Computer Organization and Computer Architecture Education

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A long and Fascinating Journey

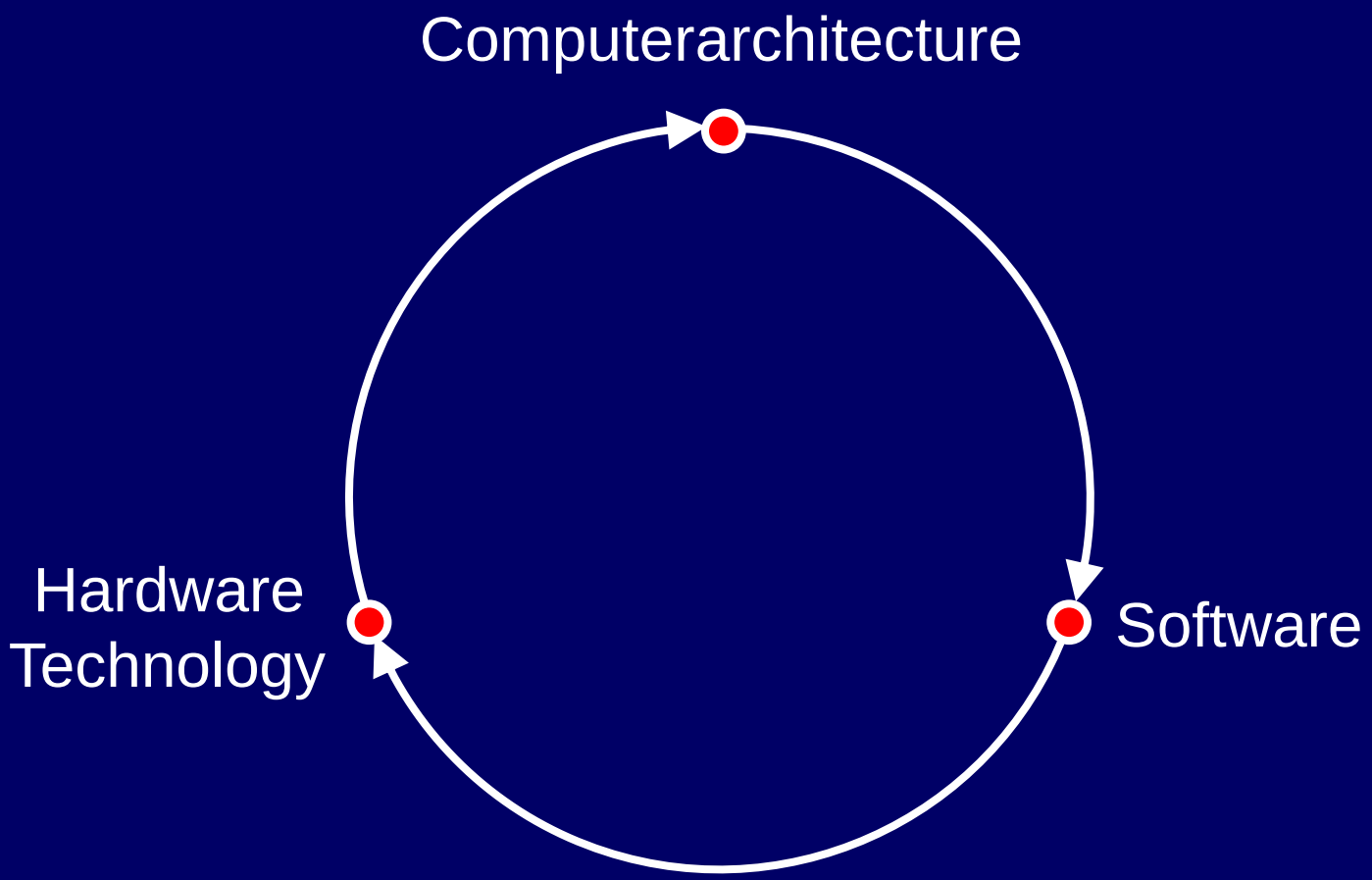
- 1946: INIAC
- 30 tons
- 18,000 vacuum tubes
- 5000 additions per second

- Today, MacBook Air
- 1.06 kg
- Dual core, 2GB memory, 250 GB flash disc

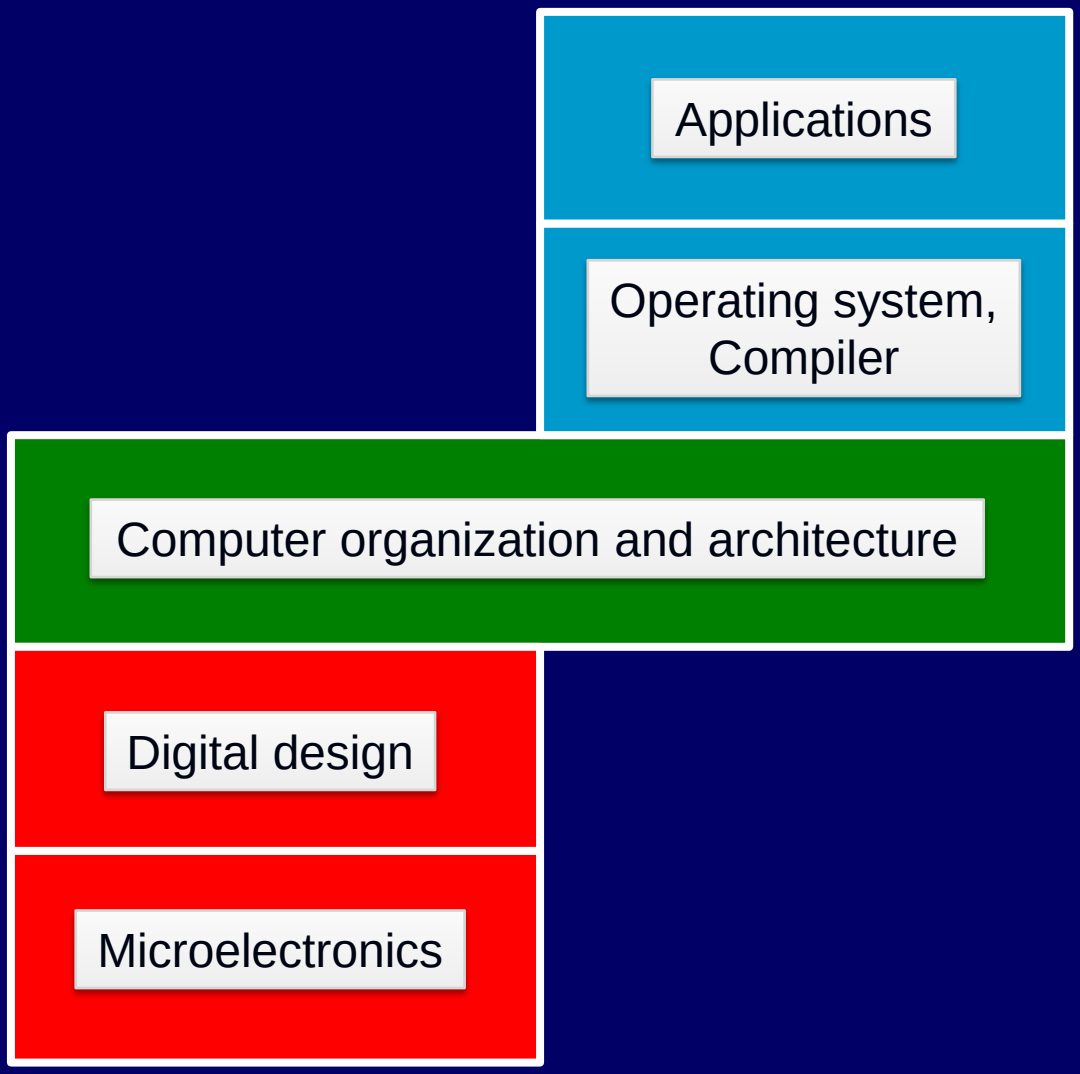
The Travelling Salesman Problem

- 1954: Solved for the optimum route to visit 49 locations
- 1987: 532 locations
- 1998: 13,509 locations
- 2006: 85,900 locations

Continuous Innovation



Is a course on computer architecture needed?


Applications
Operating system, Compiler
Computer organization and architecture
Digital design
Microelectronics

- Bob Colwell (Intel's chief architect on the Pentium project) is quoted to have said

  "*I can tell you with certainty that I did not really know how computers worked until I had to write in assembly … Only then did it truly dawn on me … what a compiler is targeting*"

  A. Clements, ASEE/IEEE Frontiers in Education Conf., 2008

"Computer architecture is a key component of computer engineering … It is difficult to design an operating system well without knowledge of the underlying architecture. Moreover, the computer designer must have an understanding of software in order to implement the optimum architecture."

IEEE CE Curriculum Report, 2004

Introduction to System Integration

- A course on computer organization/architecture provides an excellent introduction to system integration and the issues involved
- It is usually the first course to do so

- Students learn about interactions & trade-offs

Hardware ↔ Software

Parallel ↔ Serial

Cache size ↔ Miss rate ↔ Access time

Course Content

Basic content

- Digital systems
- Data representation
- ISA
- Processor and memory organization
- I/O subsystem
- Computer arithmetic

Adequate detail

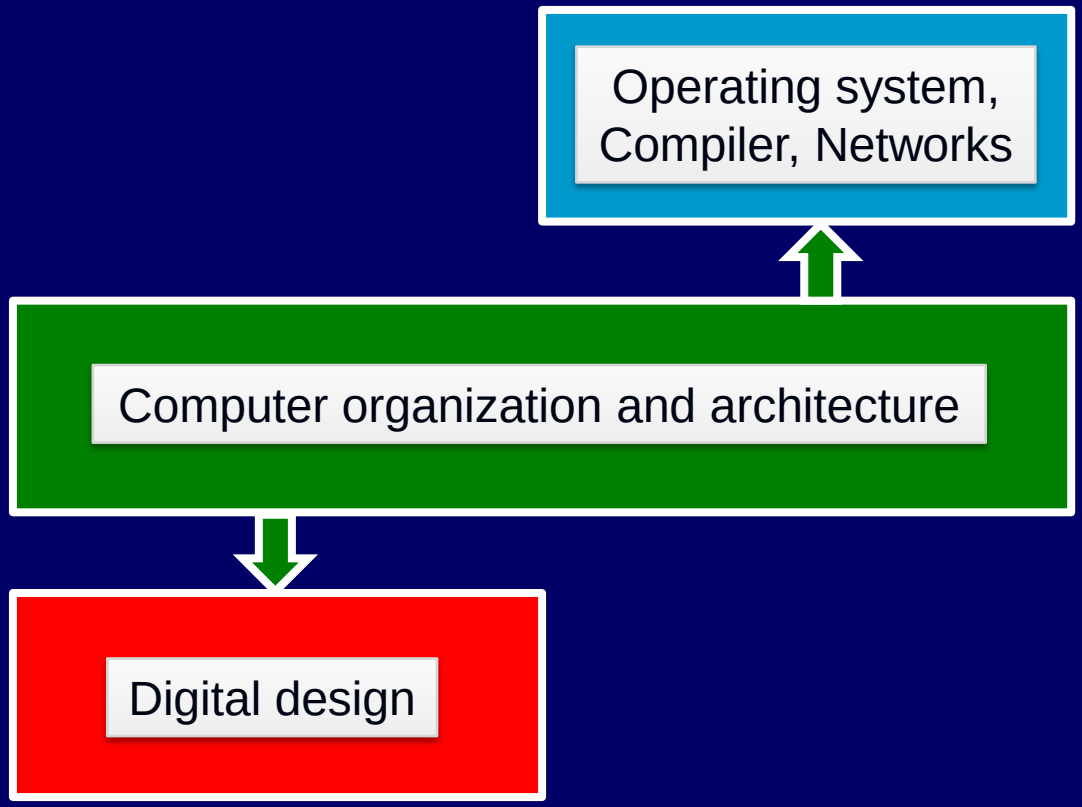
- While preparing the first edition of *Computer Organization* (1978) we wrote:

  "*Block diagrams are indispensable … However, it is important that they be supplemented with adequate details to encourage the student to dig underneath the surface.*"

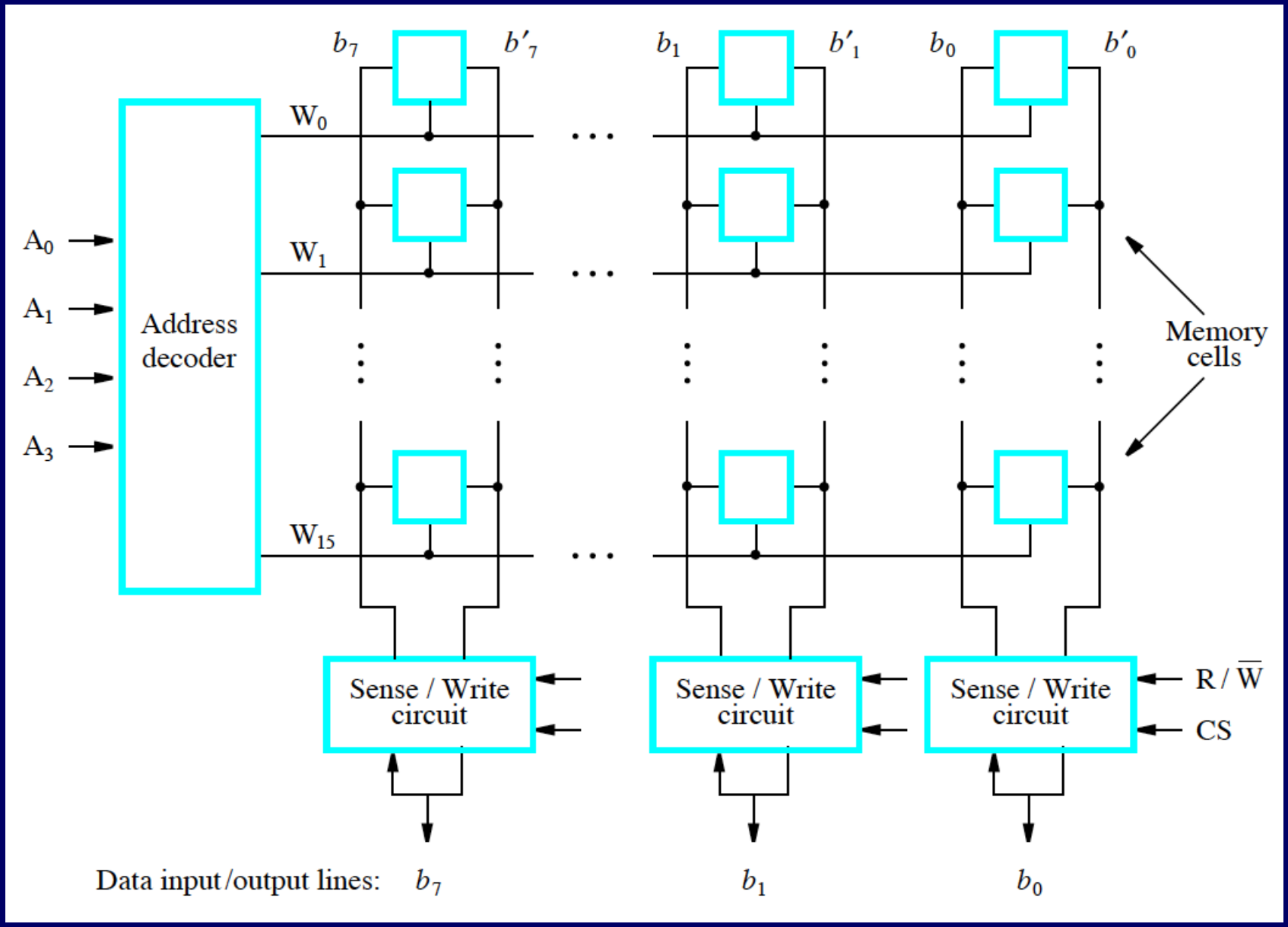
  Zaky, Hamacher and Vranesic, IEEE Trans. On Education, Feb. 1977.

Integration and Breadth of Coverage

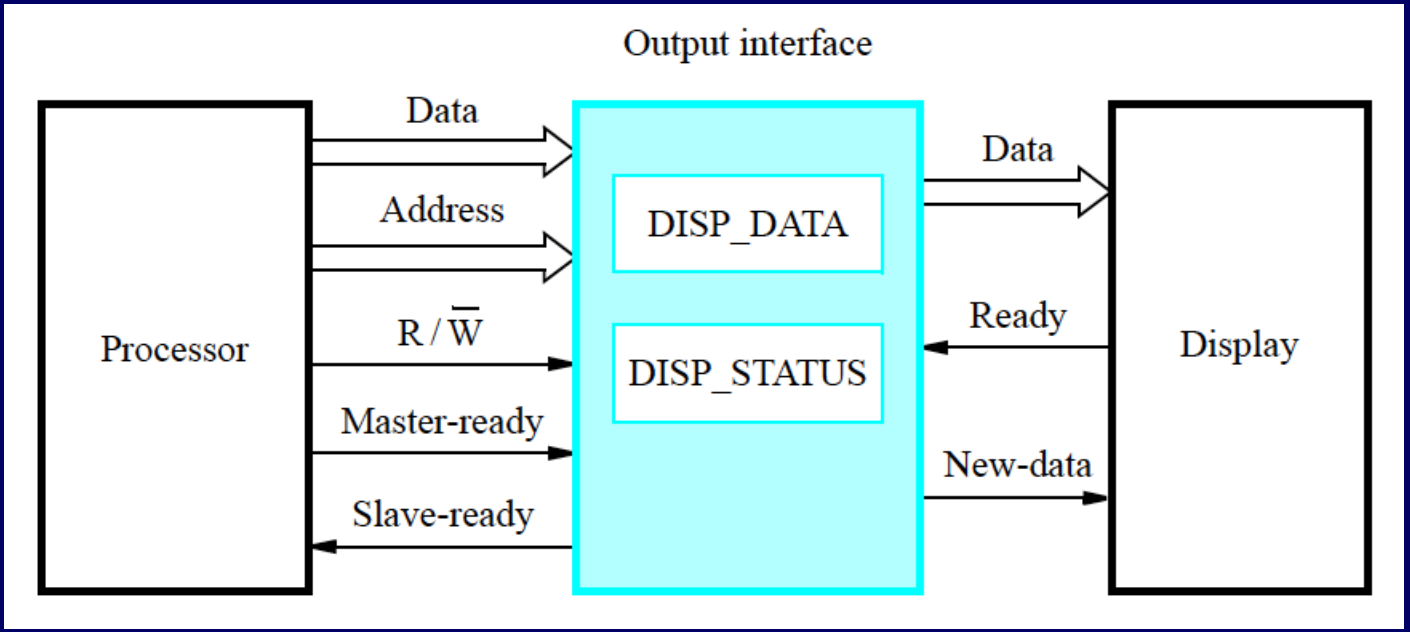
- An integrated view of hardware and software



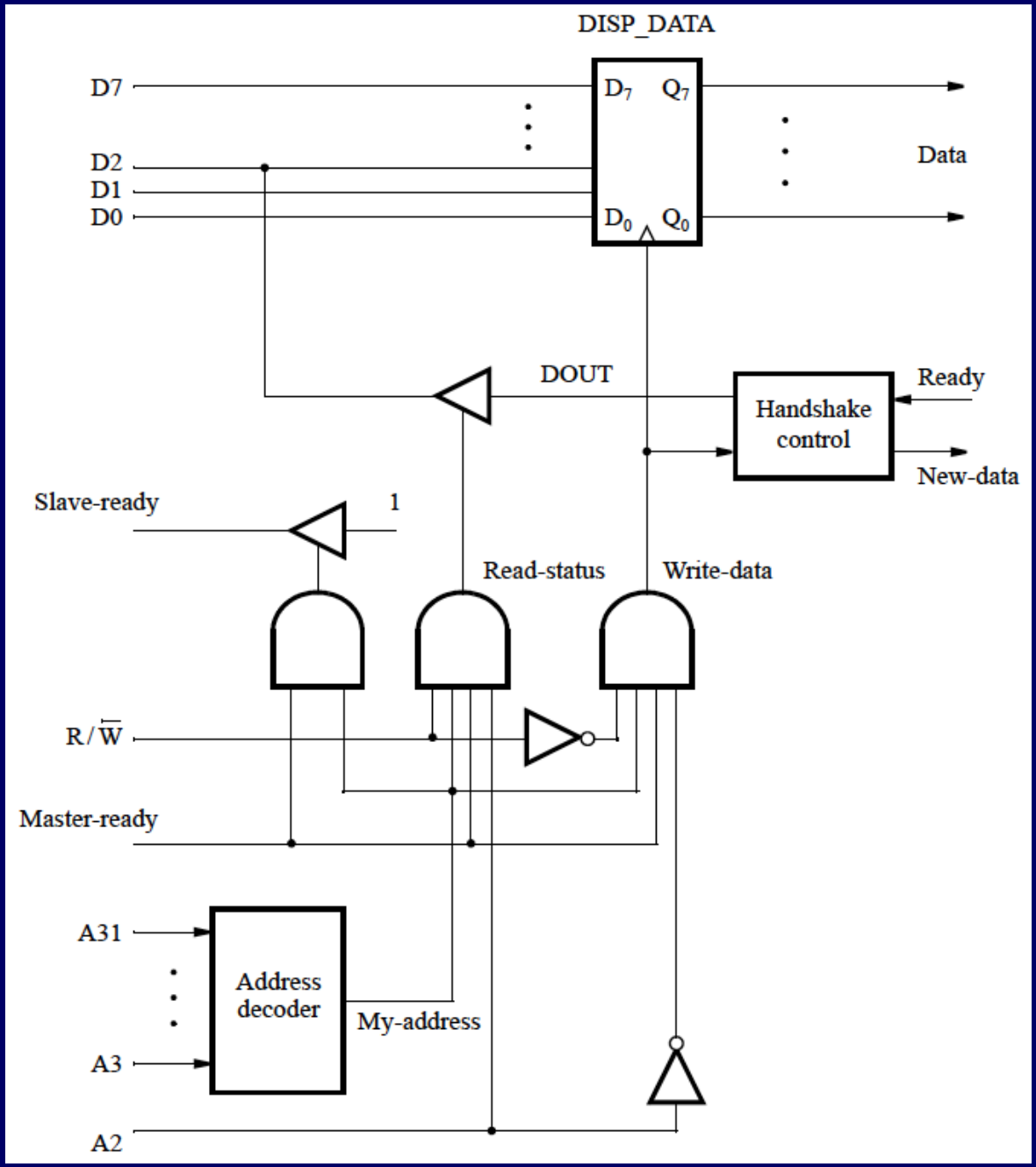
Organization of a RAM chip



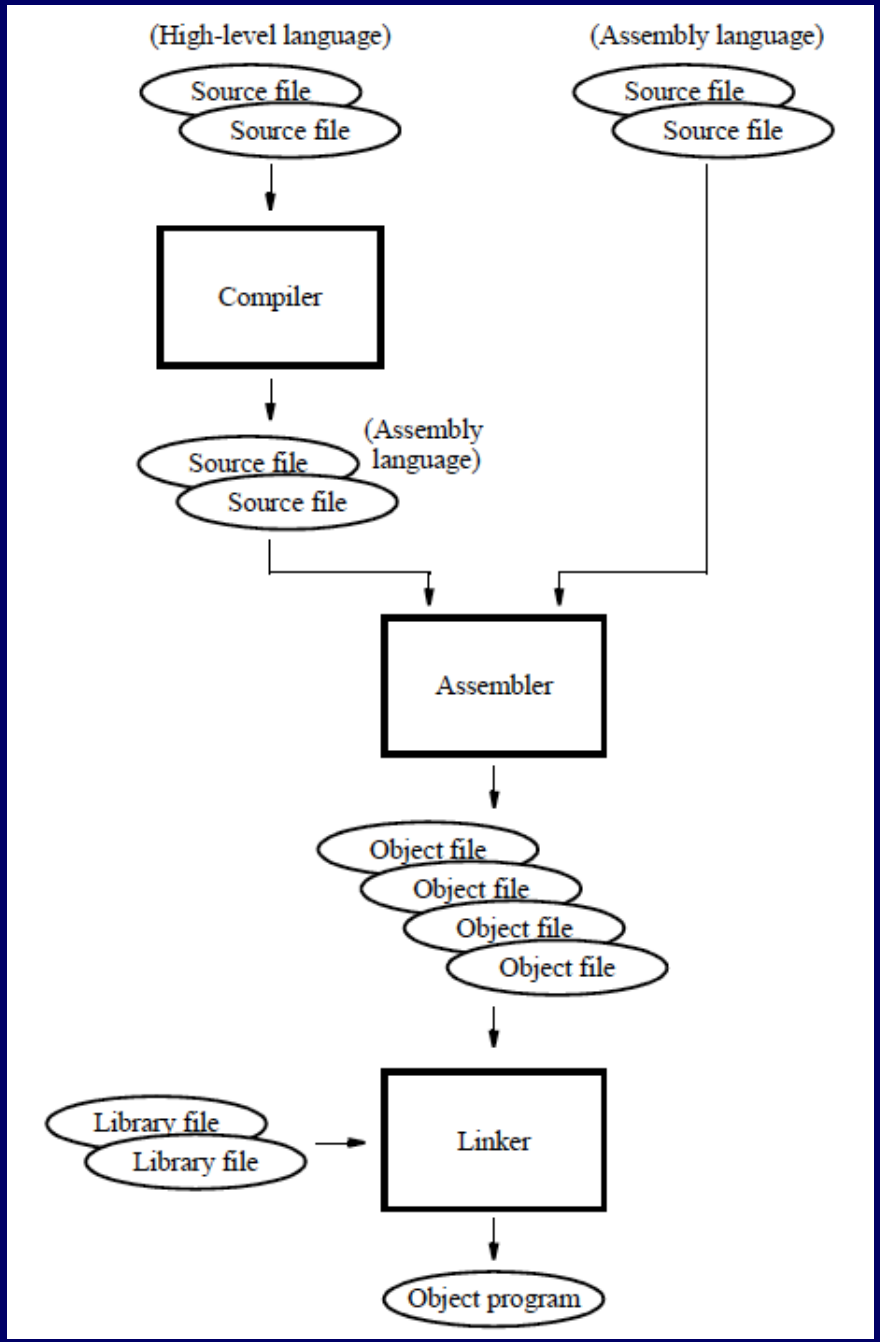
An output interface



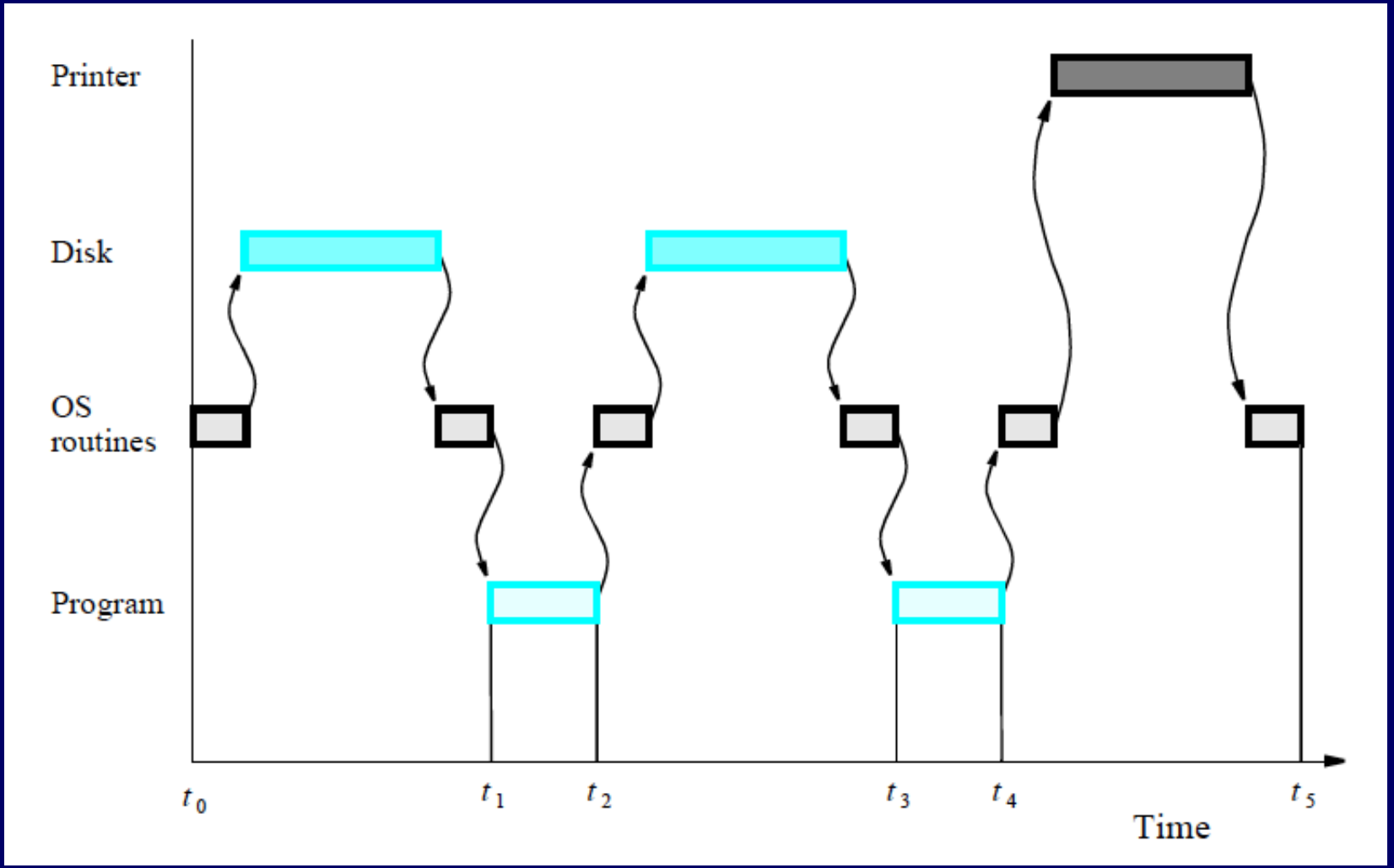
Detail


DISP_DATA
D7
D2
D1
D0
D7 Q7
D0 Q0
Data
DOUT
Handshake control
Ready
New-data
Slave-ready
1
Read-status
Write-data
R/W
Master-ready
A31
A3
A2
Address decoder
My-address

- **Generation of an object program**



Processor scheduling



IEEE/ACM Curricula

ACM	1968	CS
IEEE/ACM	1991	CS
	2001	CS
	2004	CE
	2008	CS (Update)

CC1991 - Architecture

- Digital logic
- Digital systems
- Machine-level representation of data
- Assembly-level machine organization
- Memory system organization and architecture
- Interfacing and communication
- Alternative architectures

CC2001

- Much increased emphasis on performance
  - Branch prediction, multithreading, superscaler
- Architecture for networks and distributed systems

CC2008 Update

- Multiprocessing, Instruction level parallelism:
  - Superscaler, VLIW, EPIC
    run-time vs. compile time
  - SIMD, MIMD, multithreading, multicore, GPU
- Expanded content for the I/O section, modern buses (USB, PCIe)

CC2008 -- Elective

- A new elective section: Devices
  - Transducers
  - Multimedia encoding and decoding
- More on application domains:
  - Mobile applications
  - Ubiquitous computing

CCCE 2004 Architecture and Organization

- Same basic content
- More emphasis of interfacing and processor design
- Needs updating
  - Embedded systems

Recent Books: Patt& Patel

- LC-2, later LC-3, processor has a simplified ISA, 16 instructions, 5 addressing modes
- Highly suitable for a broad introduction in a Freshman course, covering logic, programming and processor architecture

Y. Patt and S.J. Patel, "Introduction to Computing Systems: from bits & gates to C and Beyond," McGraw-Hill, 2004

Hamacher et al.

- … (basic material)
- System software
- I/O subsystem (USB, PCIe, …)
- Embedded systems
- System-on-a-chip – a case study
- Parallel processing and performance

Hamacher, Vranesic, Zaky &Manjikian, Computer Organization and Embedded Systems, 6th edition, 2011

- ISA’s of commercial computers
- Appendices
  - Logic circuits
  - The AlteraNios II processor
  - The ColdFire processor
  - The ARM processor
  - The Intel IA-32 architecture

Ramachandran& Leahy

- A course at Georgia Tech takes a very broad approach, integrating significant material on architecture, operating systems and networks

Ramachandran and Leahy, WCAE – 2007

- … (basic material)
- Operating systems
- Memory management
- File systems
- Networks and protocols

Ramachandran and Leahy, "Computer Systems, An Integrated Approach to Architecture and Operating Systems," Addison Wesley, 2011

Motivating Students

- The computer architecture course has been described as “boring” for students
- Part of the challenge is that the computer is becoming increasingly invisible
- Students are looking for:
  - Relevance
  - Value
  - Good learning experience

- What do students see?
  - Pervasive/ubiquitous/embedded computing
  - Social networking
  - Energy concerns
- Danger of fragmentation of material and creating survey-style courses
- Fundamentals must be covered in depth
- But show how architecture supports applications

Ubiquitous Computing

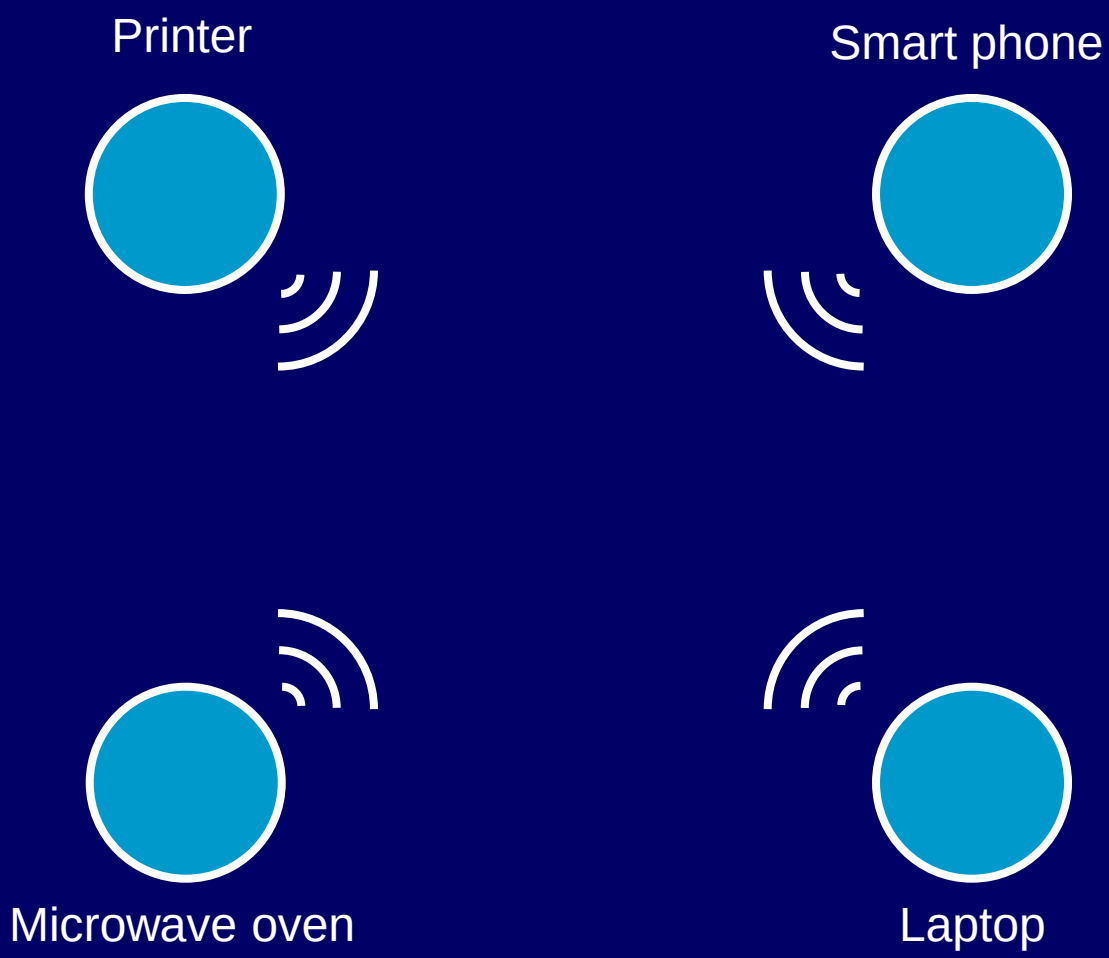
- 1991, Mark Weiser (Xerox Park):
  "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life …"
- Tabs, pads and boards
- Embedded systems

Scientific American, September 1991

Role of I/O

- Key enabling technologies are communications and input/output subsystems
- Plug and play ➔ PCI, USB
- High speed ➔ PCI express (PCIe)
- Networks ➔Protocol stack

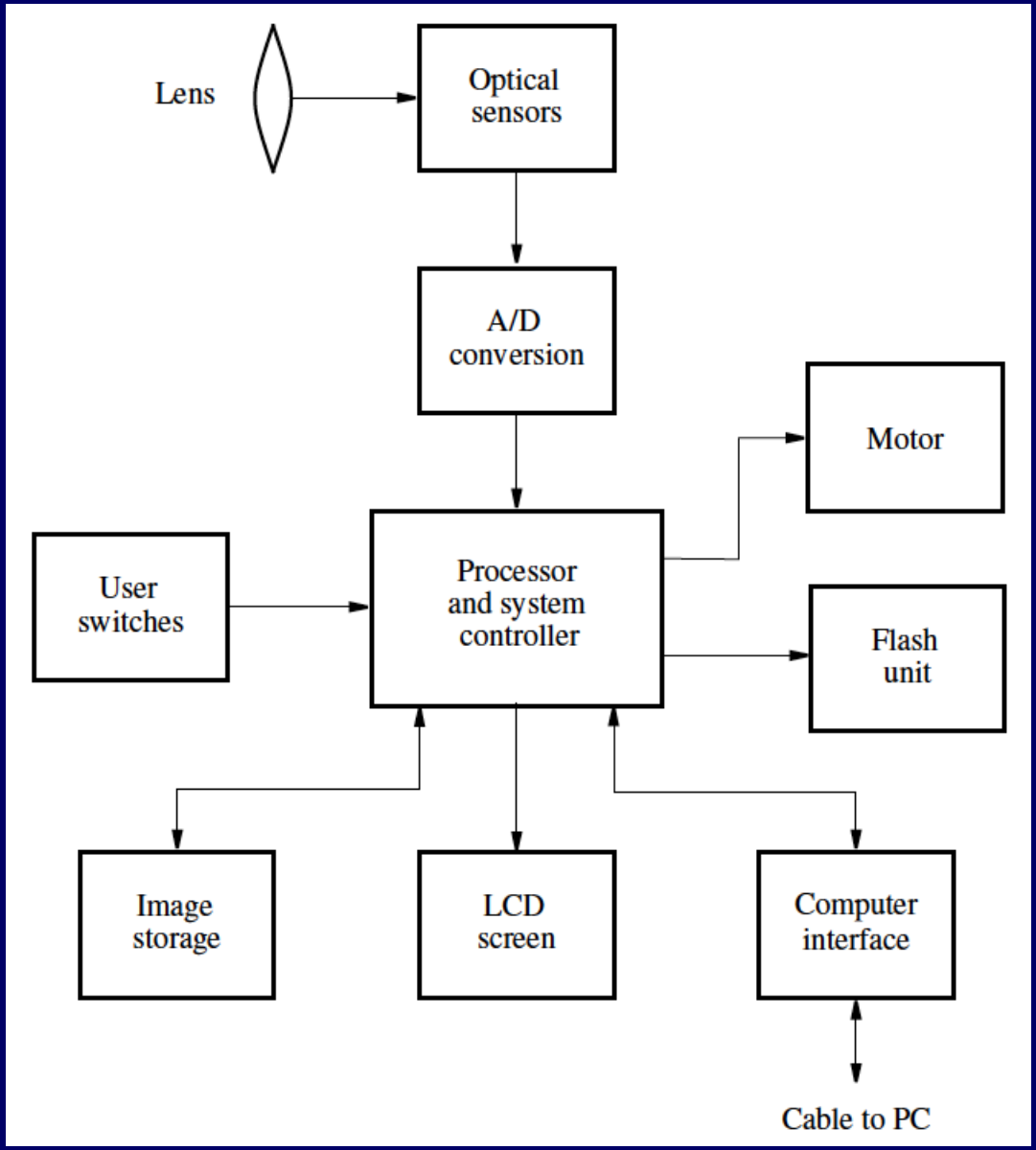
Wireless -- Bluetooth



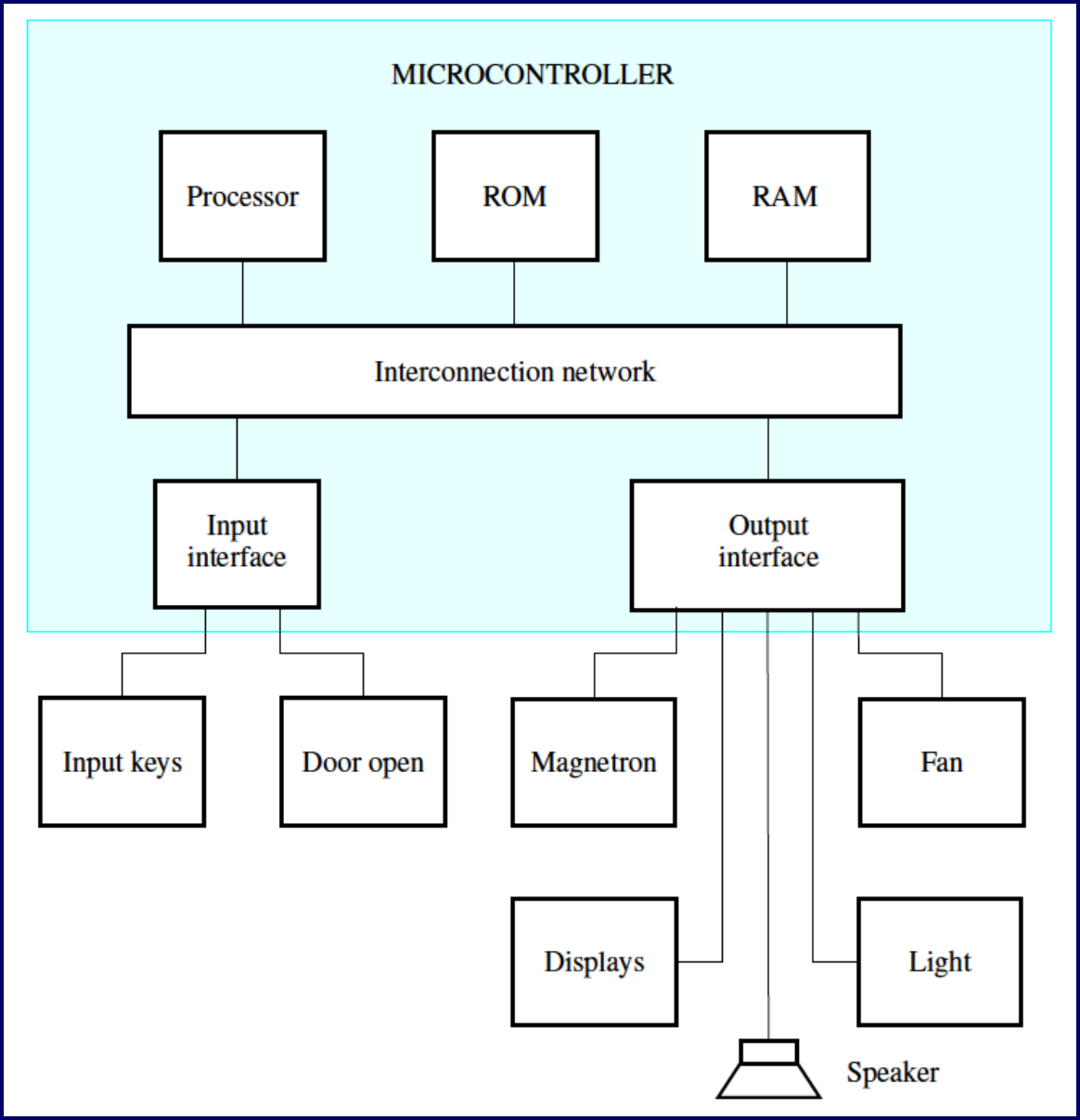
Embedded Systems

- Rapidly-expanding applications
- Many job opportunities
- CE: may emphasize interconnections, interfacing and FPGA implementations
- CS: Use of high-level languages
  Real-time software
- There are many familiar examples

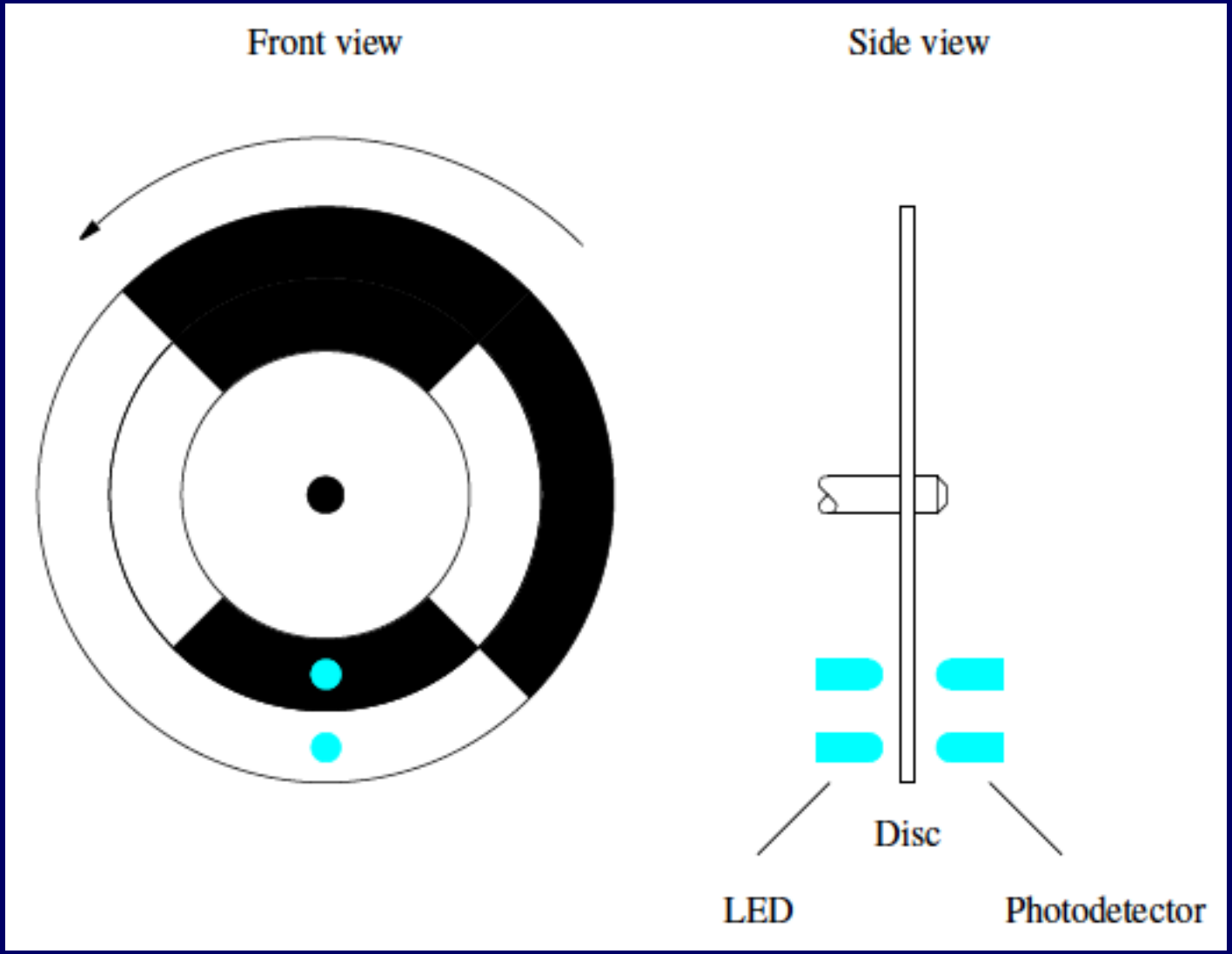
Digital camera



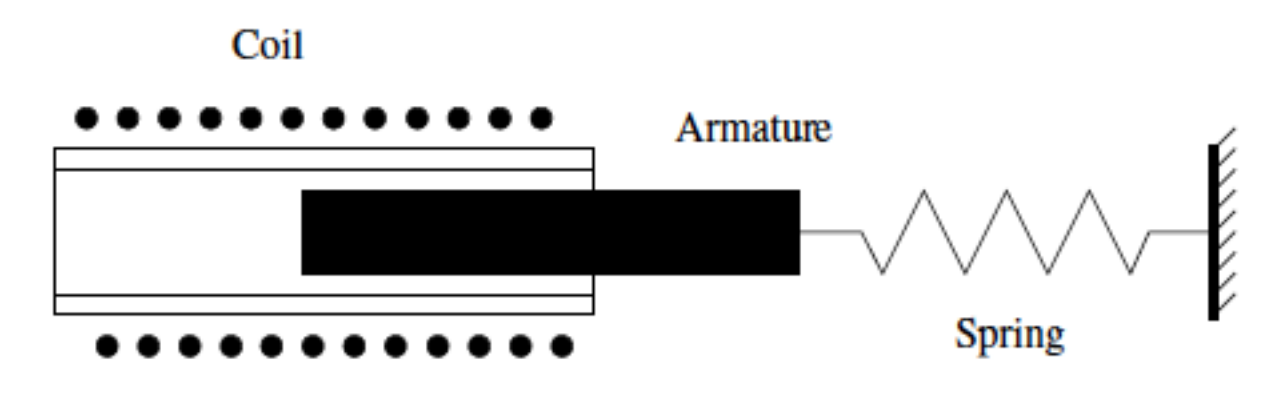
Microwave Oven



Optical position sensor



Solenoid actuator



Energy-efficient Computing

- Students are increasingly aware of the issue
  - Mobile computing
  - Conservation
- An introductory discussion would provide interest and motivation

- A good example for the benefits of multicore and many-core architectures
- Several examples in special section in Trans. Comp., Dec. 2005
- Choose topics that relate to the instructor's research

Learning experience

- Importance of laboratory
- Preferably with real hardware
- Many universities developed laboratory setups, often using FPGA's, e.g. U. of Washington

M. Holland et al, "Harnessing FPGAs for Computer Architecture Education", MSE'03

FPGA-based Setups

- FPGA manufacturers (particularly Altera and Xilinx) offer well-equipped boards, with FPGA chips, memory, displays, switches, connectors, etc., specifically for university laboratories
- Support software and documentation, including experiments

Experience at Georgia Tech

- The Systems course includes 60-90 hours of unsupervised laboratory
- Student surveys at the beginning and end of semester showed significant increase in students enthusiasm

Experience at ECE, U of T

- "*Computer Organization*" is offered in Second Year, CE and EE
- Includes a substantial laboratory component using Altera FPGA boards
- It is a key factor in attracting students to Computer Engineering

Concluding Remarks

- Computer architecture is a key course that provides a reference model, linking software and hardware
- To provide motivation and spur innovation, course should connect basic material to recent developments and exciting applications
- Today, this means emphasizing parallel processing, I/O subsystems and embedded computing

Questions/Comments