Microprocessors, Microcontrollers & Digital Signal Processors

ECE 153B
Sensor & Peripheral Interface Design
Winter 2016
Intel 4004/ 8008

- 4004 introduced in 1971
  - First microprocessor
    - All CPU components on a single chip
    - 2,300 transistors @ 10µm; 108 KHz clock
  - Four bit data path
    - Particularly suitable for BCD arithmetic (i.e., calculators)
    - Too narrow for general purpose processing

- 8008 introduced in April 1972
  - Eight bit version of 4004
  - 3,500 transistors @ 10µm; 800 KHz clock
  - Architecture based on Datapoint 2200 processor

- Both 4004 and 8008 were dedicated (vs. general purpose) processors
Intel 8080

- 8080 was first general purpose microprocessor
  - Introduced in April 1974
  - 4,500 transistors @ 6\(\mu\)m; 2MHz clock
  - Superset of 8008 instruction set

- Basis for first personal/microcomputers
  - MITS Altair 8800
  - Single chip CPU, general purpose computer

- Required +5V, -5V and +12V supplies as well as two phase clock generation
Motorola 6800

- Introduced in August 1974
  - 4,100 transistors @ 6µm; 1 MHz clock

- Architecture influenced by DEC PDP-11
  - Relatively symmetric instruction set
  - Programmer’s model much “cleaner” than 8080
    - Compilers generally not available at this point for microprocessors
  - No I/O instructions (unlike 8080)
    - Utilized memory mapped I/O

- Very popular processor in computer peripherals and test equipment
Rockwell/ MOS Technology 6502

- Introduced in November 1974
  - Architecture similar to Motorola 6800
  - 3,510 transistors @ 8µm; 1 MHz clock

- Inexpensive and functionally as powerful as Intel 8080 and Motorola 6800
  - Roughly one sixth the cost

- Used in the Apple I & II, IIe and IIc
  - Also Atari game console/computer and Commodore PET/64 computer
Zilog Z80

- Zilog
  - “The last word (Z) in Integrated LOGic (ILOG)”

- Z80 introduced in July 1976
  - 8,500 transistors @ 4 µm

- Bit (software) compatible with 8080

- Many hardware improvements over 8080
  - Two register files for efficient context switching
  - Single 5V supply (available on 8085)
  - Single phase 5V clock (available on 8085)
  - Integrated DRAM refresh
Zilog Z80

- Hugely successful microprocessor for both general purpose and control applications
  - Dual register files allowed for efficient handling of interrupts for control applications

- The Z80 and the 6502 dominated the early years of the home/personal computer industry
  - Z80 used most notably in the Osborne I (the first portable PC) and the Radio Shack TRS80

  - The “Osborne Effect”
    - The Osborne Effect states that prematurely discussing future, unavailable products damages sales of existing products

  - The “Trash 80”
    - Total lack of respect for all things Radio Shack
Intel 8085

- 8085 was a hardware extension of 8080
  - Introduced in 1977
  - 6,500 transistors @ 3 μm; 5 MHz clock

- 5V only operation

- Integrated clock generator
  - Only external crystal required

- Long product life as a controller

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Intel 8088/ 8086

- Intel’s first 16 bit processors

8086 introduced in 1978
- 29,000 transistors @ 3μm; 5 MHz clock
- 16 bit internal/external data bus

8088 introduced in June 1979
- 29,000 transistors @ 3μm; 5 MHz clock
- 16 bit internal data bus, 8 bit external data bus
  - Allows for lower cost board implementation and peripheral interface
- Used in the IBM PC
Motorola 68000

- 16/32 bit processor introduced in September 1979
  - 16 bit external interface
  - 32 bit macroinstructions and register file
  - Forward compatible with “true” 32 bit processors
    - But not backward compatible with 6800

- 40,000 transistors @ 3.5 μm; 1 MHz clock (original version)
  - Viable architecture for nearly 30 years

- Used in Apple Lisa & Macintosh (among others)

- Dominant processor in UNIX based workstation market (Sun & Apollo)
Microcontrollers

- All of the processors discussed so far were designed for general purpose (computer) applications
  - All fit the definition of a “microprocessor”
    - CPU on a single chip

- For a microprocessor to be used in control applications, additional components are required (beyond memory)
  - Parallel ports
  - UARTs
  - Timers
  - Memory controllers (DRAM, DMA, etc.)
  - LCD controllers
  - CRT controllers
  - etc., etc., etc…
Microcontrollers

- As the number of available transistors increases, the external components required to utilize a microprocessor in a control application can be incorporated with the CPU on a single chip.

- This is, by definition, a microcontroller.

- The first microcontrollers came into prominence in the 1980’s.

- In the case of general purpose microprocessors, this additional density is utilized to more effectively support operating systems and program execution.
  - By example, the x86 and Pentium implementations.
Microcontrollers

- Microcontrollers are most often used in embedded systems
  - Embedded systems are special purpose applications
    - Appliances, automotive applications, implantable medical devices, musical instruments, robotics, toys, etc.
    - All under the heading of “Computers as Components”
  - Terms embedded processor and microcontroller often used interchangeably
  - Critical issues are power, speed, package, and cost
    - Not necessarily in that order
The First Microcontrollers

- Texas Instruments TMS 1000
  - Introduced (commercially) in 1974
  - Included CPU, ROM, RAM and clock on a single chip
  - In reality, it was a calculator chip and not a general purpose microcontroller

- Intel 8048
  - Introduced in 1977
  - Included CPU, ROM and RAM
  - In reality, it was a PC keyboard controller and not a general purpose microcontroller
Early 8 bit Microcontrollers

- **Zilog Z8**
  - Introduced in 1979
  - Integrated clock oscillator
  - Two timers/counters
  - Serial line (UART)
  - 32 I/O lines (4 ports)
  - Harvard architecture
    - Separate data and program memory spaces
  - Internal program memory ranges from 0 KB to 4 KB
    - Can be expanded up to 64 KB of program memory using external ROM
  - 144 8-bit registers - 4 I/O registers, 16 control registers and 124 general registers
Early 8 bit Microcontrollers

- Intel 8051
  - Introduced in 1981
    - Implementations exist today as stand alone chips from multiple sources as well as cores (intellectual property)
  - Dual 16 bit address bus
    - It can access $2 \times 2^{16}$ memory locations – 64 KB each of RAM and ROM
  - 128 bytes of on chip RAM
  - 4 KB of on chip ROM
  - Four 8 bit bidirectional input/output ports
  - UART (serial port)
  - Two 16 bit counter/timers
Early 8 bit Microcontrollers

- Microchip Technology PIC 16X
  - Originally developed as “Peripheral Interface Controller” for General Instruments CP1600 microprocessor in 1975
  - General Instruments spun off its microelectronics division in 1985 and PIC became the flagship architecture and a registered trademark of Microchip Technology
  - Today there are literally thousands of PIC based microcontrollers
    - Range from 6 pins to 100’s of pins
  - Any discussion of a microcontroller based (embedded system) design will include a Microchip Technology PIC at some point
Intel 80186/ 80286/ 80386/ 80486

- 80186 introduced in May 1979
  - 55,000 transistors @ 3µm
  - Not a very successful product

- 80286 introduced in May 1982
  - 134,000 transistors @ 1.5µm; 6 MHz clock
  - 16 bit data path

- 80386 introduced in October 1985
  - 275,000 transistors @ 1.5µm; 16 MHz clock
  - 32 bit data path
  - First processor packaged in Pin Grid Array (PGA)

- 80486 introduced in April 1989
  - 1,200,000 transistors @ 1µm; 25 MHz clock
  - On board floating point unit as opposed to “coprocessor”
Digital Signal Processors

- Architecture optimized for signal processing applications
  - Large number of mathematical operations on a series of data samples
- Hardware implementation of Multiply/Accumulate function
  - Critical for FFT type applications
The First DSP

- The Texas Instruments TMS 5100
  - Introduced in 1978 as the Digital Signal Processor embedded in the TI “Speak and Spell”
  - Also first to utilize Linear Predictive Coding (LPC) in speech synthesis
  - Not general purpose, but got the DSP ball rolling
Texas Instruments TMS32010

- Introduced in April 1983
  - Not the first DSP per se, but ultimately defined the structure of a general purpose DSP
  - Basis of phenomenally successful family of DSP’s establishing TI as the industry leader
- 58,000 transistors @ 3µm; 20 MHz clock
- Harvard Architecture
  - Separate program and data memories
  - Similar to microcontroller architectures
- Fast Multiply/Accumulate instruction
- Not byte addressable
  - Operation on data samples, not ASCII characters
Modern DSPs

- Both fixed and floating point processors
- Highly irregular instruction sets as compared to general purpose microprocessors
- SIMD (Single Instruction, Multiple Data) instructions
  - Vectored instructions
- VLIW (Very Long Instruction Word) format
  - Instruction level parallelism
- Extensive use of DMA
  - No virtual memory due to latency of context switching
- Pipelined Architecture
- Highly parallel Multiply/Accumulate (MAC) modules
  - Direct support for matrix operations such as convolution, dot product and polynomial evaluation
The 1990’s and the Intel Pentium

- Pentium introduced March 1993
  - 3,100,000 transistors @ 0.8 µm; 66 MHz clock
  - Named vs. Numbered due to AMD litigation
    - You can trademark a name but not a number

- Pentium Pro introduced in November 1995
  - 5,500,000 transistors @ 0.6 µm; 200 MHz clock

- Pentium II introduced in May 1997
  - 7,500,000 transistors @ 0.25 µm; 300 MHz clock

- Pentium III introduced in 1999
  - 9,500,000 transistors @ 0.18 µm; 500 MHz clock

- Pentium 4 introduced in 2000
  - 42,000,000 transistors @ 0.18 µm; 1.5 GHz clock
CPU Transistor Counts 1971-2008 & Moore’s Law

Curve shows ‘Moore’s Law’: transistor count doubling every two years.

Transistor count

Date of introduction

State of the Art (2012)

- **CPU**
  - Intel 62 core Xeon Phi (2012)
  - 5,000,000,000 transistors
  - 22 nm (0.022 µm) technology

- **FPGA**
  - XILINX Virtex-7 (2011)
  - 6,800,000,000 transistors
  - 28 nm technology (0.028 µm) technology

- **Recall Intel 4004 technology (1971)**
  - 2,300 transistors
  - 10 µm technology
Modern Microcontrollers

- Thousands of variants from dozens of vendors
  - Power, performance, package, peripherals and cost

- All include
  - CPU
    - ranging from small and simple 4-bit processors to complex 32- or 64-bit processors
  - Volatile memory (RAM/register file) for data storage
  - Nonvolatile memory for program and operating parameter storage
    - Most often Flash in modern microcontrollers
    - ROM, PROM, EPROM, EEPROM in older chips
  - “Simple” serial input/output ports (UARTs)
  - Clock generator
    - An oscillator for use with a quartz crystal
    - And/or an internal RC circuit
Modern Microcontrollers

- Most include some combination of other serial communications interfaces
  - Inter Integrated Circuit (I²C)
    - Low speed peripherals
  - Serial Peripheral Interface (SPI)
    - Medium speed full duplex serial interface
  - Synchronous Serial Port (SSP/SPI)
  - Controller Area Network (CAN)
    - Automotive standard
  - Integrated Interchip Sound (I²S)
    - Serial bus standard for connecting digital audio devices
  - Ethernet
  - Universal Serial Bus (USB)
Modern Microcontrollers

- And other peripherals such as
  - General Purpose I/O pins & ports
  - LCD Controllers
  - Real Time Clock
  - SD/MMC
    - Memory card controller
  - Timers, event counters, etc.
  - PWM generators
    - Pulse Width Modulation for motor control
  - Analog to Digital Converters (ADC)
  - Digital to Analog Converters (DAC)