CENG 336 Introduction to Embedded Systems Development

Lecture 1: An Introduction to Computers and Embedded Systems

Course Schedule

- Lecture:
  - Section 1: Volkan Atalay Tue 10:40 BMB2 Thu 10:40,11:40 BMB1
  - Section 2: Ali Doğru Tue 10:40 BMB3 Thu 10:40,11:40 BMB2
- Lab:
  - To be announced
  - TAs:Alper Kilic akilic@ceng.metu.edu.tr, Fatih Gokce fgokce@ceng.metu.edu.tr
- Text Book
  - No Textbook
- Referece Material
  - PIC 16F87X Data sheets (http://www.microchip.com)
  - Design with PIC Microcontrollers, John B. Peatman, Prentice Hall,1998.
- Course webpage:
  - http://http://www.ceng.metu.edu.tr/courses/ceng336/

Grading Policy (tentative)

MIDTERM	QUIZES	FINAL	LAB
25%	15%	35%	35%

What is this course about?

CENG 336 Introduction to Embedded Systems Development (2-2)3

Assembly language and controller architecture. Peripheral interfaces: A/D and D/A conversion, parallel and serial ports, interrupts and timers/counters. I/O bus architectures. Sensors and actuators. Design and analysis techniques. Real time operating systems.

Prerequisite: CENG 232.

http://catalog.metu.edu.tr/ceng.php#desc

What is an embedded computer system?

- *What is a computer?*
  - [Merriam-Webster Dictionary] one that computes; *specifically* **:** a programmable electronic device that can store, retrieve, and process data.

- Classification of Computers

  – *by price and computing power*

  - Dedicated controllers – Embedded controllers
  - Personal computers
  - Mainframes
  - Supercomputers

Types of Computers

- Mainframes
  - largest and most powerful
    - massive amounts of memory
    - use large data words…64 bits or greater
    - mostly used for military defense and large business data processing
    - examples: IBM 4381, Honeywell DPS8

- Microcomputers
  - range from small controllers that work with 4 bit words to the PCs we are familiar with that work with 32 bit words
    - modern microcomputers are becoming indistinguishable from early minicomputers…functionally speaking
    - large variety of uses from specialized controls like a printer to personal publishing
    - the CPU is usually 1 Integrated Circuit (IC) called a microprocessor
    - examples: Intel 8051 controller chip, IBM PC, Apple Macintosh
- Supercomputers
  - fastest and most powerful mainframes
    - contains multiple central processors
    - used for scientific applications, and number crunching
    - now have teraflop performance

- Types of Computers
- Microcomputer Structure
- Microprocessor Evolution
- Internal Architecture
- Introduction to Programming the 8086

Microcomputer Structure

- Central Processing Unit (CPU)
- Memory
- Input/Output (I/O) circuitry
- Buses
  - Address bus
  - Data bus
  - Control bus

Memory

- A mixture of RAM and ROM…may also include magnetic hard disks and optical disks
- 2 purposes of memory
  - store the binary codes for the sequence of instructions specified by programs
  - store binary data that the computer needs to execute instructions

I/O

- the way the computer communicates with the outside world
- peripherals are connected to the I/O ports
  - printers, modems, keyboard, mouse, scanner
  - Universal Serial Bus (USB)
- ports
  - physical devices needed to interface with the computer’s internal buses
  - actually a set of D flip-flops connected in parallel
  - how do we distinguish between an input port and an output port?

CPU

- the “brains” of the computer
- its job is to fetch instructions, decode them, and then execute them
- contains:
  - an Instruction Pointer register which contains the address of the next instruction
  - general purpose registers for temporary storage
  - circuitry to generate signals to the control bus

Address bus

- consists of 16,20, 24, or 32 parallel signal lines (wires)
  - these lines contain the address of the memory location to read or written
  - just how many unique addresses can an address bus specify?

Data bus

- consists of 8,16, or 32 parallel signal lines
  - these are bi-directional… meaning that data can be read from/written to either memory or a port
  - only one device at a time can have its outputs enabled, even though many will have their outputs connected to the same data bus
    - this requires the devices to have three-state output

Control bus

- consists of 4 to 10 parallel signal lines
- CPU sends signals along these lines to memory and to I/O ports
  - examples: Memory Read, Memory Write, I/O Read, I/O Write

Typical CPU Behavior

Goal:

- Read a word of data from a memory location

Process:

- CPU first sends out the address along the address bus to the memory device
- CPU then sends the Memory Read signal along the control bus
- the output from the memory device travels back to the CPU along the data bus

- Types of Computers
- Microcomputer Structure
- Microprocessor Evolution
- Internal Architecture
- Introduction to Programming the 8086

history

Microprocessor Evolution

- microcomputers are commonly categorized by the number of bits that their ALU can work with at a time
  - regardless of the number of address lines or data lines
    - the first commercial microprocessor was the Intel 4004…a 4-bit device combined with other devices to make a calculator
    - next came the Intel 8008…an 8-bit device, but it required many additional devices to be a functional CPU
    - Intel 8080…another 8-bit device, but it only required 2 additional devices
      - it also used different transistors making it much faster, and started the *2nd generation* of microprocessors
      - then Motorola entered the market with the MC6800

Directions taken by Microprocessors

- Embedded controllers
  - used to control smart machines
  - printers, auto braking systems
  - also called microcontrollers
- Bit-slice processors
  - custom-designed hardware and custom-designed instruction set made by connecting devices…each part becomes a slice needed for a specific application
  - these were created because general-purpose CPUs were not fast enough or did not have a rich enough instruction set

General Purpose CPUs

- Intel released the 8086, a 16-bit microprocessor, in 1978
- Motorola followed with the MC68000 as their 16-bit processor
- the 16-bit processor works with 16 bit words, rather than 8 bit words…
  - instructions are executed faster
  - provide single instructions for more complex instructions…multiply and divide

32 bit Processors

- 16 bit processors evolved into 32 bit processors
  - now able to work with gigabytes (10^9 bytes) and terabytes (10^{12} bytes)
  - Intel released the 80386
  - Motorola released the MC68020

The 8086 Microprocessor Family

- Characteristics
  - 16 bit microprocessor
  - 16 bit data bus
    - it can read from or write to memory and I/O ports either 8 or 16 bits at a time
  - 20 bit address bus
    - it can address 2^{20} memory locations
      - each location is 1 byte (8 bits) wide, thus 16 bit words will require consecutive memory locations

Members of this family

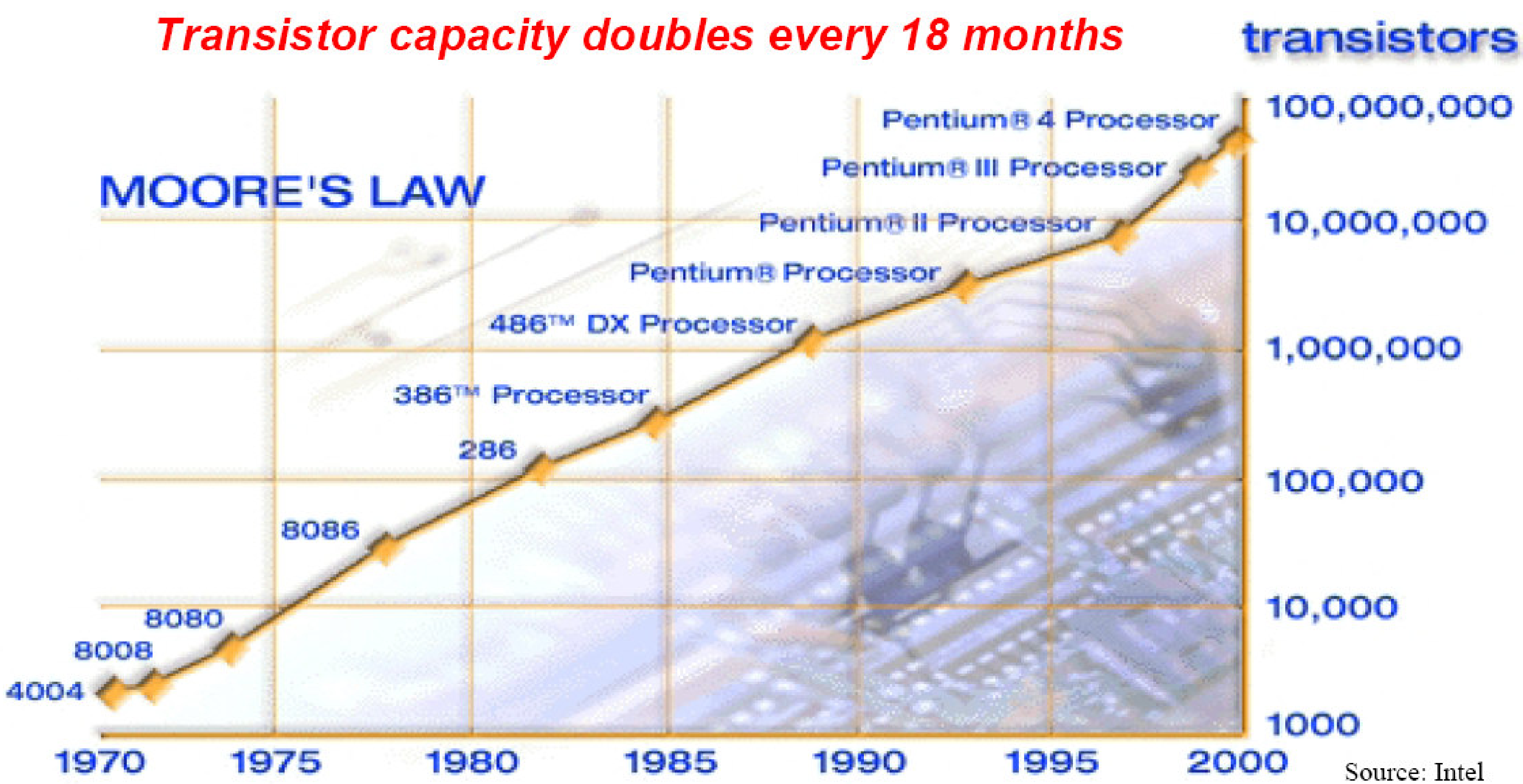
- 8088
  - same as 8086 but has an 8 bit data bus
- 80186/80188
  - enhanced instruction set…but still backwards compatible
- 80286
  - designed for a multi-user, multi-tasking microcomputer
  - users a virtual address mode to prevent collision of users' programs
- 80386/80486
  - first Intel 32 bit processor
  - can directly address up to 4 GB of memory

Intel 80x86

Story of the Humble Transistor

- 1947 – Shockley, Brattain, and Bardeen invented the transistor at Bell Labs
- 1961 – First commercial IC by Fairchild/TI
- 1963 – CMOS invented
- 1965 – Moore's law
- 1968 – State of the art: 64 transistor chip
- 1978 – IA 8086: ~10K transistors
- 1986 – IA 386: ~100K transistors
- 1990 – IA 486: ~1 M transistors
- 1998 – IA P2: ~ 10 M transistors
- 2004 – IA P6: ~ 1 B transistors

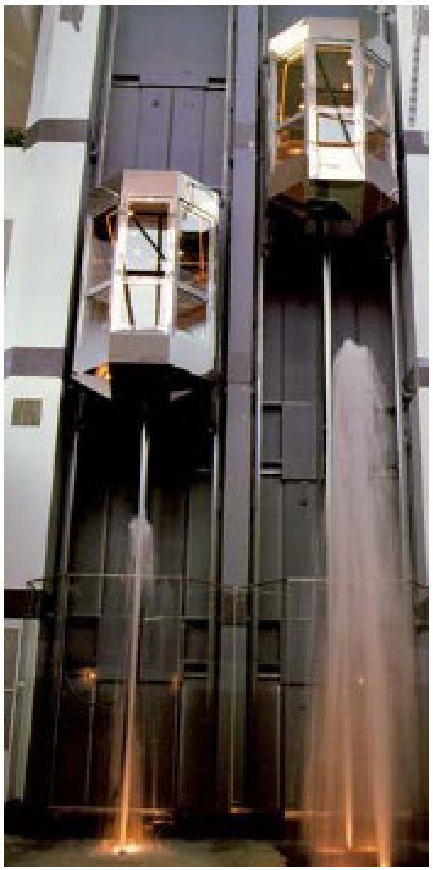
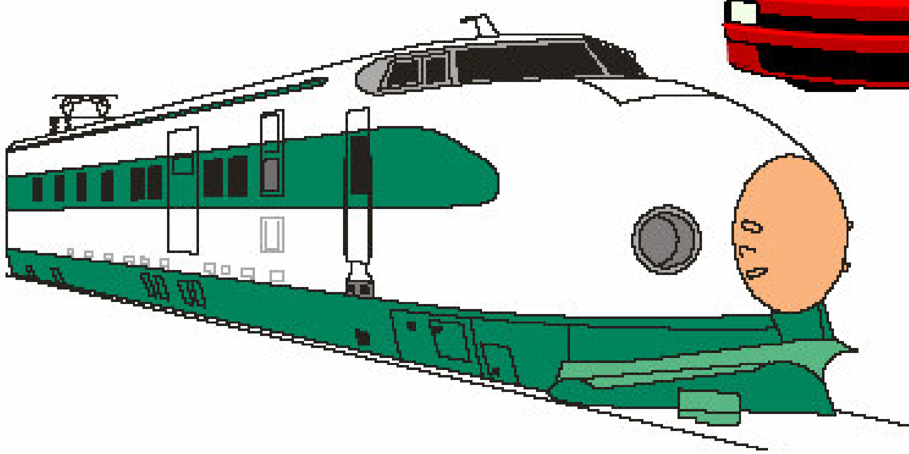
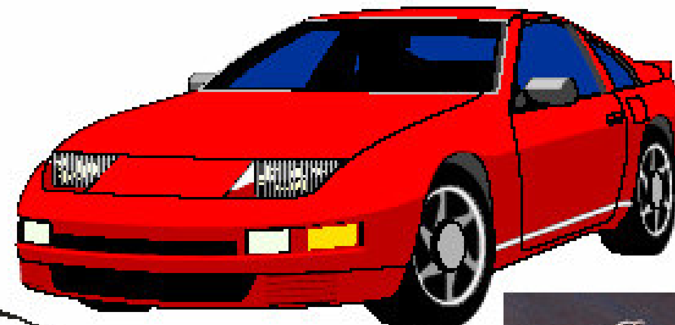
Moore's Law



Source: Intel



Embedded System =
Computers Inside a Product


Definition

- Embedded system: any device that includes a programmable computer but is not itself a general-purpose computer.
- Computer purchased as part of some other piece of equipment
  - Typically dedicated software (may be user- customizable)
  - Often replaces previously electromechanical components
  - Often no "real" keyboard
  - Often limited display or no general- purpose display device: don't need all the general-purpose bells and whistles.

Embedded systems: Applications

- Consumer segment, e.g. cameras, camcorders, VCRs, washers, microwave ovens, …
- Automobiles, e.g., engine control, anti-lock brake, air bags, …
- Office automation, e.g., copiers, printers, FAX machines, …
- Telecommunications, e.g.,, cellular phones, PDAs, interactive game boxes, answering machines, …
- Other industrial products, e.g., door locks in hotel rooms, automatic faucets, …

Embedded Systems: Typical Characteristics

- Perform a single or tightly knit set of functions (not usually "general purpose")
- Is part of a larger system that may not be a "computer"
- Works in a reactive and time-constrained environment
- Employs a combination of hardware & Software
  - Software provides features and flexibility
  - Hardware provides performance (Application specific processor design)

What makes an embedded system unique? – Hardware perspective

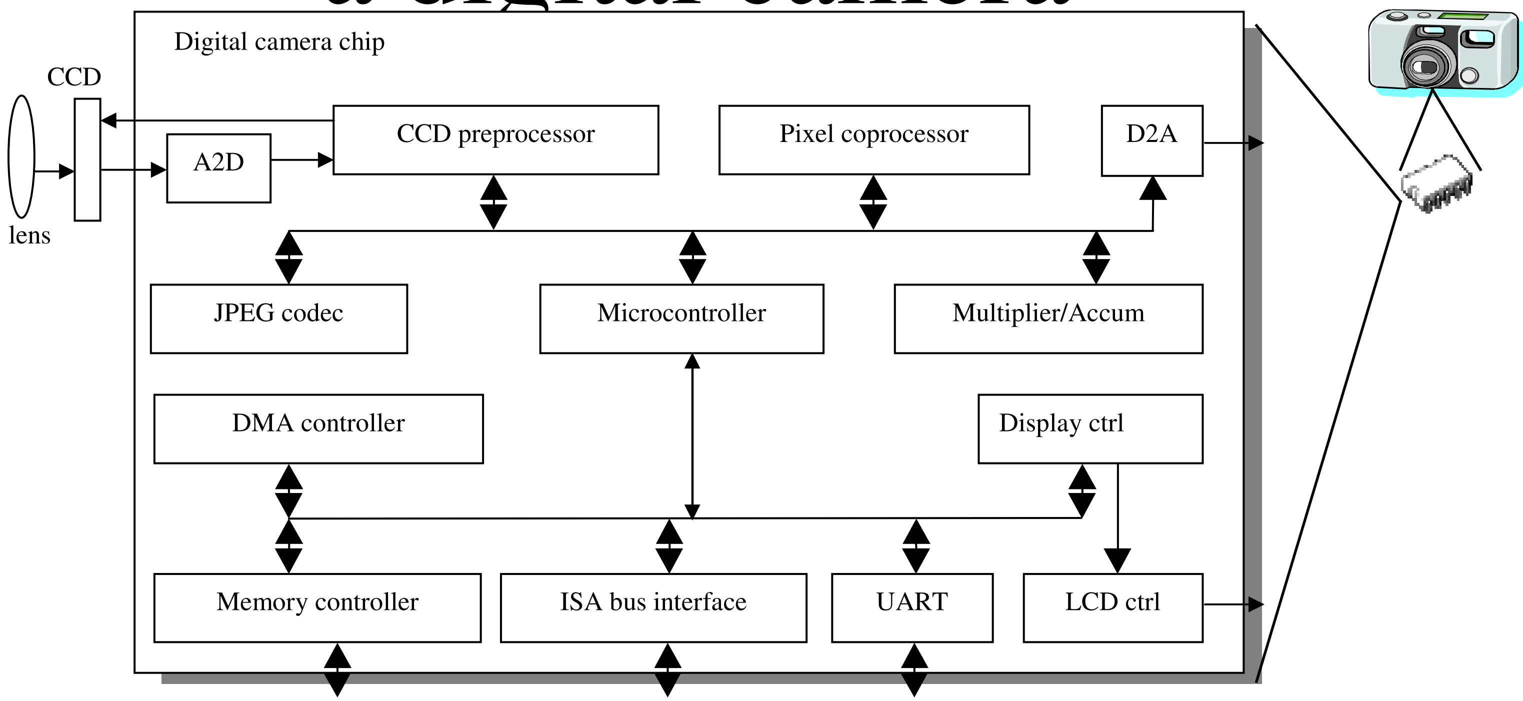
- Microprocessor technology
  - Personal computers
    - Pentium Chips, Power-PC chips
    - General purpose computers, raw computing power
    - 75 million units per year
  - Embedded controllers
    - Special purpose microcontrollers
    - 2.5 billion units per year, 30 times larger in unit volume

- GartnerGroupestimates 70 Billion μP used in embedded systems in 2001
- Other estimates say 50 to 120 Billion μP
- Average embedded system has 4 μP
- Of all μP sold, 90% go into "non-computers", 10% in "computers"
- You will most likely end up working with a "non-computer"at some point in your career

What makes an embedded system unique? – Software perspective

- No operating systems
- Execute a single program, tailored exactly to the controller hardware
- Assembly language (vs. High-level language)
  - Not transportable, machine specific
  - Programmer need to know CPU architecture
  - Speed
  - Program size
  - Uniqueness

An embedded system example -- a digital camera

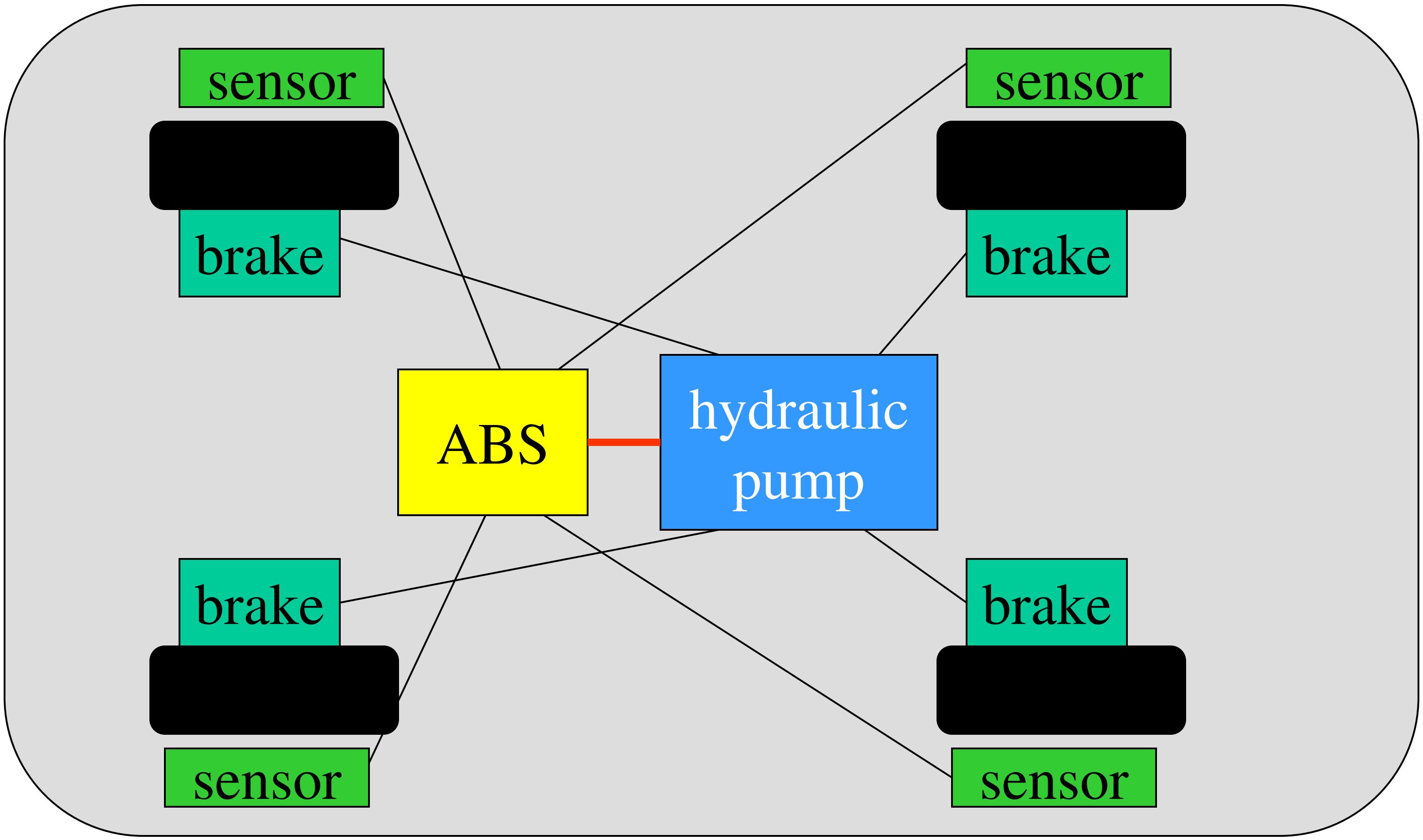


- Single-functioned -- always a digital camera
- Tightly-constrained -- Low cost, low power, small, fast
- Reactive and real-time -- only to a small extent

BMW 850i brake and stability control system

- Anti-lock brake system (ABS): pumps brakes to reduce skidding.
- Automatic stability control (ASC+T): controls engine to improve stability.
- ABS and ASC+T communicate.
  - ABS was introduced first---needed to interface to existing ABS module.

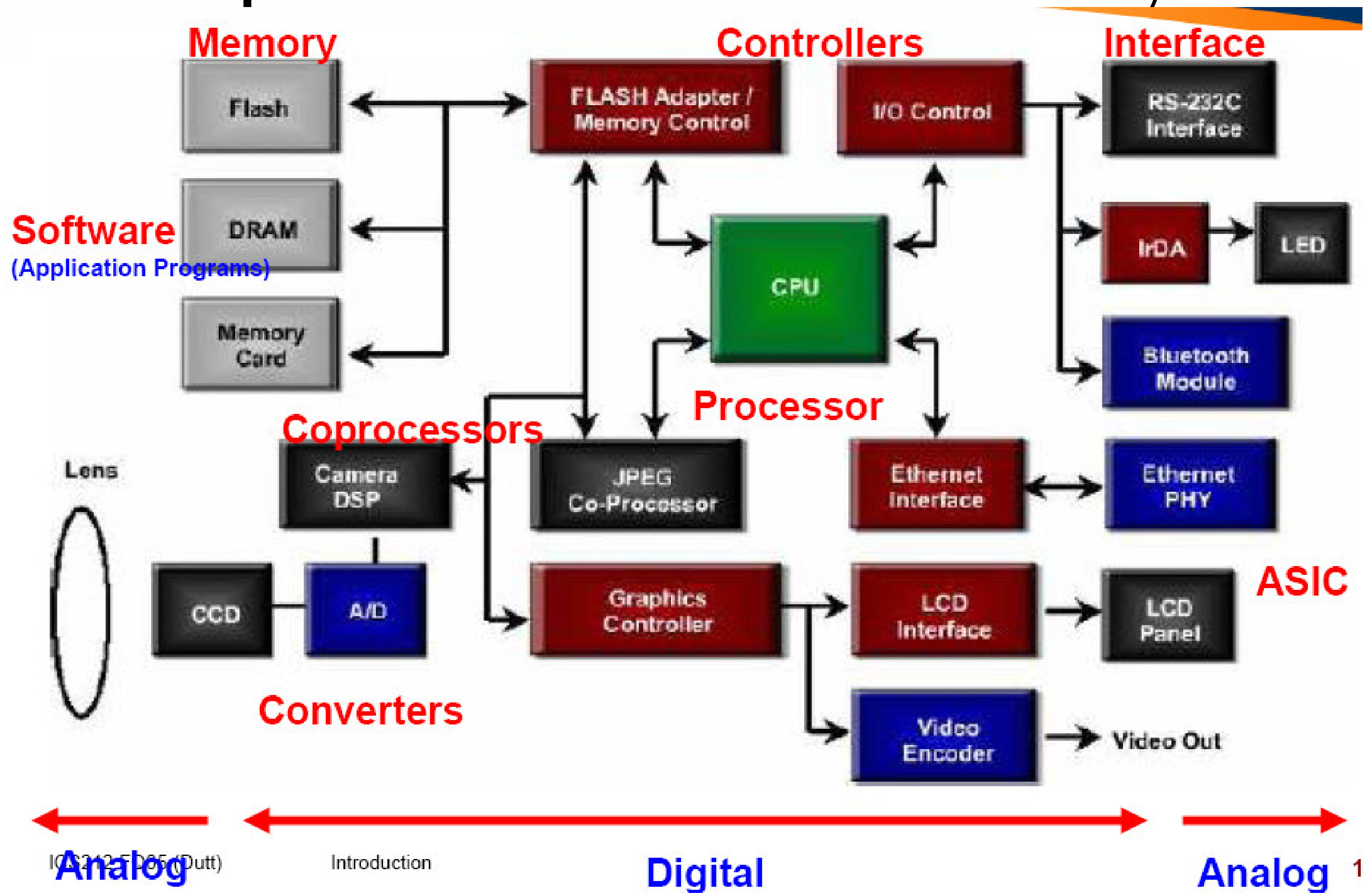
BMW 850i, cont'd.



Example: BMW 745i

- 2, 000, 000 LOC
- Windows CE OS
- 53 8-bit μP
- 11 32-bit μP
- 7 16-bit μP
- Multiple Networks
- Buggy!

Components of Embedded Systems



- Analog Components
- Sensors, Actuators, Controllers, …
- Digital Components
- Processor, Coprocessors
- Memories
- Controllers, Buses
- Application Specific Integrated Circuits (ASIC)
- Converters –A2D, D2A, …
- Software
- Application Programs
- Exception Handlers

Characteristics

- **Application Specific**
  - Applications are known a priori
  - Optimize for cost, area, power, and performance
- **Digital Signal Processing**
  - Signals are represented digitally
- **Reactive**
  - Reacts to changes in the system's environment
- **Real-time**
  - Compute certain tasks before deadline
- **Distributed, Networked, …**

- **Reliability**
  - Probability of system working correctly provided that is was working at t=0
- **Maintainability**
  - Probability of system working correctly $d$time units after error occurred.
- **Safety**
  - Not harmful for user
- **Security**
  - Confidential and authentic communication

Traditional Design Challenges

- **Low cost**
- **Light weight**
- **Reliability**
- **Low power**
- **Portable**
- **Complexity**
- **Ease of use**

- **Mixed digital/analog requirements**
- **Shrinking time-to-market**
- **Short product lifetime**
- **Real-time processing**
- **Inherent concurrency**
- **HW/SW co-design**

Recent Design Challenges

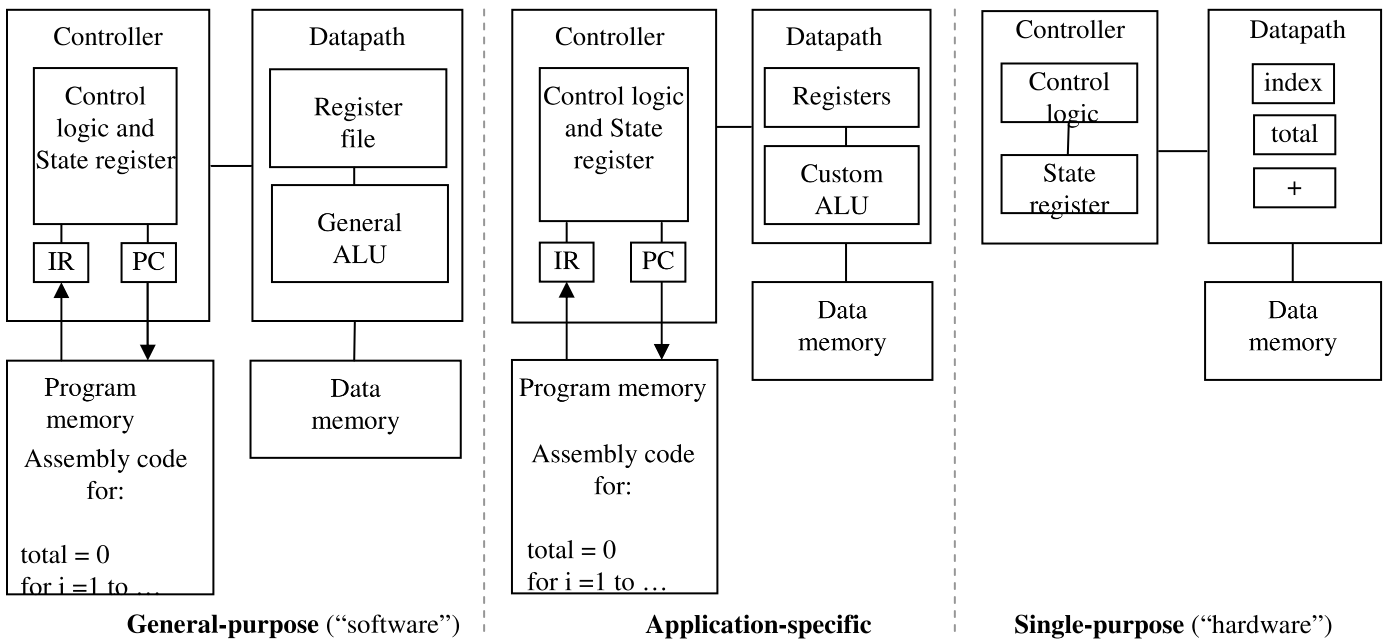
- **Design Complexity**
- **Ultra low power**
  - Highly adaptive
  - Active power management (voltage scaling, etc.)
  - Alternative energy source (scavenge, solar, etc.)

- **Internet aware**
  - Incorporate RF technologies
  - Networking capabilities

- **Verification**
- **Security**

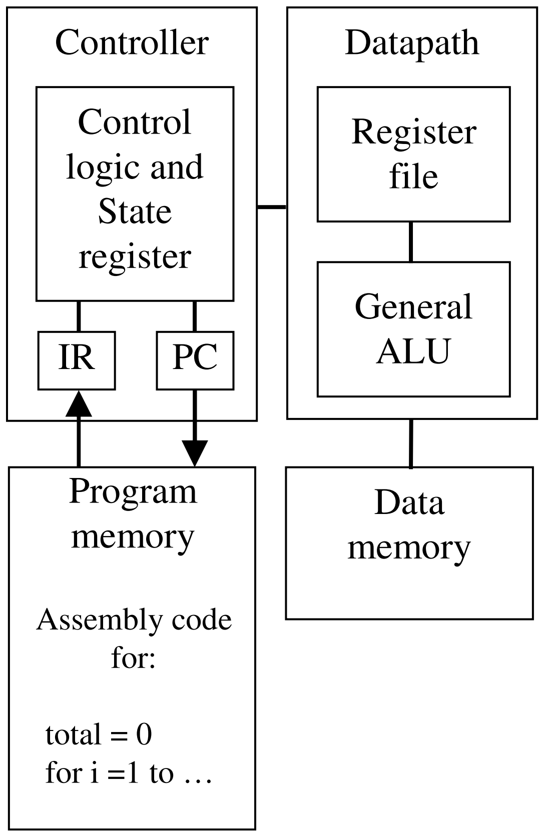
Processor technology

- The architecture of the computation engine used to implement a system's desired functionality
- Processor does not have to be programmable
  - "Processor" *not* equal to general-purpose processor



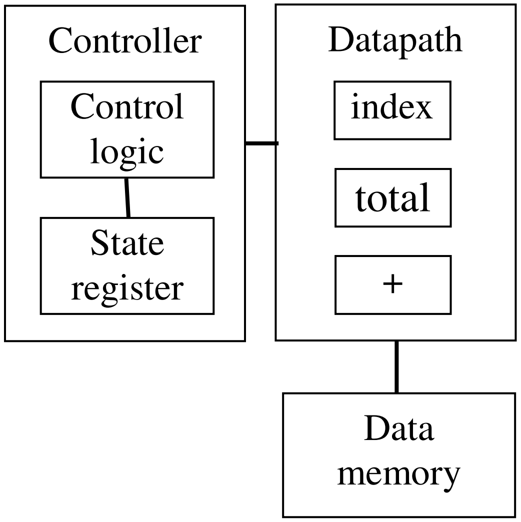
General-purpose processors

- Programmable device used in a variety of applications
  - Also known as "microprocessor"
- Features
  - Program memory
  - General datapath with large register file and general ALU
- User benefits
  - Low time-to-market and NRE costs
  - High flexibility
- "Pentium" the most well-known, but there are hundreds of others



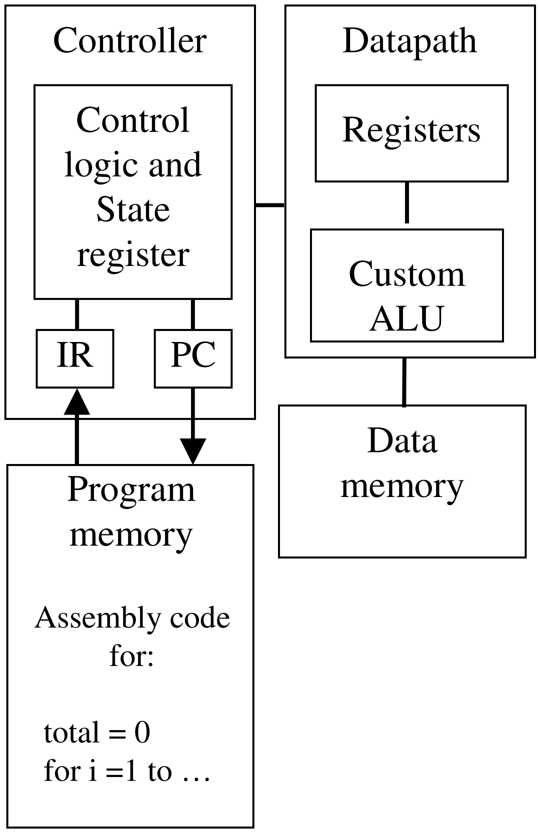
Single-purpose processors

- Digital circuit designed to execute exactly one program
  - a.k.a. coprocessor, accelerator or peripheral
- Features
  - Contains only the components needed to execute a single program
  - No program memory
- Benefits
  - Fast
  - Low power
  - Small size



Application-specific processors

- Programmable processor optimized for a particular class of applications having common characteristics
  - Compromise between general-purpose and single-purpose processors
- Features
  - Program memory
  - Optimized datapath
  - Special functional units
- Benefits
  - Some flexibility, good performance, size and power



- Applications