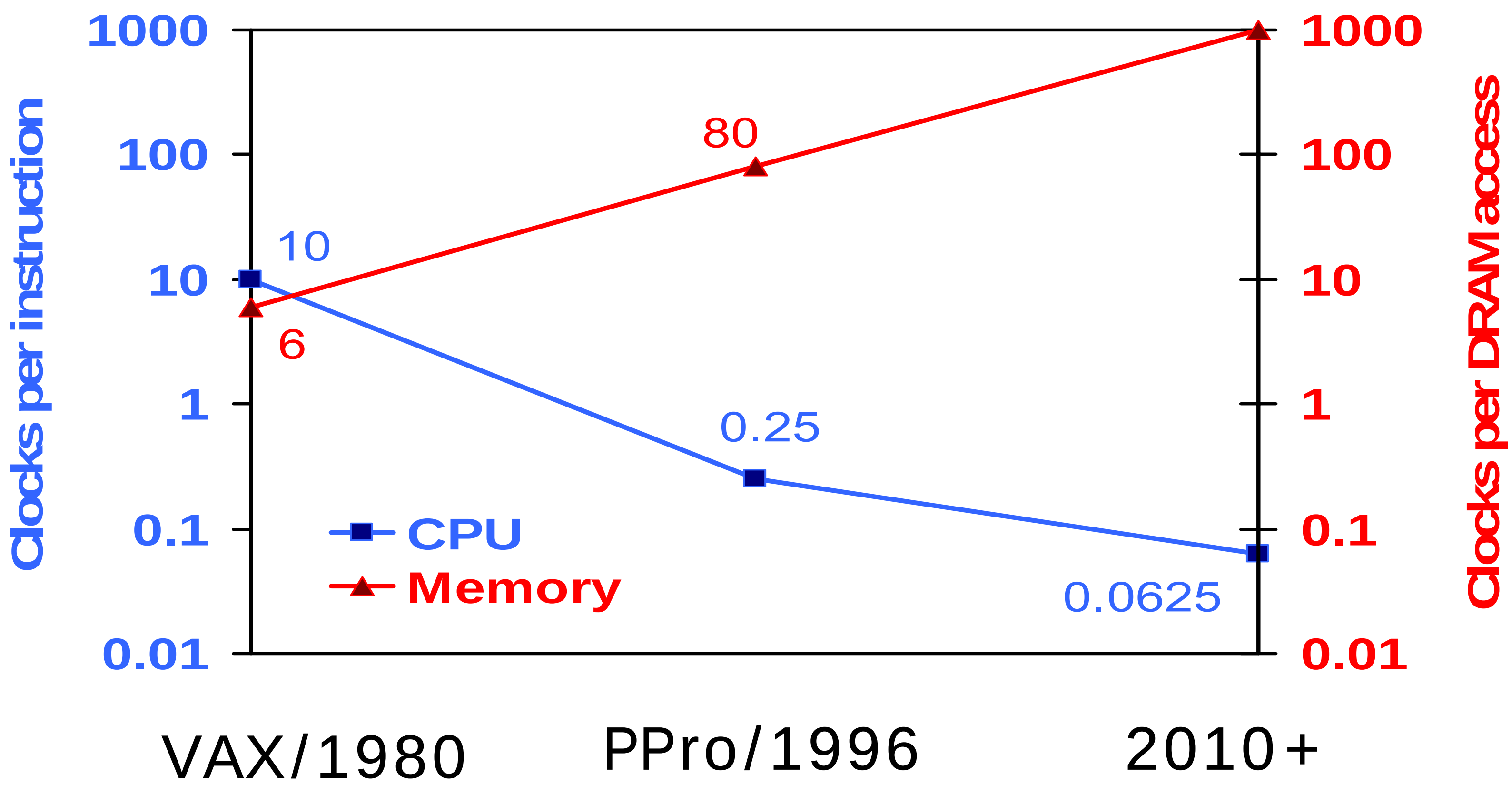
128 cores on-chip by 2015!

But,

- Memory is getting big & slow
- Too many
  - Unreliable transistors
  - Power-hungry transistors
  - ...
- Software is getting big & buggy
- Multiprocessor chips
  - E.g., Intel's Core Duo
  - 2x procs every 18 months
  - No parallel software!
- Slow design tools



Problem #1: The Memory Wall



Processor/memory performance gap will continue to increase!

Current research: memory systems to bridge the gap

Problem #2: The Reliability Wall

High rate of failure in future

- Physical limits in manufacturing smaller transistors
- Hard to test chips
- Smaller transistors prone to cosmic rays (bitflips)

High design complexity (100 billion trans/chip)

Reliability/availability already key in enterprise applications

- Downtime cost for brokerage operations: $6,450,000/h [Patterson, ROC keynote]

Current research:

- Make systems “bullet-proof” for future technologies

Problem #3: The Power Wall

Power consumption is hitting the roof

- Chip power has hit 1KW
- Buildings → Hundreds of multi-KW desktops/servers
- Battery is classic problem example
- You also run out of electricity → e.g., California

But, heat density prohibitive in high-perf. systems!

- Heat adversely affects reliability (remember AMD?)
- Some rack-mounted blades are already heat-limited

Current research:

- Reduced energy/heat with minimal perf. impact

Problem #4: The SW Wall

Low SW productivity

- Complex HW → SW must adapt

Low SW reliability

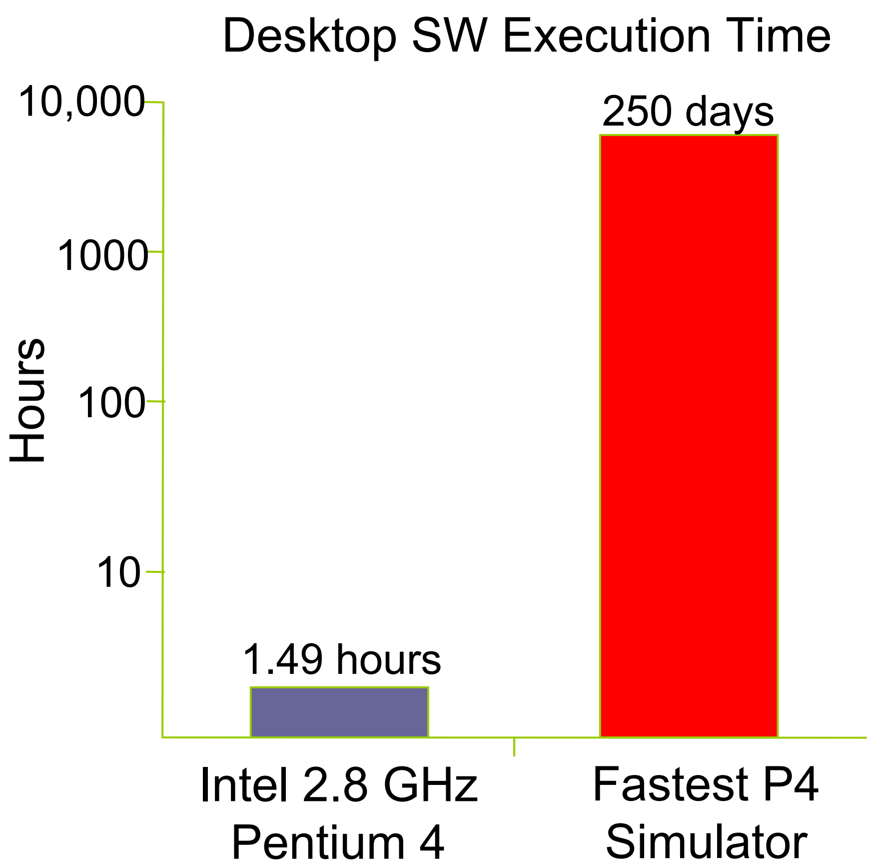
- Complexity → buggy code
- Buggy code → low security

Parallel SW not mainstream

- # CPU's/chip doubles every 18 months
- Today's SW runs on one CPU!

Current research: Machines that allow for simple, parallel and robust programs

Problem #5: Slow Design Tools



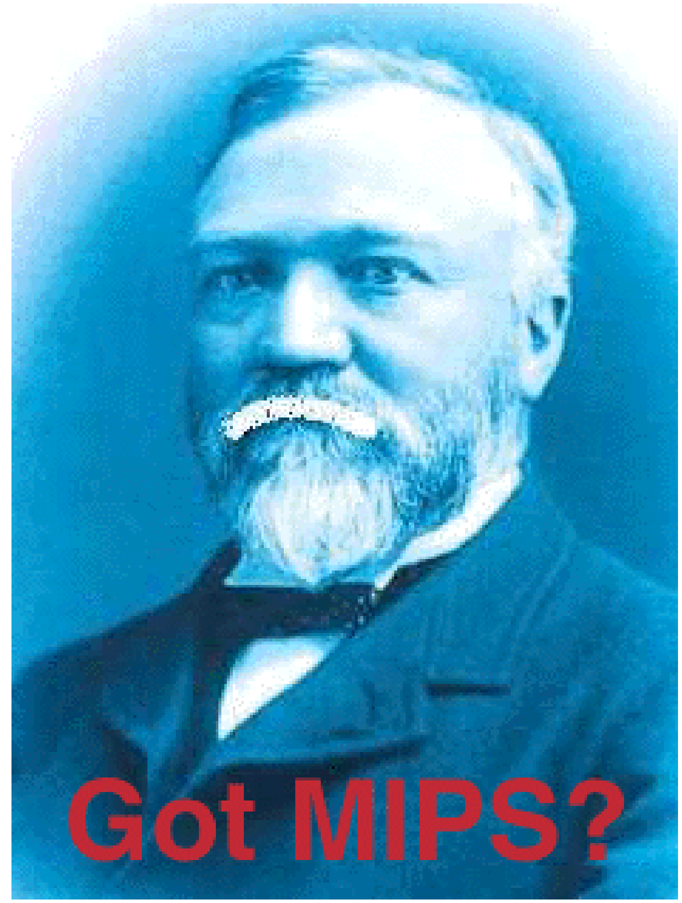
Current research:

- Fast, accurate & flexible sims.
- FPGA-based prototyping

Full-benchmark simulation is not tractable

Computer Architecture Lab at Carnegie Mellon (CALCM)

- Pronounced "calcium"
- Architecture students & faculty
- 8 faculty
- Lots of stellar students (over 30 at last count)
- Projects to tackle the mentioned challenges
- Seminar on Tuesdays @ 4:30pm in HH D210



http://www.ece.cmu.edu/CALCM