Embedded Systems

- Other computers such as PCs, laptops, workstations or mainframes – are wide-spread in our daily life.
- Definition: Embedded Systems
  are hidden computing or control systems that are embedded in electrical devices.
- Features:
  - Executes a function (repeatedly)
  - Strong conditions/constraints like costs, energy, measurement …
  - Real time reaction
- Example: Digital camera
  - Function: Taking a picture
  - Conditions: low cost, low power, small/light
  - Photos are generated and saved in limited time frame

Examples

- Data processing
  - Point Of Sale (POS)
  - Handheld computing
- Wired and Wireless communications
  - Networking
  - Handsets
- Consumer electronics
  - Digital cameras
  - Gaming equipment
- Automotive
  - Infotainment
  - Safety and control
- Industrial
  - Medical
  - Automation and drives …









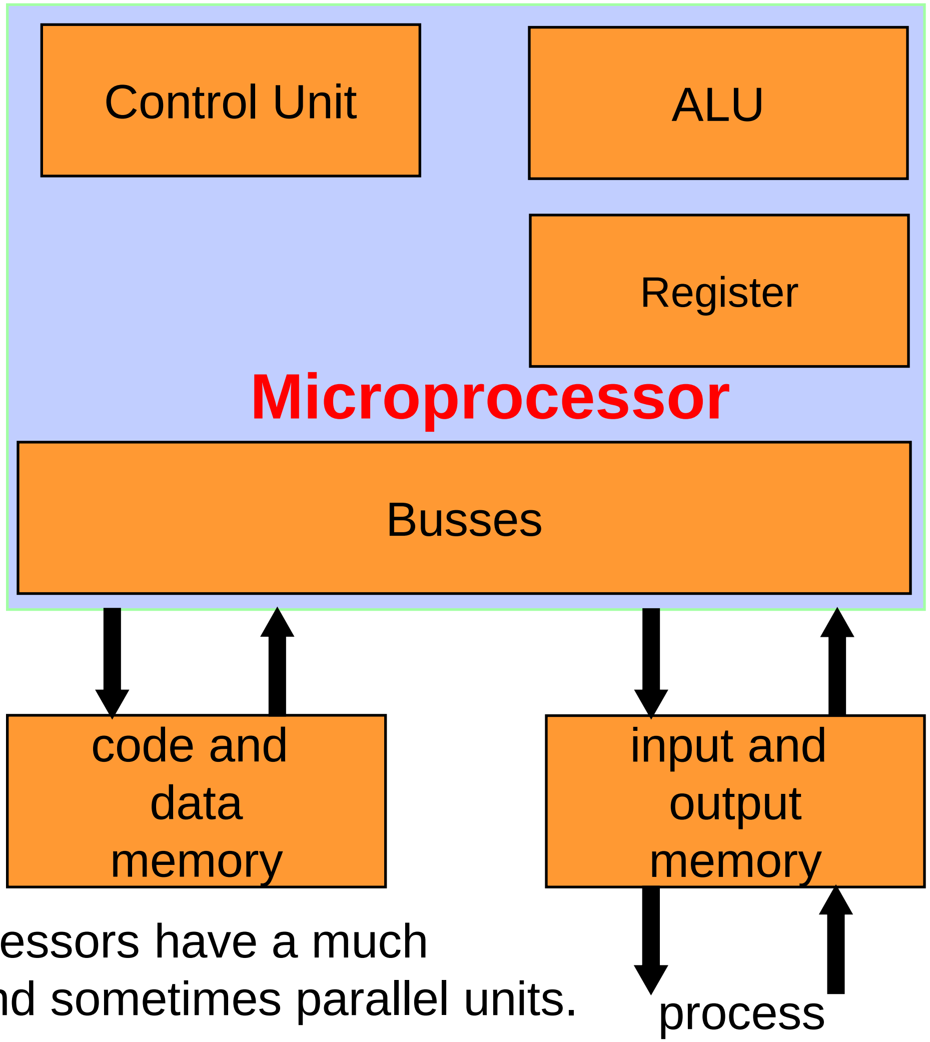
Microprocessors

- Embedded systems are part of our daily life
- Devices contain embedded microprocessors
- Widely-used specialised microprocessors are: microcontrollers and digital signal processors
- The Cortex™-M3 is a microcontroller family designed for embedded systems

Microprocessors

- Central Processing Unit (CPU)
  - Arithmetic-Logic Unit (ALU): numerical operations
  - Control unit: controlling execution flow
    - Address unit
      - Read data and instruction from memory; write data into memory
    - Instruction decoder
      - Analyses current instruction and controls subsequent actions of other modules
  - Registers – a few internal memory cells for operands
    - Store data for instantaneous instruction and computation
    - Program counter (PC), status register (SR), stack pointer (SP)
    - General purpose
  - Busses: address-, data-, control-bus
- Microprocessor (µP, MP)
  - CPU integrated on a chip
- Microcomputer: a system using one or more microprocessor(s) and central device(s)
- Note: A µP needs additional external devices to operate properly

Block Diagram



- Note:
  - Modern microprocessors have a much finer granularity and sometimes parallel units.
  - However, the basics are still very much the same.

Arithmetic Logic Unit

- Arithmetic Logic Unit (ALU)
  calculates arithmetical and / or logical functions:
- At least:
  - Arithmetical: Addition (ADD)
  - Logical: Negation (NEG)
    Conjunction (AND)
- Typical:
  - Arithmetical: Subtraction (SUB)
    Multiplication (MUL)
  - Logical: Comparison (CMP)
    Disjunction (OR)
    Antivalence (EXOR)
  - Miscellaneous: Right- and Left Shift (ASR,ASL)
    Rotation (ROL, ROR)
    Register-Bit-Manipulation (set, clear, toggle, test)

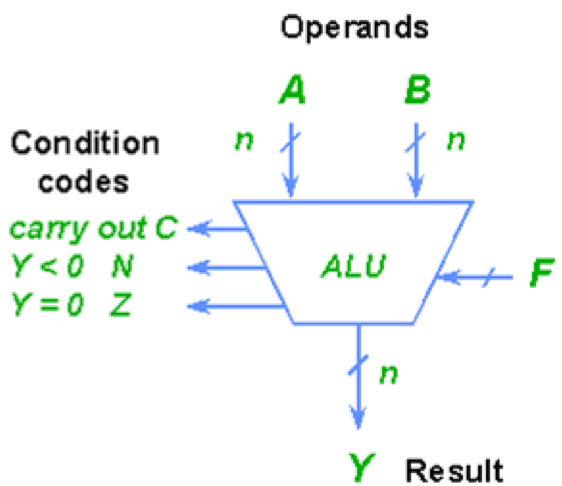
Arithmetic Logic Unit (cont.)

- An ALU is able to process two binary values with equal length (N) $\rightarrow$ N-Bit ALU with N = 4, 8,16, 32 or 64
- Most ALUs process Fixed Point Numbers
- A few ALUs, used especially those in Digital Signal Processors and desktop processors are capable of operating on both Floating Point Numbers and on Fixed Point Numbers.

Example: a simple ALU structure

Arithmetic/Logic Unit (ALU)

Purely combinational logic

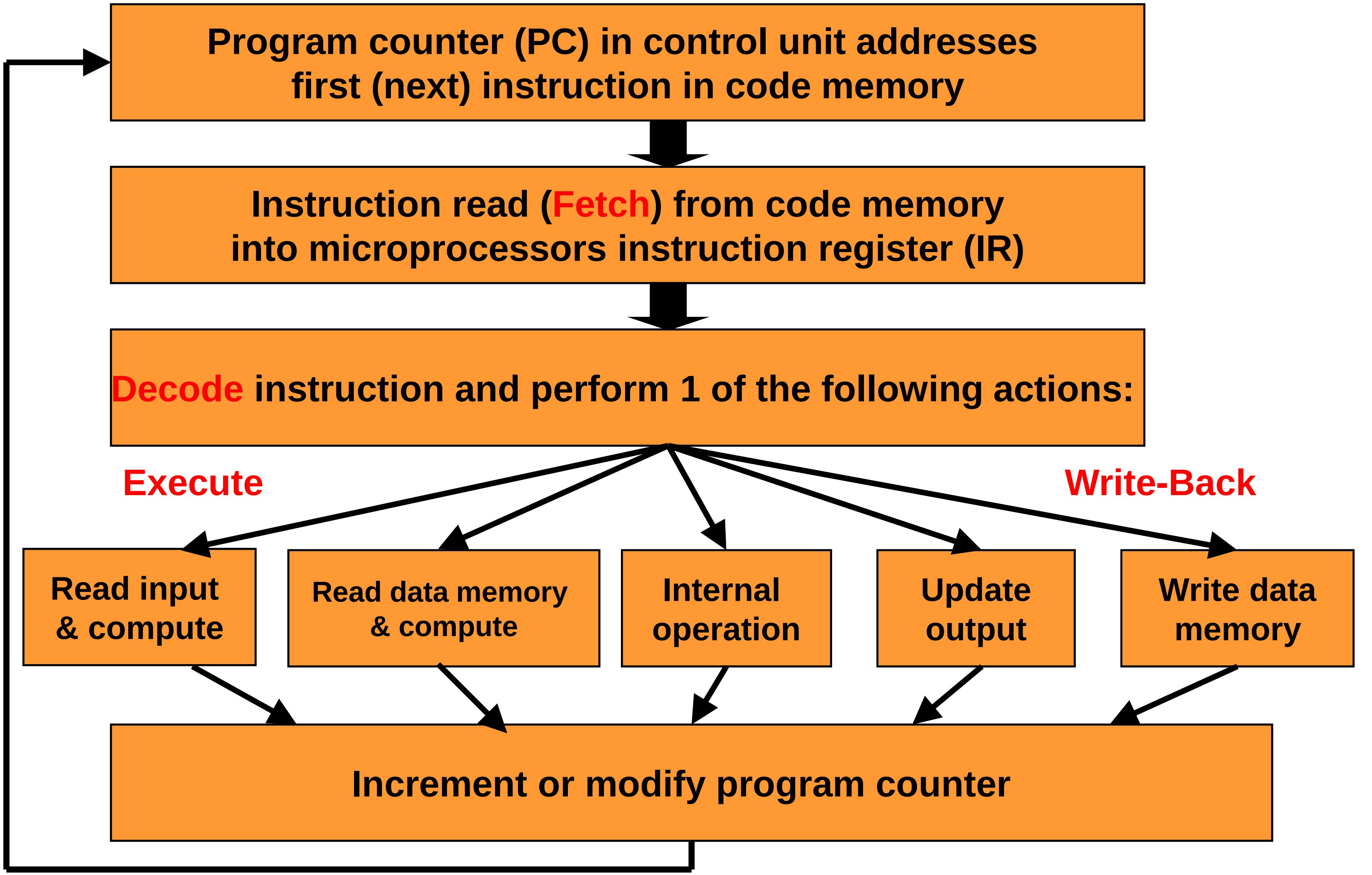


F	Y
000	A + B
001	A - B
010	A - 1
011	A and B
100	A or B
101	A * B
.	
.	

A, B, Y: **Internal register**
F: **Functional code**
C: **Carry – Bit**
N: **Negative – Bit**
Z: **Zero - Bit**

- Note:
  - Most ALUs will generate a size of 2*n for register Y in case of a multiply operation Y = A * B
  - ALUs are also available as standalone ICs:
    - SN 74 LS 181

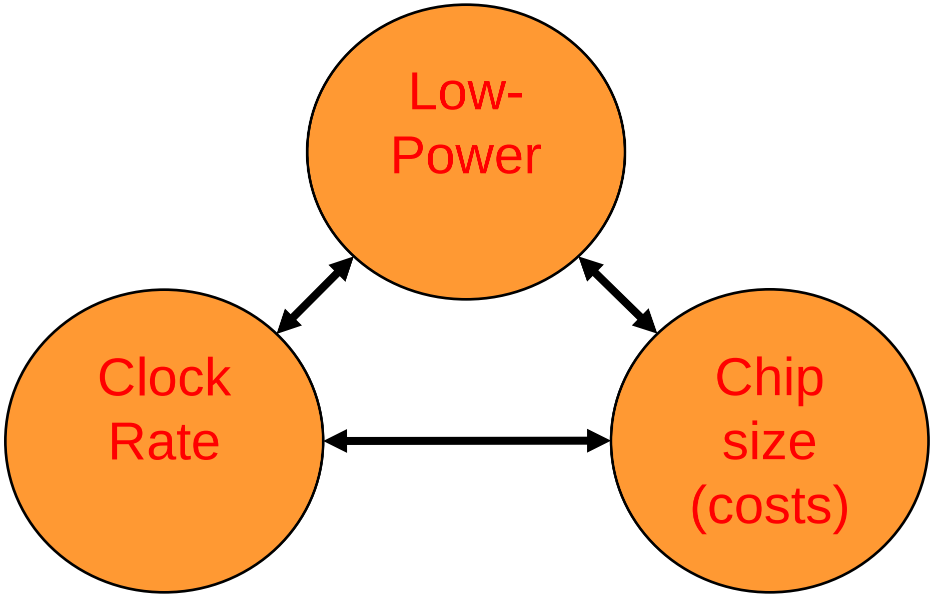
Control Unit: execution flow



Characteristics

- Important selection features:
  - Word length:
    - Typical 16 or 32 bits
    - Important feature for performance
  - Clock Cycles:
    - Million Instructions Per Second (MIPS)
    - Cycles Per Instruction (CPI)
    - depends on architecture
  - Clock frequency [Hz] (f_{CLK}):
    - Frequency of an crystal oscillator
  - Low-Power (CMOS):
    - $P = \sigma \cdot f_{CLK} \cdot C_L \cdot V_{DD}^2$
      - σ: switching activity
      - f_{CLK}: clock frequency
      - C_L: load capacitance
      - V_{DD}: supply voltage
    - Important for longer battery life
  - Architecture:
    - Von Neumann, Harvard
  - Instruction set:
    - CISC, RISC

Embedded System trade-offs



History

- First Microprocessor – Intel 4004 [5]:
  - Production start: 1971
  - Complexity: approx. 2,300 transistors; today: > 1,000,000,000 transistors
  - Integration: gate number
    - < 100 Small Scale Integration (SSI)
    - > today: 1 million gates
  - Clock rate (f_{CLK}): < 1 MHz; today: > 4 GHz
  - Word length: 4 bits; today > 64 bits
- First Microcontroller – TI TMS1000
  - Production start: 1974
  - Clock rate: 0.4 MHz
  - Word length: 4 bits
- Note: Typical features for Embedded Systems.
  - Clock rate: 100 MHz
  - Word length: 32 bits

Architectures

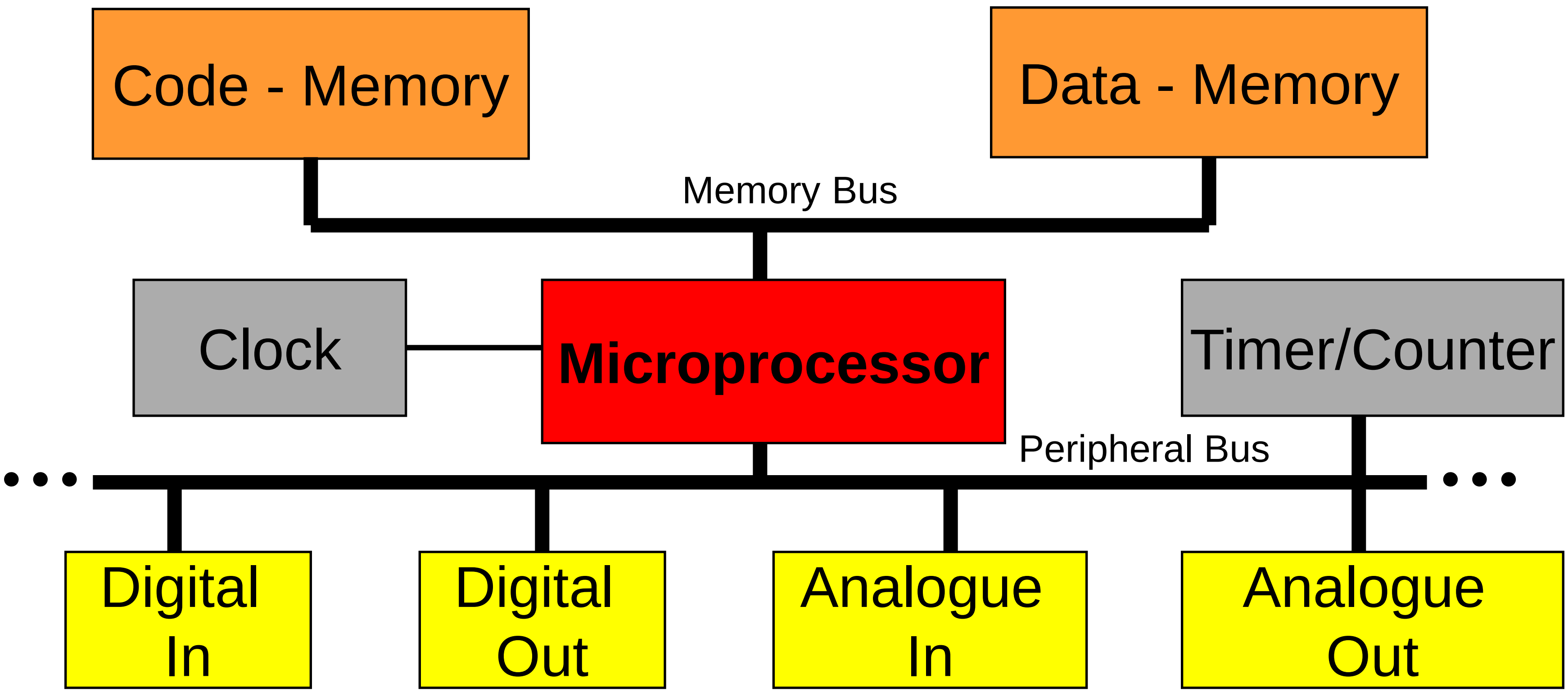
- Two basic microprocessor architectures:
  - “Von Neumann”- Architecture
  - “Harvard” - Architecture
- “Von Neumann” - Architecture:
  - Shared memory space between code and data
  - Shared memory busses between code and data
  - Example: typically microcontrollers
    such as the TI MSP430 family, Motorola 68000 family
- “Harvard” – Architecture:
  - Two independent memory spaces for code and data
  - Two memory bus systems for code and data
  - Example: typically Digital Signal Processors (DSPs)
    such as the TI C2000, C5000 and C6000 family, Intel 8051 family, PIC family

CISC/RISC

- Complex Instruction Set Computer (CISC)
  - Between 1971 until ≈ 1980 favoured architecture for general purpose processors
  - Extensive and complex instructions sets
- Reduced Instruction Set Computer (RISC)
  - Since 1980
  - Features
    - Single cycle instructions: one instruction per clock
      - CPI=1; Clock Cycle per Instruction (CPI)
    - Uniform instructions: all instructions have the same format
    - Load/Store architecture: only a few commands have memory-access
    - High-level languages support: architectures and compilers are co-coordinated
- Note: Today's Microprocessor architectures have the advantages of both CISC and RISC – these architectures are called Hybrid Architectures

Our Desktop – PC is a?

- Microcomputer
  - Microcomputer = microprocessor (µP) + memory + peripherals
  - Example: your Desktop -PC



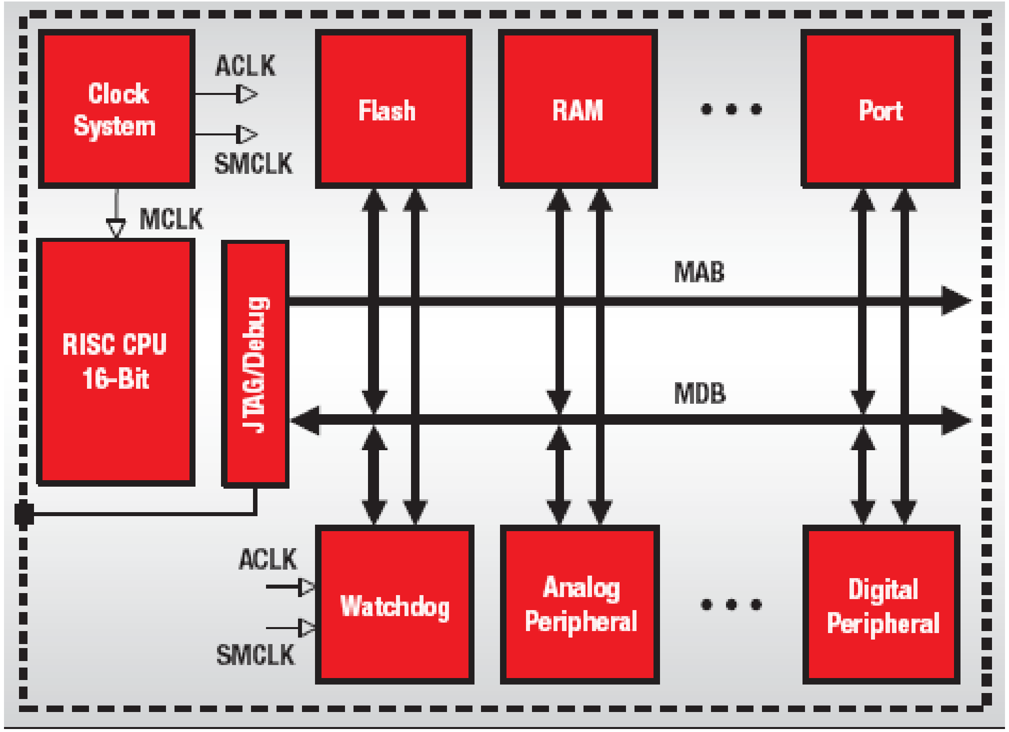
Microcomputer - peripherals

- Peripherals include
  - Digital Input / Output
  - Analogue to Digital Converter (ADC)
  - Digital to Analogue Converter (DAC)
  - Timer / Counter units
  - Pulse Width Modulation (PWM) Digital Output Lines
  - Digital Capture Input Lines
  - Direct Memory Access (DMA)
  - Network Interface Units:
    - Serial Communication Interface (SCI) - UART
    - Serial Peripheral Interface (SPI)
    - Inter Integrated Circuit (I^2C) – Bus
    - Controller Area Network (CAN)
    - Local Interconnect Network (LIN)
    - Universal Serial Bus (USB)
    - Local / Wide Area Networks (LAN, WAN)
  - Graphical Output Devices
  - and more …

Microcontroller

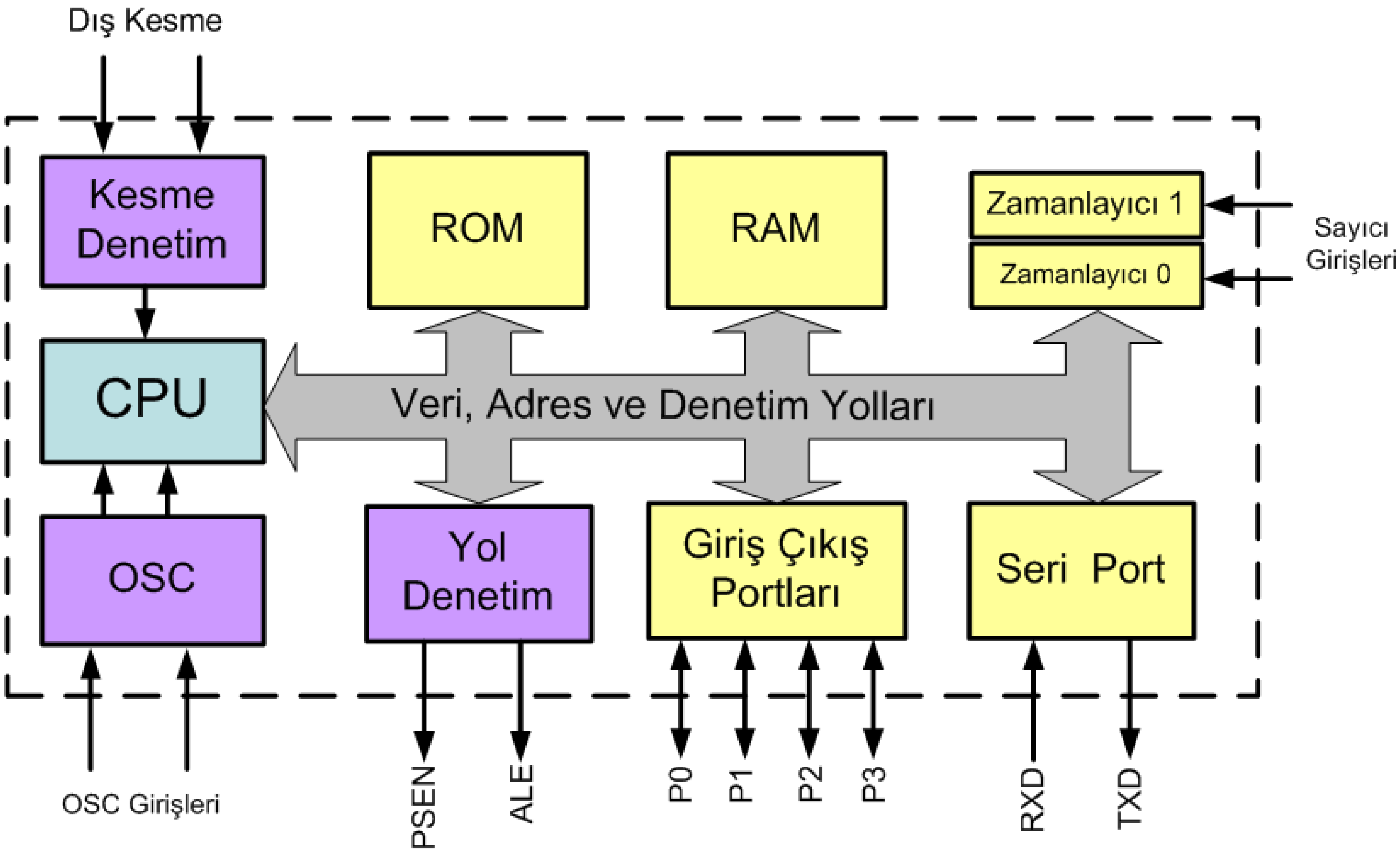
- Microcontroller (µC, MCU)
  - Nothing more than a Microcomputer as a single silicon chip!
    - A System On Chip (SOC)
  - All computing power and input/output channels that are required to design a real time control system are “on chip”
  - Guarantee cost efficient and powerful solutions for embedded control applications
  - Backbone of almost every type of modern product
  - Over 200 independent families of µC
  - Both µP – Architectures (“Von Neumann” and “Harvard”) are used inside Microcontrollers

Example: µC MSP430



- Note: Texas Instruments MSP430
  Von Neumann architecture:
  all program, data memory and peripherals
  share a common bus structure.

Example: μC 8051



- Note: Intel 8051 core Microcontroller Harvard architecture: program, data memory and peripherals have different bus structure.

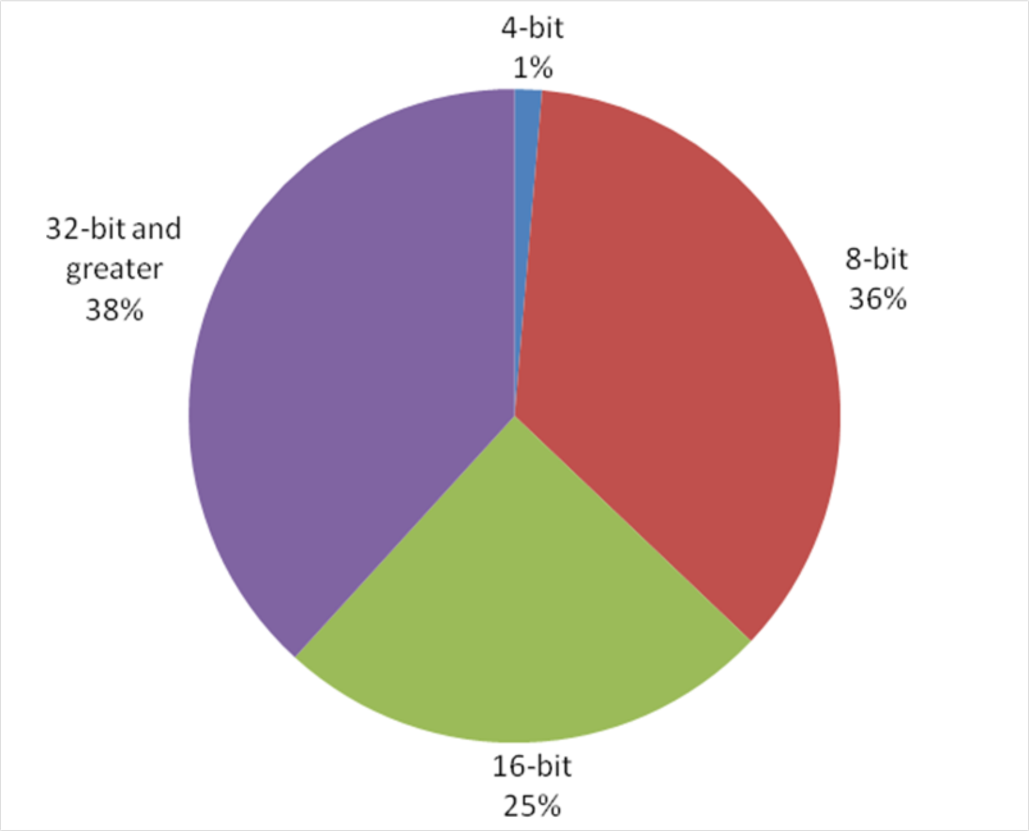
Digital Signal Processor

- A Digital Signal Processor (DSP) is
  - Similar to a microprocessor (µP), e.g. core of a computing system
  - Additional Hardware Units to speed up computing of sophisticated mathematical operations:
    - Additional Hardware Multiply Unit(s)
    - Additional Pointer Arithmetic Unit(s)
    - Additional Bus Systems for parallel access
    - Additional Hardware Shifter for scaling and/or multiply/divide by 2^n
  - Example: Texas Instruments C5000 DSP – family
- Note: Most Embedded Systems use Microcontrollers and Digital Signal Processors

Digital Signal Controller

- Digital Signal Controller (DSC)
  - Recall: a Microcontroller (MCU) is a single chip Microcomputer with a Microprocessor (µP) as core unit.
  - Now: a Digital Signal Controller (DSC) is a single chip Microcomputer with a Digital Signal Processor (DSP) as core unit.
  - By combining the computing power of a DSP with memory and peripherals in one single device we derive the most effective solution for embedded real time control solutions that require lots of math operations.
  - Example: Texas Instruments C2000 DSC – family

MCU Market Segmentation

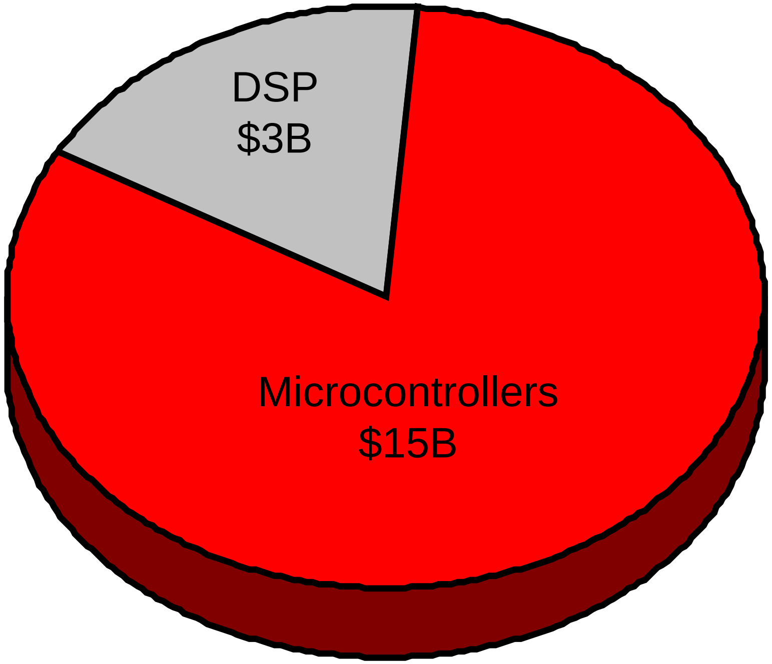


Source: WSTS 2010 MCU TAM by architecture

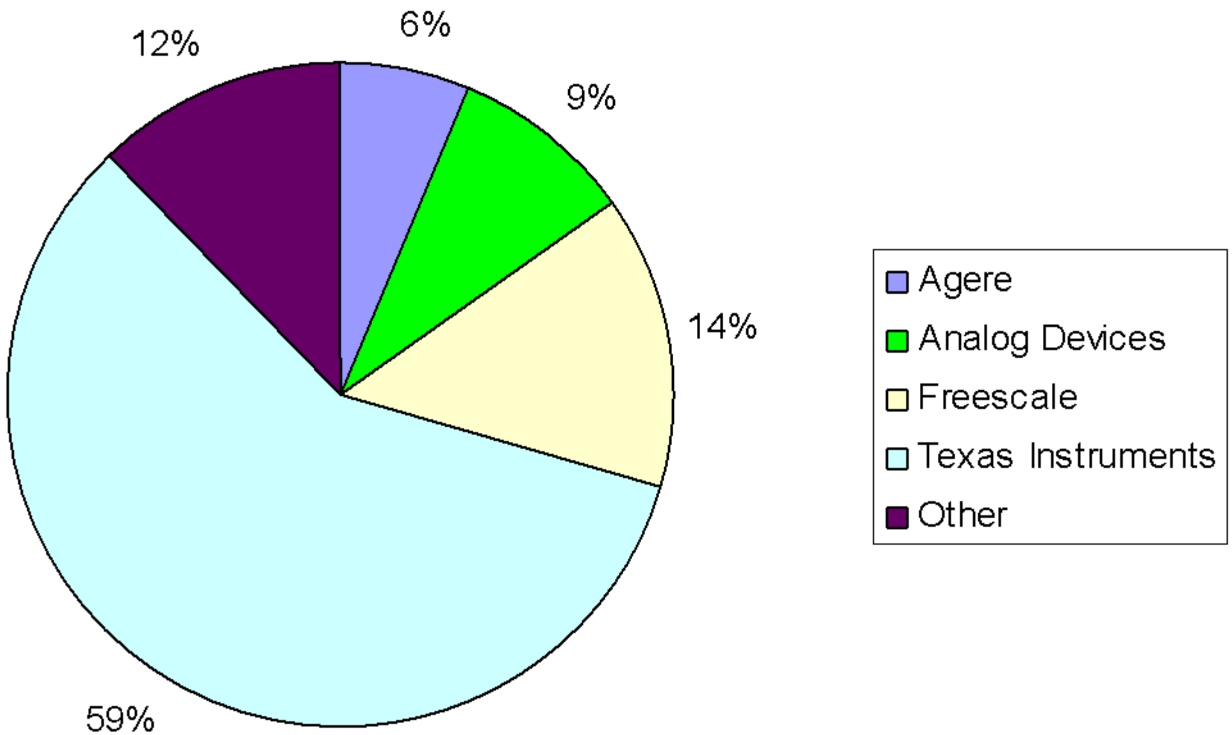
Embedded Processing Market

- Projected annual growth of 7% per year
- ~12 Billion units

Embedded Processing Market 2010 $18B



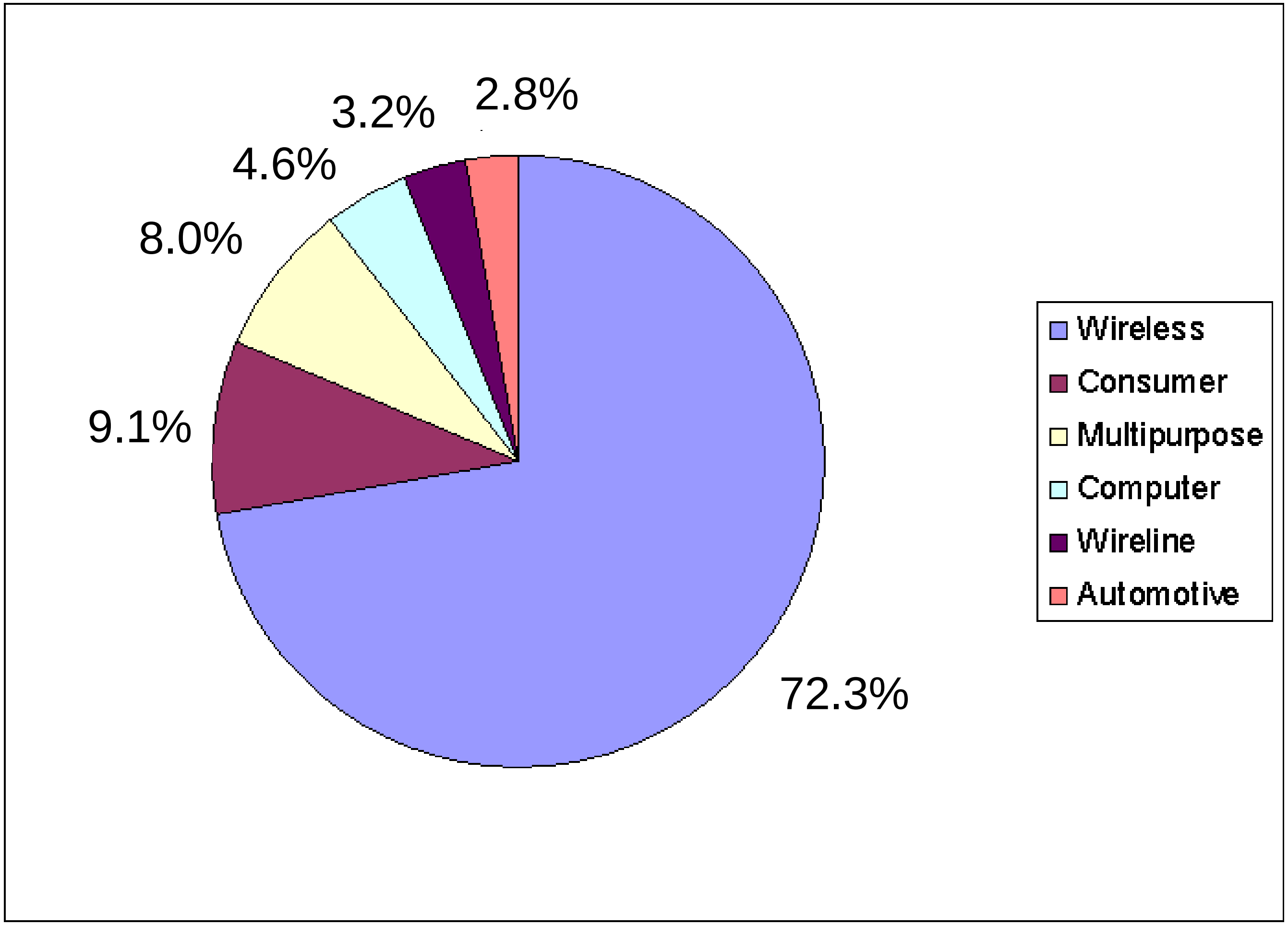
DSP Market Share in 2006



Total Revenue: 7635 Million US-$

Source: www.forwardconcepts.com

DSP Market Areas in 2006



Source: www.forwardconcepts.com

Texas Instruments Portfolio

µC	DSC	Arm-Based			DSP
16-bit MCU	32-bit Real-time	32-bit ARM	ARM+	ARM + DSP	DSP
MSP430	C2000™	Stellaris Cortex™ M3	ARM9 Cortex A-8	C64x+ plus ARM9/Cortex A-8	C647x, C64x+, C55x
Ultra-Low Power	Fixed & Floating Point	Industry Std Low Power	Industry-Std Core, High-Perf GPP	Industry-Std Core + DSP for Signal Proc.	Leadership DSP Performance
Up to 25MHz	Up to 150MHz	Up to 100MHz	Accelerators	4800 MMACs/ 1.07 DMIPS/MHz	24,000 MMACS
Flash 1KB to 256KB	Flash 32KB to 512KB	Flash 8KB to 256KB	MMU	MMU, Cache	Up to 3MB L2 Cache
Analog I/O, ADC LCD, USB, RF	PWM, ADC, CAN, SPI, I^2C	USB, ENET, ADC, PWM, HMI	USB, LCD, MMC, EMAC	VPSS, USB, EMAC, MMC	1G EMAC, SRIO, DDR2, PCI-66
Measurement, Sensing, General Purpose	Motor Control, Digital Power, Lighting	Host Control, general purpose, motor control	Linux/WinCE User Apps	Linux/Win + Video, Imaging, Multimedia	Comm, WiMAX, Industrial/ Medical Imaging
\$0.49 to \$9.00	\$1.50 to \$20.00	\$2.00 to \$8.00	\$8.00 to \$35.00	\$12.00 to \$65.00	\$4.00 to \$99.00+
					

TI Microcontrollers: Connectivity

MSP430
Ultra low power microcontroller

- USB
- I^2C, SPI, UART, LIN
- RFID

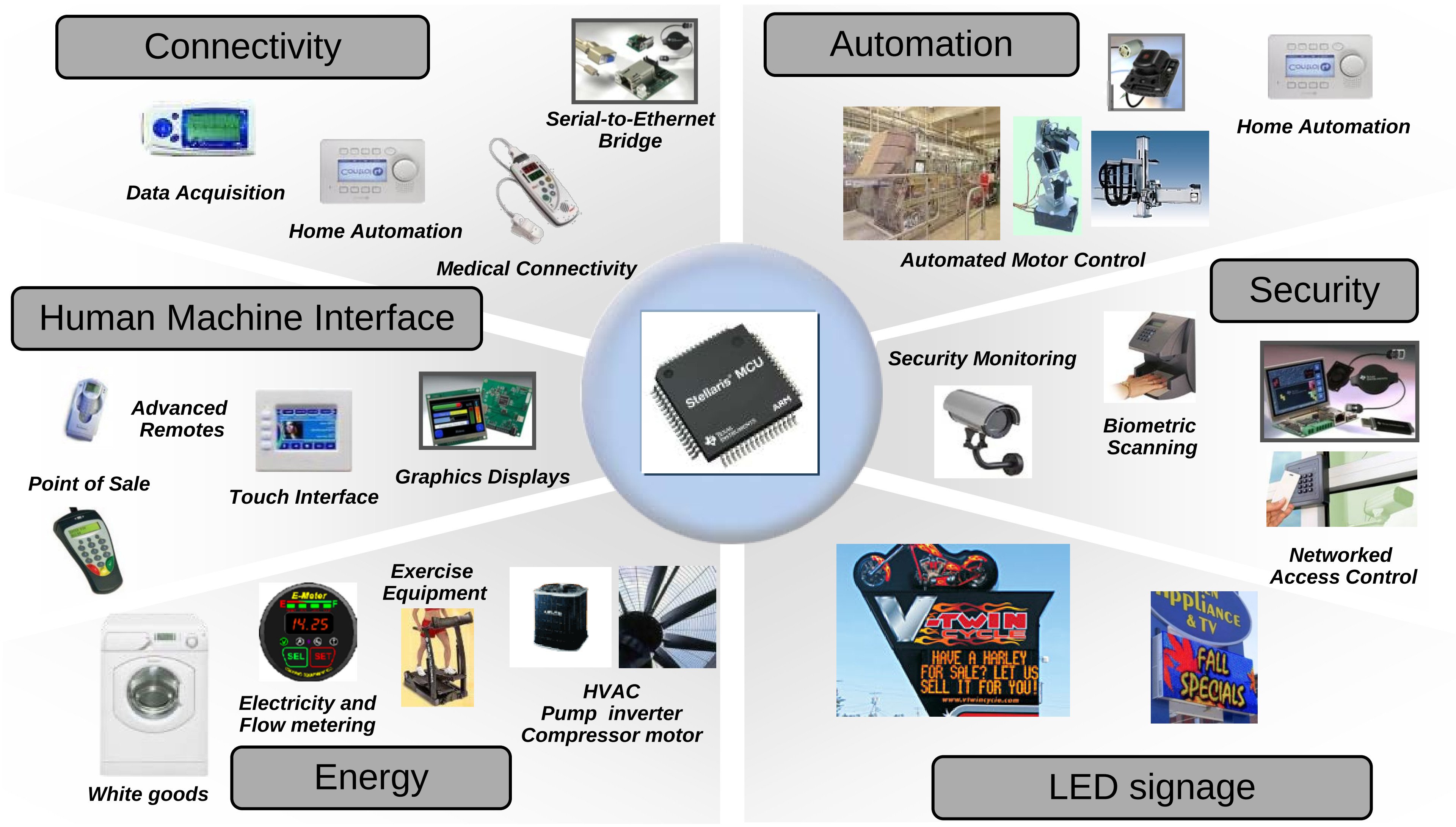
Stellaris
ARM Cortex-M3 general purpose MCU

- 10/100 Ethernet
- I^2S
- USB
- CAN Controller Area Network
- EPIx32 M2M / Mem Interface
- I^2C, SPI, UART

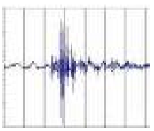
C2000
Real-time controller

- USB
- CAN Controller Area Network
- I^2C, SSI, UART

Stellaris Family: Applications

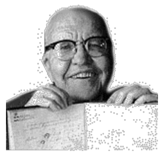


History Embedded Processing



Revolutionizes oil exploration by measuring reflected signals

Applies signal measurement to magnetic anomaly detection



Invents the integrated circuit

Invents the handheld calculator

Applies signal processing to consumer products

Introduces single-chip digital signal processor

OMAP™
TEXAS INSTRUMENTS TECHNOLOGY

Creates first apps processor for multi-media cell phones

Launches Code Composer Studio™ software for development of all TI processors

Texas Instruments
DaVinci

Introduces best-in-class video SoC to fuel video revolution

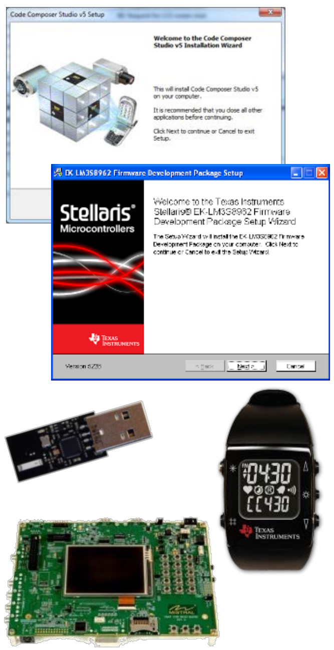
Introduces first single-chip digital cell phone SoC

Launches highest performance DSP core and multicore DSPs

1930s 1940s 1950s 1960s 1970s 1980s 1990s 2000s 2010s

Extensive support

Software, Tools and Kits



- Low cost development kits starting at <$5
- Evaluation Modules
- Reference designs

Support

- Local language field sales support

- >1000 FAEs deployed worldwide
- 24/7 support available on-line

TI E2E™ Community

Training

IN-PERSON

- TI Tech Days
- Application specific workshops
- Technical workshops

ON_LINE

- Virtual e-training events

Applications

- Application-specific reference designs
- Application notes
- Software libraries and codecs
- System expertise