Chapter 1: INTRODUCTION

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EMBEDDED SYSTEMS:

Theory and Applications Using the MSP430

UPRM - Fall 2012

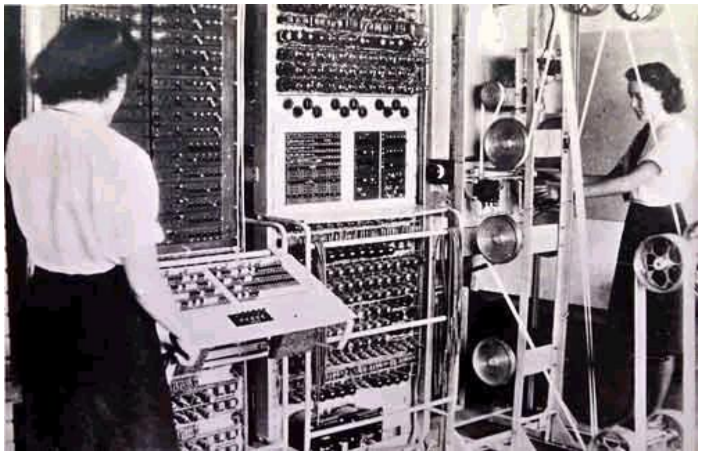
Chapter Outline

- Embedded Systems Overview
  - Early Forms
  - Birth and Evolution of Modern Systems
  - Contemporary Systems
- System Structure
  - Hardware Components
  - Software Components
- System Classification
- Life Cycle of Embedded Designs
- Design Constraints
  - Functionality
  - Cost
  - Performance
  - Power and Energy
  - Time-to-Market
  - Reliability & Maintainability
- Summary

Embedded System Definition

- Electronic systems containing tightly coupled hardware and software components
  - Perform a single function
  - Form part of a larger system
  - Are not intended to be independently programmable by the user
  - Are expected to work with minimal or no human interaction
  - Reactive, Real-time Operation
  - Tightly Constrained

Early Embedded Systems



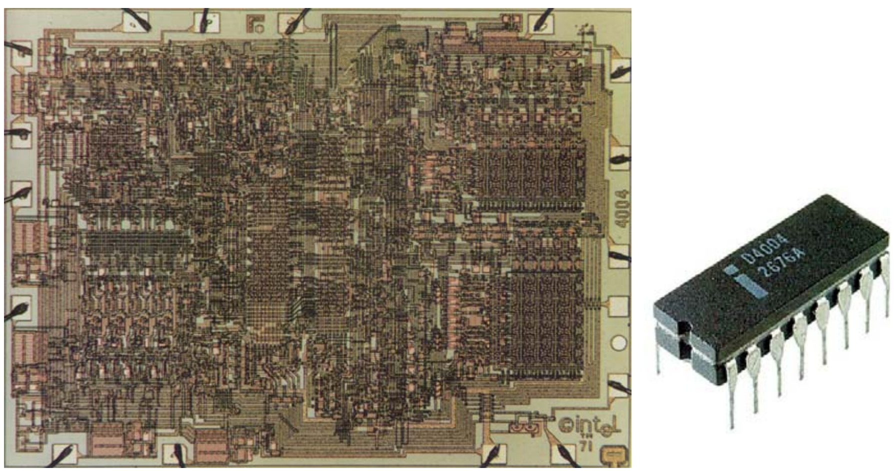
Colossus Mark II

Apollo Guidance Computer

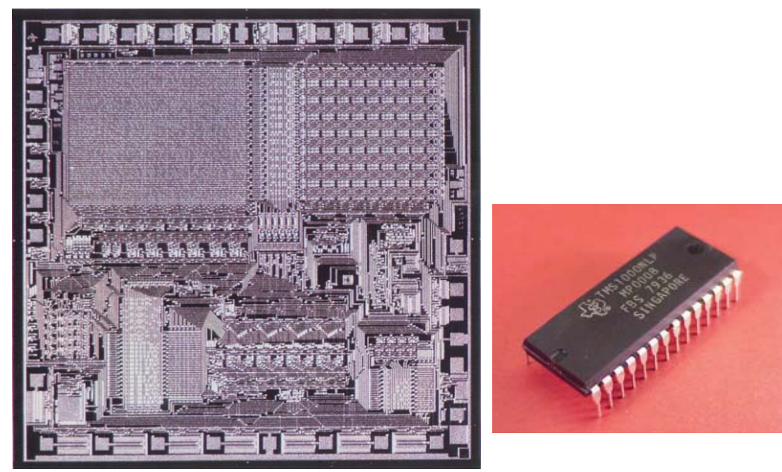
- Early Computers
  - Similar to an ESYS
    - Single functioned
    - Not user programmable
  - Unlike Today's ESYS
    - Large and power thirsty
    - Not integrated
- First Modern ESYS
  - The Apollo Guidance Computer (AGC)
    - Guidance & Navigation
    - CPU+MEM+I/O
    - Assembly Programmed

Modern Embedded Systems

- Born with the Microprocessor
  - TMS1000: The first microcontroller
  - Intel 4004: The first commercial microprocessor
  - US Navy CADC: High-performance embedded system



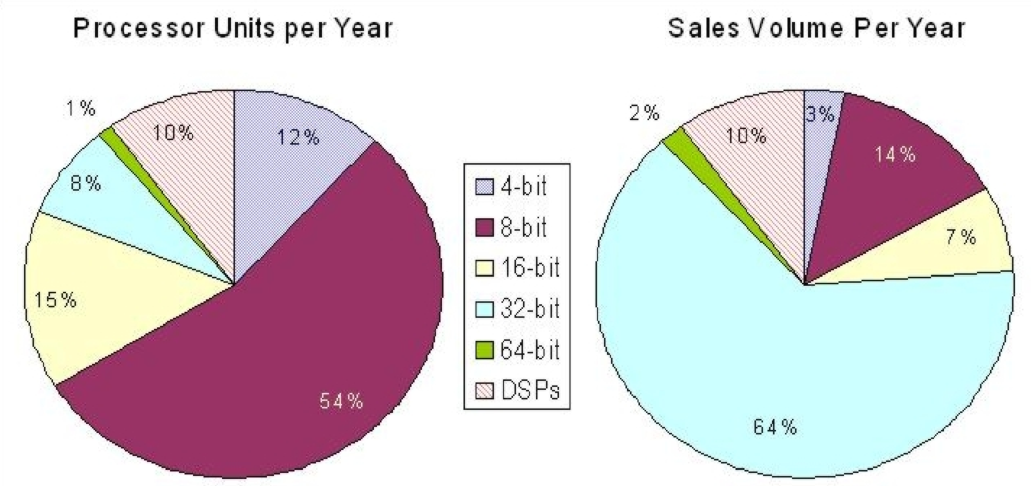
Intel 4004



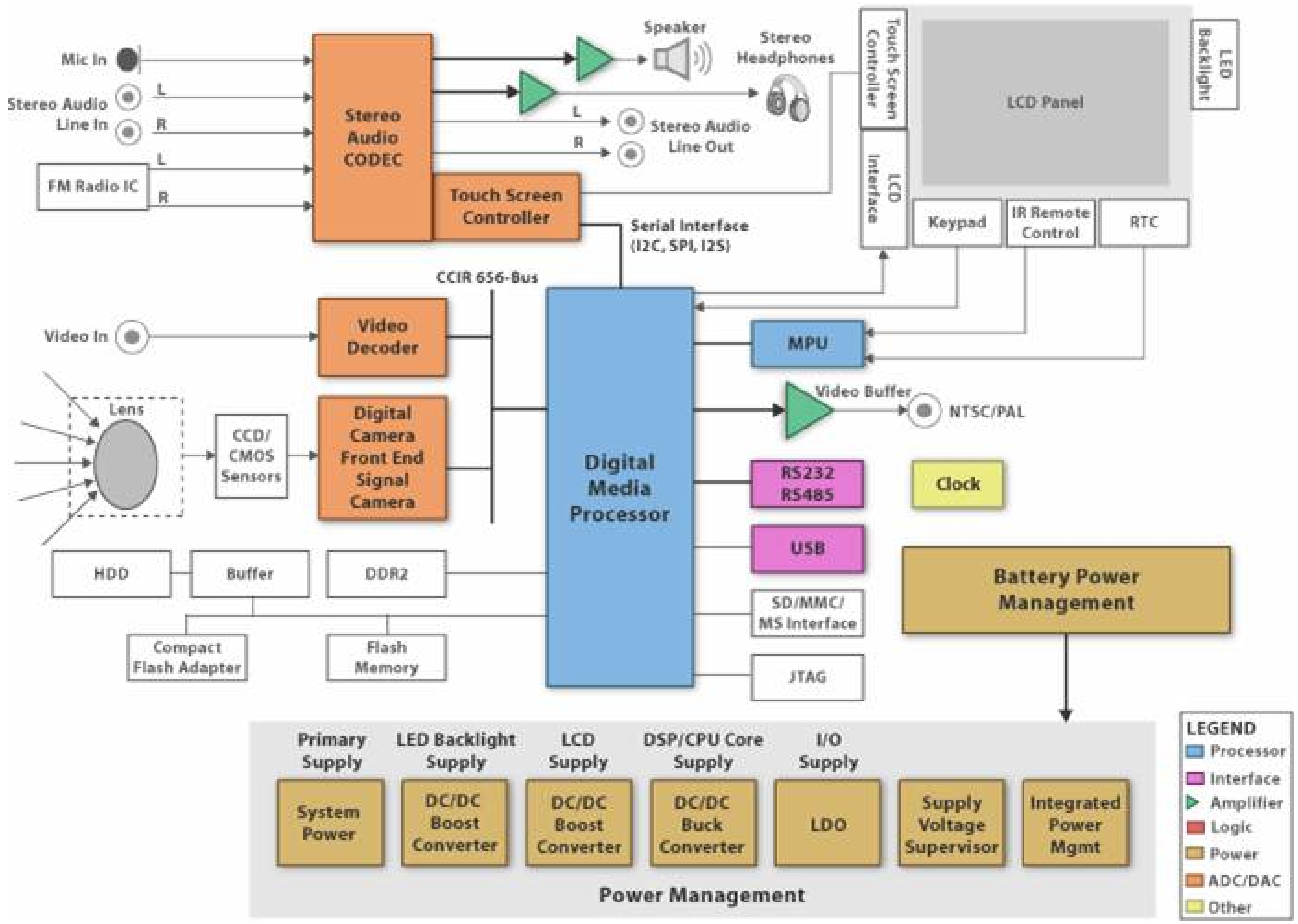
TI's TMS1000

Today's MCU Market

- Plenty of Vendors
  - TI (MSP430)
  - Microchip (PIC)
  - Intel (8051, 80x86)
  - Freescale (HC11, HC08)
  - Zilog (Z80, Z8000)
  - ARM Ltd. (ARM7)
  - Natl. Inst (COP)
- Plenty of Sizes
  - 4-bit, 8-bit, 16-bit, 32-bit, 64-bit
  - CISC Vs. RISC
  - Harvard Vs. vonNeumann
- Wide Market
  - Over 6 Billion chips per year
  - Nearly $50 billion sales



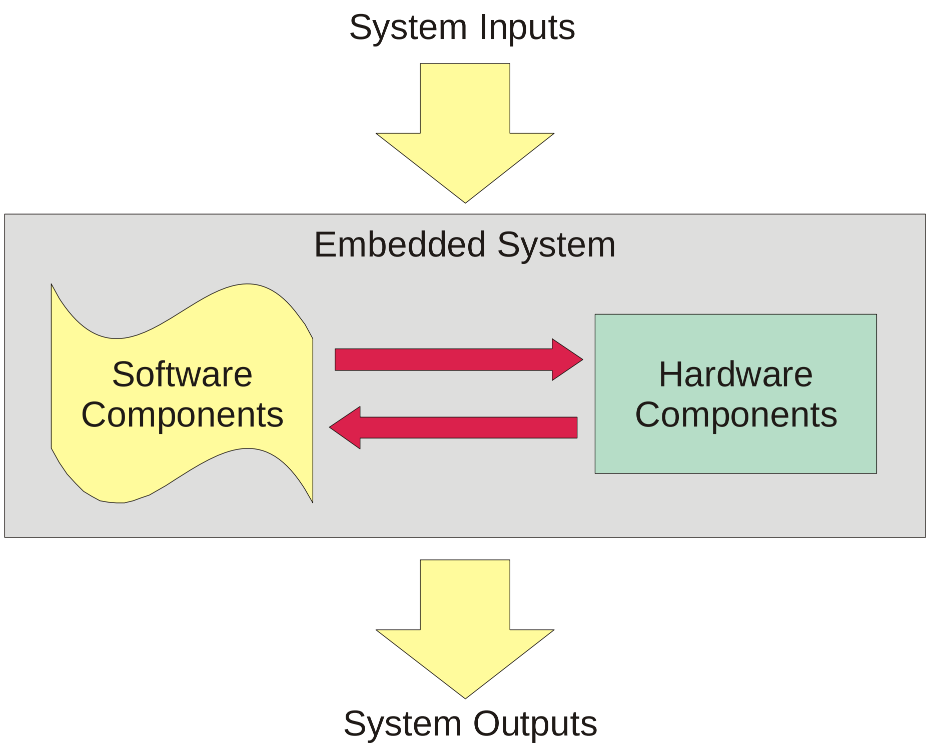
Contemporary Systems



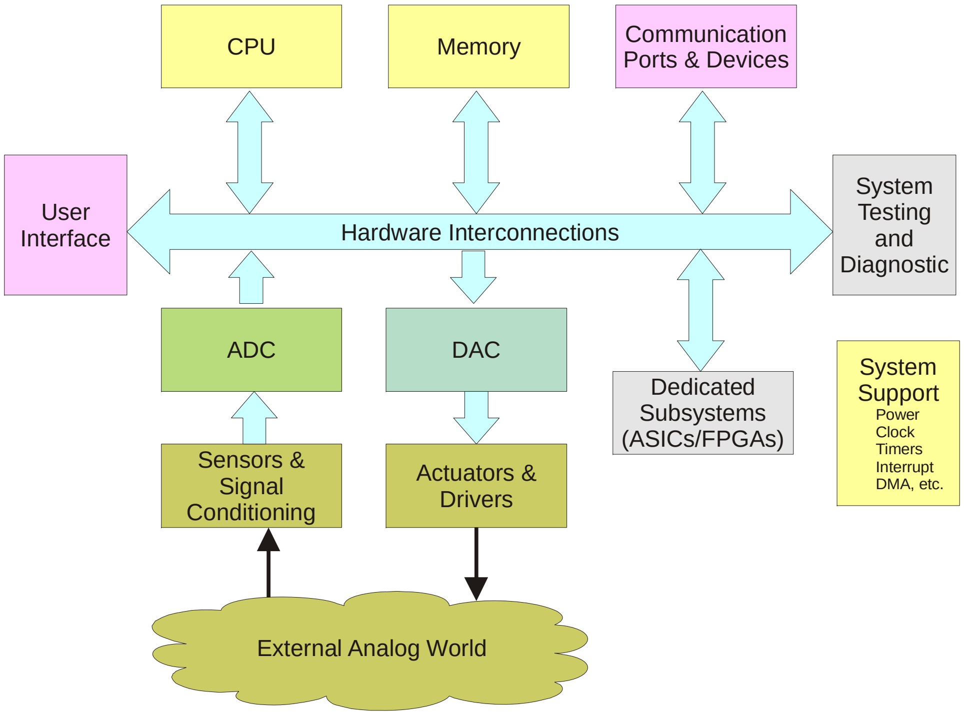
Media Player Example

Embedded System Structure

- Hardware Components: Electronics Infrastructure
  - CPU
  - Memory
  - I/O Subsystem
- Software Components: System Functionality
  - Firmware
  - Operating System
  - Application Programs

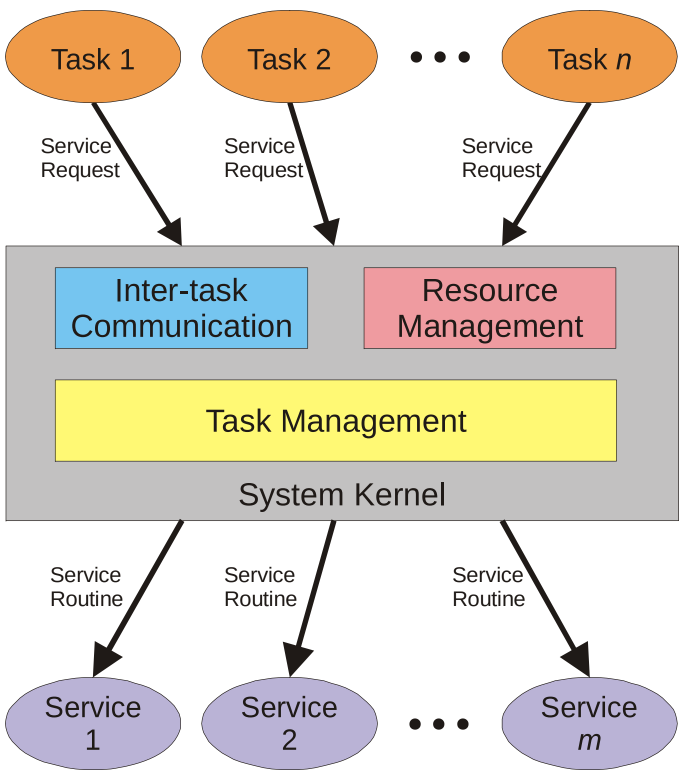


Hardware Components



- Central Processing Unit
  - Registers, ALU, CU
- Memory
  - Program Memory
  - Data Memory
- I/O Devices
  - Communication Ports
  - User Interfaces
  - Sensors & Actuators
  - Diagnostics Support
  - System controllers
  - Dedicated Hardware

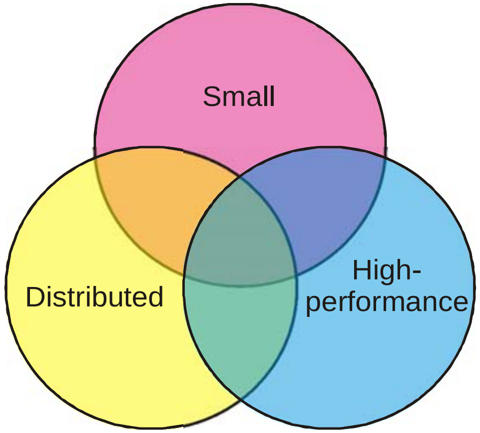
Software Components



- System Tasks
  - Actions making use of system resources
- System Kernel
  - Component managing system resources
  - Coordinates task services
- Services
  - Routines performing specific tasks

Types of Embedded Systems

- Small
  - MCU-based, low component count
  - Large volume
  - Single tasked
  - Low-cost, maintenance free
- Distributed
  - Multi-chip, board-level
  - Multi-tasked
  - Medium volume & cost
  - Maintainable, upgradeable
- High-performance
  - Dedicated board-level hardware
  - Task intensive, RTOS-based
  - Low-volume, high cost
  - High maintenance



Embedded Systems Life Cycle

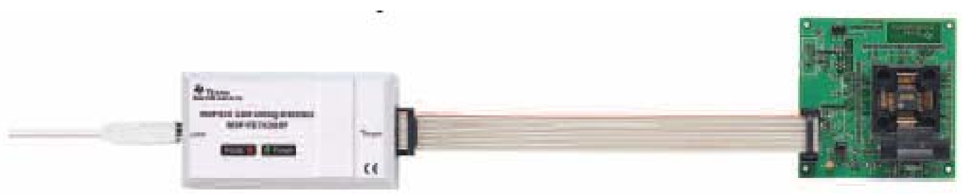
- Birth
  - Need & opportunity
  - Specifications
- Design
  - Proof-of-concept
  - Manufacturing design
- Growth
  - Production & deployment
- Maturity
  - Maintenance & upgrade
- Decline
  - System disposal

Design Constraints

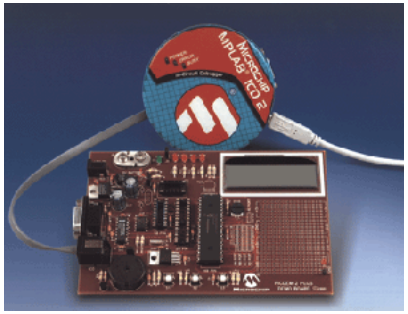
- **Functionality**
  - System ability to perform the function it was designed for (REQ)
- **Cost**
  - Amount of resources needed to conceive, design, and produce an embedded system
- **Performance**
  - System ability to perform its function in time.
  - Affected by both HW & SW factors
- **Size**
  - Physical space taken by a system solution.
- **Power and Energy**
  - Energy required by a system to perform its function.
- **Time to Market**
  - The time it takes from system conception to deployment.
- **Maintainability**
  - System ability to be kept functional during its mature life.

Functionality

- Functional verification is a difficult task
  - Can consume up to 70% of development time
- Verification Methods
  - Simulation Techniques
    - Behavioral (HDL-based)
    - Logic (Circuit Modeling)
    - Processor (Software)
  - JTAG Debugger
    - Hardware supported through dedicated ports
    - Used also for testing (boundary scan test)
    - Cost effective



MSP430 FET Tool
Courtesy of Texas Instruments Inc.



PIC In-circuit Debugger
Courtesy of Microchip Corporation

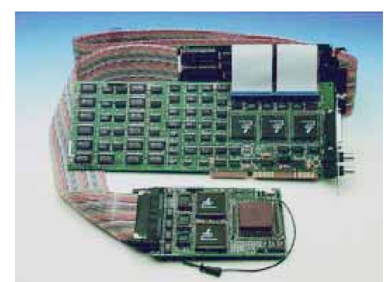
Functionality (Cont.)

- In-Circuit Emulators
  - Replace MCU in target system
  - A powerful debugger
  - Expensive
- ROM Monitors
  - Monitor functions in ROM
  - Status sent via serial port

68HC11 In-circuit Emulator
Courtesy of Nohau Systems

8051 In-circuit Emulator
Courtesy of Signum Systems

ICE Test Pod
Courtesy of Signum Systems



8086 In-circuit Emulator
Courtesy of Nohau Systems

System Cost

- The cost of a given Volume (V) of units:

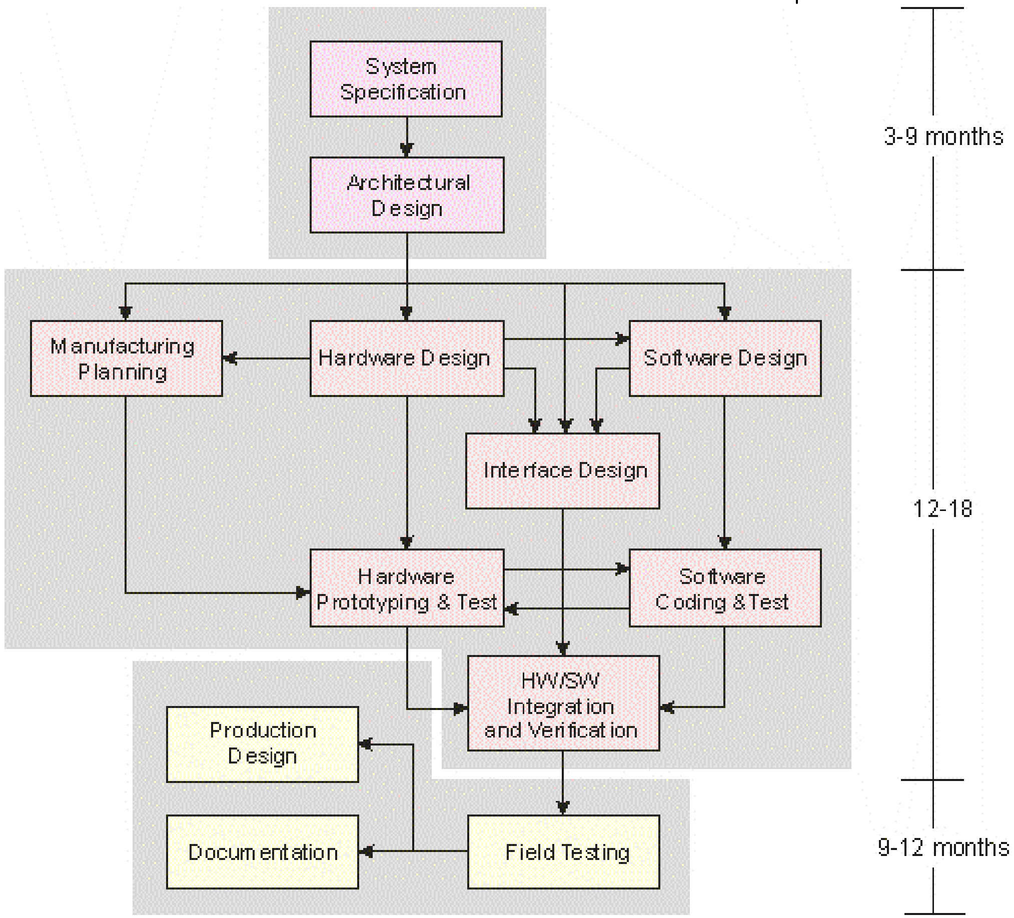
$$C_T = NRE + (RP \cdot V) \therefore$$

$$U_C = \frac{C_T}{V} = \frac{NRE}{V} + RP$$

- NRE = Non-Recurrent Engineering costs (Fixed)
  - Investment to complete all design aspects
  - Very large and independent of volume in C_T
  - Include man-hours, infrastructure, and R&D
- RP = Recurrent Production costs (Variable)
  - Expenses in producing each unit of a given volume
  - Small but affected by V in C_T
  - Include components, boards, packages, and testing

COTS-based NRE Costs

- *Commercial off-the-shelf* parts-based design
  - Traditional methodology for Embedded Systems
  - Minimizes Hardware costs
  - Increases design & verification costs
- NREs in U_C are diluted by a large production volume
- Balance between technology choice and production volume



Performance: HW Factors

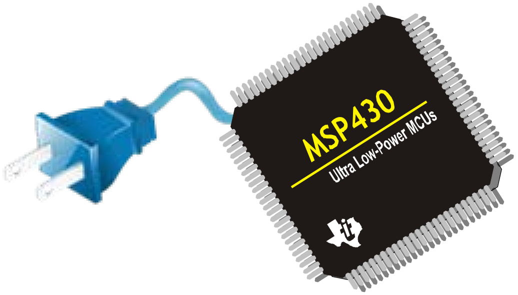
- Clock Frequency
  - System clock speed: not an absolute performance metric
- Architecture
  - Determines how clock cycles are used
- Component Speed
  - Response time and access time
- Handshaking
  - Signalization required to complete a transaction
- Low-power Modes
  - Wake-up times might affect application speed
- High speed is *expensive!!!*
  - Use it wisely

Performance: SW Factors

- Algorithm Complexity
  - Steps and resources needed to complete a task
- Task Scheduling
  - Affects waiting time in multitasking system
- Inter-task Communication
  - Time taken by tasks to exchange information
- Level of Parallelism
  - Software usage of system hardware resources

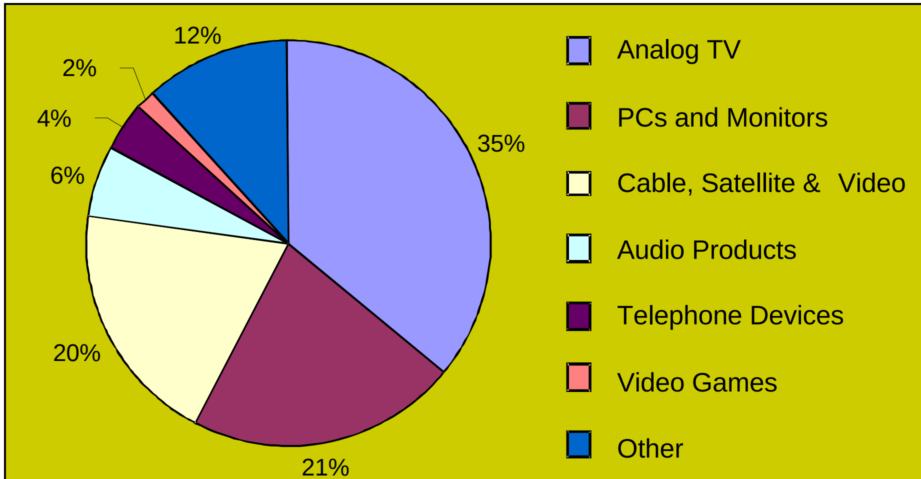
Power & Energy

- Critical parameter for a long chain of design events
  - System reliability
    - Stress, noise, and heat
  - Cooling Costs
    - High power = lot of heat to remove
  - Power Supply Requirements
    - Larger batteries of power supply
  - Size, Weight, and Form
    - Mechanical system parameters affected by heat density



Power & Energy (Cont.)

- Environmental Impact of Embedded Systems
  - Average individual uses 60 microprocessors per day
  - Household electronics accounts for 11% of all energy consumed in the USA
    - 147,000,000,000 KWh (147TWh) per year
  - Excludes digital TVs and large appliances
  - Excludes industry, schools, hospitals, etc
  - Trend continues to grow… Is there a limit?



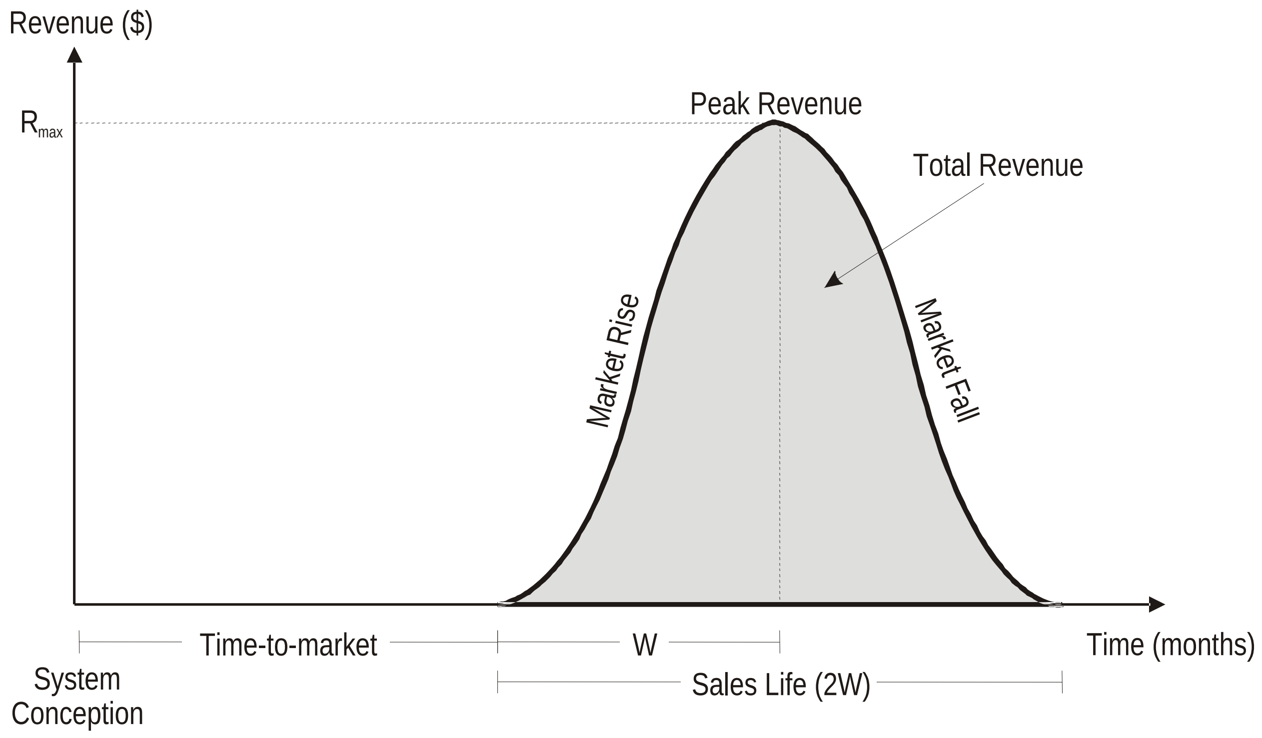
Household Energy Usage in the US (2006)

Power and Energy (Cont.)

- Save the Planet! Design Power Efficient Embedded Systems
  - Use low-power MCUs and peripherals
    - Activate CPU standby and sleep modes
  - Write power efficient code
    - Every wasted CPU cycle is energy that will never come back
  - Use power management techniques
    - Power and clock gating plus efficient coding techniques

Time-to-Market

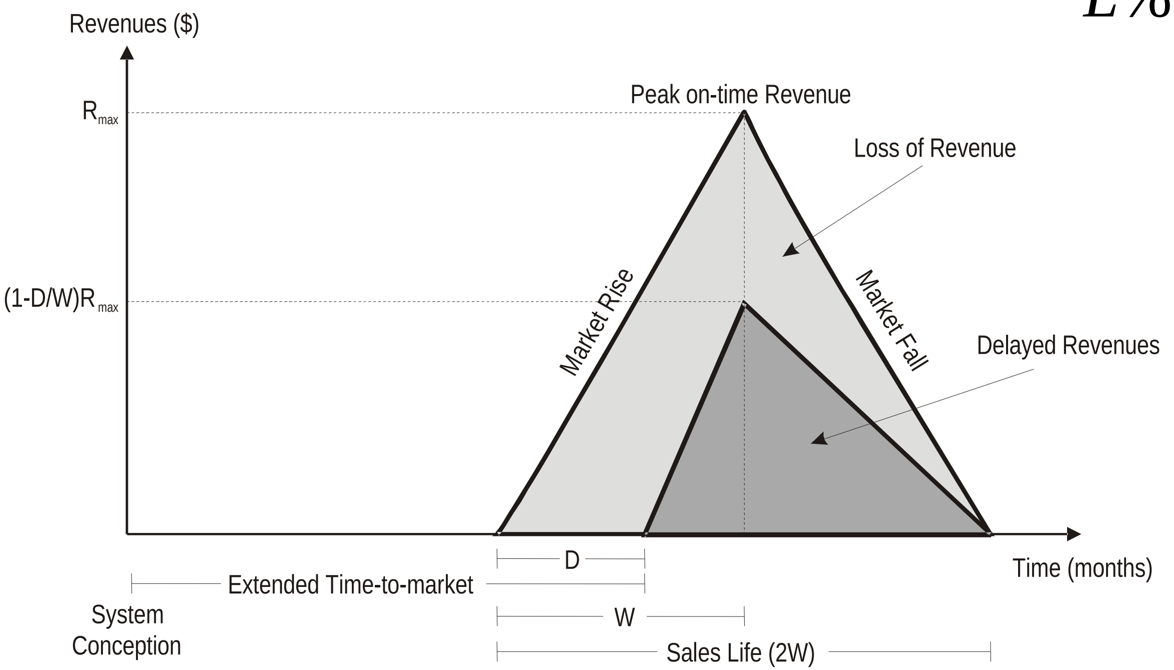
- Critical Constraint for Applications with a Narrow Market Window (W)



Time-to-Market (Cont.)

- A Moderate Market Entry Delay Could Cause a Large Loss of Revenue

$$L\% = \frac{D(3W - D)}{2W^2} \times 100\%$$



Assume:

- 2W = 24 months
- D = 4 months

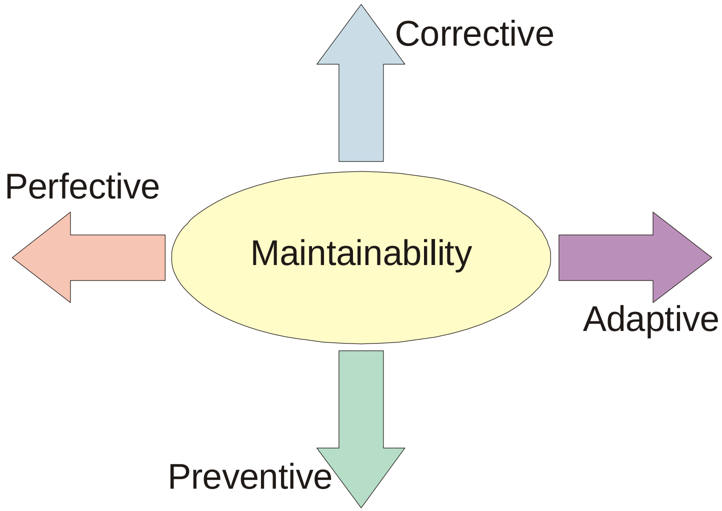
Estimated Revenue Loss:

- L% = 50%

Maintainability

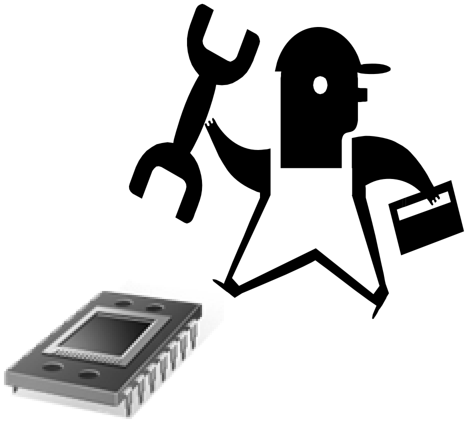
- Maintenance enables reliable system operation throughout entire useful life
- Relevance of maintenance depends on application
  - Expected lifespan
  - Application criticality
- Maintainability is a design requirement
  - Must be included among system specifications
- Must consider both aspects:
  - Hardware Maintenance
  - Software Maintenance

- Four maintenance dimensions
  - Corrective: Fixes faults
  - Adaptive: Copes with a changing environment
  - Perfective: Adds enhancements
  - Preventive: Anticipates events



Hardware Maintenance Issues

- Increased NREs
  - Design overhead to support HW maintenance
- Time-to-market Impact
  - Additional development time
- Increases Recurrent Cost
  - More components in system
- Component Obsolescence
  - Limit system useful life span



Software Maintenance Issues

- Hardware Constraints
  - Stringent HW constraints leave little room for support functions
- Cost of Verification
  - Undiscovered software bugs become maintenance headaches
- Inadequate Code Documentation
  - Meaningful and up-to-date
- Technology Changes
  - Compatibility with tool newer versions
- Ripple Effect of Changes
  - Identifying effect down the code
- Qualified Personnel
  - Everybody wants to design

Summary

- Birth and evolution of Embedded Systems
  - From origins to current trends
- Embedded Systems Structure & Classification
  - Hardware and software components
  - Scope and consideration for diverse target applications
- Life Cycle of Embedded Applications
  - Global perspective from birth to disposal
- Design Constraints and Challenges
  - Functionality, cost, performance, energy, time-to-market, and maintenance
- Overall view of implications of design decisions