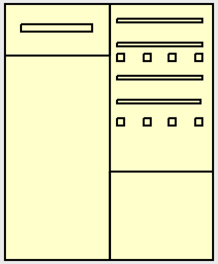
Microcontrollers

Lecture 1: Introduction

Artist's concept of Mars Exploration Rover. Courtesy NASA

What is a Computer?



- **Acknowledgement: the bulk of the material in this lecture is adapted from:**
  - **Embedded System Design– A Unified Hardware/Software Introducton, by Frank Vahid and Tony Givargis, John Wiley & Sons Inc., 2002**
- **Most of us think of "desktop" computers**
  - **PC's, Laptops**
  - **Servers, Mainframes**
- **But, there is another kind of computing system that is far more common: embedded systems**

Embedded Systems are Everywhere

Picture is from the cover of Embedded Systems Design, A Unified Hardware/Software Approach, by Frank Vahid and Tony Givargis

A "Short List" of Embedded Systems

- Anti-lock brakes
- Auto-focus cameras
- Automatic teller machines
- Automatic toll systems
- Automatic transmission
- Avionic systems
- Battery chargers
- Camcorders
- Cell phones
- Cell-phone base stations
- Cordless phones
- Cruise control
- Curbside check-in systems
- Digital cameras
- Disk drives
- Electronic card readers
- Electronic instruments
- Electronic toys/games
- Factory control
- Fax machines
- Fingerprint identifiers
- Home security systems
- Life-support systems
- Medical testing systems
- Modems
- MPEG decoders
- Network cards
- Network switches/routers
- On-board navigation
- Pagers
- Photocopiers
- Point-of-sale systems
- Portable video games
- Printers
- Satellite phones
- Scanners
- Smart ovens/dishwashers
- Speech recognizers
- Stereo systems
- Teleconferencing systems
- Televisions
- Temperature controllers
- Theft tracking systems
- TV set-top boxes
- VCR's, DVD players
- Video game consoles
- Video phones
- Washers and dryers

Today, almost all nontrivial electronic systems have at least one embedded processor

Embedded Systems vs. Desktop Computing

- Most Embedded Systems are single-functioned
  - Executes a single program, repeatedly
- Generally, Embedded Systems are tightly-constrained
  - Low cost, low power, small, fast, etc.
- Most Embedded Systems are reactive and real-time
  - Continually react to changes in the system’s environment
  - Must compute results in “real-time” as opposed to “batch” or “off-line”

Embedded Design Challenge: Optimizing Design Metrics

- **Obvious design goal:**
  - **Construct an implementation with desired functionality**
- **Key design challenge:**
  - **Simultaneously optimize numerous design metrics**
- **Design metric**
  - **A measurable feature of a system's implementation**
  - **Optimizing design metrics is a key challenge**

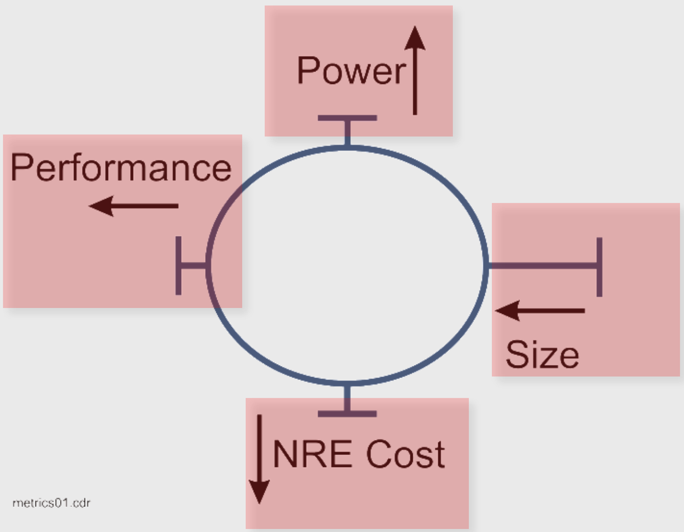
Embedded Systems Design Metrics

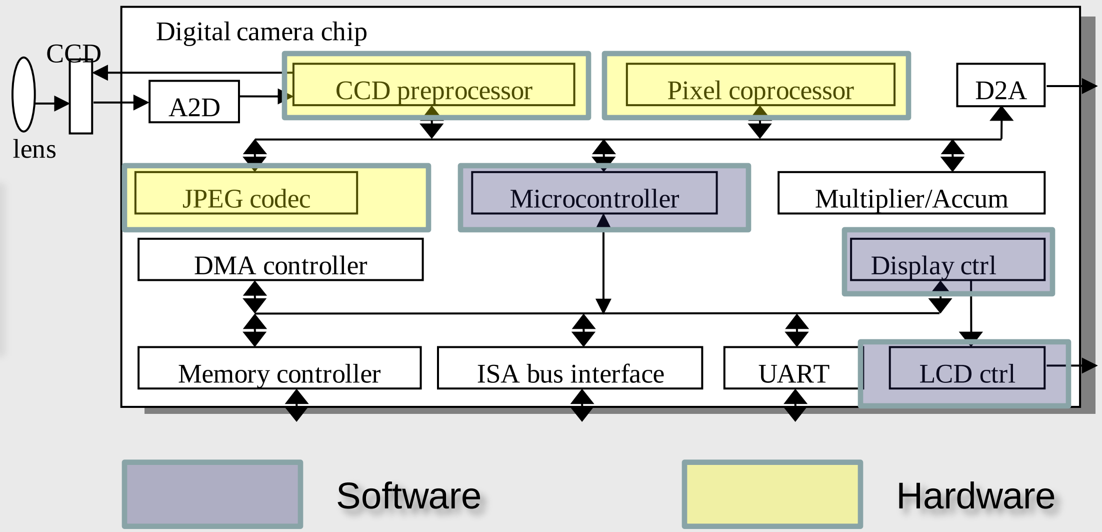
- **NRE cost (Non-Recurring Engineering cost)**
  - **One-time monetary cost of designing the system**
- **Unit cost**
  - **Monetary cost of manufacturing each copy of the system, excluding NRE cost**
- **Size**
  - **Physical space required by the system**
- **Performance**
  - **Execution time or response time of the system**
- **Memory**
  - **Amount of memory required to hold the program and data**
- **Power**
  - **Amount of power consumed by the system**

Embedded Systems Design Metrics

- **Flexibility**
  - Ability to change functionality without incurring heavy NRE cost
- **Time-to-prototype**
  - Time needed to build a working version of the system
- **Time-to-market (TTM)**
  - Time required to develop a system to the point that it can be released and sold to customers
- **Maintainability**
  - Ability to modify the system after its initial release
- **Robustness**
  - System stability and reliability
- **Safety**
  - Assurance that the system will not expose people to dangers

Design Metrics are Often at Odds





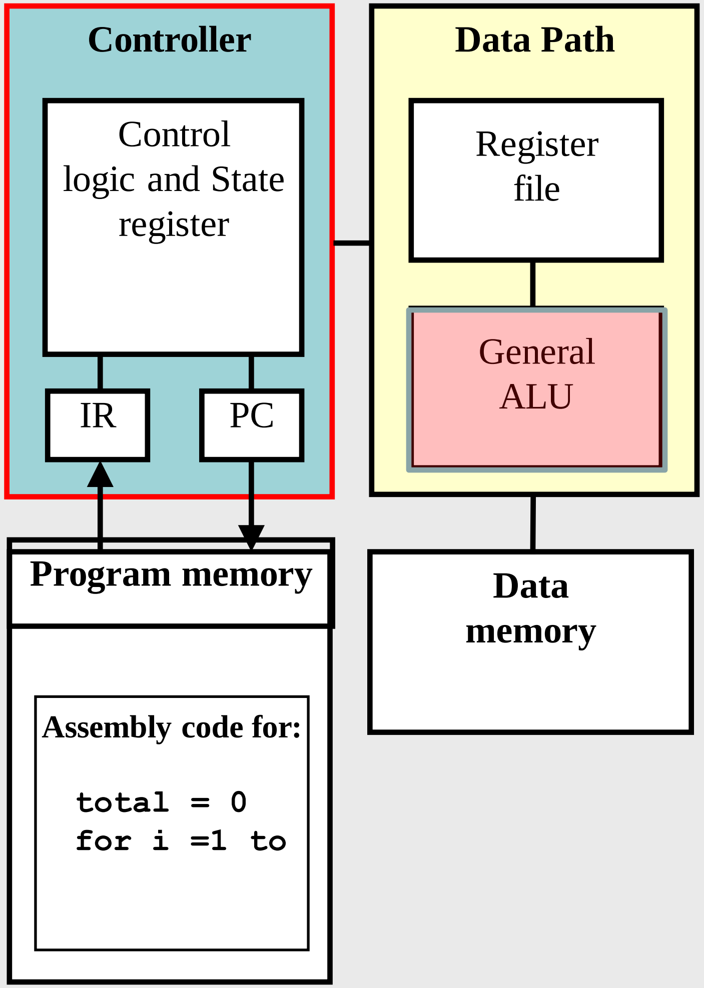
- **Expertise with both software and hardware is needed to optimize design metrics**
- **Not just a hardware or software expert, as is common**
- **A designer must be comfortable with various technologies in order to choose the best for a given application and constraints**

Embedded Processor Technologies

- **General-Purpose**
- **Single-Purpose**
- **Application-Tailored**

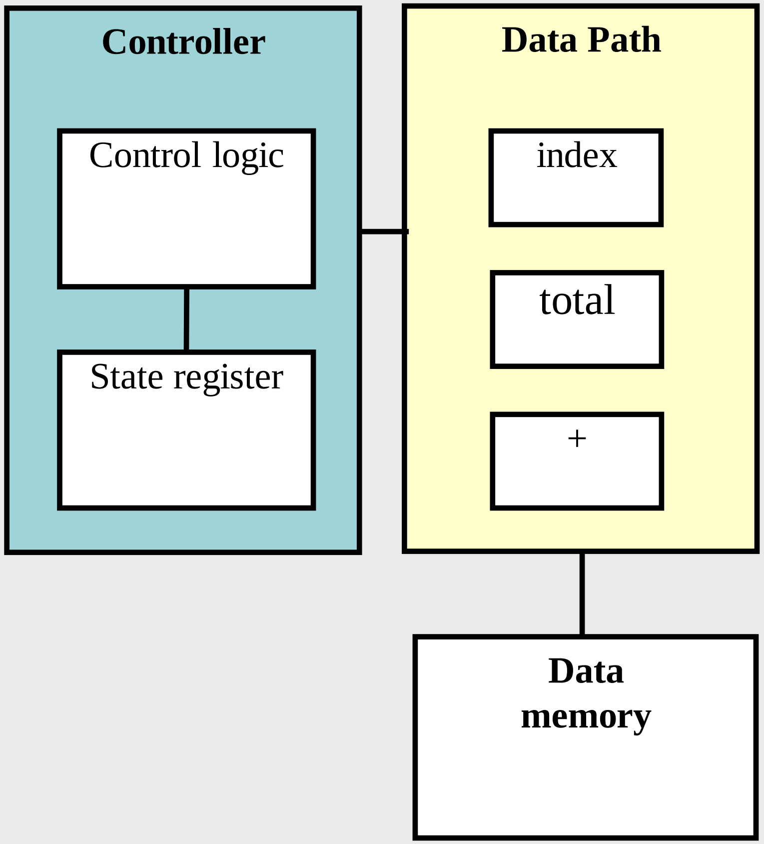
General-Purpose Processor

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



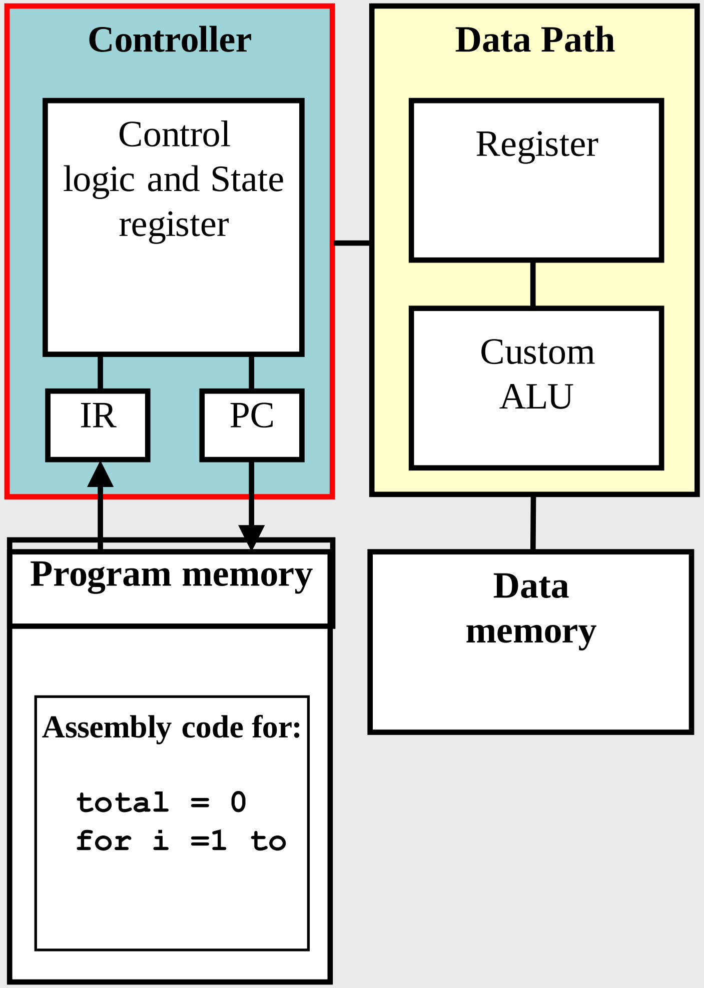
Single-Purpose Processor

- 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-Tailored 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 data path
  - Special functional units
- **Benefits**
  - Some flexibility, good performance, size and power



Key Player in Embedded Design: Microcontroller

- Compromise between general-purpose and application-tailored processor
- Simple processor architecture
  - Reduced instruction set (RISC) and functionality
  - Small data path (often only 4 or 8 bits vs. 32 or 64 bits for typical general purpose processor)
- On-board memory (volatile and non-volatile)
- Multiple on-chip devices to support embedded applications
  - Timers
  - Digital and I/O serial I/O
  - Support for various interfacing protocols—e.g. I^2C
- Available in many different configurations, performance levels, etc.

Processor Comparison

Processor	Clock	Peripherals	Bus Width	MIPS	Power	Trans.	Price
General Purpose Processors							
Intel PIII	1 GHz	2x16 K L1, 256K L2, MMX	32	~900	97W	~7M	$900
IBM PowerPC 750X	550 MHz	2x32 K L1, 256K L2	32/64	~1300	5W	~7M	$900
MIPS R5000	250 MHz	2x32 K 2 way set assoc.	32/64	NA	NA	3.6M	NA
StrongARM SA-110	233 MHz	None	32	268	1W	2.1M	NA
Microcontrollers							
Intel 8051	12 MHz	4K ROM, 128 RAM, 32 I/O, Timer, UART	8	~1	~0.2W	~10K	$7
Motorola 68HC811	3 MHz	4K ROM, 192 RAM, 32 I/O, Timer, WDT, SPI	8	~.5	~0.1W	~10K	$5
Digital Signal Processors							
TI C5416	160 MHz	128K, SRAM, 3 T1 Ports, DMA, 13 ADC, 9 DAC	16/32	~600	NA	NA	$34
Lucent DSP32C	80 MHz	16K Inst., 2K Data, Serial Ports, DMA	32	40	NA	NA	$75

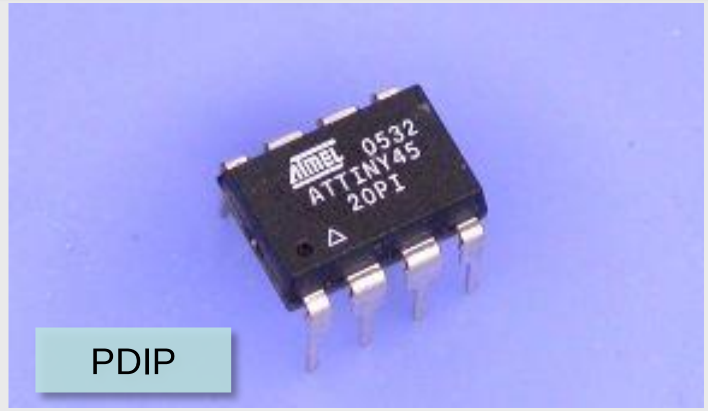
Sources: Intel, Motorola, MIPS, ARM, TI, and IBM Website/Datasheet; Embedded Systems Programming, Nov. 1998

The Advantages of Microcontrollers

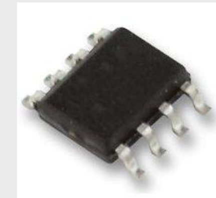
- Low cost due to high volume production
- Low "chip count" due to integrated on-board features
- Good development tools and environments
- Extensive product families allow tailoring of processor to system design metrics
- Short product design cycles (compared to custom hardware design).
- Compatible with hardware/software co-design
  - Many microcontrollers are available as "VHDL Cores" for integration into a custom VLSI chip

A Low End Microcontroller: ATtiny25/45/85

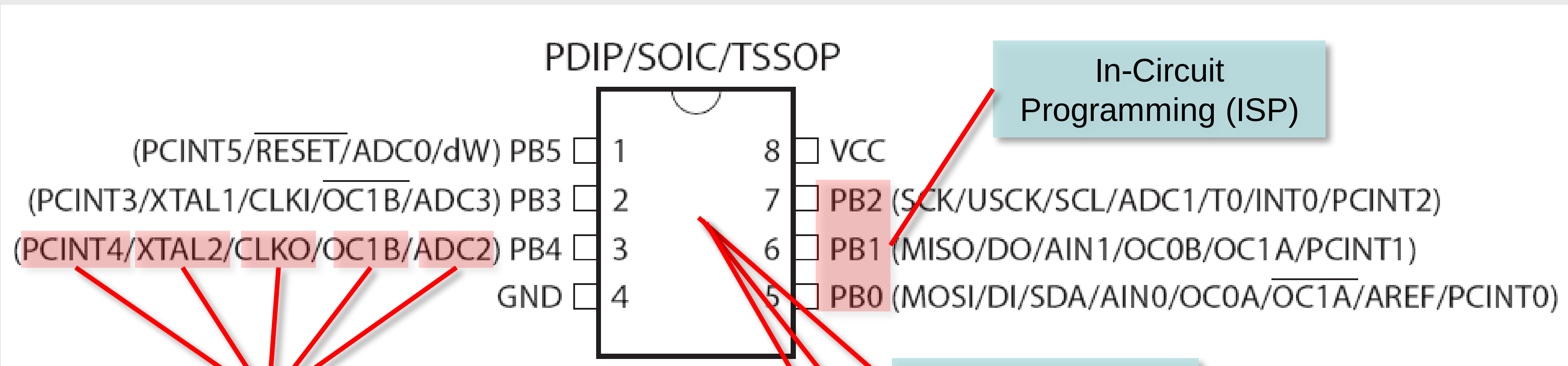
Pinout for ATtiny25/45/85



PDIP



SOIC



In-Circuit Programming (ISP)

Most pins have multiple uses

Built-in 10-bit A/D

Internal Oscillator

Built-in Analog Comparator

Up to 20 MHz clock

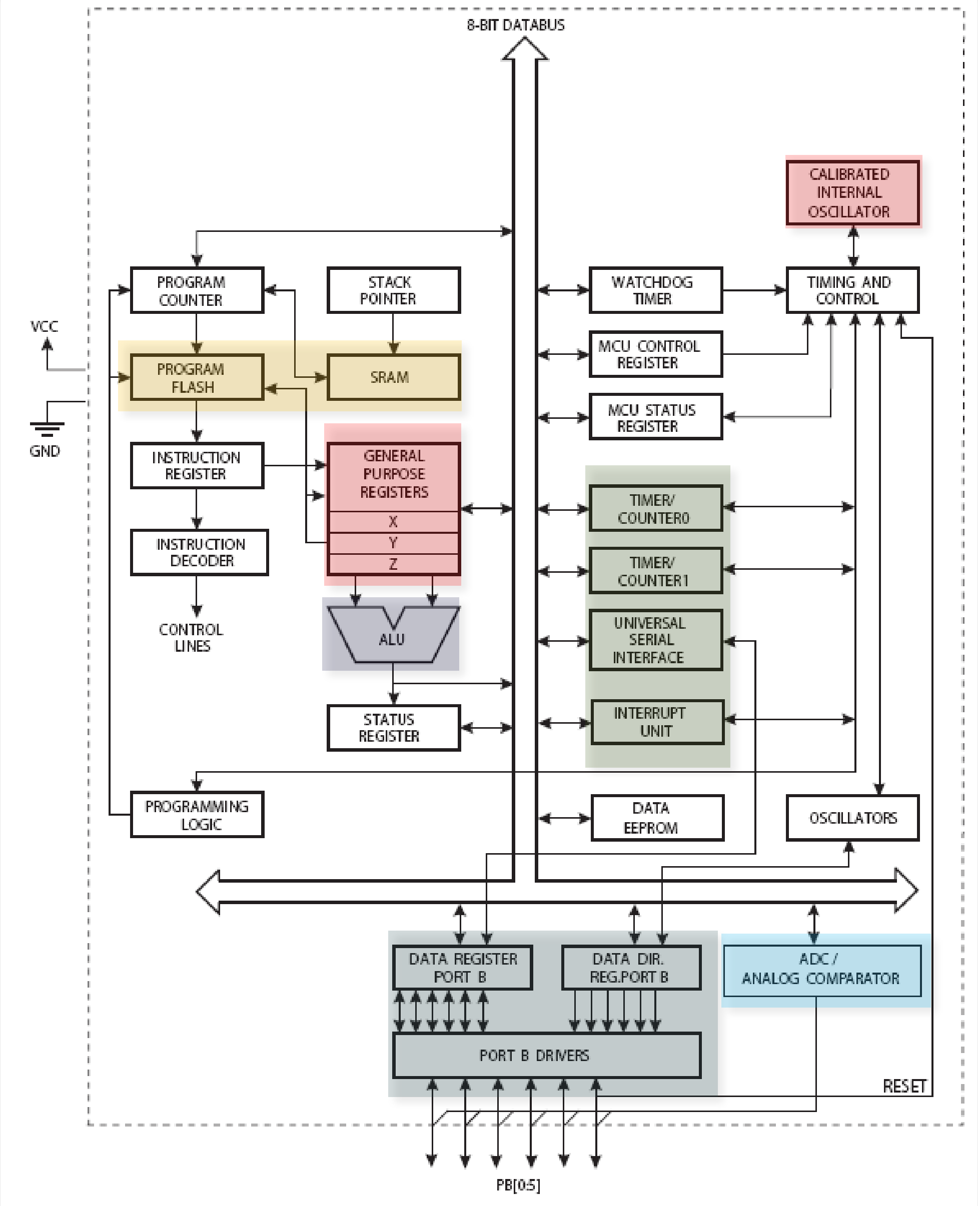
$1, $2 in Large quantities

I_{supply} at 1 MHz, 1.8 V: 300 μA

V_{cc} for some variants as low as 1.8 V

A Low End Microcontroller: ATtiny25/45/85

Block Diagram of ATtiny25/45/85



A Low End Microcontroller: ATtiny25/45/85

ATtiny25/45/85 Features

- Advanced RISC Architecture
  - 120 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
- Non-volatile Program and Data Memories
  - 2/4/8K Bytes of In-System Programmable Program Memory Flash
    - Endurance: 10,000 Write/Erase Cycles
  - 128/256/512 Bytes In-System Programmable EEPROM
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  - 128/256/512 Bytes Internal SRAM
  - Programming Lock for Self-Programming Flash Program and EEPROM Data Security
- Peripheral Features
  - 8-bit Timer/Counter with Prescaler and Two PWM Channels
  - 8-bit High Speed Timer/Counter with Separate Prescaler
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    - Programmable Dead Time Generator
  - USI – Universal Serial Interface with Start Condition Detector
  - 10-bit ADC
    - 4 Single Ended Channels
    - 2 Differential ADC Channel Pairs with Programmable Gain (1x, 20x)
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  - debugWIRE On-chip Debug System
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  - External and Internal Interrupt Sources
  - Low Power Idle, ADC Noise Reduction, and Power-down Modes
  - Enhanced Power-on Reset Circuit
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  - Internal Calibrated Oscillator
- I/O and Packages
  - Six Programmable I/O Lines
  - 8-pin PDIP, 8-pin SOIC, 20-pad QFN/MLF, and 8-pin TSSOP (only ATtiny45/V)
- Operating Voltage
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- Speed Grade
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- Industrial Temperature Range
- Low Power Consumption
  - Active Mode:
    - 1 MHz, 1.8V: 300 µA
  - Power-down Mode:
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ATxmega128A4 Features

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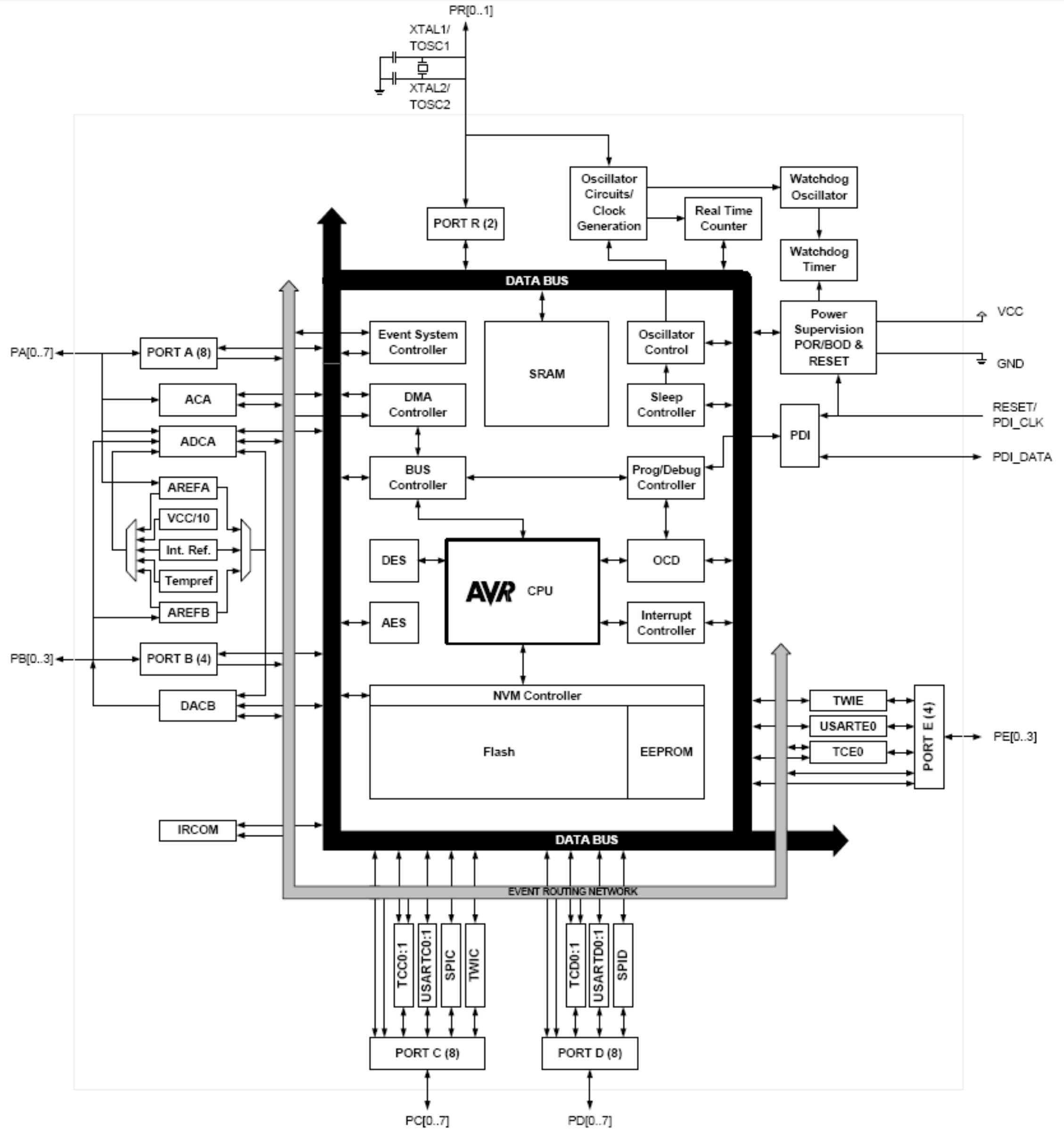
A High-End Microcontroller: ATxmega128A4

Block Diagram of ATxmega128A4



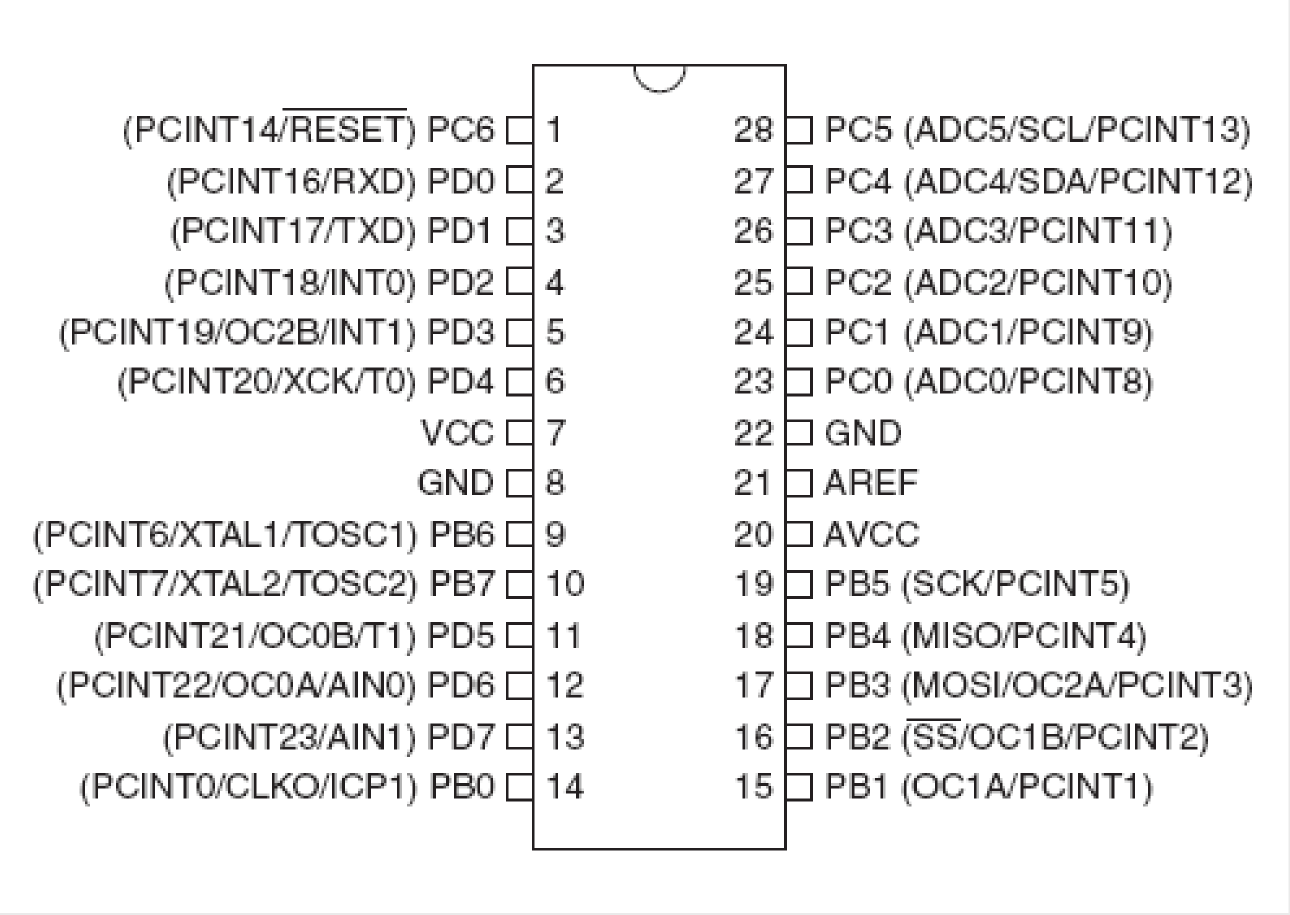
A High-End Microcontroller: ATxmega128A4

ATxmega128A4 Features

- Non-volatile Program and Data Memories
  - 16 KB - 128 KB of In-System Self-Programmable Flash
  - 4 KB - 8 KB Boot Code Section with Independent Lock Bits
  - 1 KB - 2 KB EEPROM
  - 2 KB - 8 KB Internal SRAM
- Peripheral Features
  - Four-channel DMA Controller with support for external requests
  - Eight-channel Event System
  - Five 16-bit Timer/Counters
    - Three Timer/Counters with 4 Output Compare or Input Capture channels
    - Two Timer/Counters with 2 Output Compare or Input Capture channels
    - High-Resolution Extensions on all Timer/Counters
    - Advanced Waveform Extension on one Timer/Counter
  - Five USARTs
    - IrDA Extension on one USART
  - Two Two-Wire Interfaces with dual address match (I^2C and SMBus compatible)
  - Two SPIs (Serial Peripheral Interfaces) peripherals
  - AES and DES Crypto Engine
  - 16-bit Real Time Counter with Separate Oscillator
  - One Twelve-channel, 12-bit, 2 Msps Analog to Digital Converter
  - One Two-channel, 12-bit, 1 Msps Digital to Analog Converter
  - Two Analog Comparators with Window compare function
  - External Interrupts on all General Purpose I/O pins
  - Programmable Watchdog Timer with Separate On-chip Ultra Low Power Oscillator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal and External Clock Options with PLL
  - Programmable Multi-level Interrupt Controller
  - Sleep Modes: Idle, Power-down, Standby, Power-save, Extended Standby
  - Advanced Programming, Test and Debugging Interfaces
    - PDI (Program and Debug Interface) for programming, test and debugging
- I/O and Packages
  - 34 Programmable I/O Lines
  - 44 - lead TQFP
  - 44 - pad VQFN/QFN
  - 49 - ball VFBGA
- Operating Voltage
  - 1.6 – 3.6V
- Speed performance
  - 0 – 12 MHz @ 1.6 – 3.6V
  - 0 – 32 MHz @ 2.7 – 3.6V

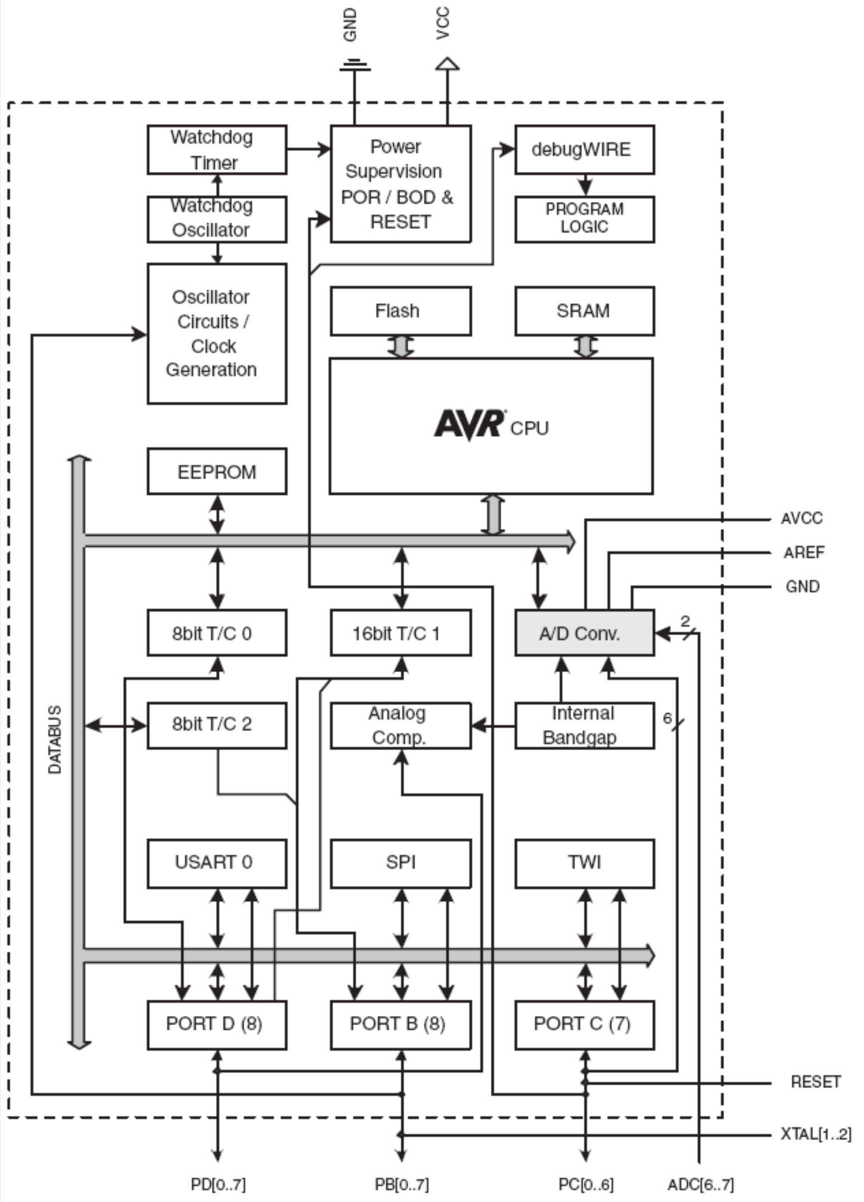
"Smaller" Microntroller: ATmega48P/88P/168P/328P

Pinout for ATmega48P/88P/168P/328P



"Smaller" Microntroller: ATmega48P/88P/168P/328P

Block Diagram for ATmega48P/88P/168P/328P



Some ATmega48P/88P/168P/328P Features

- Clock rate up to 20 MHz
- Up to 20 MIPS throughput at 20 MHz
- 4/8/16/32K Bytes of In-System Self-Programmable Flash Program Memory
- 512/1K/1K/2K Bytes Internal SRAM
- 256/512/512/1K Bytes EEPROM
- 35 digital I/O
- 4 timers
- 2 PWM/Capture/Compare modules
- UART for serial I/O
- 6-channel 10-bit ADC in PDIP Package
- Interrupt sources
- Cost: Approx $2.30 in quantity


"That's all Folks!"