Computer Architecture
（计算机体系结构）

Lecture #1 – Introduction

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“I stand on the shoulders of giants…”

Prof David Patterson

Prof Dan Garcia

Thanks to these talented folks (& many others) whose contributions have helped make this course a really tremendous course!

What are prerequisites of this course ?

- Programming languages ?
- Data structures ?
- Digital logic design ?

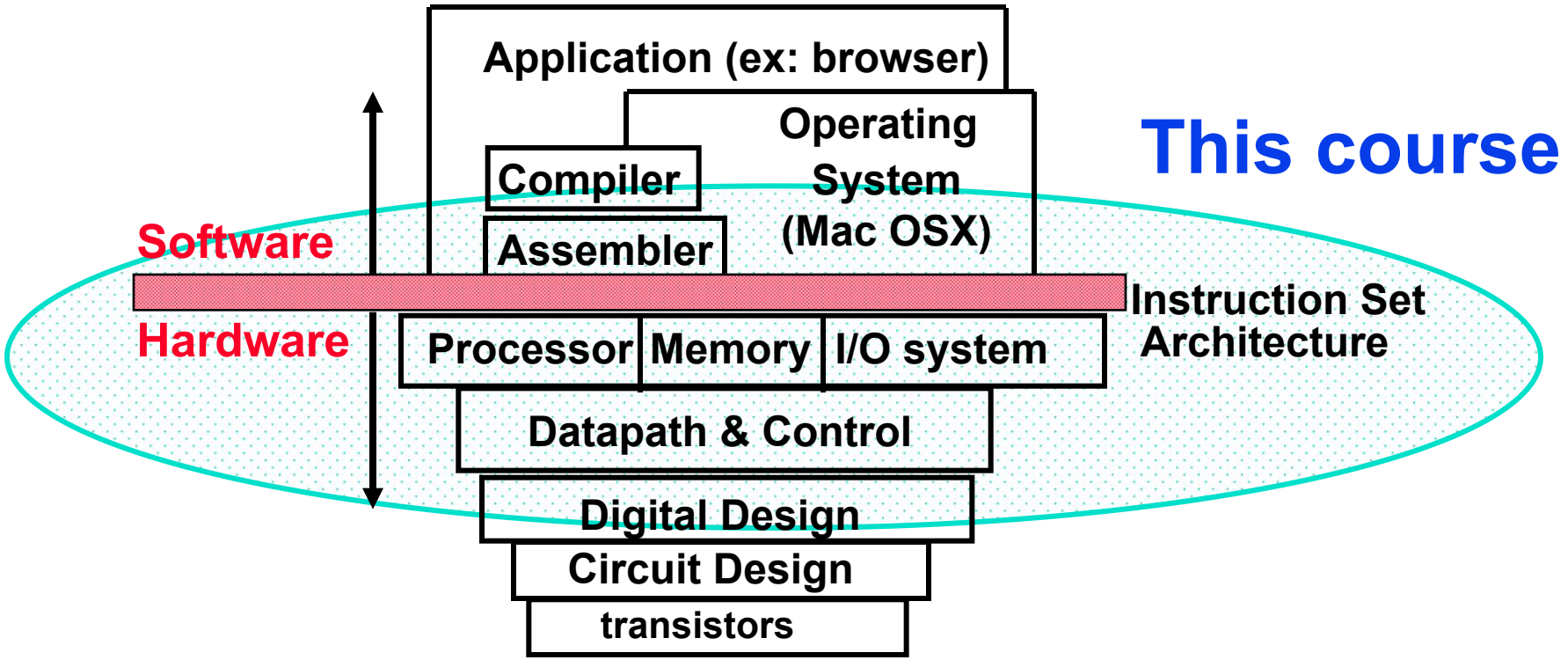
Are Computers Smart?

- To a programmer:
  - Very complex operations / functions:
    - `(map (lambda (x) (* x x)) '(1 2 3 4))`
  - Automatic memory management:
    - `List l = new List;`
  - "Basic" structures:
    - Integers, floats, characters, plus, minus, print commands

Are Computers Smart?

- In real life at the lowest level:
  - Only a handful of operations:
    - {`and`, `or`, `not`}
  - No automatic memory management.
  - Only 2 values:
    - {0, 1} or {low, high} or {off, on}

What are "Computer Architecture"?



Coordination of many
levels (layers) of abstraction

Levels of Representation

High Level Language Program (e.g., C)

Compiler

Assembly Language Program (e.g.,MIPS)

Assembler

Machine Language Program (MIPS)

Machine Interpretation

Hardware Architecture Description (e.g., block diagrams)

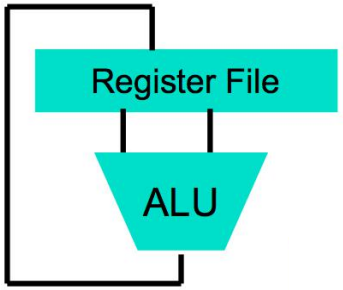
Architecture Implementation

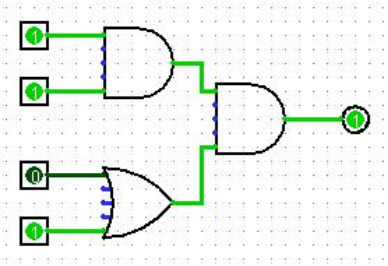
Logic Circuit Description (Circuit Schematic Diagrams)

```
temp = v[k];
v[k] = v[k+1];
v[k+1] = temp;
```

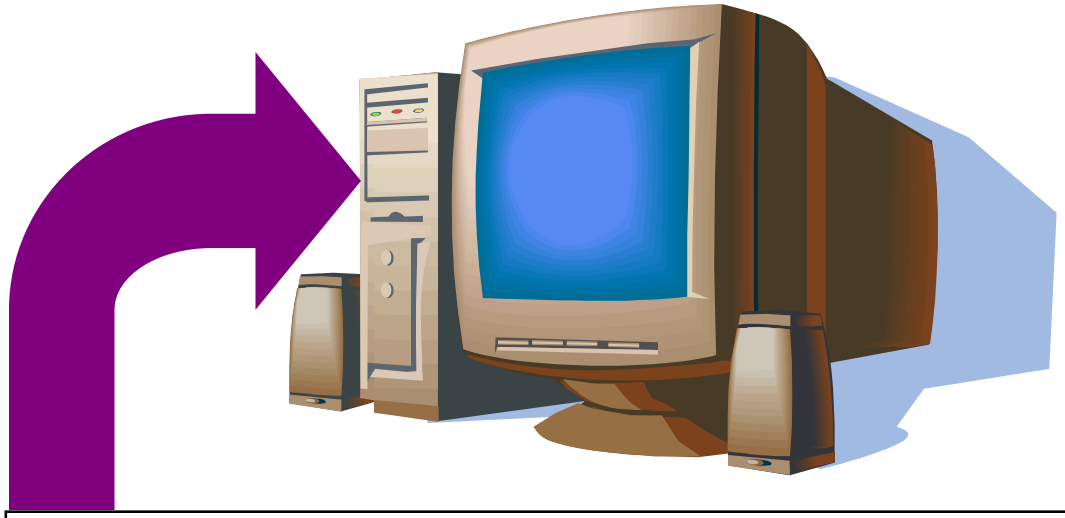
```
lw   $t0, 0($2)
lw   $t1, 4($2)
sw   $t1, 0($2)
sw   $t0, 4($2)
```

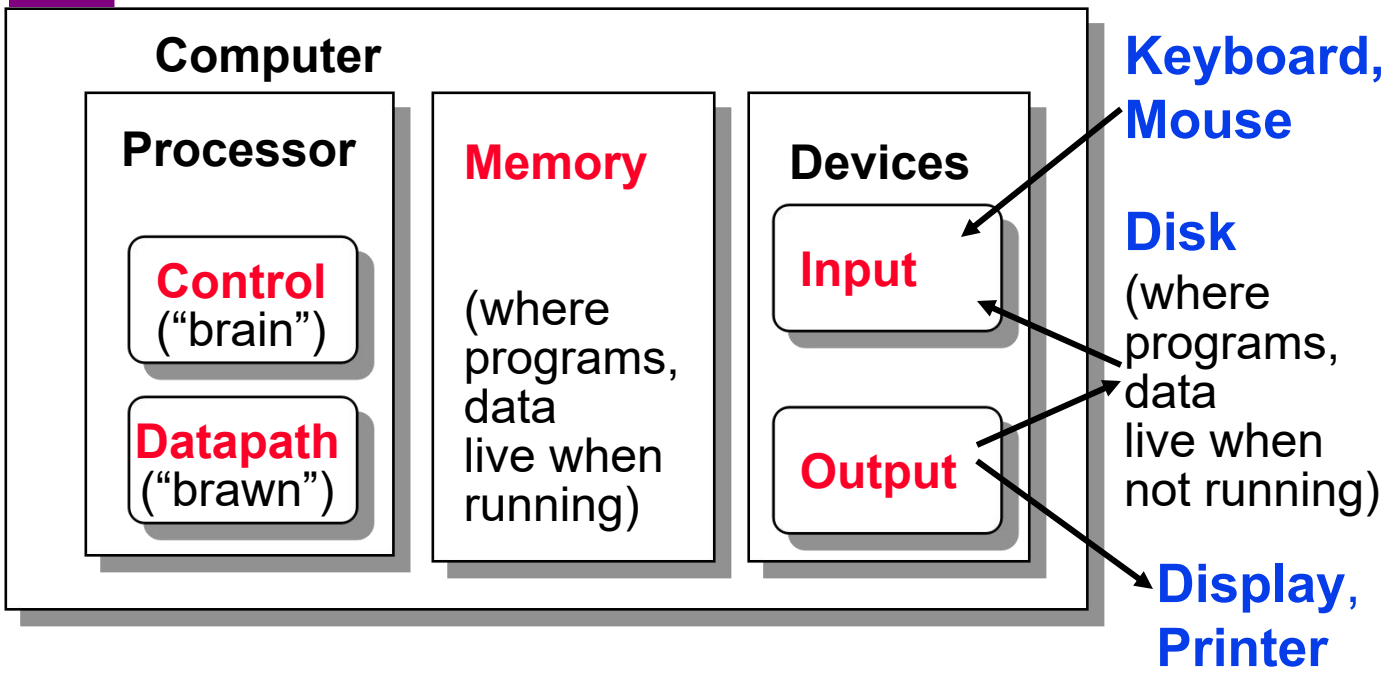
```
0000 1001 1100 0110 1010 1111 0101 1000
1010 1111 0101 1000 0000 1001 1100 0110
1100 0110 1010 1111 0101 1000 0000 1001
0101 1000 0000 1001 1100 0110 1010 1111
```





Anatomy: 5 components of any Computer





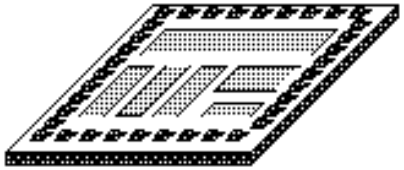
Overview of Physical Implementations

The hardware out of which we make systems.

- **Integrated Circuits (ICs)**
  - **Combinational logic circuits, memory elements, analog interfaces.**
- **Printed Circuits (PC) boards**
  - **substrate for ICs and interconnection, distribution of CLK, Vdd, and GND signals, heat dissipation.**
- **Power Supplies**
  - **Converts line AC voltage to regulated DC low voltage levels.**
- **Chassis (rack, card case, ...)**
  - **holds boards, power supply, provides physical interface to user or other systems.**
- **Connectors and Cables.**

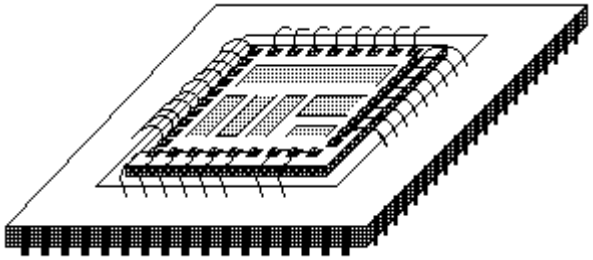
Integrated Circuits (2020 state-of-the-art)

Bare Die



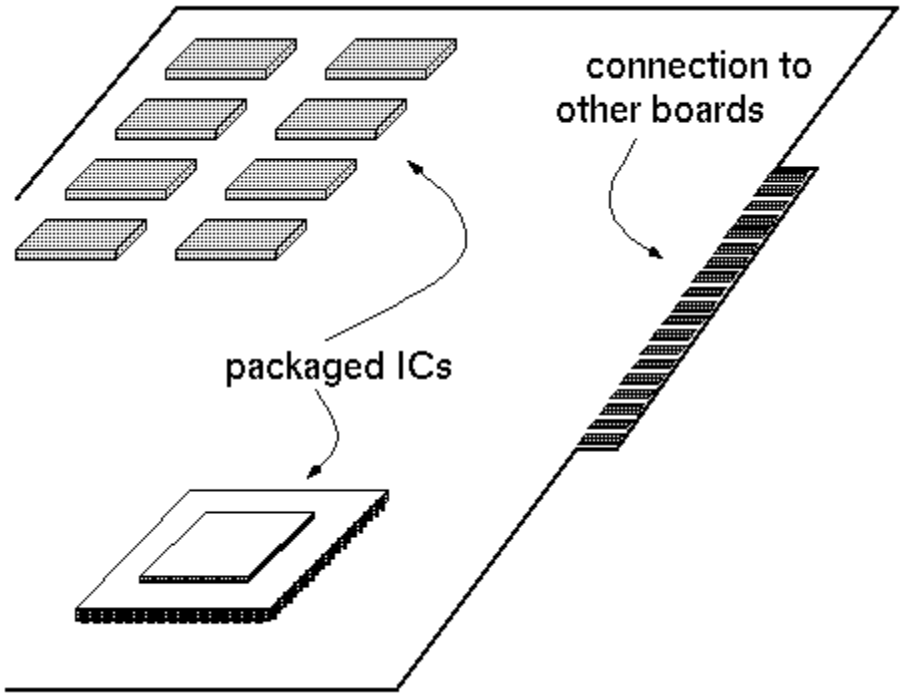
- Primarily Crystalline Silicon
- 1mm - 25mm on a side
- feature size ~ 14/7 nm
- Billions of transistors
- (25 - 100M “logic gates”)
- 3 - 12 conductive layers
- “CMOS” (complementary metal oxide semiconductor) - most common.

Chip in Package



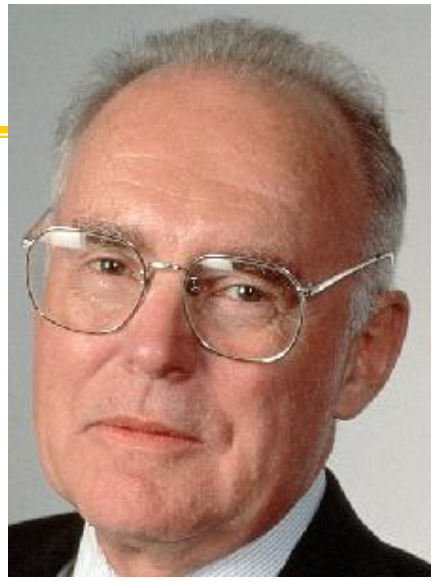
- Package provides:
  - spreading of chip-level signal paths to board-level
  - heat dissipation.
- Ceramic or plastic with gold wires.

Printed Circuit Boards

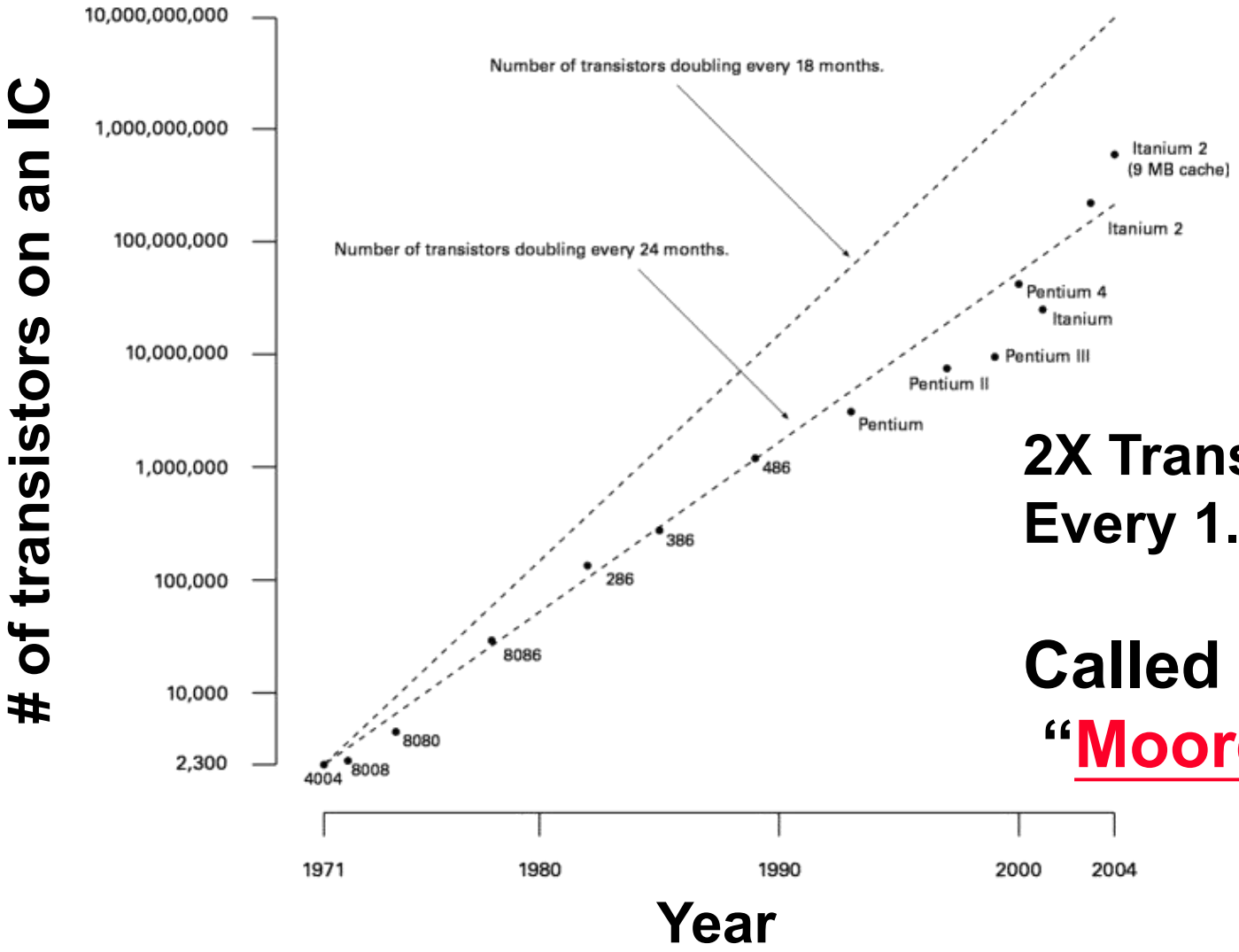


- fiberglass or ceramic
- 1-20 conductive layers
- 1-20 in on a side
- IC packages are soldered down.
- Provides:
  - Mechanical support
  - Distribution of power and heat.

Technology Trends:
Microprocessor Complexity



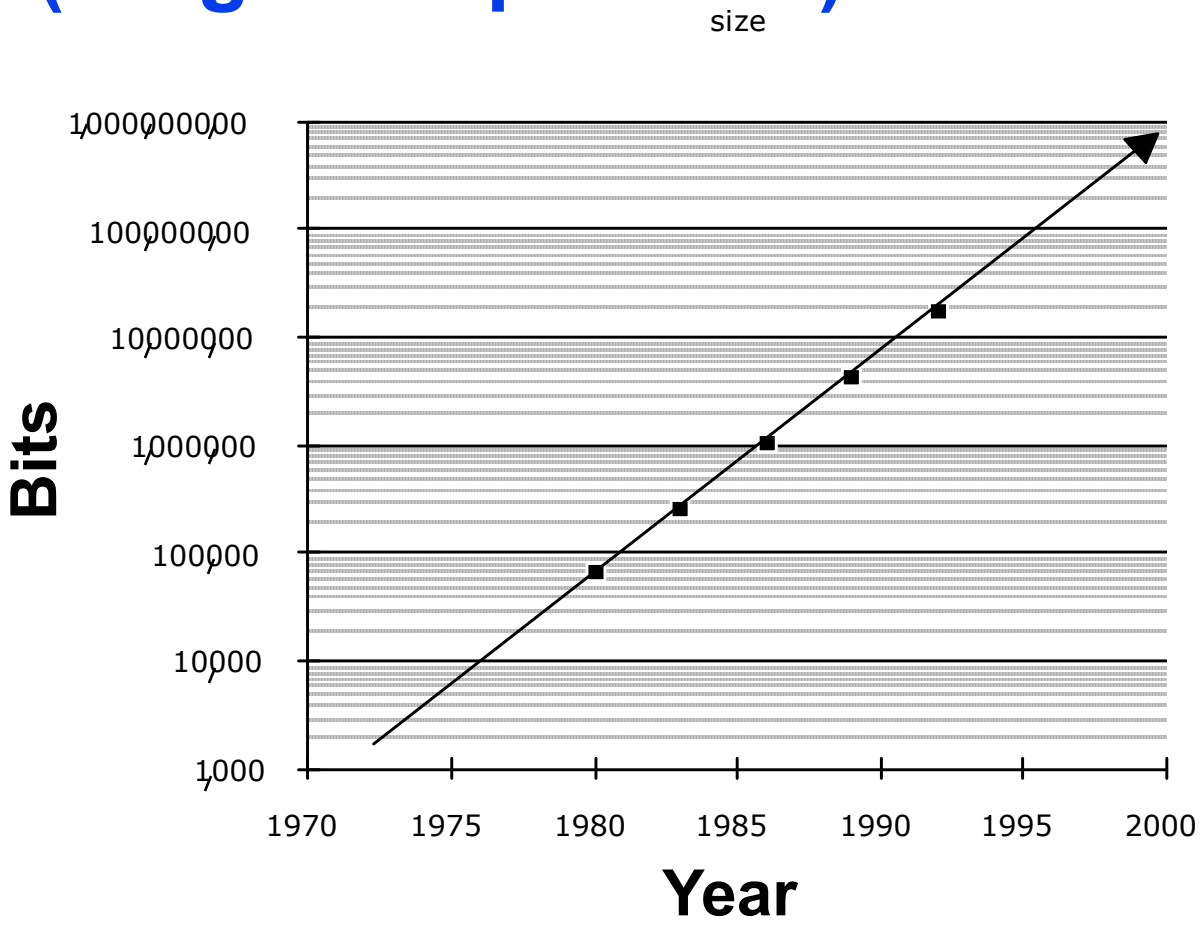
Gordon Moore
Intel Cofounder!



2X Transistors / Chip
Every 1.5 years

Called
"Moore's Law"

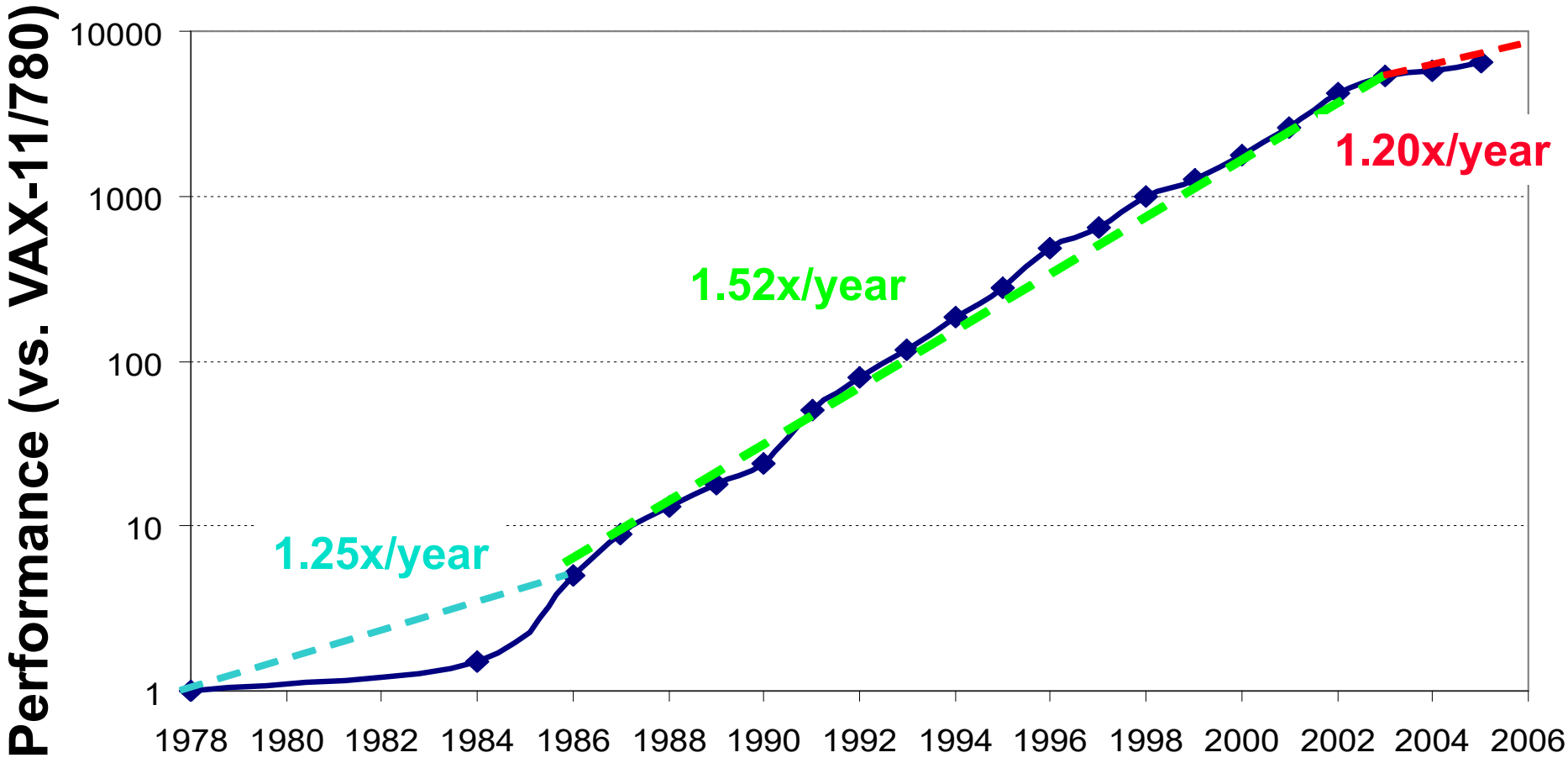
Technology Trends: Memory Capacity (Single-Chip DRAM)



year	size (Mbit)
1980	0.0625
1983	0.25
1986	1
1989	4
1992	16
1996	64
1998	128
2000	256
2002	512
2004	1024 (1Gbit)
2006	2048 (2Gbit)
2010	8192 (8Gbit)

- Now 1.4X/yr, or 2X every 2 years.
- 8000X since 1980!

Technology Trends: Uniprocessor Performance (SPECint)



- VAX : 1.25x/year 1978 to 1986
- RISC + x86: 1.52x/year 1986 to 2002
- RISC + x86: 1.20x/year 2002 to present

Computer Technology - Dramatic Change!

- **Memory**
  - **DRAM capacity: 2x / 2 years (since ‘96); 64x size improvement in last decade.**
- **Processor**
  - **Speed 2x / 1.5 years (since ‘85); [slowing!] Now almost remain the same.**
- **Disk**
  - **Capacity: 2x / 1 year (since ‘97) 250X size in last decade.**

Computer Technology - Dramatic Change!

You just learned the difference between (Kilo, Mega, …) and (Kibi, Mebi, …)!

- **State-of-the-art PC : (at least…)**
  - **Processor clock speed:** 4,000 MegaHertz (4.0 GigaHertz)
  - **Memory capacity:** 65,536 MebiBytes (64.0 GibiBytes)
  - **Disk capacity:** 2,000 GigaBytes (2.0 TeraBytes)
  - **New units! Mega ⇒ Giga, Giga ⇒ Tera**

  (Tera ⇒ Peta, Peta ⇒ Exa, Exa ⇒ Zetta
  Zetta ⇒ Yotta = 10^{24})

Computer arch. : So, what's in it for me?

- Learn some of the big ideas in CS & Engineering:
  - Principle of abstraction
    - Used to build systems as layers
  - 5 Classic components of a Computer
  - Data can be anything
    - Integers, floating point, characters, …
    - A program determines what it is
    - Stored program concept: instructions just data
  - Principle of Locality
    - Exploited via a memory hierarchy (cache)
  - Greater performance by exploiting parallelism
  - Compilation v. interpretation through system layers
  - Principles / Pitfalls of Performance Measurement

Others Skills learned in this course

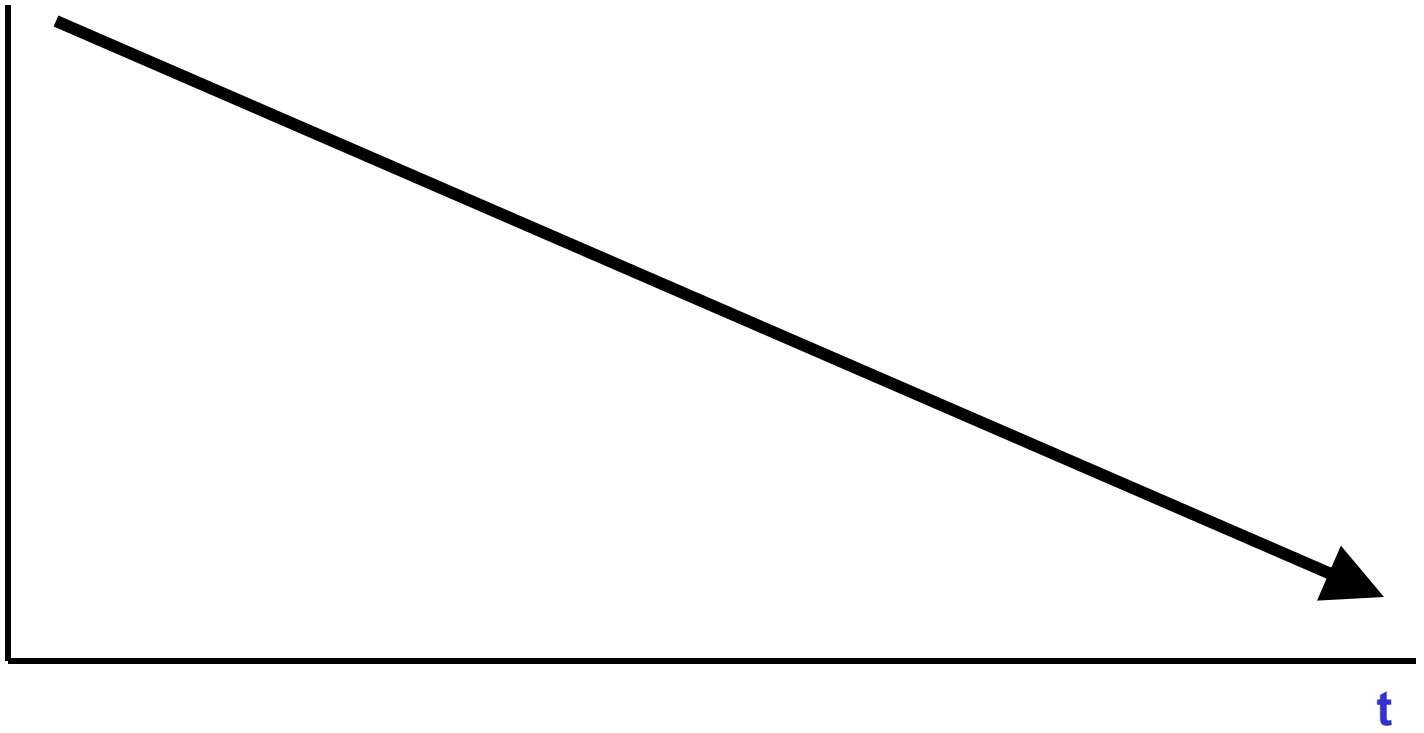
- **Enhance C programming skill**
  - If you know one, you should be able to learn another programming language largely on your own
  - If you know C++ or Java, it should be easy to pick up their ancestor, C
- **Assembly Language Programming**
  - This is a skill you will pick up, as a side effect of understanding the Big Ideas
- **Hardware design**
  - We'll learn just the basics of hardware design
  - We'll this in more detail in following courses

Yoda says…

“Always in motion is the future…”

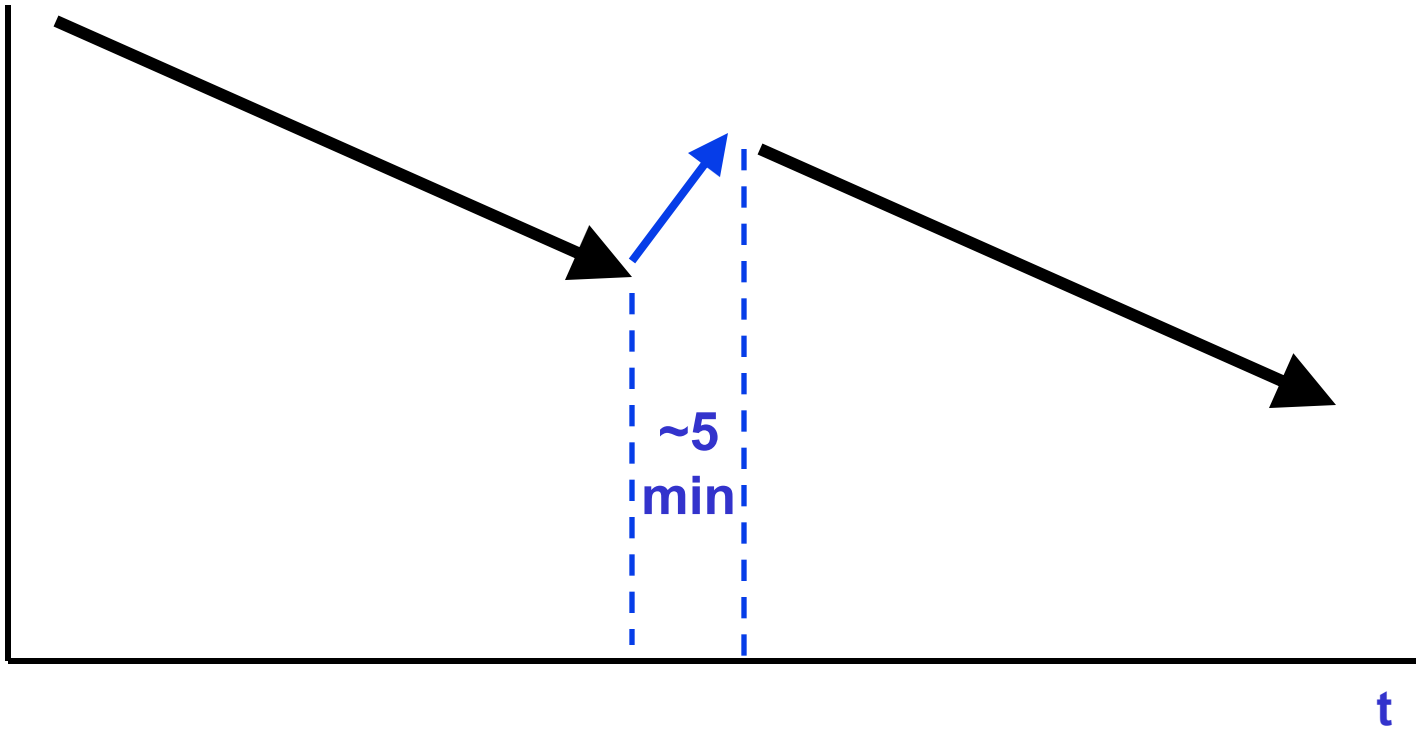
Our schedule may change slightly depending on some factors. This includes lectures, assignments & labs…

What is this?



Attention over time!

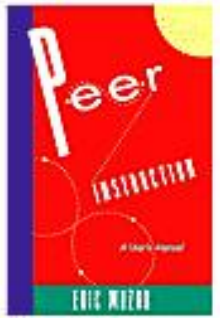
What is this?!



Attention over time!

Tried-and-True Technique: Peer Instruction

- Increase real-time learning in lecture, test understanding of concepts vs. details



- As complete a "segment" ask multiple choice question
  - 1-2 minutes to decide yourself
  - 3 minutes in pairs/triples to reach consensus. Teach others!
  - 5-7 minute discussion of answers, questions, clarifications

Extra Credit: EPA!

- **E**ffort
  - Attending my or my TA's office hours, completing all assignments, turning in HW, doing reading quizzes
- **P**articipation
  - Attending lecture and voting in Peer Instruction
  - Asking great questions in discussion and lecture and making it more interactive
- **A**ltruism
  - Helping others in lab or wechat
- EPA! extra credit points have the potential to bump students up to the next grade level!

Course Problems…Cheating

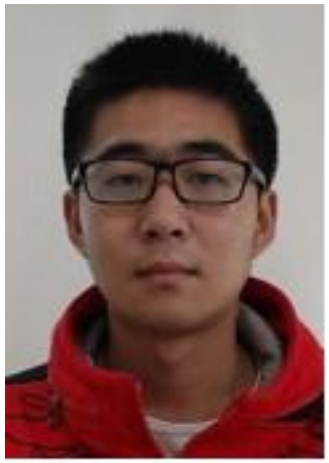
- What is cheating?
  - Studying together in groups is encouraged.
  - Turned-in work must be *completely* your own.
  - Common examples of cheating: running out of time on a assignment and then pick up output, take homework from box and copy, person asks to borrow solution "just to take a look", copying an exam question, …
  - You're not allowed to work on homework/projects/exams with anyone (other than ask Qs walking out of lecture)
  - Both "giver" and "receiver" are equally culpable
- Cheating points: 0 EPA, negative points for that assignment / project / exam (e.g., if it's worth 10 pts, you get -10) In most cases, F in the course. .

My goal as an instructor

- To make your experience in this course as enjoyable & informative as possible
  - Enthusiasm, graphics & technology-in-the-news in lecture
  - Fun, challenging projects & HW
  - Pro-student policies
- To be a good-teaching man
  - Please give me feedback so I improve! Why am I not excellent teacher for you? I will listen!!

Teaching Assistants

- Jiacheng Ni



Summary

- Continued rapid improvement in computing
  - 2X every 2.0 years in memory size;
    every 1.5 years in processor speed;
    every 1.0 year in disk capacity;
  - Moore's Law enables processor
    (2X transistors/chip ~1.5-2 yrs)
- 5 classic components of all computers

Control Datapath Memory Input Output

Processor

Reference slides

You ARE responsible for the material on these slides (they're just taken from the reading anyway) ; we've moved them to the end and off-stage to give more breathing room to lecture!

Course Lecture Outline

- Machine Representations
  - Numbers (integers, reals)
  - Assembly Programming
  - Compilation, Assembly
- Processors & Hardware
  - Logic Circuit Design
  - CPU organization
  - Pipelining
- Memory Organization
  - Caches
  - Virtual Memory
- I / O
  - Interrupts
  - Disks, Networks
- Advanced Topics
  - Performance
  - Virtualization
  - Parallel Programming

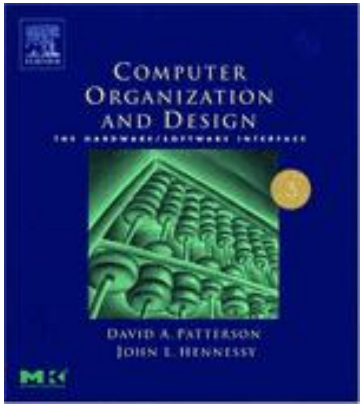
Homeworks and Projects

- Homework exercises
- Projects
- All exercises, reading, homeworks, projects on course web page www.cadetlab.cn/courses
- We will DROP your lowest HW, Lab!
- Only one final exam

Your final grade

- **Grading (max: 100 pts)**
  - 20pts = 20% Homework
  - 20pts = 20% Projects
  - 50pts = 50% Final exam
  - 10pts = 10% Attendance
  - Extra EPA points (5pts)

Texts



- Required: ***Computer Organization and Design: The Hardware/Software Interface, Third Edition***, Patterson and Hennessy (COD).
- Reading assignments on web page

Peer Instruction and Just-in-time-learning

- Read textbook
  - Reduces examples have to do in class
  - Get more from lecture (also good advice)
- Fill out 3-question on web
  - Graded for effort, not correctness…
  - This counts toward EPA score