CS632/SEP564: Embedded Operating Systems (Fall 2008)

Embedded Systems

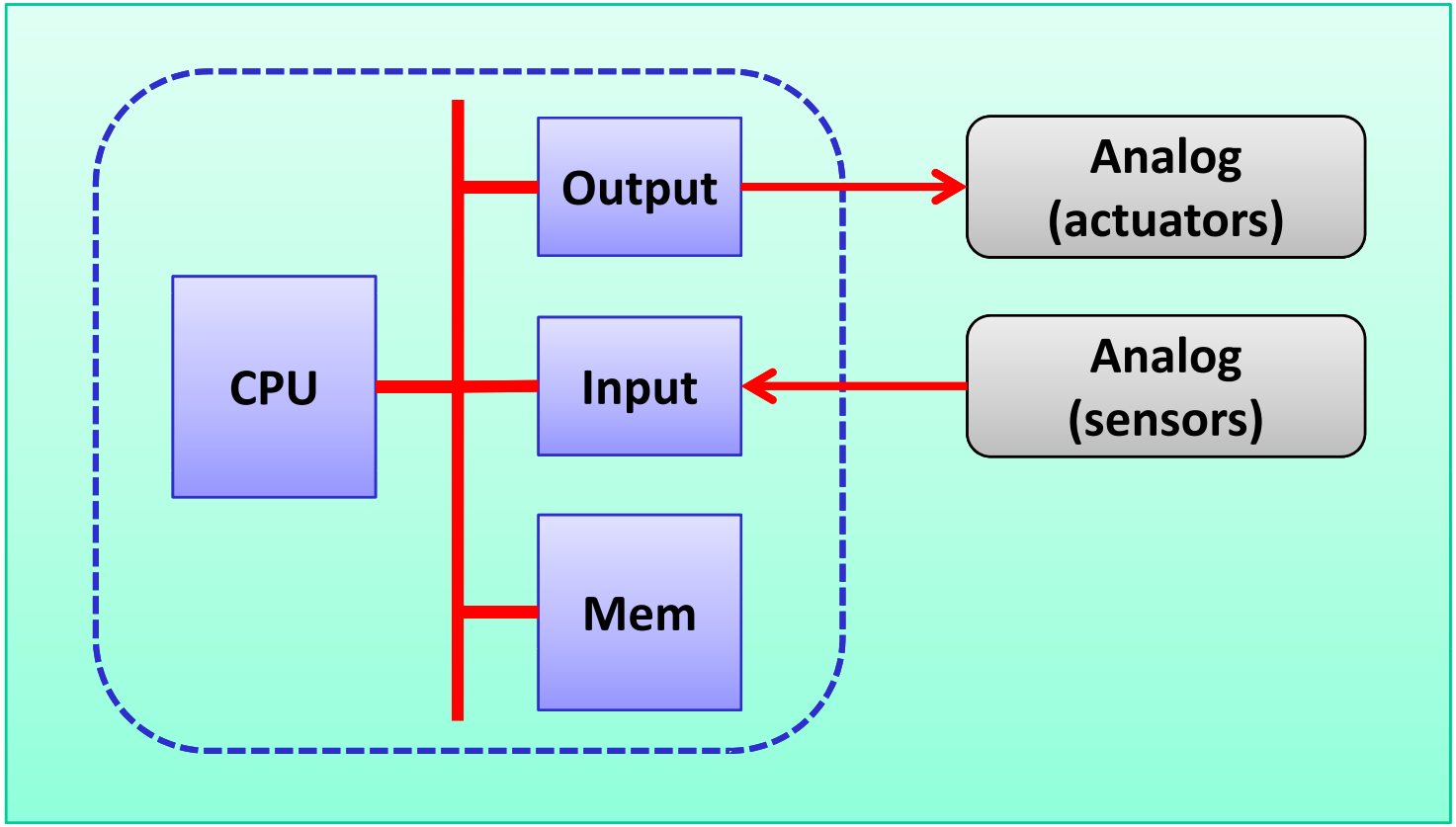
KAIST

Embedded Systems (1)

- **What is an embedded system?**
  - A special-purpose computer system built into a larger device
- **General-purpose vs. Embedded?**
  - Cost
  - Performance
  - Power
  - Limited resources
  - Real-time constraints
  - Many design alternatives
  - Hard to develop and debug

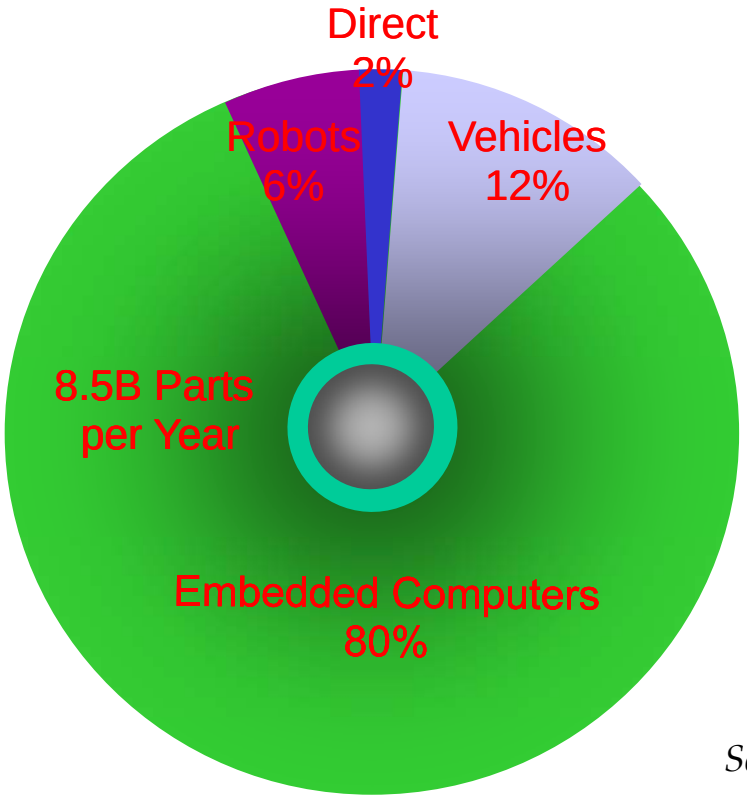
Embedded Systems (2)

- **Embedding a computer system**



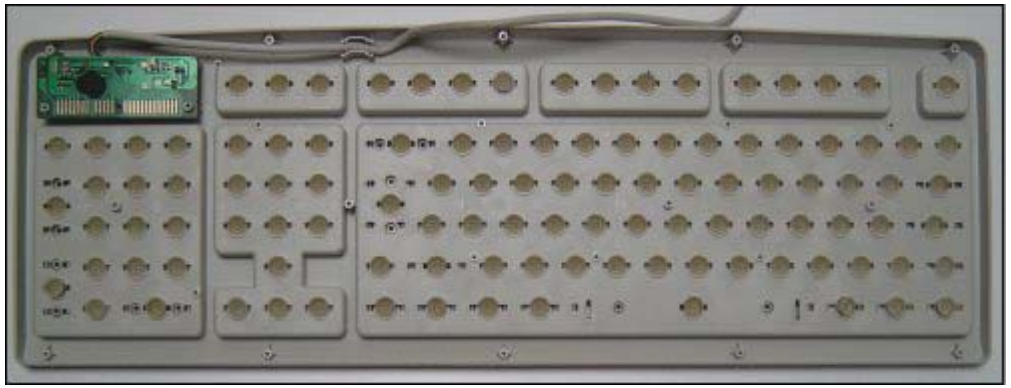
Embedded Systems (3)

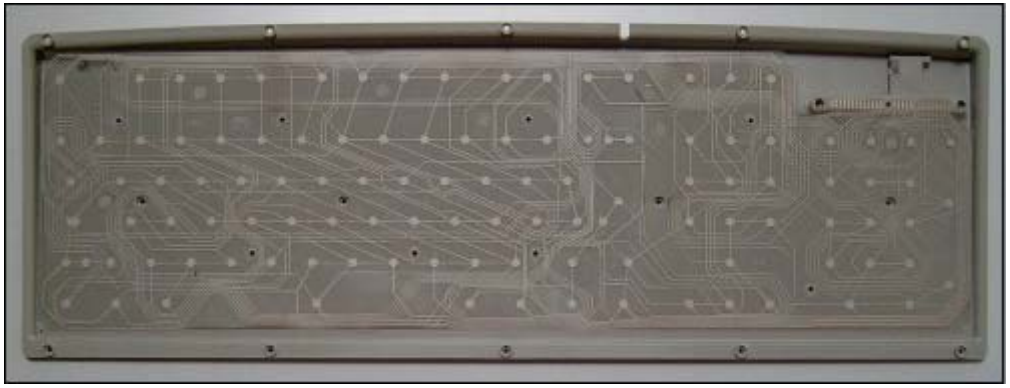
- **Where are the CPUs?**
  - Estimated 98% of 8 billion CPUs produced in 2000 used for embedded applications.

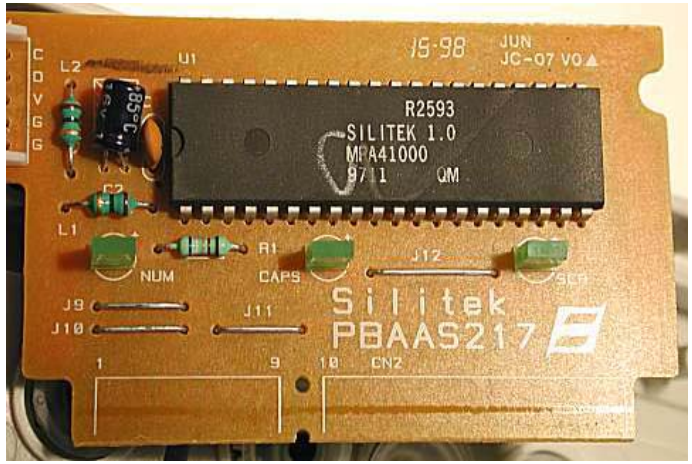


Source: DARPA/Intel (Tennenhouse)

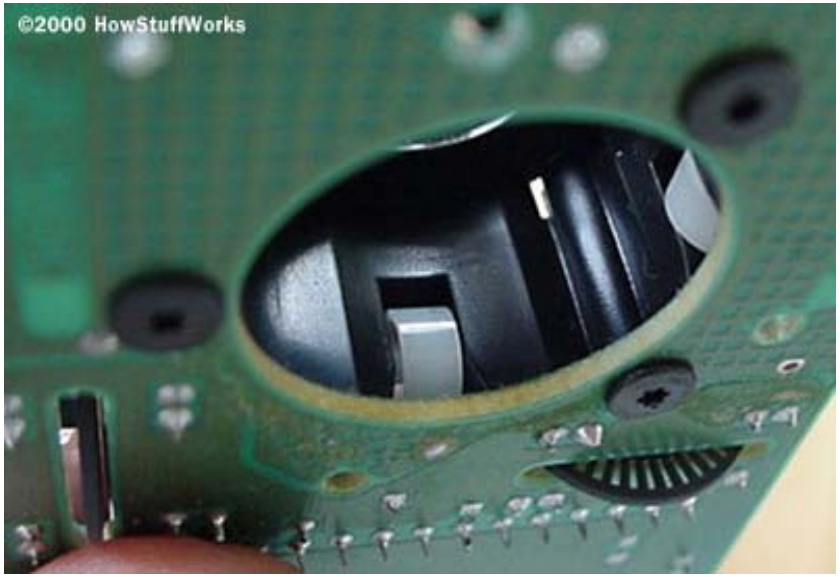
Keyboard



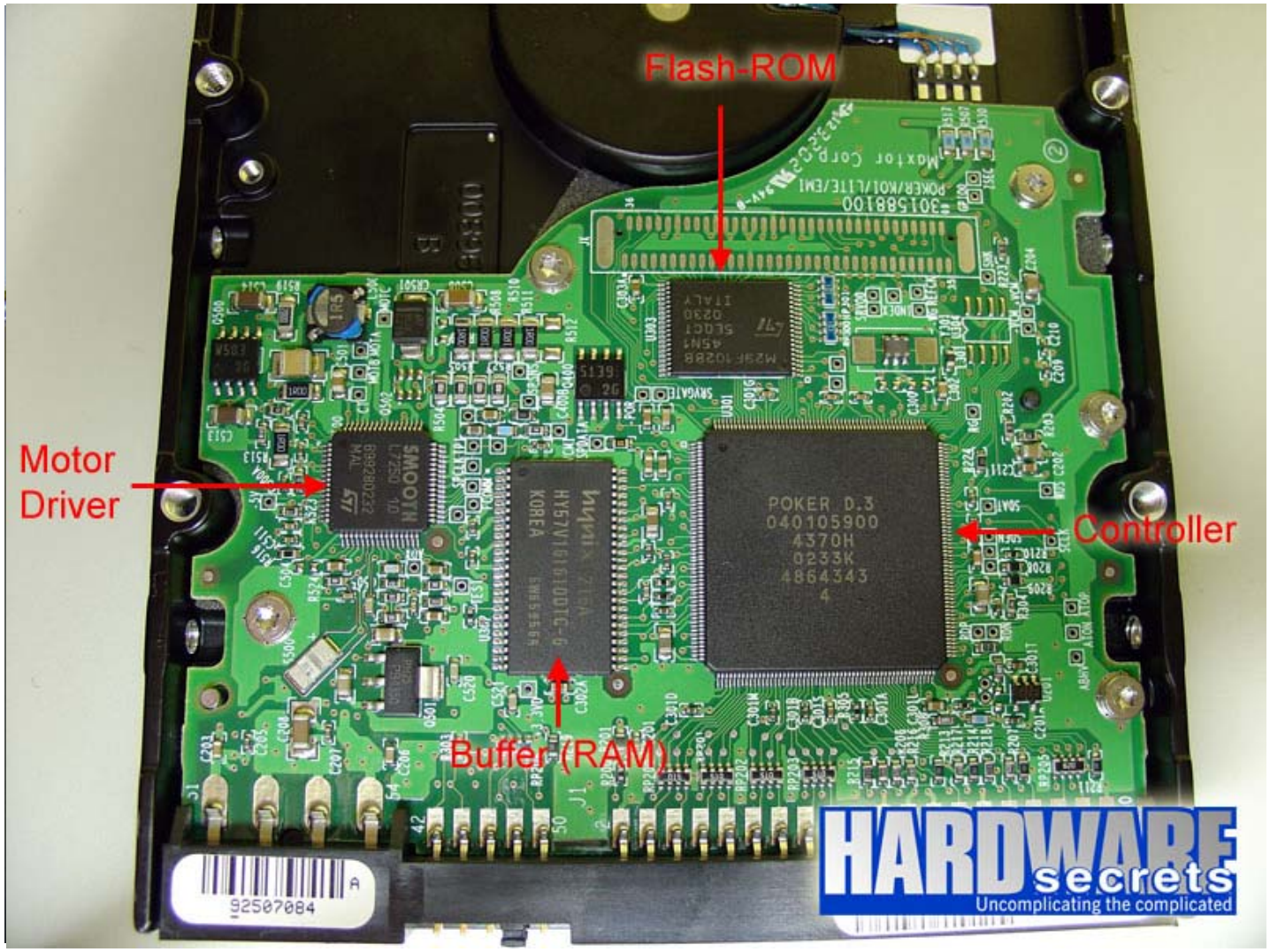




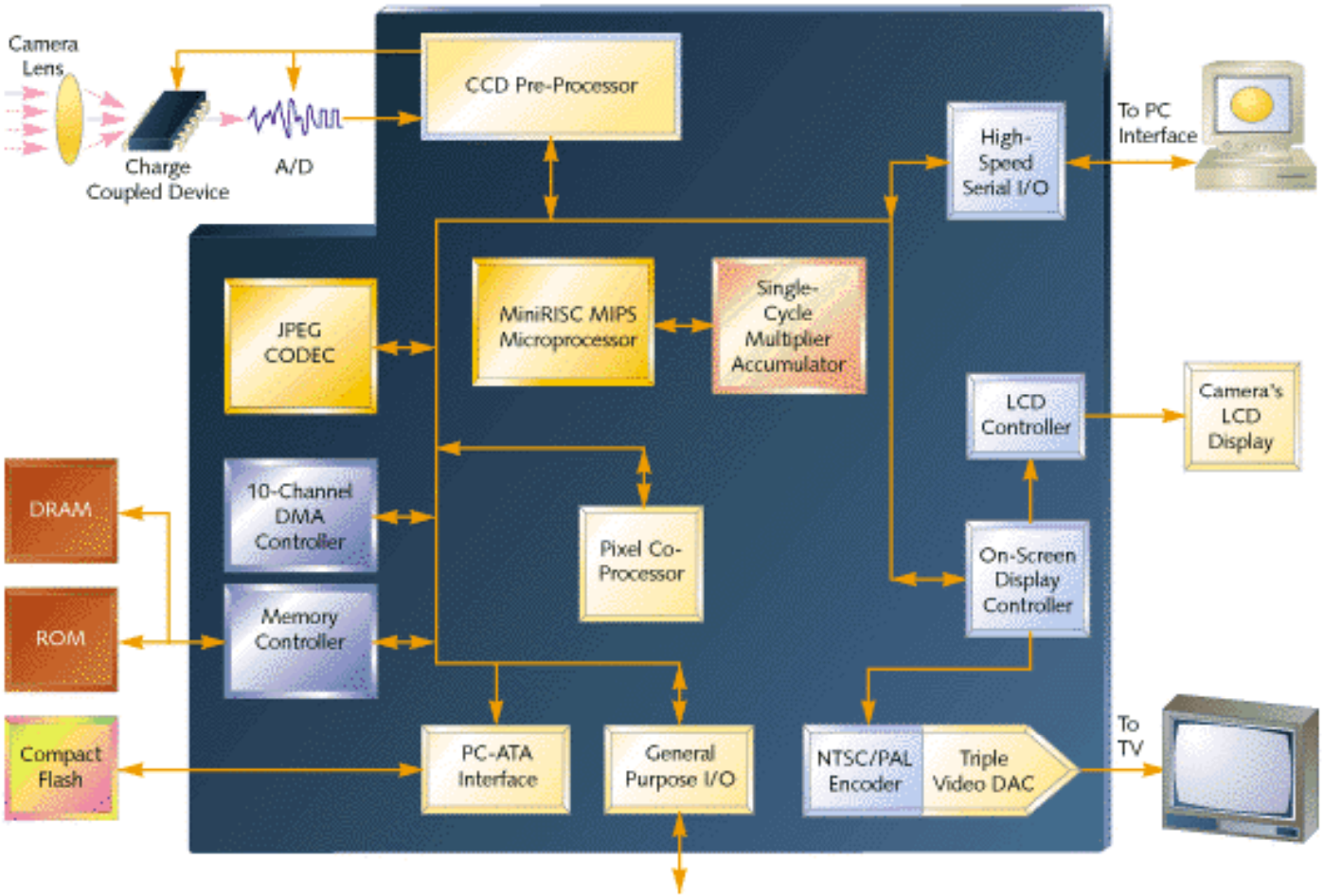
Mouse



Hard Disk Drive

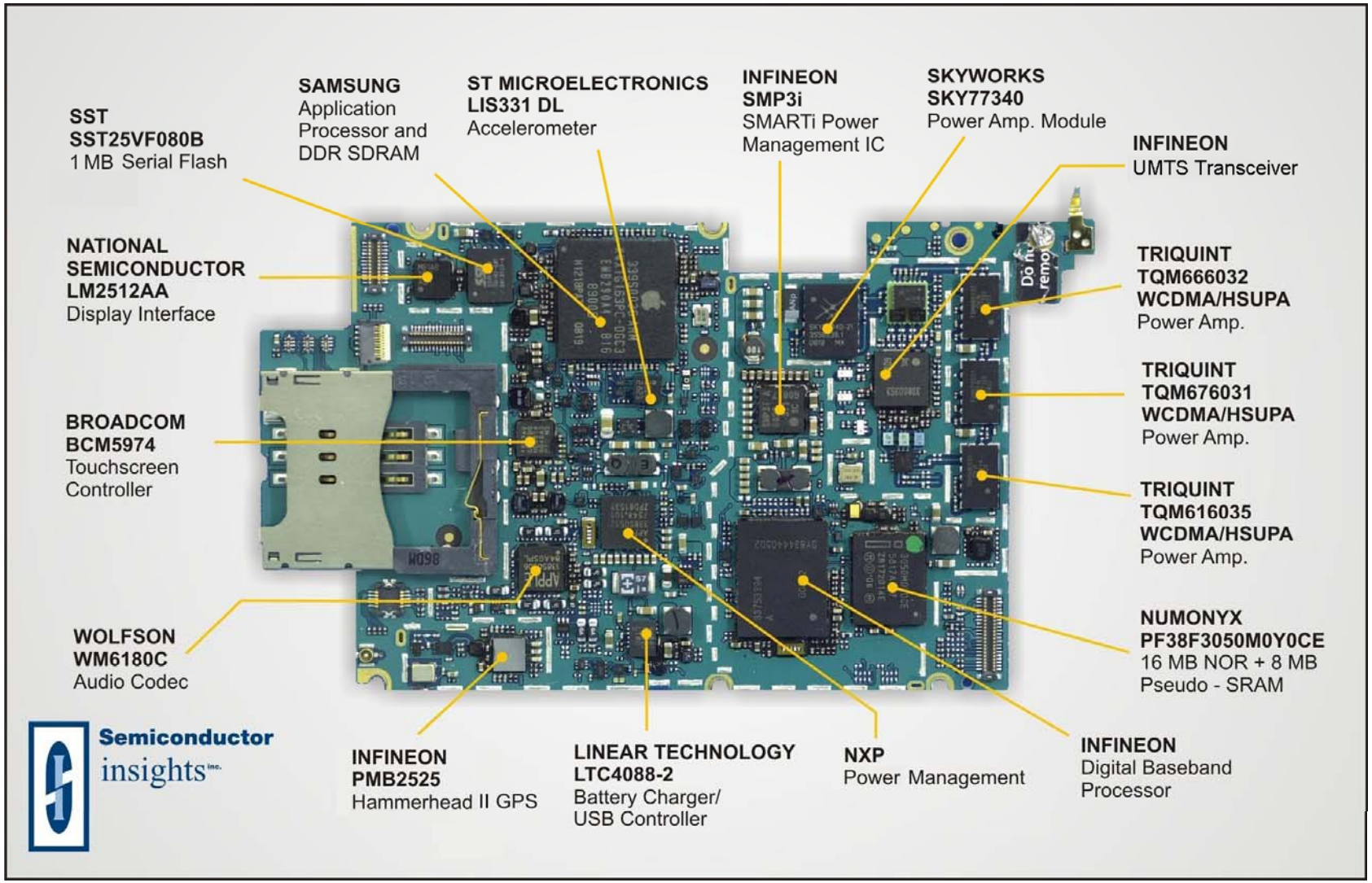


Digital Still Camera

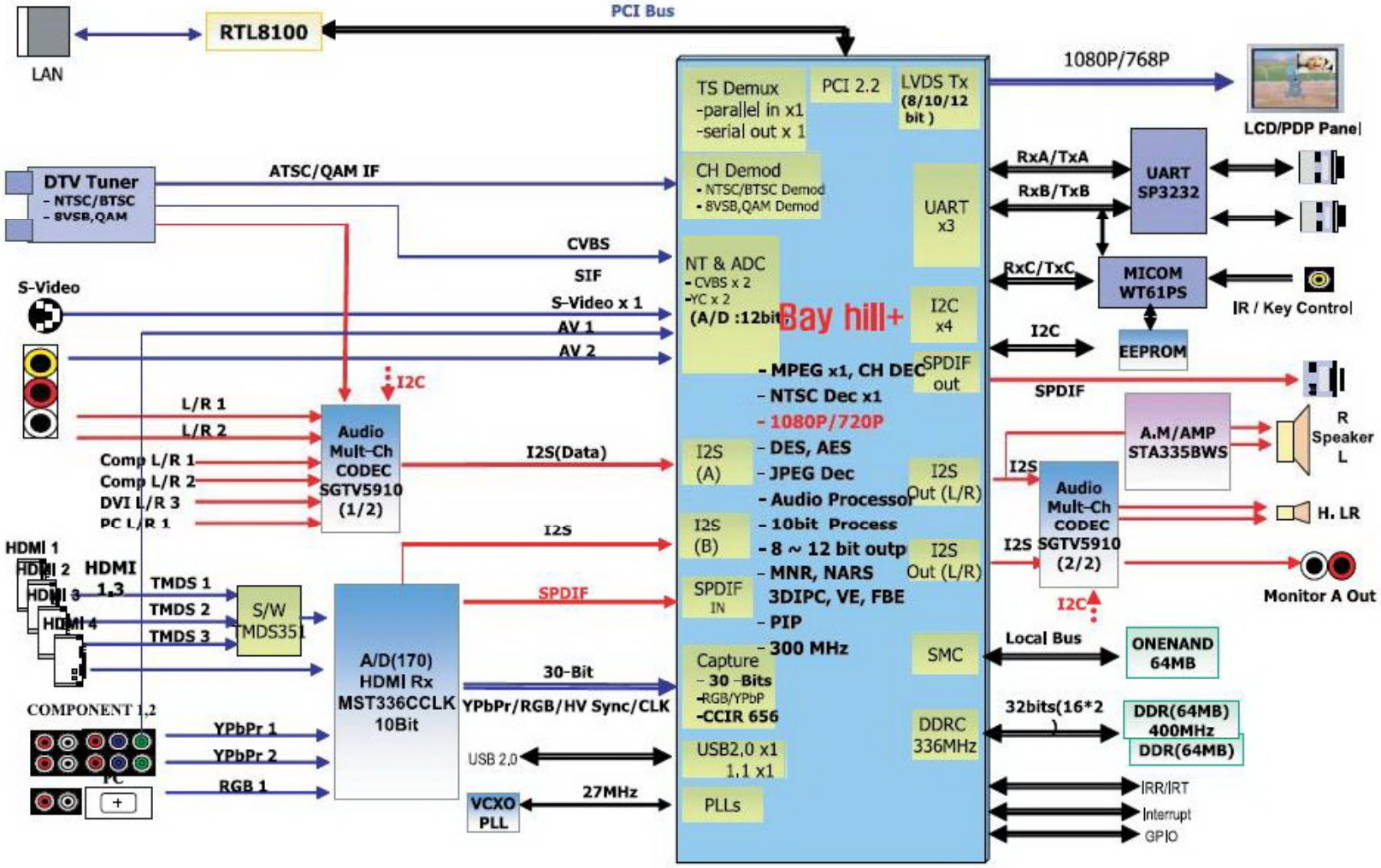


- Canon EOS 3 has three microprocessors.

iPhone 3G

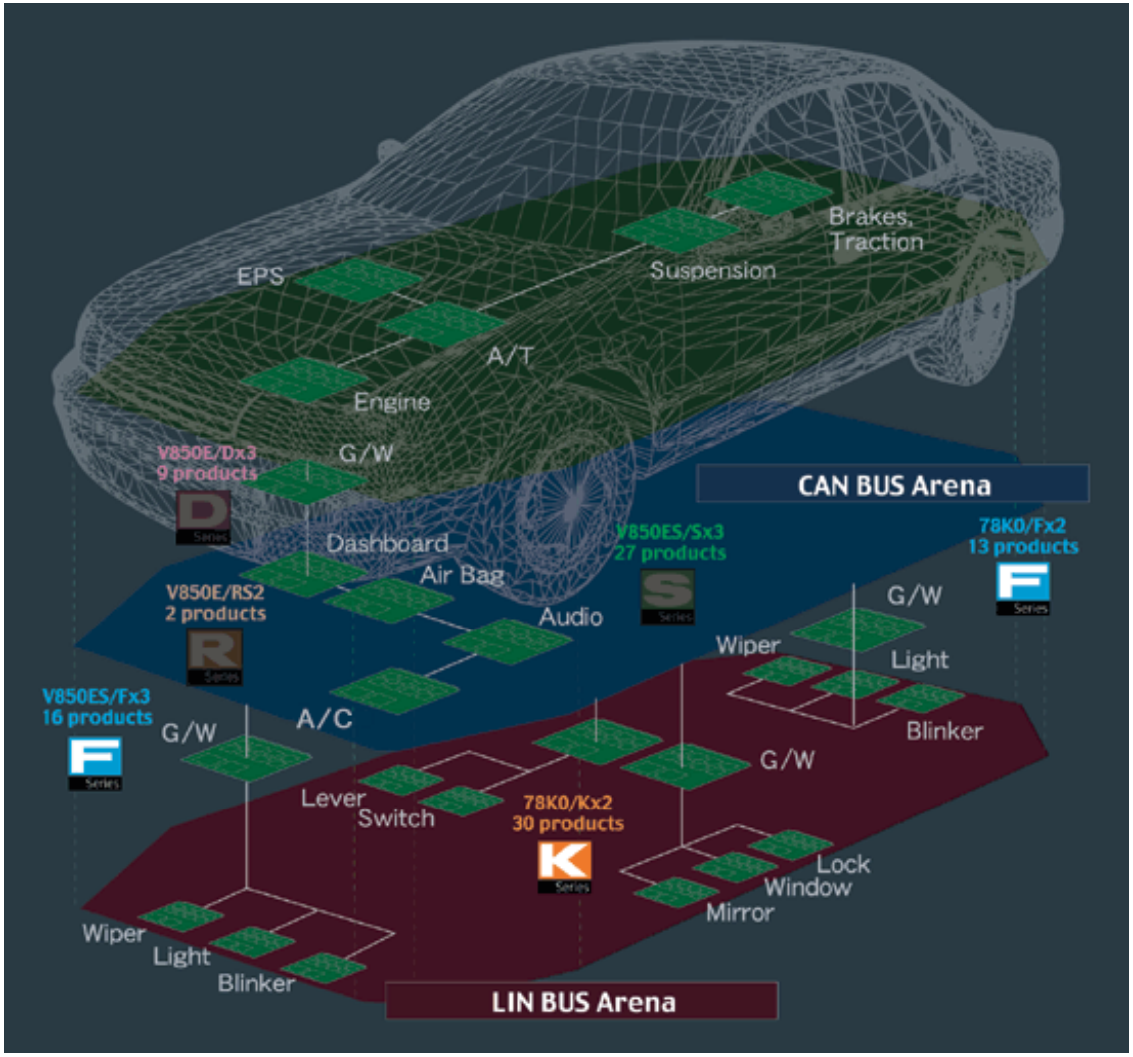

SST
SST25VF080B
1 MB Serial Flash
SAMSUNG
Application
Processor and
DDR SDRAM
ST MICROELECTRONICS
LIS331 DL
Accelerometer
INFINEON
SMP3i
SMARTi Power
Management IC
SKYWORKS
SKY77340
Power Amp. Module
INFINEON
UMTS Transceiver
NATIONAL
SEMICONDUCTOR
LM2512AA
Display Interface
TRIQUINT
TQM666032
WCDMA/HSUPA
Power Amp.
TRIQUINT
TQM676031
WCDMA/HSUPA
Power Amp.
BROADCOM
BCM5974
Touchscreen
Controller
TRIQUINT
TQM616035
WCDMA/HSUPA
Power Amp.
NUMONYX
PF38F3050M0Y0CE
16 MB NOR + 8 MB
Pseudo - SRAM
WOLFSON
WM6180C
Audio Codec
Semiconductor
insights
INFINEON
PMB2525
Hammerhead II GPS
LINEAR TECHNOLOGY
LTC4088-2
Battery Charger/
USB Controller
NXP
Power Management
INFINEON
Digital Baseband
Processor

Digital TV



Source: http://www.avforum.com

Automotive



- ~ 100 ECUs
- 16/32-bit microcontrollers
- 2 ~ 3 CAN buses

Other Examples

- **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

And the list goes on and on …

Recent Trends

- **Key recent trends**
  - Increasing computation demands
  - Increasingly networked
  - Increasing need for flexibility

  - Getting complex
  - Increasingly platform-based

Basic Architecture (1)

- **Control unit**
  - Custom logic
  - FPGAs (Field-Programmable Gate Arrays)
  - Microcontrollers
  - Microprocessors
    - ARM, MIPS, PowerPC, SuperH, Cell, x86, …
    - Mostly less than 1 GHz
  - DSPs (Digital Signal Processors)
  - ASIPs (Application Specific Instruction-set Processors)
  - Multicore? (symmetric vs. asymmetric)
  - Typical word sizes: 8-bit, 16-bit, 32-bit

Basic Architecture (2)

- **RAM (Random access memory)**
  - SRAM
    - Easier to integrate on the same chip as processor
  - DRAM
    - SDRAM (Synchronous DRAM): SDR, DDR, DDR2, DDR3
    - Mobile SDR/DDR SDRAM
    - RDRAM (Rambus DRAM)
  - NVRAM (Nonvolatile RAM)
  - Future Nonvolatile RAMs: PRAM, MRAM, FeRAM
  - Cache memory
  - SPM (Scratch Pad Memory)

Basic Architecture (3)

- **ROM (Read-only memory)**
  - Mask-programmed
  - One-time programmable (OTP) ROM
  - Erasable programmable ROM (EPROM)
  - Electrically erasable programmable ROM (EEPROM)

- **Flash memory**
  - NOR
  - NAND
  - OneNAND

Basic Architecture (4)

- **Interfacing**
  - ARM AMBA (Advanced Microcontroller Bus Architecture)
  - ISA (Industry Standard Architecture)
  - PCI (Peripheral Component Interconnect)

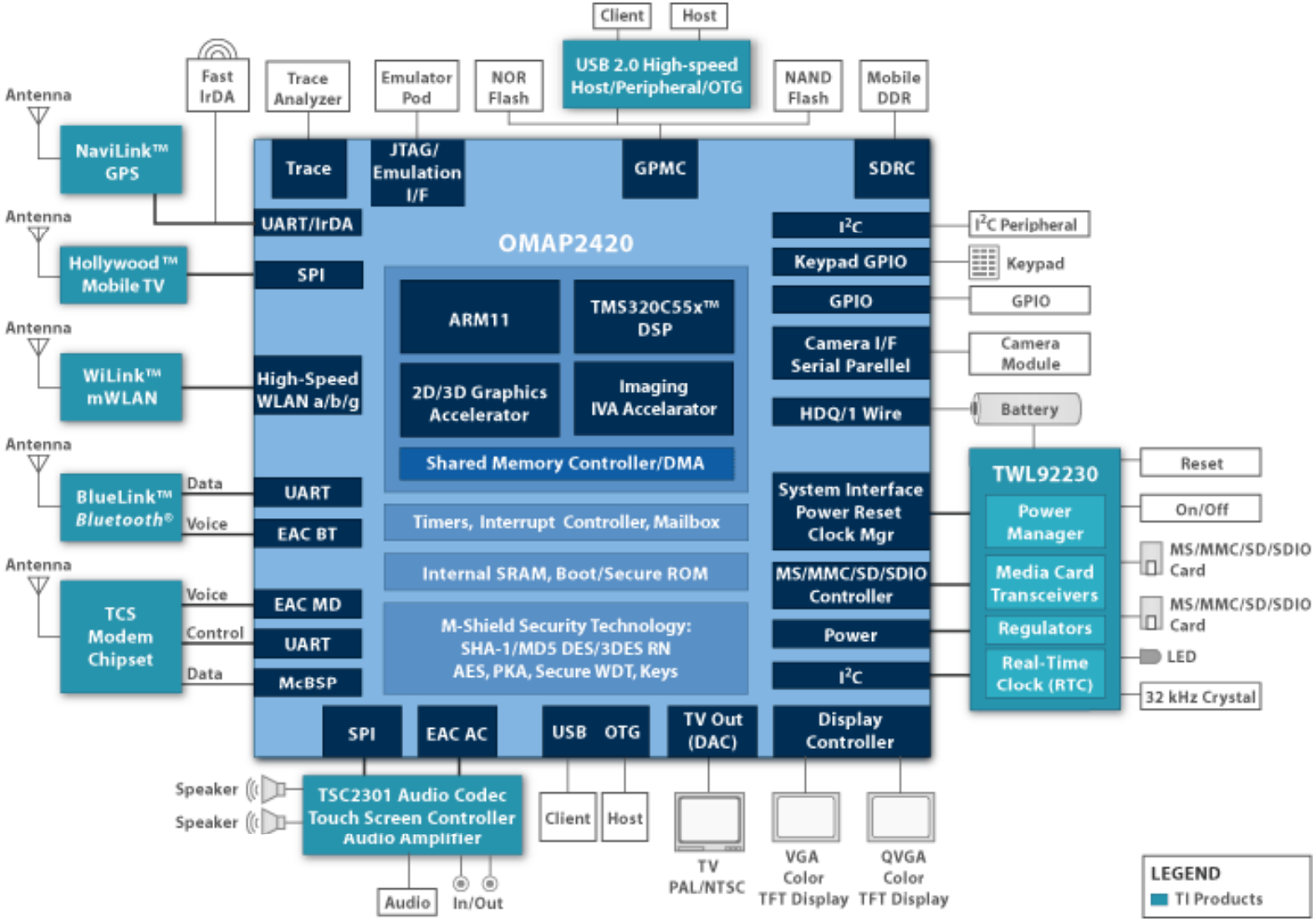
  - I^2C (Inter-IC) bus
  - USB

Basic Architecture (5)

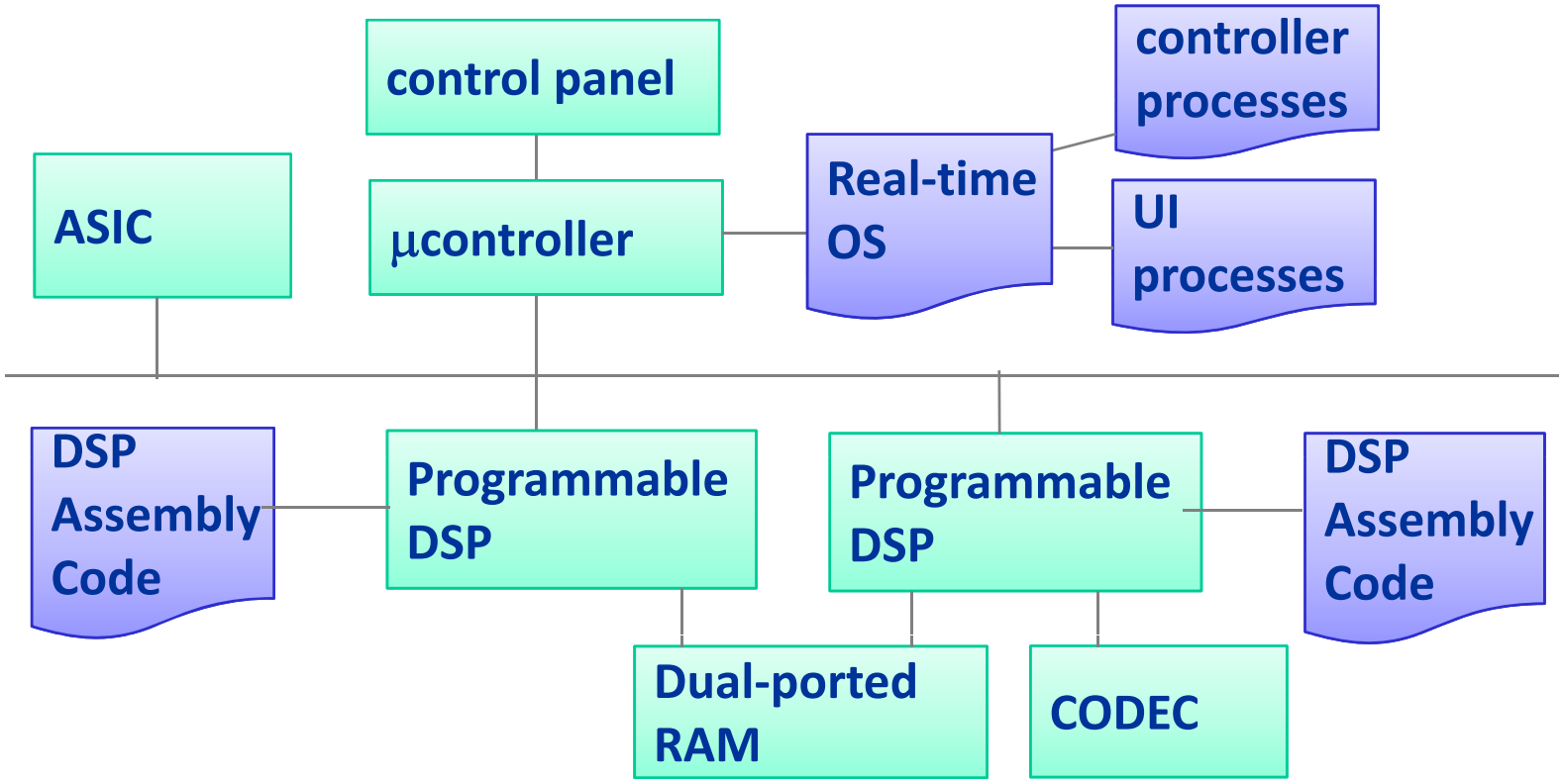
- **Common peripheral devices**
  - Interrupt controller
  - DMA controller
  - Timer / Counter
  - Real-time clock
  - Watchdog timer
  - UART (Universal Asynchronous Receiver Transmitter)

  - IrDA (Infrared)
  - Ethernet (wired/wireless)
  - Bluetooth

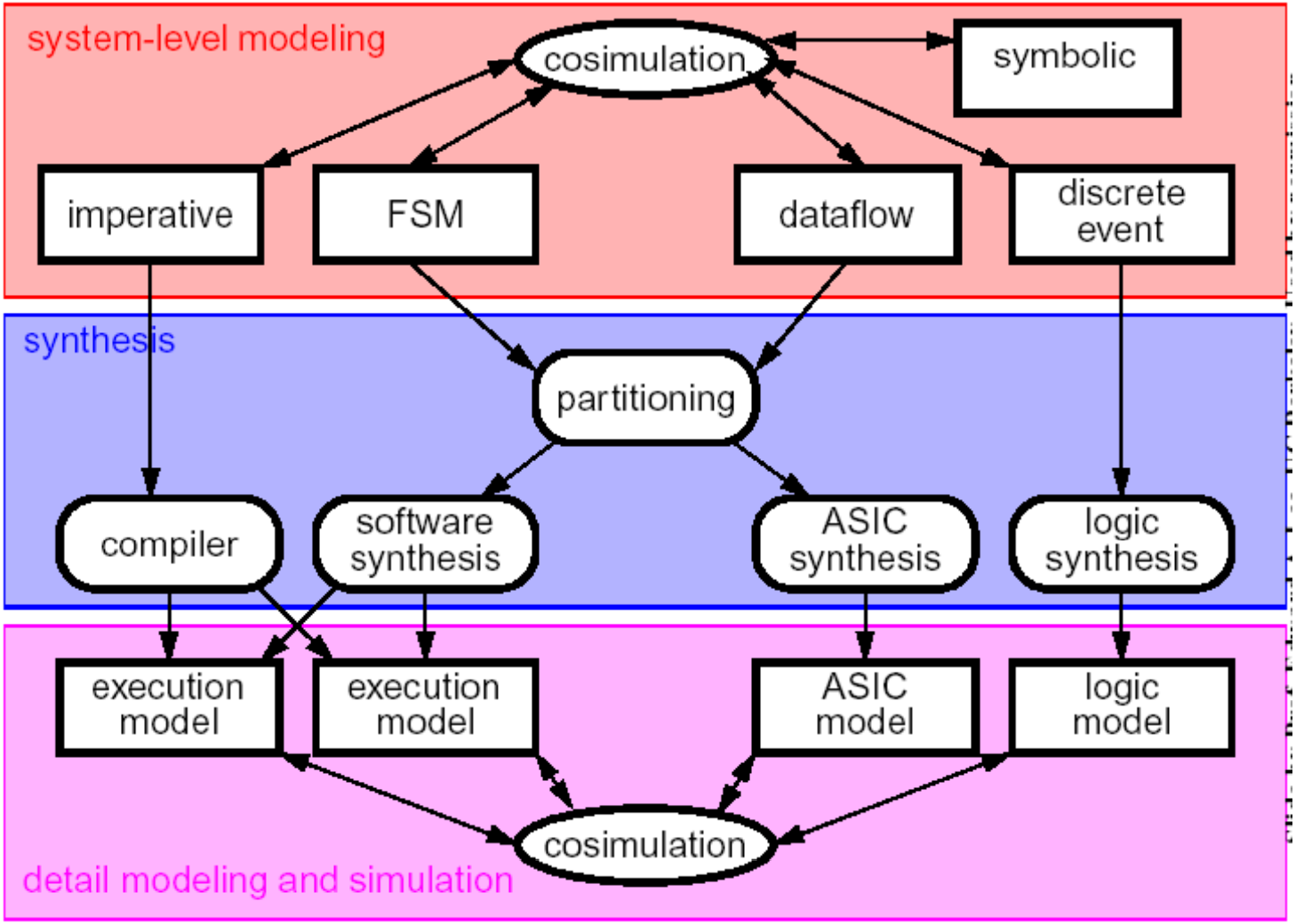
TI OMAP2420


Client
Host
USB 2.0 High-speed Host/Peripheral/OTG
Fast IrDA
Trace Analyzer
Emulator Pod
NOR Flash
NAND Flash
Mobile DDR
Antenna
NaviLink™ GPS
Antenna
Hollywood™ Mobile TV
Antenna
WiLink™ mWLAN
Antenna
BlueLink™ Bluetooth®
Antenna
TCS Modem Chipset
Trace
JTAG/ Emulation I/F
GPMC
SDRC
UART/IrDA
SPI
High-Speed WLAN a/b/g
Data
Voice
Voice
Control
Data
UART
EAC BT
EAC MD
UART
McBSP
OMAP2420
ARM11
TMS320C55x™ DSP
2D/3D Graphics Accelerator
Imaging IVA Accelarator
Shared Memory Controller/DMA
Timers, Interrupt Controller, Mailbox
Internal SRAM, Boot/Secure ROM
M-Shield Security Technology:
SHA-1/MD5 DES/3DES RN
AES, PKA, Secure WDT, Keys
I²C
Keypad GPIO
GPIO
Camera I/F Serial Parellel
HDQ/1 Wire
System Interface Power Reset Clock Mgr
MS/MMC/SD/SDIO Controller
Power
I²C
I²C Peripheral
Keypad
GPIO
Camera Module
Battery
TWL92230
Power Manager
Media Card Transceivers
Regulators
Real-Time Clock (RTC)
Reset
On/Off
MS/MMC/SD/SDIO Card
MS/MMC/SD/SDIO Card
LED
32 kHz Crystal
SPI
EAC AC
USB OTG
TV Out (DAC)
Display Controller
Speaker
Speaker
TSC2301 Audio Codec
Touch Screen Controller
Audio Amplifier
Audio
In/Out
Client
Host
TV PAL/NTSC
VGA Color TFT Display
QVGA Color TFT Display
LEGEND
TI Products

Complexity / Heterogeneity



Handling Heterogeneity



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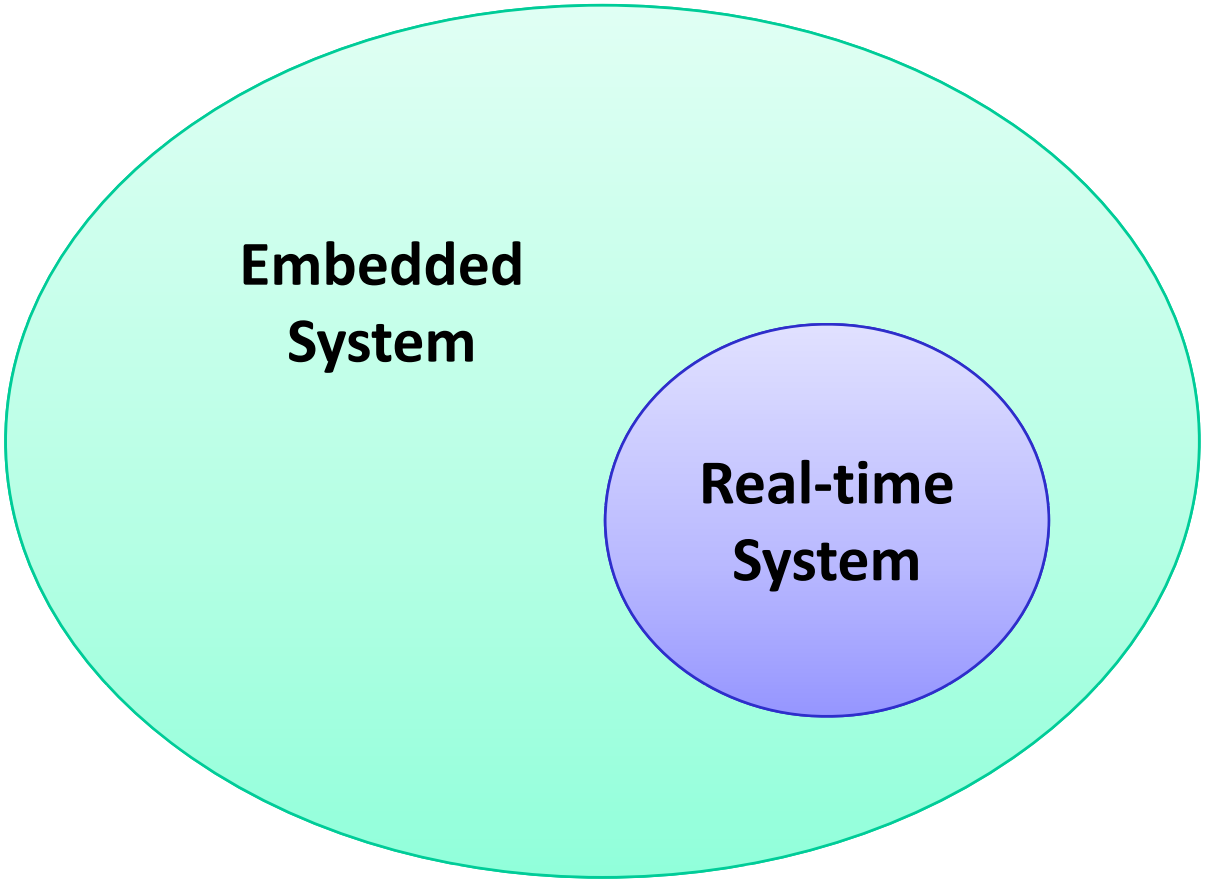
Embedded Operating Systems

KAIST

Embedded vs. Real Time (1)

- **What is real time?**
  - Definition (by Donald Gillies):
    - A real time system is one in which the correctness of the computations not only depends upon the logical correctness of the computation, but also upon the time at which the result is produced. If the timing constraints of the system are not met, system failure is said to have occurred.
  - Real time in operating systems:
    - The ability of the operating system to provide a required level of service in a bounded response time.
      -- (POSIX Standard 1003.1)
  - Hard vs. soft real time

Embedded vs. Real Time (2)



OS Flavors

- **Desktop**
  - Microsoft Windows (2K/XP/Vista)
  - Mac OS X
  - Linux
- **Server**
  - Microsoft Windows (2K/XP/Vista Data Center/Enterprise)
  - Unix Variants: Sun Solaris, IBM AIX, HP HP-UX, Linux, OpenBSD/NetBSD/FreeBSD, ...
- **Embedded**
  - Many
  - Why do we need embedded OS?

Embedded OS vs. GPOS (1)

- **Similarities**
  - Some level of multitasking
  - Software and hardware resource management
  - Provision of underlying OS services to applications
  - Abstracting the hardware from the software application

Embedded OS vs. GPOS (2)

- **Differences**
  - Better reliability in embedded application contexts
  - The ability to scale up or down to meet application needs
  - Faster performance
  - Reduced memory requirements
  - Scheduling policies tailored for real-time embedded systems
  - Support for diskless embedded systems by allowing executables to boot and run from ROM or RAM
  - Better portability to different hardware platforms

Criteria

- **What makes a good embedded OS?**
  - Modular
  - Scalable
  - Configurable
  - Small footprint
  - CPU support
  - Device drivers
  - Integrated Development Environments (IDE)
  - etc, etc, etc...

Embedded OS Players (1)

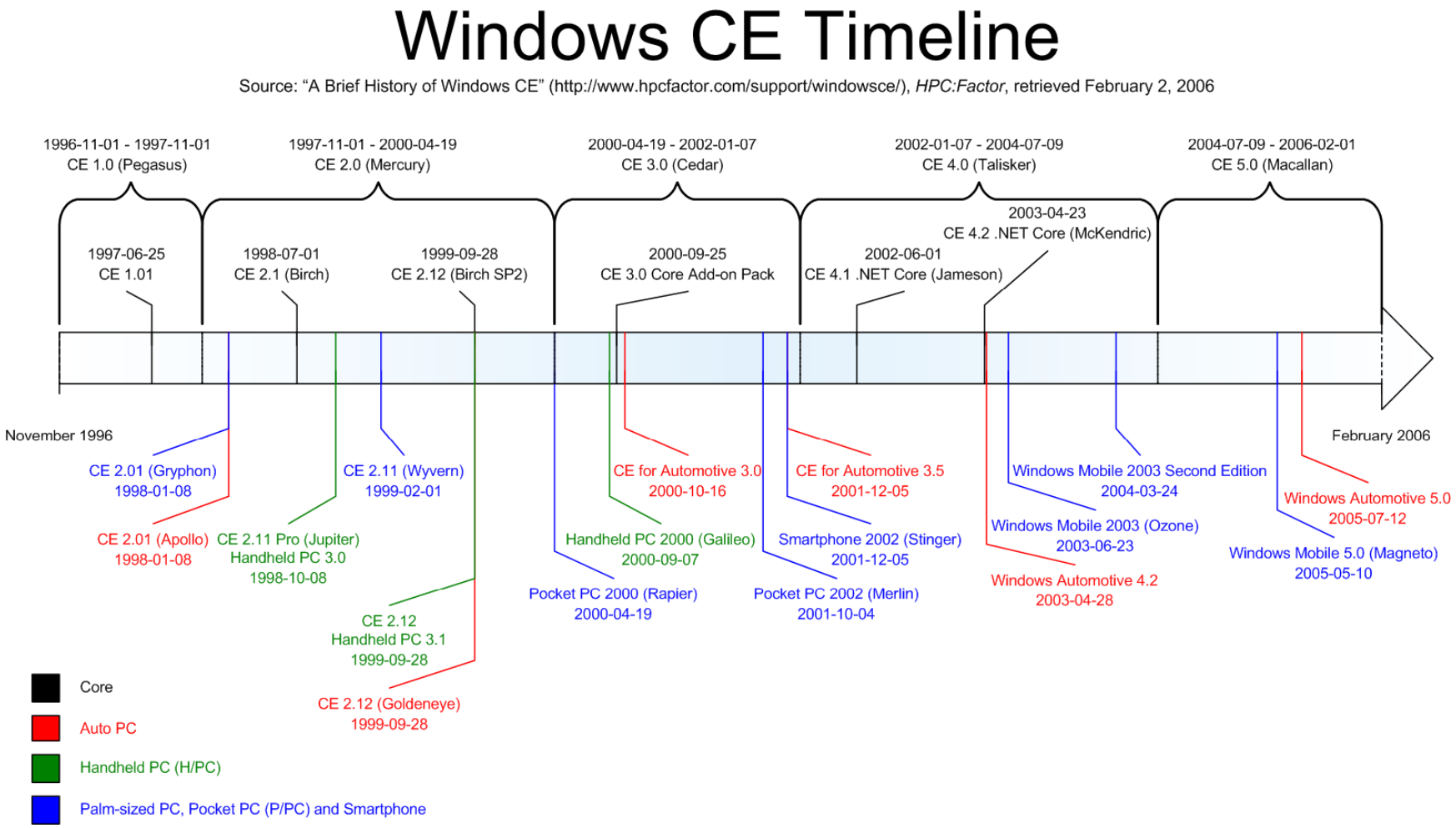
- **Wind River Systems**
  - VxWorks
  - pSOS
  - http://www.wrs.com
- **QNX Software Systems**
  - QNX
  - http://www.qnx.com
- **Green Hills Software, Inc.**
  - Integrity, velOSity
  - http://www.ghs.com

Embedded OS Players (2)

- **Mentor Graphics**
  - VRTX
  - Nucleus
  - http://www.mentor.com
- **Palm Computing**
  - PalmOS
  - http://www.palm.com
- **Symbian**
  - SymbianOS
  - http://www.symbian.com

Embedded OS Players (3)

- **Microsoft**

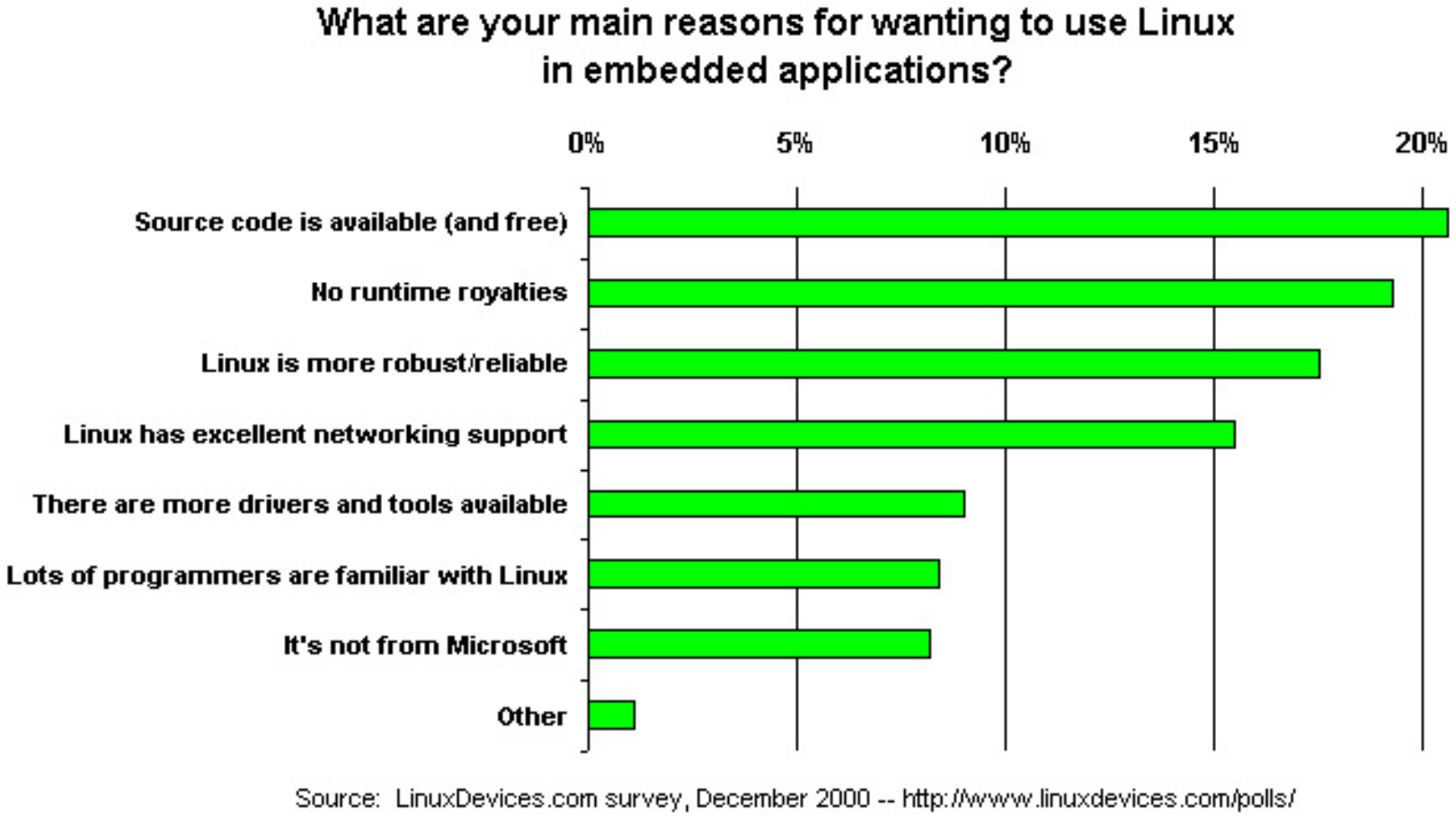


Embedded Linux (1)

- **What's so special about Linux?**
  - Vendor independence
  - Source code is freely available
  - No runtime licenses
  - Robust and reliable
  - Modular, configurable, scalable
  - Diverse hardware support
  - Superb support for networking and Internet
  - Large pool of skilled developers
  - A rich set of toolsets and utilities
  - Standards compliance

Embedded Linux (2)

- **What's so special about Linux? (cont'd)**



Embedded Linux (3)

- **Embedded Linux vs. Linux**
  - Configured with a different set of device drivers, file systems, and kernel modules
    - Flash driver
    - Flash file system
  - More focus is paid to a set of cross-development tools.
  - Shipped with different utilities
  - Lightweight windowing and GUI environments
  - Systems mostly run in single-user mode with almost no system administration capabilities.
  - Real-time support

Embedded Linux (4)

- **Linux and Real-time**
  - Linux can not be considered as a hard real time system.
  - There are long sections of code where all interrupts are masked.
  - Kernel code (system calls) not preemptible until they complete or decide to release the processor by calling the scheduler.
  - Linux 2.6 improves this by offering a preemptible option.
    - Kernel code can be interrupted at almost any time (except when spinlocks are held)
    - This reduces latency for high priority processes.

Open Source Embedded Linux (1)

- **Embedded Linux Development Kit (ELDK)**
  - Open source Linux distribution from Denx Software Engineering
  - U-Boot open source boot loader
  - http://www.denx.de
- **Embedded Debian (Emdebian)**
  - Open source embedded Linux distribution derived from Debian project
  - http://www.emdebian.org

Open Source Embedded Linux (2)

- **uClinux**
  - For microprocessors that don't have MMU
  - http://www.uclinux.com
- **ETLinux**
  - A complete Linux-based system designed to run on very small industrial computers (PC104 SBC's)
  - http://www.prosa.it/etlinux
- **ETRI Qplus/Esto**
  - Linux-based embedded operating system and integrated development environment

Commercial Embedded Linux (1)

- **MontaVista Linux**
  - A leading global supplier of commercial Linux-based system software and development tools
  - Licensed by Samsung
  - http://www.mvista.com
- **BlueCat Linux**
  - A commercial distribution based on the Linux 2.6 kernel.
  - Targeted for use in embedded systems ranging from small consumer-type devices to large-scale, multi-CPU systems.
  - http://www.lynuxworks.com

Commercial Embedded Linux (2)

- **Freescale (formerly Metrowerks)**
  - A Motorola subsidiary
  - Acquires Embedix Inc. (former Lineo) in 2002.
  - Integrates Lineo Embedix with CodeWarrior Development Studio
  - Offers a complete end-to-end commercial embedded Linux development solution.
  - http://www.freescale.com
- **Timesys Linux**
  - Low latency enhanced kernel
  - http://www.timesys.com

Commercial Embedded Linux (3)

- **Cadenux**
  - Provides embedded Linux distributions for MMU-less ARM7 and ARM9 processors.
  - Built around uClinux.
  - Merged with RidgeRun.
  - http://www.ridgerun.com
- **ELinOS**
  - A commercial Linux-based development environment.
  - The core of ELinOS is a Linux kernel custom-tailored for the target.
  - http://www.sysgo.com

Commercial Embedded Linux (4)

- **Red Hat Embedded Linux**
  - General purpose embedded solution
  - http://www.redhat.com
- **Coollogic Coollinux**
  - Combines Linux and Java for Internet applications
  - http://www.coollogic.com
- **미지리서치 미지리눅스**
  - Linux-based embedded operating system
  - http://www.mizi.com

Commercial Linux RTOS

- **FSMLabs RTLinux**
  - http://www.fsmlabs.com
- **LynuxWorks BlueCat RT**
  - http://www.lynuxworks.com
- **MontaVista Linux Real Time Extensions**
  - http://www.mvista.com
- **TimeSys Linux/Real-Time**
  - http://www.timesys.com

Open Source Linux RTOS

- **RTAI**
  - "Hard" Real-Time Application Interface
  - http://www.rtai.org
- **Kansas Univ. Real-Time Linux (KURT)**
  - Microsecond timing resolution and event-driven real-time scheduling
  - http://www.ittc.ku.edu/kurt/
- **ART Linux**
  - A Real-Time extension to Linux inspired by RT-Linux.
  - http://www.movingeye.co.jp
- **Univ. of Mass, Qlinux**
  - A QoS enhanced Linux Kernel for Multimedia Computing
  - http://lass.cs.umass.edu/software/qlinux/

RTLinux

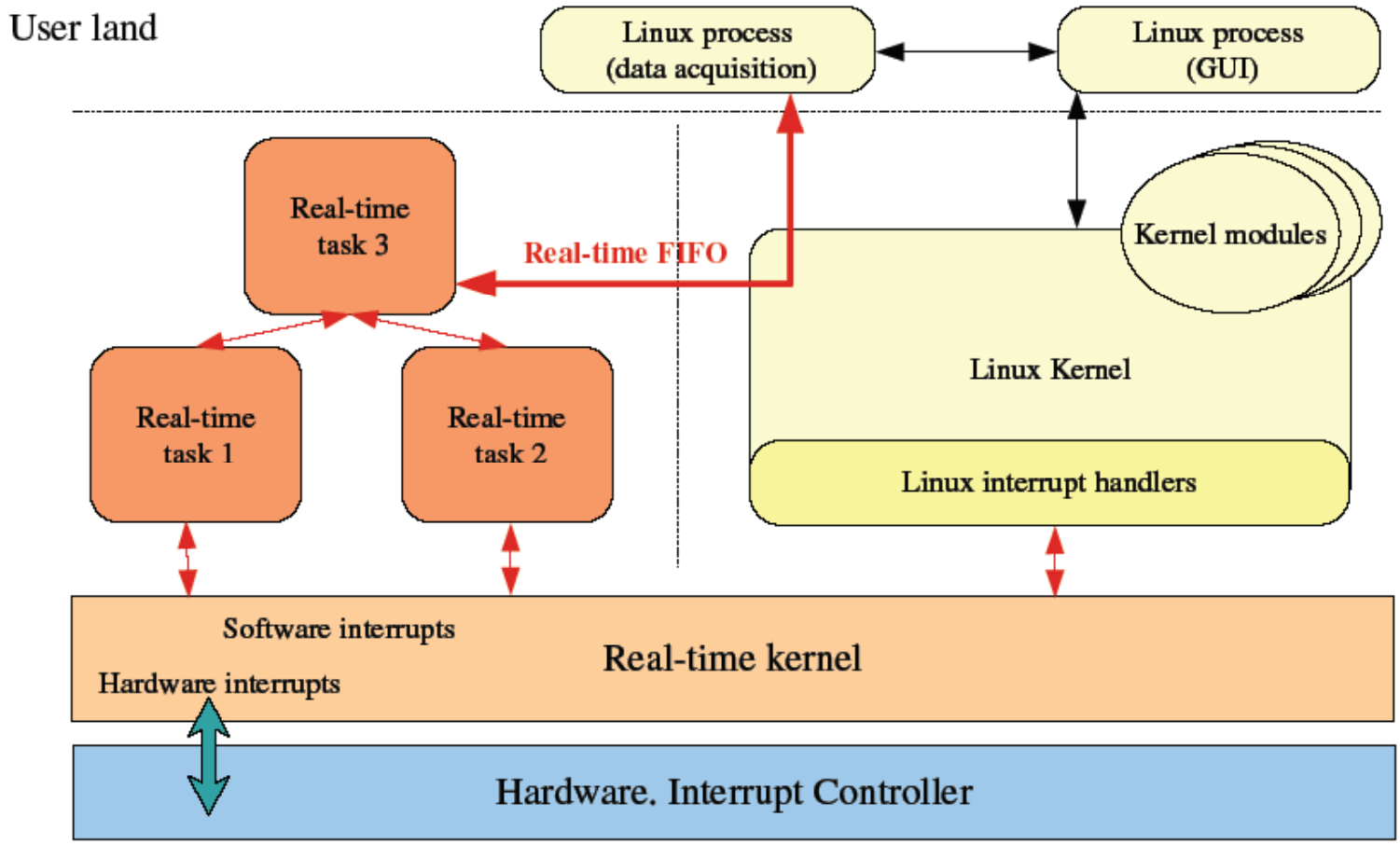
- **RTLinux**
  - Linux real-time extension
  - The author filed a software patent covering the addition of real time support to general OS as implemented in RTLinux.
  - Offers two products:
    - RTLinuxPro, RTLinuxFree
  - Community unfriendly.
  - The patent issue and uncertainty drew many developers away and frightened users.

RTAI (1)

- **RTAI**
  - Real-Time Application Interface for Linux
  - Supports Linux 2.6 since April 2004.
  - Community project, large user base.
  - Excellent documentation
  - Supported architectures (+ SMP support):
    - x86, PowerPC, ARM, MIPS, CRIS, ...
  - License: LGPL
  - Modularity
  - Support for POSIX and other RTOS APIs

RTAI (2)

- **RTAI Architecture**



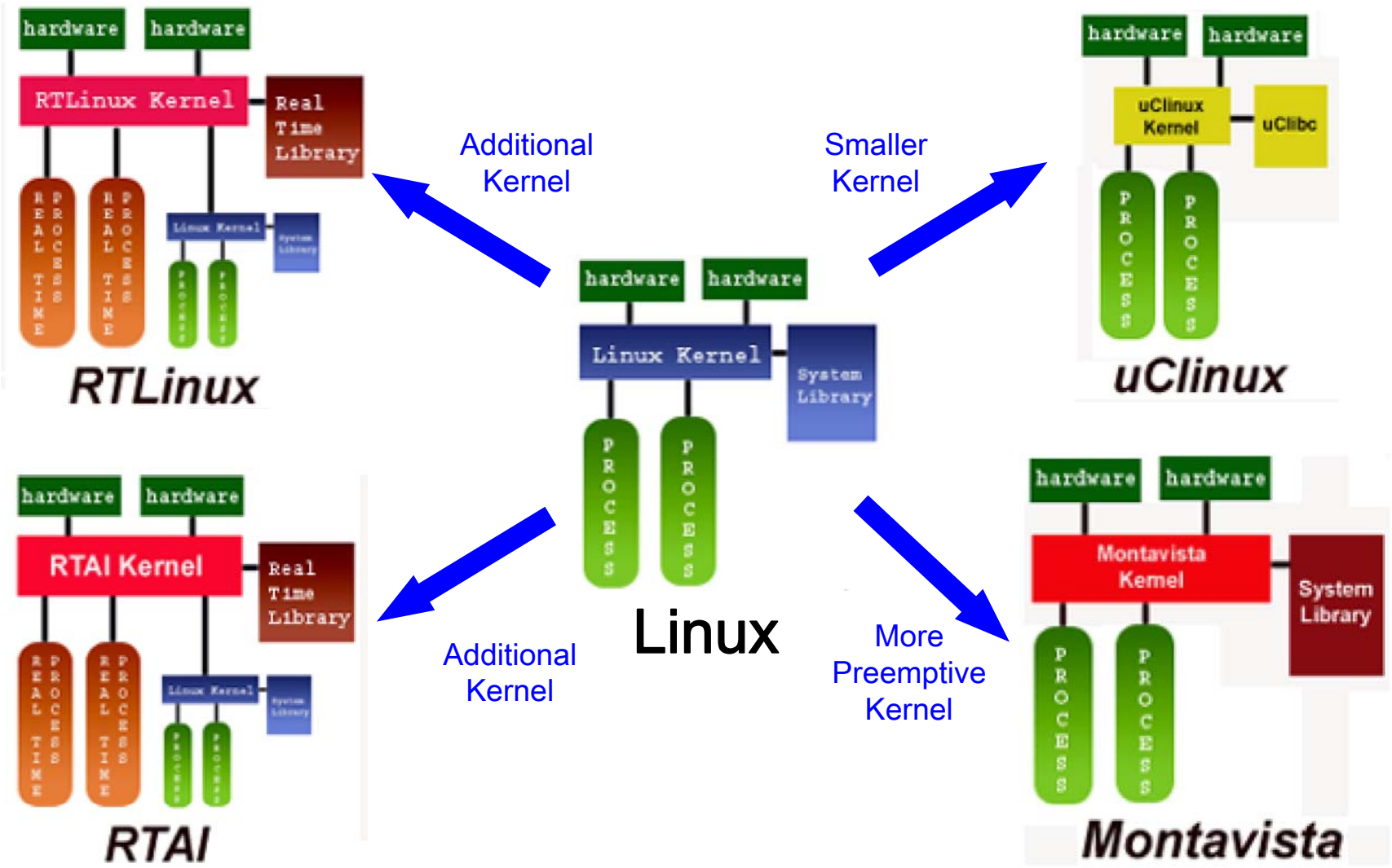
Montavista (1)

- **Montavista Linux Professional Edition**
  - Employs some of the most active kernel hackers, in particular on the ARM platform.
  - All kernel development shared with the community kernel core and drivers
    - Linux 2.6 example: preemption option, many drivers, etc.
  - O(1) fixed overhead / fixed priority scheduler for real-time running in front of the Linux scheduler.
    - Handles real-time POSIX pthreads, and leaves the other to the standard scheduler.

Montavista (2)

- **Montavista Characteristics**
  - Keeps the standard Linux API
  - Emulates VxWorks and pSOS API
  - Can be tried through a preview kit.
  - Supports an impressive list of processors.
  - Tools to analyze performance and track down latency sources.
  - Development tools seem to be proprietary.

Linux Real Time Support



References (1)

- **General Linux**
  - http://www.kernel.org
  - http://www.lwn.net
  - http://kerneltrap.org
  - http://slashdot.org
  - http://kernelnewbies.org
  - http://www.lkml.org
  - http://www.linux-tutorial.info
  - http://www.linuxjournal.com
  - http://www.linux-mag.com
  - http://www.kldp.org

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  - http://www.elinux.org
  - http://www.ddjembedded.com
  - http://www.embedded.com

  - http://www.kelp.or.kr
  - http://www.embeddedworld.co.kr
  - http://elinus.net