Lecture 1

CME331: Microprocessor

Microprocessor: Introductory Concepts

KHAN WAHID
2013-14 (Term 1)

UNIVERSITY OF SASKATCHEWAN
College of Engineering

Microprocessor-based Embedded System

- What is an embedded system?
  - The definition is simple!
  - An engineering product that needs control, and if a computer/processing engine is incorporated to undertake the control, is known as ***embedded system***
  - ***"A system whose principal function is not computational, but which is controlled by a computer embedded within it."***

Source: Designing Embedded Systems with PIC Microcontrollers: Principles and Applications, Tim Wilmshurt, 2007, ISBN: 978-0750667555

  - Most embedded systems do not have keyboard, monitor (display), and/or extra memory (hard disk)
    - These days embedded systems are everywhere, appearing in the home, office, factory, car, hospital, etc.

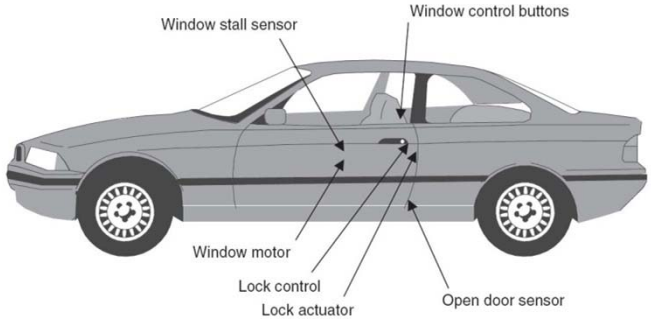
Source: Designing Embedded Systems with PIC Microcontrollers: Principles and Applications, Tim Wilmshurt

Microprocessor-based Embedded System

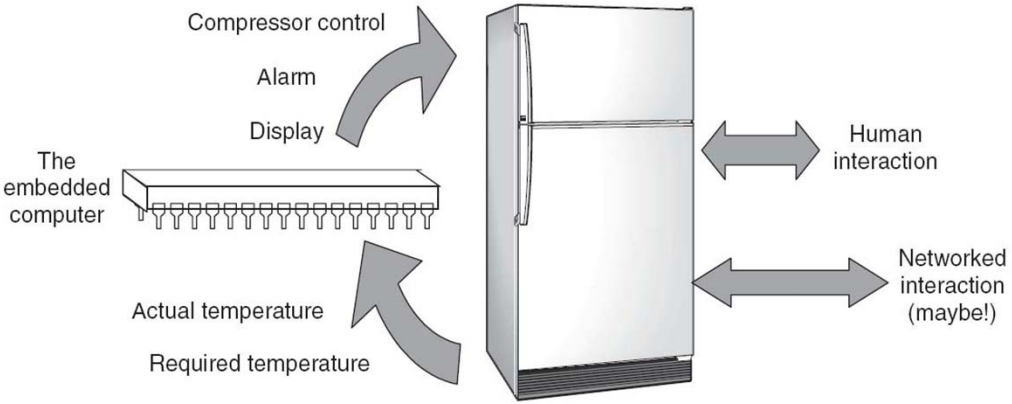
- Examples of embedded system:

Table 1.1 Some familiar examples of embedded systems

Home	Office and commerce	Motor car
Washing machine	Photocopier	Door mechanism
Fridge	Checkout machine	Climate control
Burglar alarm	Printer	Brakes
Microwave	Scanner	Engine control
Central heating controller		In-car entertainment
Toys and games		



Embedded system example 2: the car door



Embedded system example 1: the refrigerator

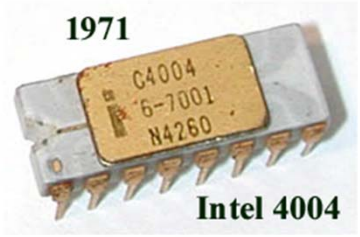
For more examples, see p.52 in vol.1

Types of Embedded Systems

- Microprocessor based embedded systems
  - Software is developed using assembly, C, etc.
    - No operating system
    - Low-cost, low-performance (uses ARM Cortex-M series)
  - Real-time operating system is developed
    - High-performance (uses ARM Cortex-A series)
    - First designed on a development platform and then software and hardware are migrated to a stand-alone embedded platform
- DSP-based embedded systems
- FPGA-based embedded systems

What is a Microprocessor?

- The microprocessor (MPU) is the integration of a number of useful functions into a single IC package:
  - The ability to execute a stored set of instructions to carry out user defined tasks
  - The ability to be able to access external memory chips to both read and write data from and to the memory

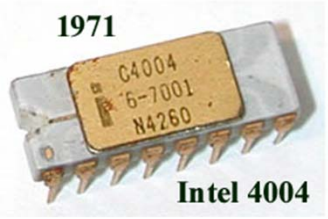


Source: http://mic.unn.ac.uk/miclearning/modules/micros/ch1/micro01hist.html

Microprocessor vs. Microcontroller

- What is a Microprocessor (MPU)?
  - A single LSI chip (around 10k transistors), known as Central Processing Unit (CPU), to perform all computation (without memory and I/O interface circuit)
  - The first microprocessors appeared in Nov 1971 (Intel 4004)
    - For the first time a computer CPU was put onto a single IC
    - All other functions, like memory and I/O interfacing, were outside the microprocessor (MPU)
    - Gradually, different memory types have been added on to the same chip
    - At the same time, the CPU became more powerful and faster (from 8-bit to 16- and 32-bit devices)

World's first general purpose 8-bit microprocessor: Intel 8080 (April 1974)



Source: http://mic.unn.ac.uk/miclearning/modules/micros/ch1/micro01hist.html

A Brief History of Microprocessors

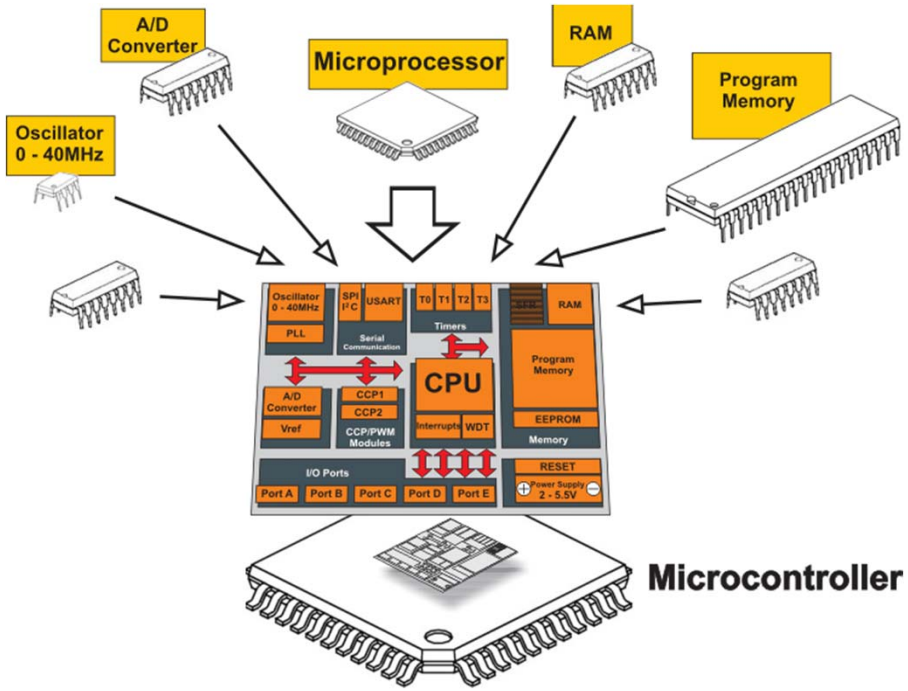
- The first microprocessor was developed by what was then a small company called Intel (short for Integrated Electronics) in the early 1970s. The chipset was a success and within a short while Intel developed a general purpose 4 bit microprocessor called the 4004.
- In 1974 the more powerful second generation microprocessor (the 8008) was announced fabricated as a single chip. This was quickly followed by the Intel 8080.
- At about the same time Motorola released its first microprocessor, the 6800, which was also an 8 bit processor with about the same processing power as that of the Intel 8080.
- The architectures used in the Intel 8080 and the Motorola 6800 were very different.
- In due course the Intel 8080 core processor was used for a range of microcontrollers (8048 and 8051 to name but two).
- Motorola followed in a similar vein with a range of microcontrollers based on the 6800 (6805, 6808, 6811 which survive to this day).

Source: http://mic.unn.ac.uk/miclearning/modules/micros/ch1/micro01hist.html

Source: PIC Microcontrollers, Milan Verle, free online (www.mikroe.com/en/books/picmcubook/)

Microprocessor vs. Microcontroller

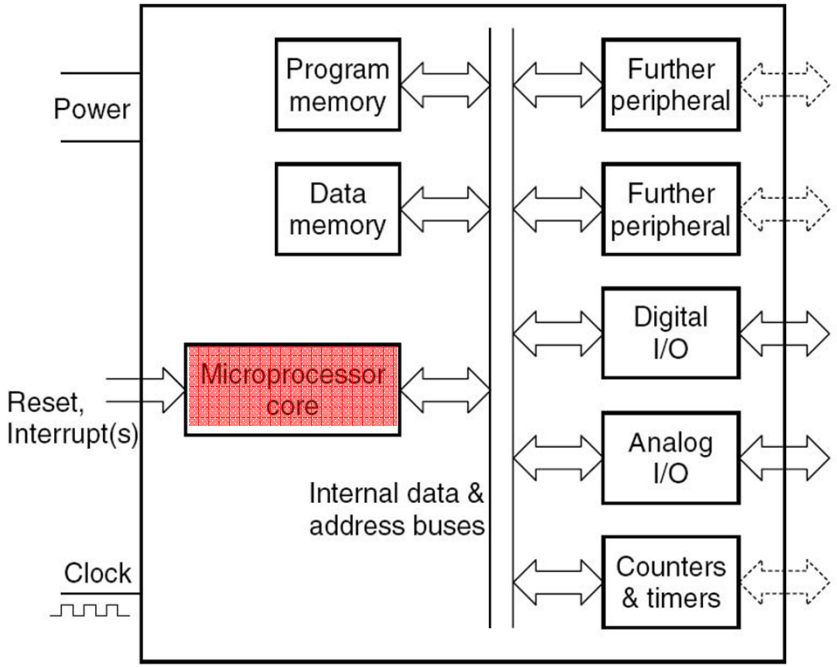
- What is a Microcontroller (MCU)?
  - A microcontroller differs from a microprocessor in many ways
  - A system where microprocessor along with memory, I/O, and other necessary functionalities are added for **control activities** mainly – all integrated into a single chip
  - Like a microprocessor, a microcontroller needs to be able to compute also, though not necessarily big numbers
  - Now the microcontroller has taken over the role of the embedded computer in embedded systems



Source: Microprocessors/Microcontrollers – Course Notes, Delmar Cengage Leaning, ISBN: 1435453816

Microcontroller – A Generic View

- Essentially, it contains a simple microprocessor core, along with all necessary data and program memory
- To do this, it adds all the peripherals needed to do the interfacing
  - These may include digital and analog input and output, or counting and timing elements

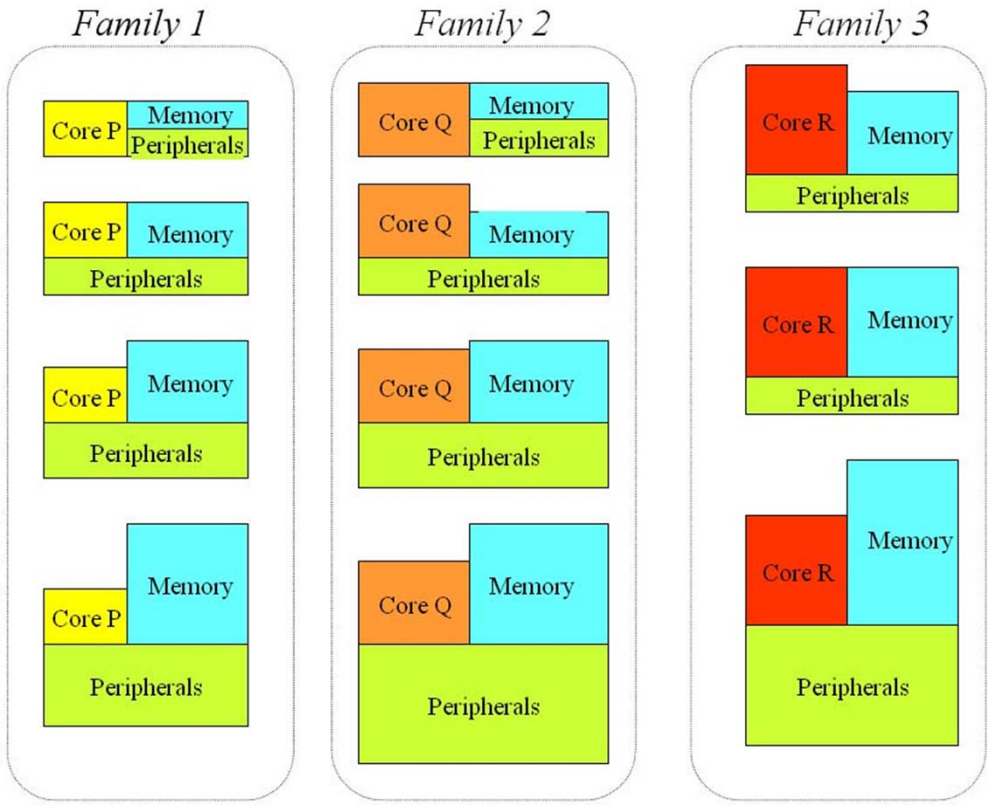


Microcontroller = Microprocessor core + Memory + Peripherals

Source: Designing Embedded Systems with PIC Microcontrollers: Principles and Applications, Tim Wilmshurt

Microcontroller Family

- Manufacturer's Microcontroller Portfolio:
- A manufacturer builds a MCU family around one fixed microprocessor core
  - But different combinations of memory and peripherals
- Because the core is fixed for all members of one family, the instruction set is fixed
  - users have little difficulty in moving from one family member to another

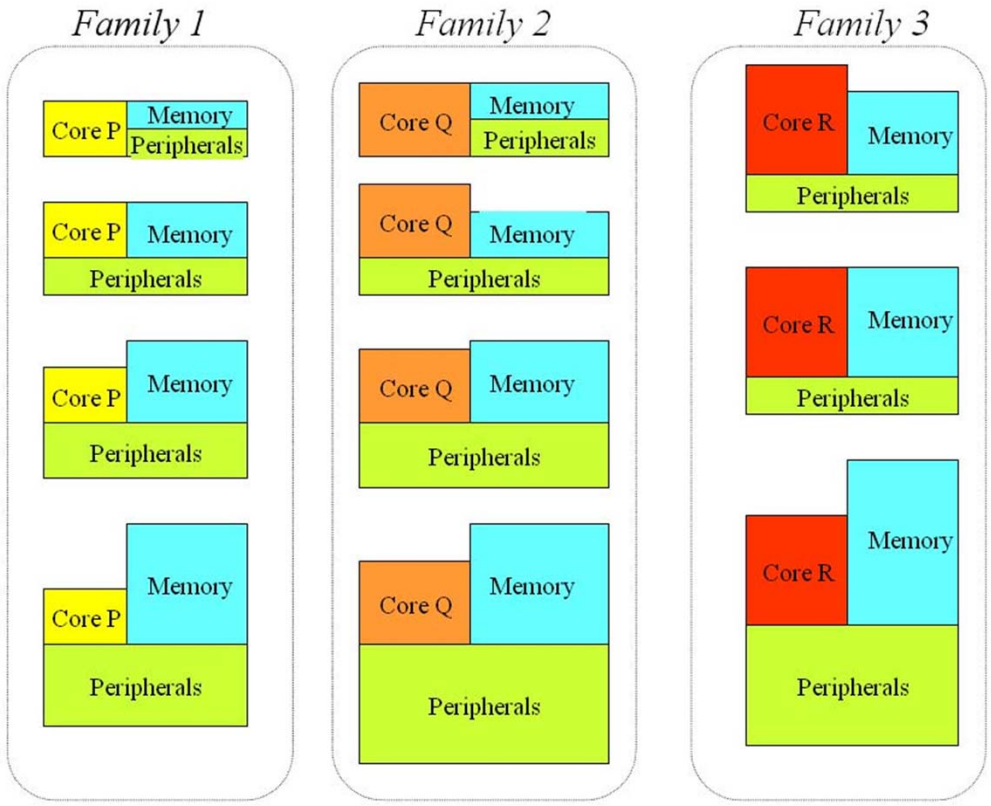


Microcontroller = Microprocessor core + Memory + Peripherals

Source: Designing Embedded Systems with PIC Microcontrollers: Principles and Applications, Tim Wilmshurt

Microcontroller Family

- Manufacturer's Microcontroller Portfolio:
- A manufacturer builds a MCU family around one fixed microprocessor core
  - But different combinations of memory and peripherals
- Example: TM4Cxxxx, TMS470M, AM5K2Ex, etc.
  - All MCU in TM4C series have the same MPU core (ARM CortexM4F)
  - *http://www.ti.com/lit/sg/spmt285a/spmt285a.pdf*



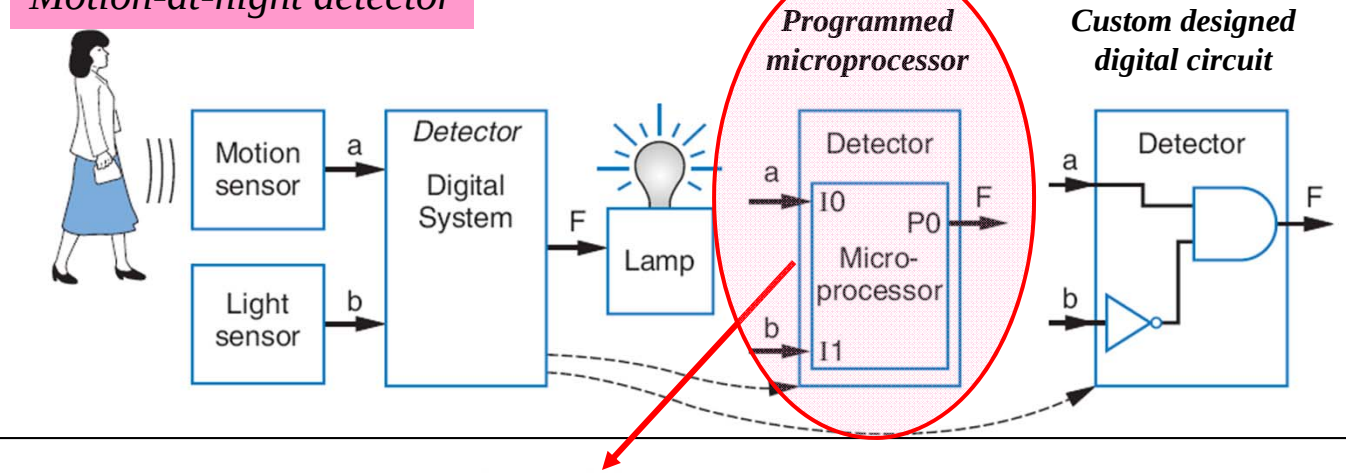
Microcontroller = Microprocessor core + Memory + Peripherals

Implementing Embedded Systems:

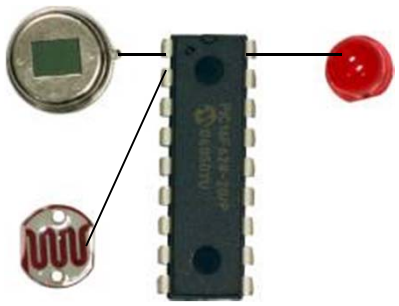
Programming Microprocessor Vs. Designing Digital Circuit

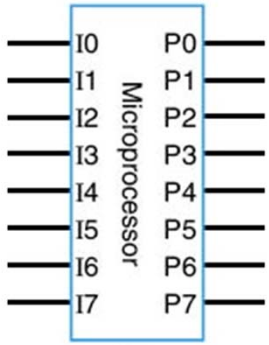
Our focus in this course

Motion-at-night detector

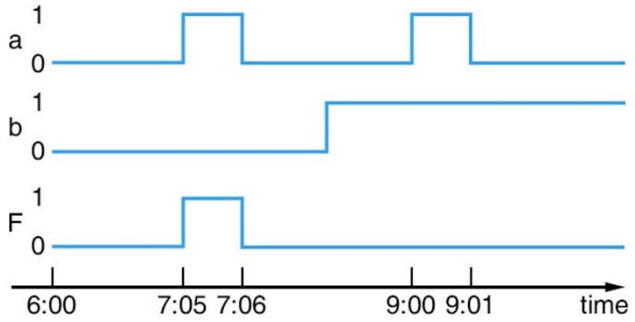


- MPU a common choice to implement a digital system
  - Easy to program / re-program
  - Cheap (as low as $1)
  - Widely available






```
void main()
{
  while (1) {
    P0 = I0 && !I1;
    // F = a and !b,
  }
}
```



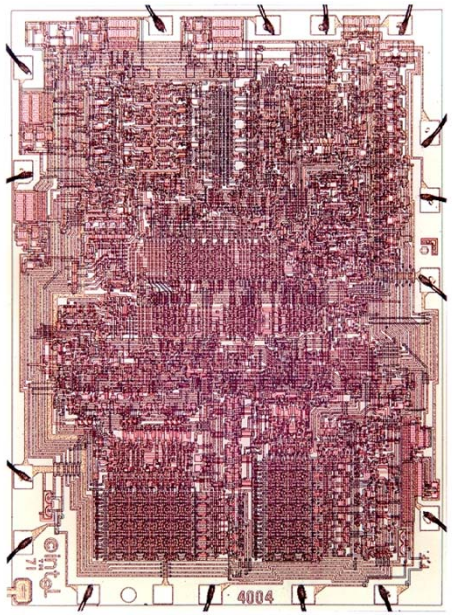
Source: Digital Design, Frank Vahid, 1st ed, 2006
http://www.cs.ucr.edu/~vahid/dd

Microcontroller Applications

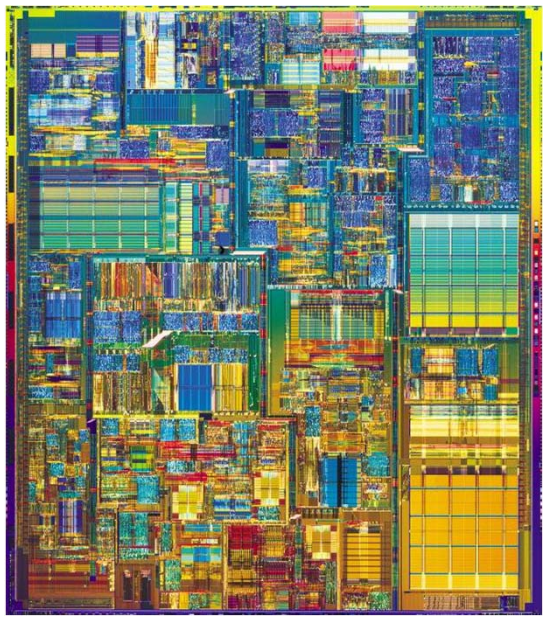
- **Industrial Control:** motors, factory automation, tools, robotics, test equipment, networks
- **Office Automation:** printers, plotters, copiers, hard disk drives
- **Home Appliances:** white goods, home automation, security
- **Consumer Electronics:** TVs, DVD players, digital cameras, personal media players
- **Security:** Smart cards, SIM cards, mobile phones, biometrics
- **Automotive:** convenience systems, safety, powertrain, infotainment

http://www.mips.com/everywhere/microcontrollers/

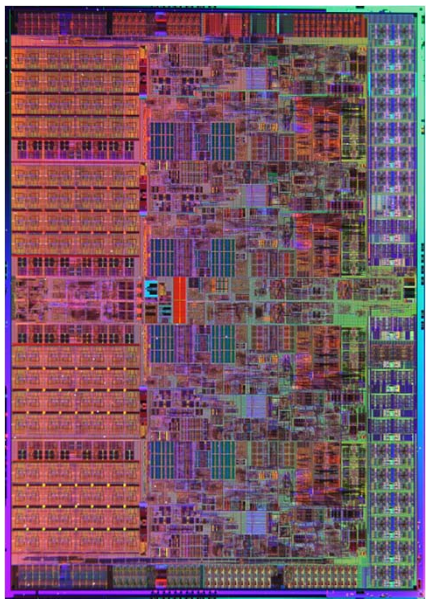
Advancements over the years…



- © Intel 4004 Processor
- 4-bit CPU
- Introduced in Nov 1971
- 2300 Transistors (10um)
- 740 kHz Clock

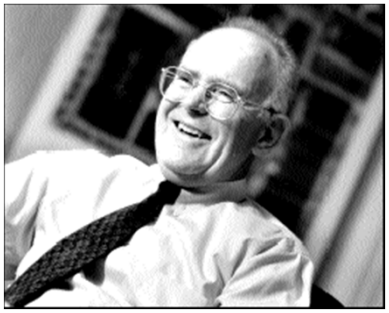


- © Intel P4 Processor
- 32-bit CPU
- Introduced in Nov 2000
- 40 Million Transistors (0.18um or 180nm)
- 1.5 GHz Clock

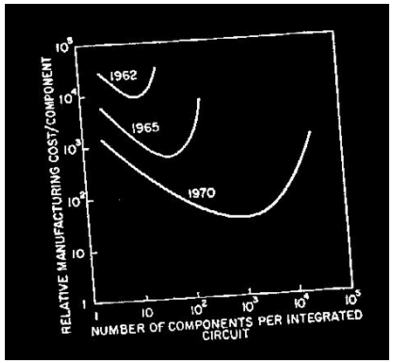


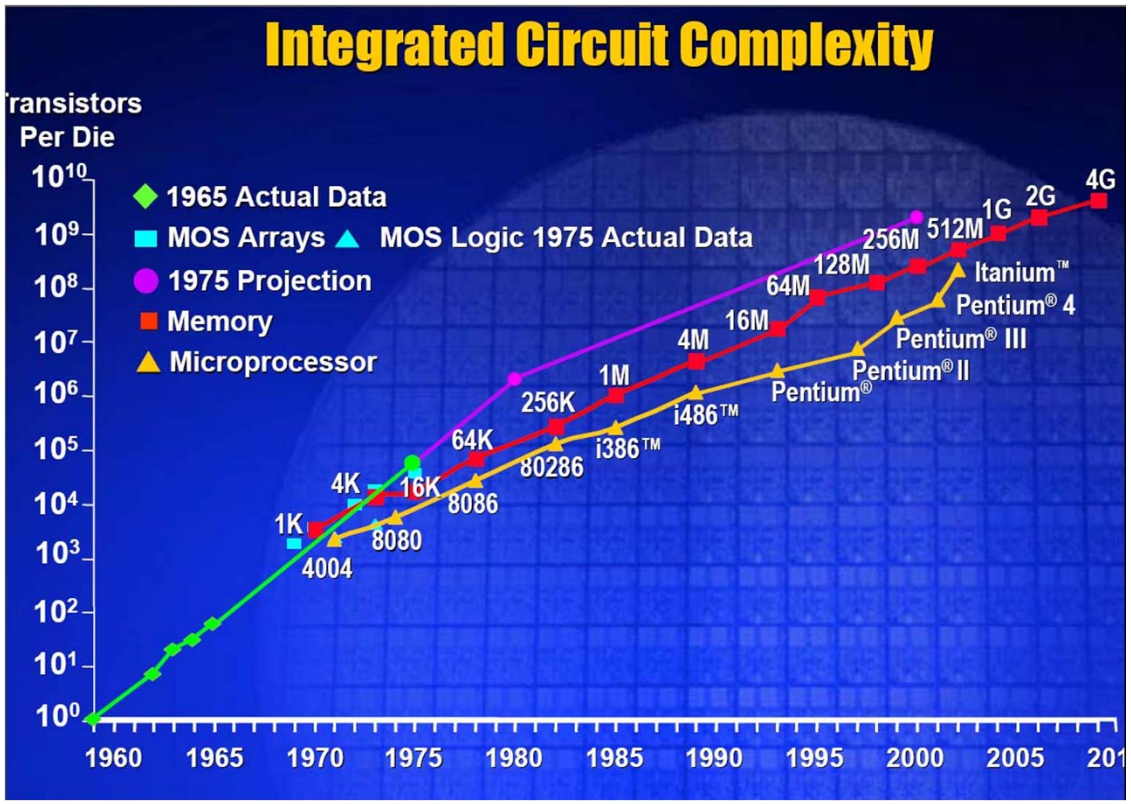
- © Intel Core™ i7 Microprocessor (“Nehalem”)
- Introduced in Nov 2008
- 4 cores/chip
- 731 M Transistors (45nm)
- 3.33 GHz Clock

Advancements over the years…



Moore's Law – *IC capacity doubles in every 18 months* (Gordon Moore, cofounder of Intel; predicted in 1965)





Gordon Moore, ISSCC 2003

http://www.sscs.org/History/MooresLaw.htm

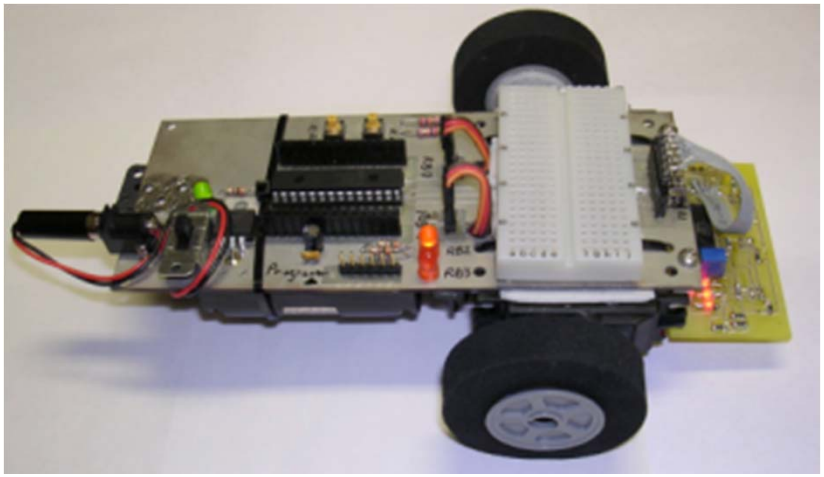
History of Computers

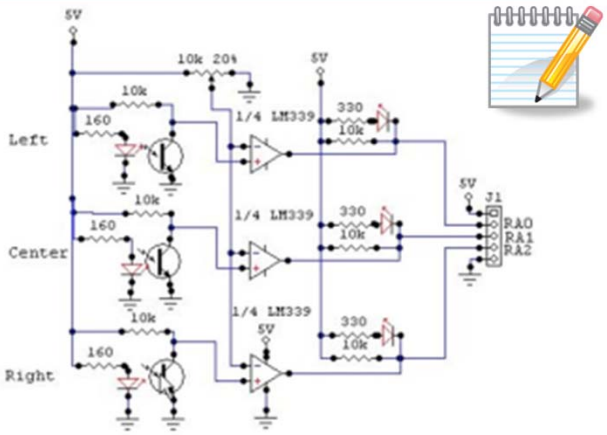
- History of Computers – 1 (Prof. Dr. Miroslaw Malek, pdf)
- History of Computers – 2 (Timeline of Computing History, pdf)

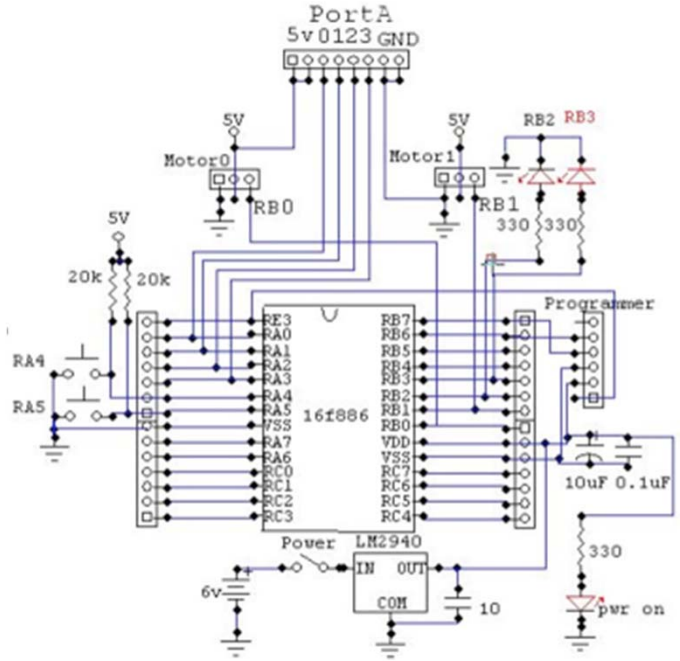
From class website (under 2010 lecture notes)

Embedded System

- Auto Tracking Robot
  - A robot (moving machine) that follows a black line automatically
  - How to design the hardware?
    - Problem description, resource budget, H/W assembly, programming, testing

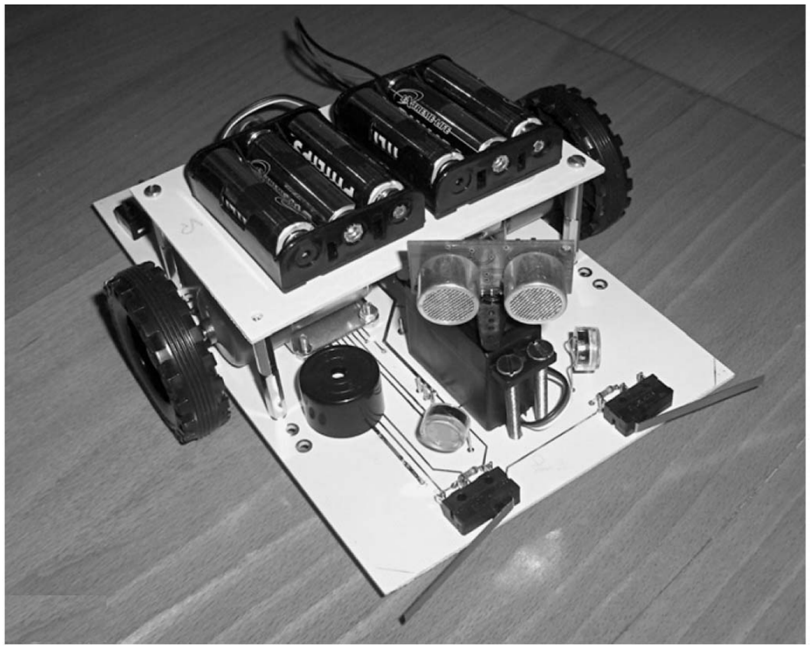


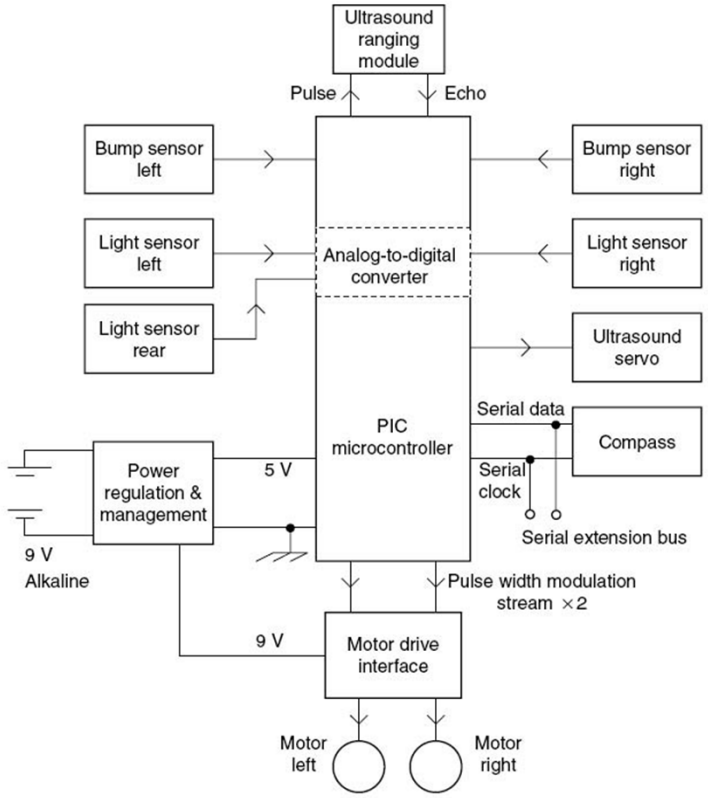




Embedded System

- Autonomous Guided Vehicle (AVG)





Source: Designing Embedded Systems with PIC Microcontrollers: Principles and Applications, Tim Wilmshurt

Embedded System – Car Odometer

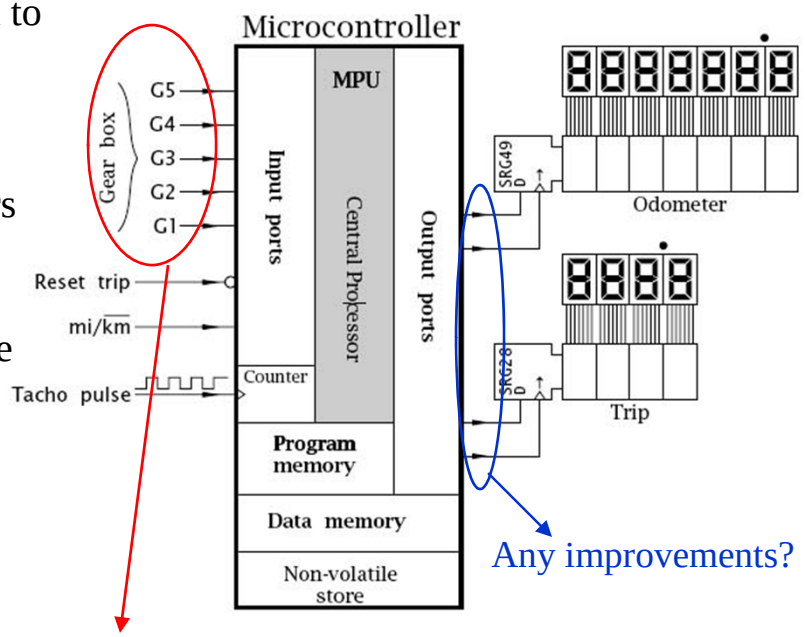
- Consider a car odometer monitoring system that displays two things: (a) total distance since manufactured and (b) a trip odometer

Resource Budget (List of subsystem):

1. An edge-triggered input for the tachometer pulse train to add up engine revolutions
2. Gear ratio, mi/km option and trip reset

3. Four output digital lines to clock the two shift registers and provide segment data

4. An MPU to do the calculations and to read/write to the input/output ports
5. Program memory, usually ROM of some kind
6. Data memory for temporary storage of program variables, usually static RAM
7. Non-volatile memory to store physical variables

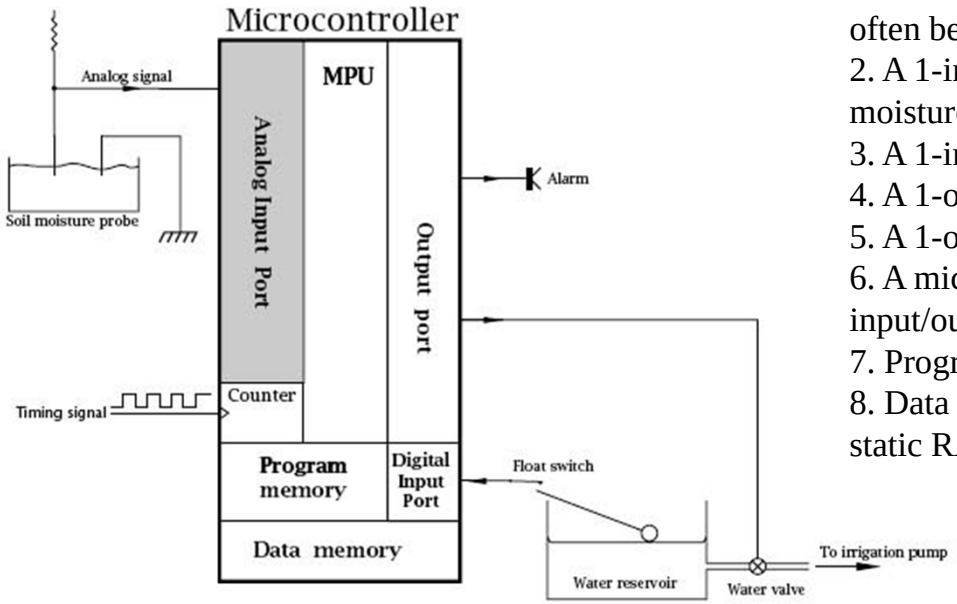


Source: The Quintessential PIC® Microcontroller, Sid Katzen, 2nd edition, 2005, ISBN: 978-1-85233-942-5

Source: The Quintessential PIC® Microcontroller, Sid Katzen, 2nd edition, 2005, ISBN: 978-1-85233-942-5

E3.1 – Greenhouse Environment Controller

- A greenhouse controller is to monitor an analog signal from a soil moisture probe and if below a certain value turn on a water valve for 5 seconds and off for 5 seconds.

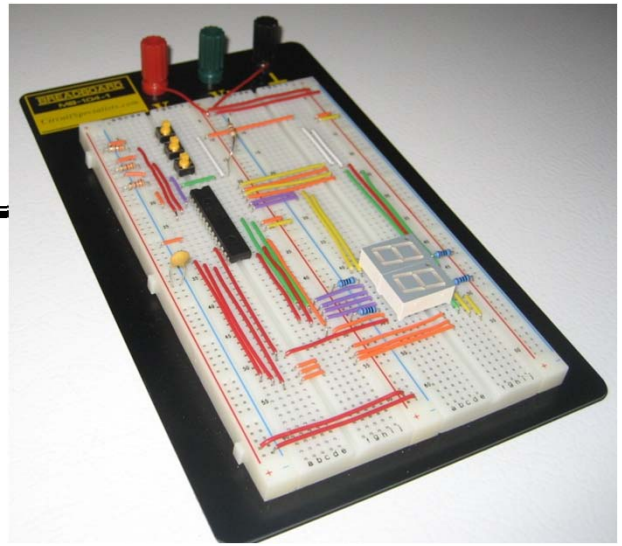


Resource Budget (List of subsystem):

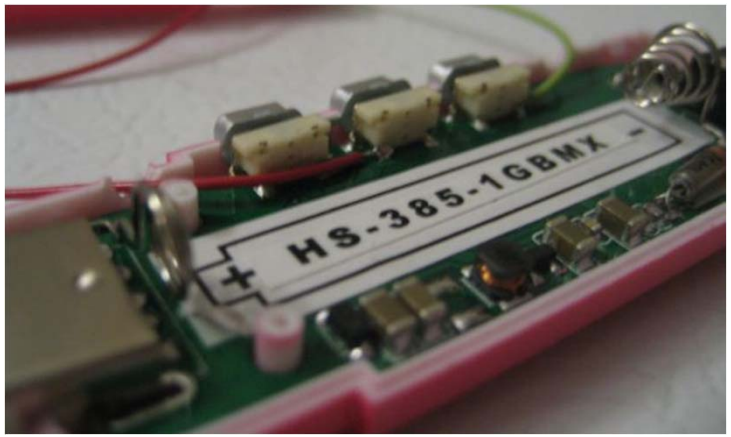
1. An input for an external oscillator, connected to a counter/timer to allow the MCU to calculate time. In practice the system clock can often be used by this internal timer to measure duration.
2. A 1-input analog input line to measure the analog signal from the moisture detector
3. A 1-input digital line to check the level of the reservoir water tank
4. A 1-output digital line to open and close the water valve
5. A 1-output digital line to activate the buzzer alarm
6. A microprocessor to do the calculations and to read/write to the input/output ports, respectively
7. Program memory, usually ROM of some kind
8. Data memory for temporary storage of program variables, usually static RAM

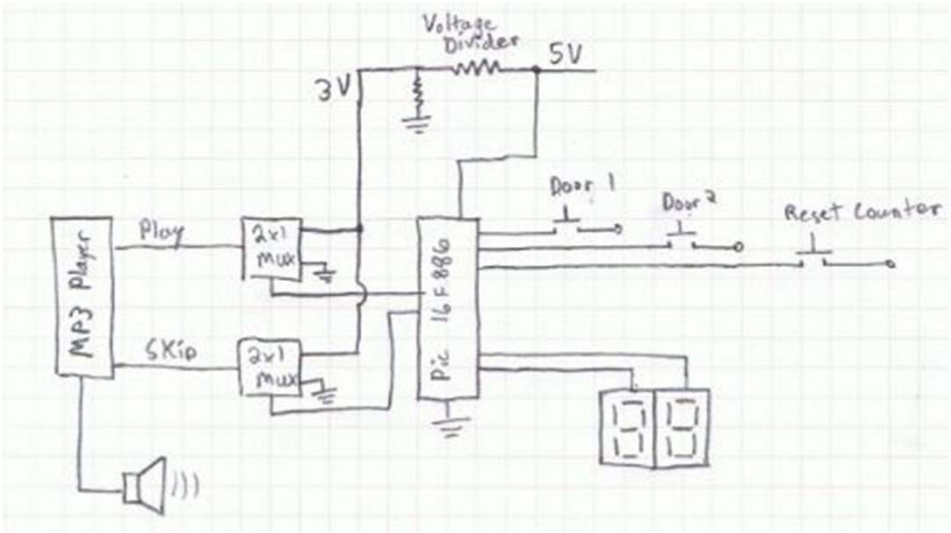
HW: MCU controlled robot to cross a road

Embedded System



- **Doorbell with MP3 Player** [Kyle Weisgarber, Craig Lytle, Curtis Flavel]
  - Two door bells, with MP3 player, displays on 7-segment (how many times bell pushed)
  - Problem description, resource budget, H/W assembly, programming, testing





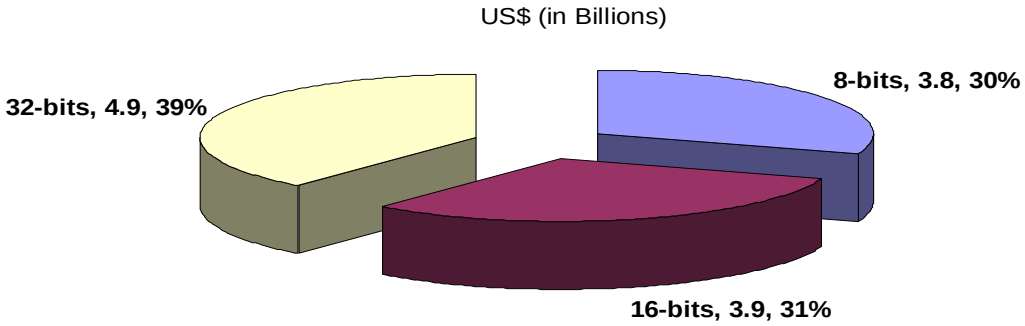
Microcontroller Market

- Microcontroller manufacturer
  - STMicro
  - Texas Instruments
  - Renesas
  - Analog Devices
  - Atmel
  - Freescale (ex. Motorola)
  - Hitachi Semiconductor
  - Intel
  - Microchip
  - National Semiconductor
  - Dallas Semiconductor
  - …
- > 40 suppliers
- > 50 architectures
- US$44 Billion market
- Shipments: 10 Billion in 2007
- Major Players:

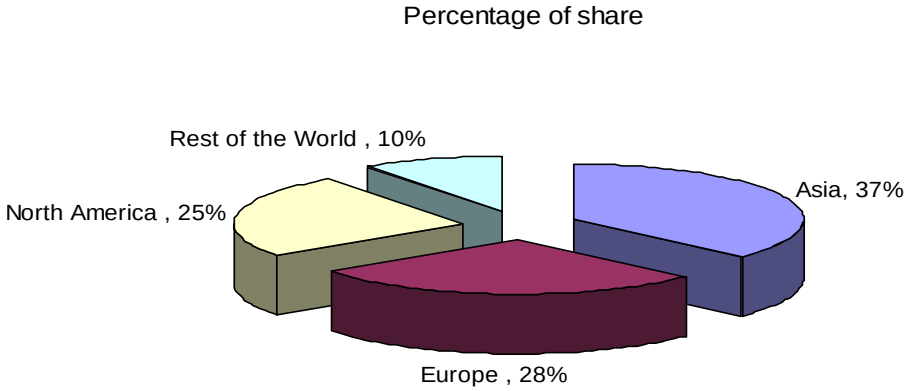
Processor Core	Company developed
PIC	Microchip
ARM	ARM
V850	NEC Electronics Corp.
8051	Intel
HCS08/HCS12X	Freescale
C166SV2	Infineon Tech
T8K/0	NEC Electronics Corp.
E200Z (PowerPC)	Freescale
H8S/H8SX	Renesas
XC800	Infineon Tech

ARM Market: *http://www.arm.com/markets/embedded/index.php*

Microcontroller Market (2007)



Company	Core	Share (%)
Intel (8051)	8051	19
Renesas	740, H8/S, M32R	17
Freescale	68XX	15
PIC	PIC	12
ARM	ARM	10
NEC	V850, 78K0, K3/K4	9
ST	Proprietary 8-bit	6
Atmel	AVR	3
Infineon	C16X	3
Others	Others	6



http://www.emittsolutions.com/images/microcontroller_market_analysis_2008.pdf

Microcontroller Market (2008)

2007 and 2008 Worldwide Microcontroller Revenue Share by Supplier

Company	2008 Rank	2008 $M	2008 Share	2007 Rank	2007 $M	2007 Share	Y/Y %
Renesas Technology	1	2,770	20.1%	1	2,944	21.2%	-6%
Freescale Semiconductor	2	1,518	11.0%	2	1,743	12.6%	-13%
NEC	3	1,330	9.7%	3	1,296	9.3%	3%
Fujitsu	4	1,065	7.7%	4	1,115	8.0%	-5%
Infineon Technologies	5	983	7.2%	5	1,023	7.4%	-4%
Microchip Technology	6	812	5.9%	6	778	5.6%	4%
STMicroelectronics	7	645	4.7%	7	662	4.8%	-3%
Texas Instruments	8	601	4.4%	8	607	4.4%	-1%
Atmel	9	511	3.7%	9	458	3.3%	12%
NXP Semiconductors	10	286	2.1%	10	303	2.2%	-6%
Other		3,229	23.5%		2,936	21.2%	10%
Total		**13,749**			**13,866**		-1%

databeans estimates, Company Reports

http://eetimes.com/news/latest/showArticle.jhtml?articleID=216500727&pgno=5
http://www.openicon.com/confsums/mchp_main.html

- As a result of its recent merger with NEC, **Renesas** has become even more dominant in the microcontrollers product area, perhaps owning **up to one-quarter of the market now**

Which one is the "best" MCU?

Depends on what you are doing…

Microcontroller Market (2008)

2007 and 2008 Worldwide Microcontroller Revenue Share by Supplier

Company	2008 Rank	2008 $M	2008 Share	2007 Rank	2007 $M	2007 Share	Y/Y %
Renesas Technology	1	2,770	20.1%	1	2,944	21.2%	-6%
Freescale Semiconductor	2	1,518	11.0%	2	1,743	12.6%	-13%
NEC	3	1,330	9.7%	3	1,296	9.3%	3%
Fujitsu	4	1,065	7.7%	4	1,115	8.0%	-5%
Infineon Technologies	5	983	7.2%	5	1,023	7.4%	-4%
Microchip Technology	6	812	5.9%	6	778	5.6%	4%
STMicroelectronics	7	645	4.7%	7	662	4.8%	-3%
Texas Instruments	8	601	4.4%	8	607	4.4%	-1%
Atmel	9	511	3.7%	9	458	3.3%	12%
NXP Semiconductors	10	286	2.1%	10	303	2.2%	-6%
Other		3,229	23.5%		2,936	21.2%	10%
Total		**13,749**			**13,866**		-1%

databeans estimates, Company Reports

http://eetimes.com/news/latest/showArticle.jhtml?articleID=216500727&pgno=5
http://www.openicon.com/confsums/mchp_main.html

AVR Microcontroller

- A much more modern MCU which was developed in 1996
- Better architecture than PIC
- Can be programmed with Public Domain "C" compiler
- More powerful than PIC but not many variations for built-in functions
- Almost as cheap as PIC

PIC vs. AVR
http://www.ladyada.net/library/picvsavr.html

Microcontroller Market (2008)

2007 and 2008 Worldwide Microcontroller Revenue Share by Supplier

Company	2008 Rank	2008 $M	2008 Share	2007 Rank	2007 $M	2007 Share	Y/Y %
Renesas Technology	1	2,770	20.1%	1	2,944	21.2%	-6%
Freescale Semiconductor	2	1,518	11.0%	2	1,743	12.6%	-13%
NEC	3	1,330	9.7%	3	1,296	9.3%	3%
Fujitsu	4	1,065	7.7%	4	1,115	8.0%	-5%
Infineon Technologies	5	983	7.2%	5	1,023	7.4%	-4%
Microchip Technology	6	812	5.9%	6	778	5.6%	4%
STMicroelectronics	7	645	4.7%	7	662	4.8%	-3%
Texas Instruments	8	601	4.4%	8	607	4.4%	-1%
Atmel	9	511	3.7%	9	458	3.3%	12%
NXP Semiconductors	10	286	2.1%	10	303	2.2%	-6%
Other		3,229	23.5%		2,936	21.2%	10%
Total		**13,749**			**13,866**		-1%

databeans estimates, Company Reports

ARM Processor

- Becoming increasing popular in industry
- Recently, focus shifted more towards advanced computation
- Very efficient chip with high speed and low power consumption
- In fact, the ARM Cortex™-M0 processor is one of the smallest and most energy-efficient MPU available today
- ARM processors are widely used in cell phones, especially in all Apple iPhone and iPods

ARM Cortex-M0

http://www.electronics-eetimes.com/en/arm-cortex-m0-based-32-bit-mcus-for-cost-sensitive-motor-and-lcd-control.html?cmp_id=7&news_id=222909083#

http://eetimes.com/news/latest/showArticle.jhtml?articleID=216500727&pgno=5

http://www.openicon.com/confsums/mchp_main.html

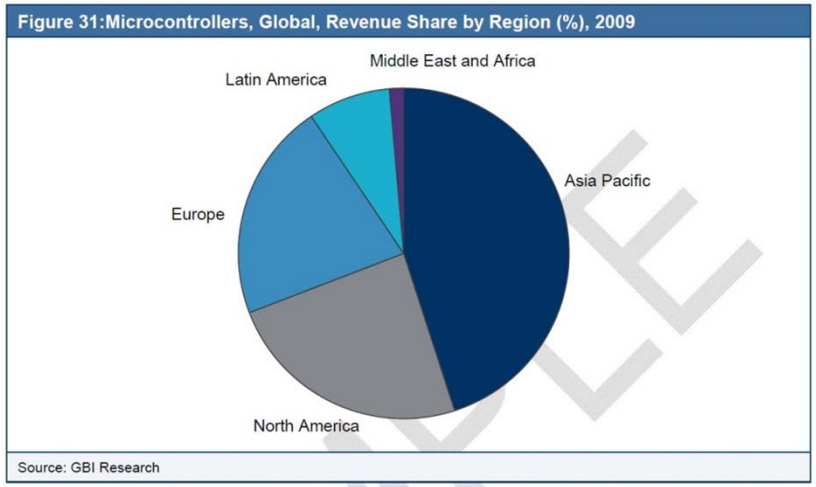
A4 chip drives AppleTV, iPod Touch (Sep 1, 2010)

http://www.eetimes.com/electronics-news/4207280/A4-drives-AppleTV-iPod-Touch

Microcontroller Market (2011)

- Microcontroller market forecasted to reach over $16 billion worldwide in 2011 (was $10 billion in 2007)

- **Current Trends**
  - The Asia Pacific region is the largest and highest growth market for MCU, and the Chinese automotive industry has been identified as a major driver
  - Over 80 percent of MCU revenue comes from industrial and automotive market applications
  - The higher resolution 32-bit microcontrollers are showing the most growth in units shipped, but there are considerable opportunities to be found for the lower resolution products as well



www.electronics.ca/presscenter/articles/1364/1
www.frost.com/prod/servlet/market-insight-top.pag?docid=191547329
www.marketreports.com/Sample/Global_Data/GBISC007MR_sample.pdf

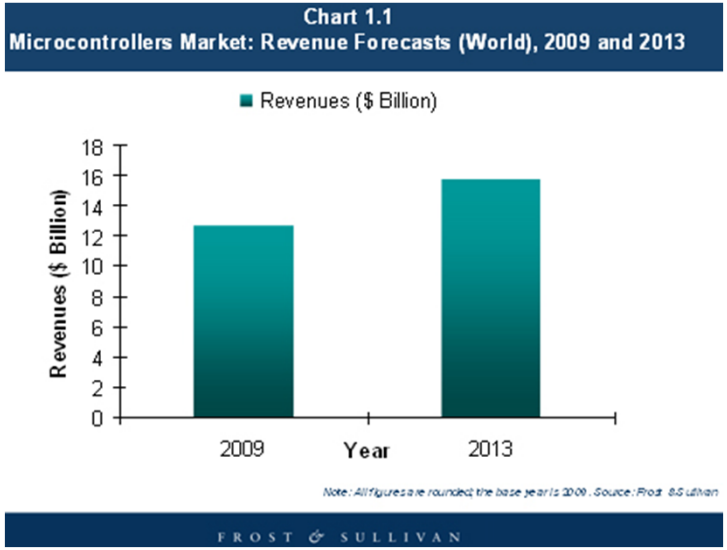
Microcontroller Market (2011)

- Recent research (by Frost & Sullivan in N714-26 Strategic Analysis of the Global Microcontrollers Market) indicates that this market is expected to grow at 5.5 percent from 2009 to 2013

  - ***8-bit MCU rules the Southeast Asian Electronics Industry.*** The presence of newer applications in markets such as medical electronics, automotive, and consumer electronics, which require MCUs that offer low-cost solutions and deliver on performance, functionality, and connectivity, have created a huge market for 8-bit MCUs.

  - "*The 8-bit MCUs are the mainstay and vital to the processor ecosystem; they initiate the use of digital electronics in a wide array of applications*," says the analyst of this research. ***"For many new system designs and applications, 8-bit MCUs are still considered an ideal choice."***

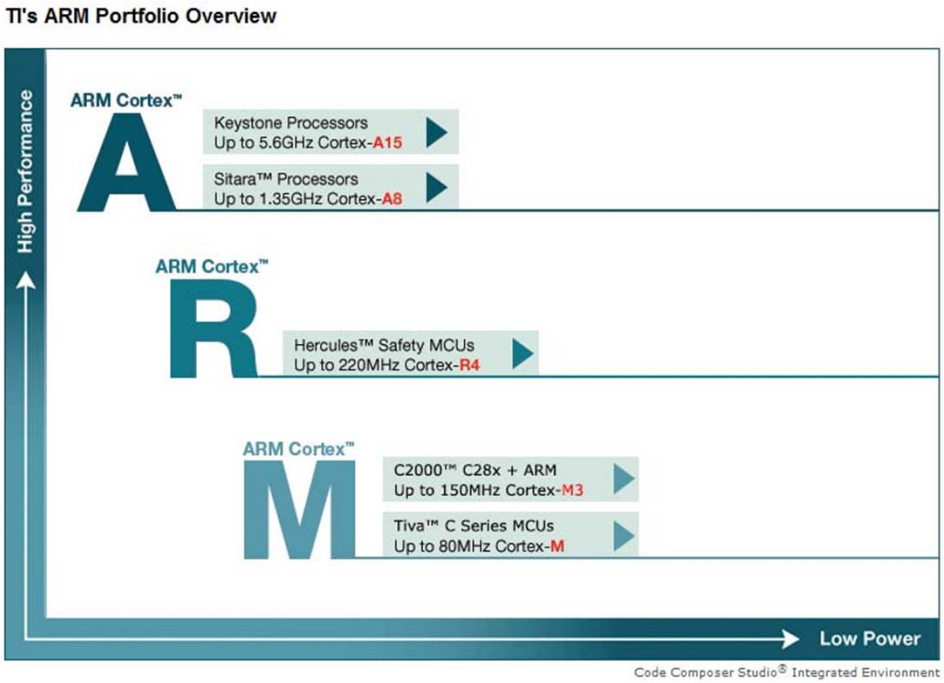
  - The 16-bit and 32-bit MCUs will be driven by automotive, high-end consumer products, and industrial controls



http://www.frost.com/prod/servlet/market-insight-top.pag?docid=191547329
http://www.researchandmarkets.com/reportinfo.asp?report_id=835349&tracker=related

Some vendors for ARM…

- Texus Instruments:
  - *http://www.ti.com/lsds/ti/arm/overview.page*
- Atmel products:
  - *http://www.atmel.com/products/microcontrollers/arm/*
- Keil tool chain and products:
  - *http://www.keil.com/boards/cortexm.asp*



Acknowledgments

- These slides have been prepared by Khan Wahid and may contain material copyrighted by:
  - Krste Asanovic (University of California, Berkley)
  - **Designing Embedded Systems with PIC Microcontrollers: Principles and Applications**, Tim Wilmshurt, 2007, ISBN: 978-0750667555
  - **Digital Design**, Frank Vahid, 1st ed, 2006
  - **The Quintessential PIC® Microcontroller**, Sid Katzen, 2nd edition, 2005, ISBN: 978-1-85233-942-5
  - Jonathan W. Valvano, http://users.ece.utexas.edu/~valvano