嵌入式系统

实时嵌入式系统基础

邝 坚

嵌入式系统与网络通信研究中心

北京邮电大学 计算机学院/软件学院

实时嵌入式系统基础

1. Embedded System
2. Real Time
3. HW Core
4. SW Core

A General Definition

- **Embedded systems are computing systems with tightly coupled HW and SW integration, that are designed to perform a DEDICATED function.**

- **The word embedded reflects the fact that these systems are usually an internal part of a larger system, known as the embedding system.**

- **Multiple embedded systems can coexist in an embedding system.**
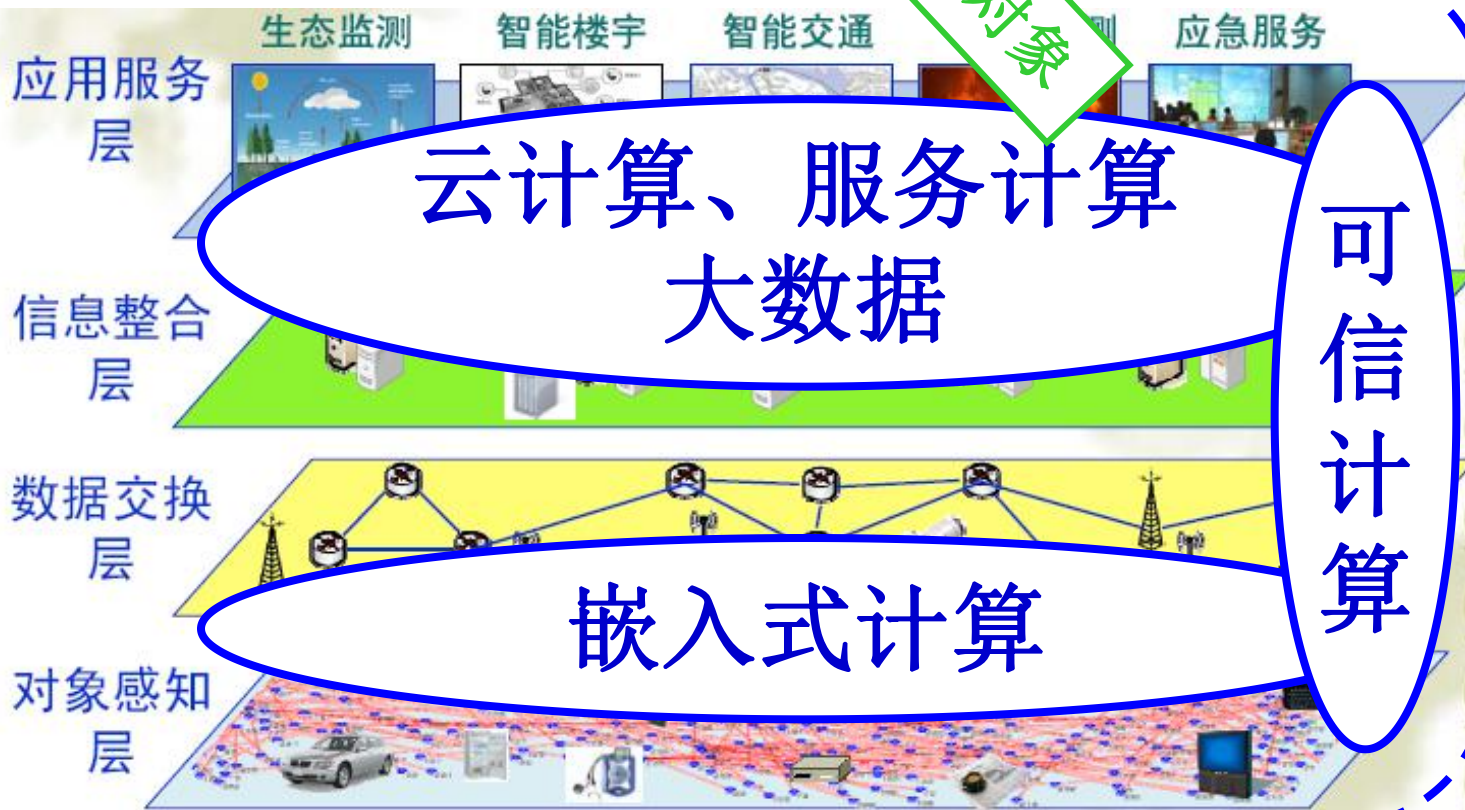
- Real-Time Concepts for Embedded Systems
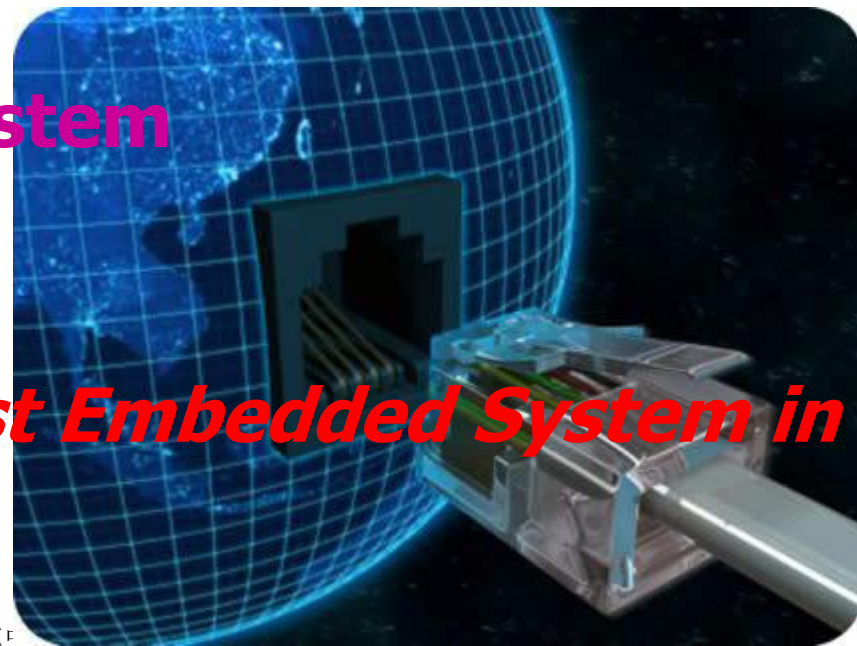
嵌入式系统无所不在

从热点看嵌入式系统

移动互联网

服务对象

生态监测　智能楼宇　智能交通　　　　　应急服务

应用服务层

信息整合层

数据交换层

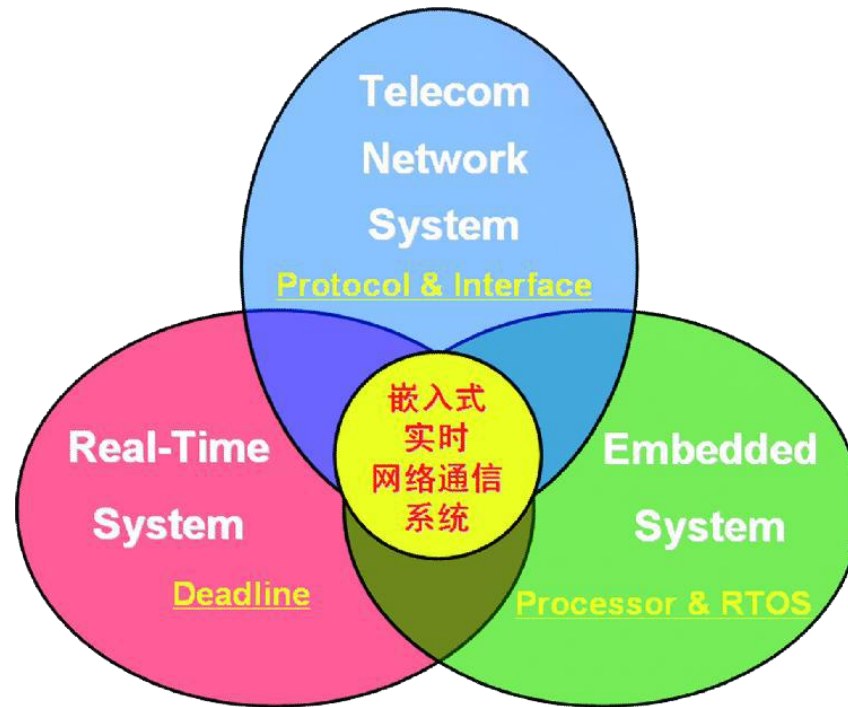对象感知层

服务

理解

安全

交换

感知

云计算、服务计算
大数据

嵌入式计算

可信计算

嵌入式系统应用的主要领域

- **Aerospace, Defense**
- **Industrial Measurement & Control, Robotics**
- **Telecom System**
- **Personal & Consumer Device**
- **Automobile**
- **Medical Computer System**
- *…*

- *Internet – The Largest Embedded System in the world.*

What-Why-How

- **HW core - Embedded Microprocessor**
- **SW core - Embedded OS (RTOS)**
- **RT TeleCom SYS - RT Framework + SDL**

实时嵌入式系统基础

1. Embedded System
2. Real Time
3. HW Core
4. SW Core

What is a real-time system?

- **Real-time computing is computing where the system correctness depends not only on the correctness of the *logical* result of the computation but also on the result delivery *time*.**

- **Pertaining a system or mode of operation in which computation is performed during the actual time that an external process occurs, in order that the computation results may be used to control, monitor, or respond in a timely manner to the external process. (IEEE 610.12 - 1990)**

  - **KEY – Use *determinate time* to process every *asynchronous event*.**
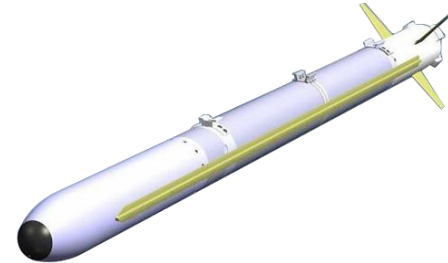
Essential Characteristics

- **_Logical_ or Functional Correctness** –
  - **system must produce correct computational result.**
- **_Timing_ Correctness** –
  - **The computations must conclude within a predefined period - DEADLINE**

RT categories (Deadline)

- **Hard real-time:** missing a deadline has catastrophic results for the system;

Value
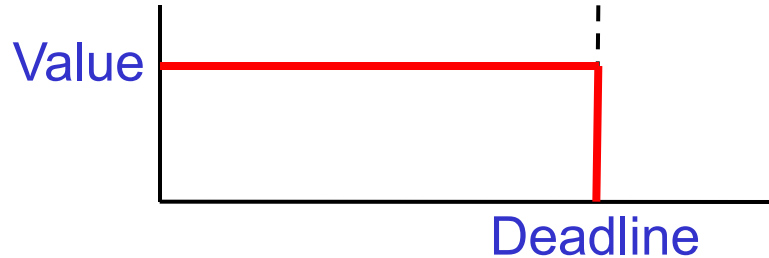
Deadline

- **Firm real-time:** missing a deadline has a non acceptable quality reduction as a consequence;
- **Soft real-time:** deadlines may be missed and can be recovered from. The reduction of system quality is acceptable;

Value
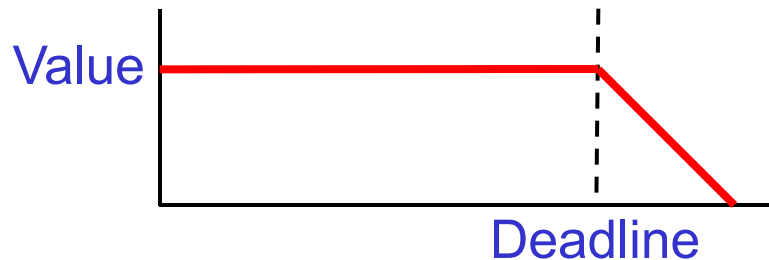
Deadline

- **Non real-time:** no deadlines have to be met.

Structure of Embedded real-time system

Dedicate Job List

Management

Sensors

Trigger Generator

Actuators

Execution

Display

Tick(Clock)

Environment
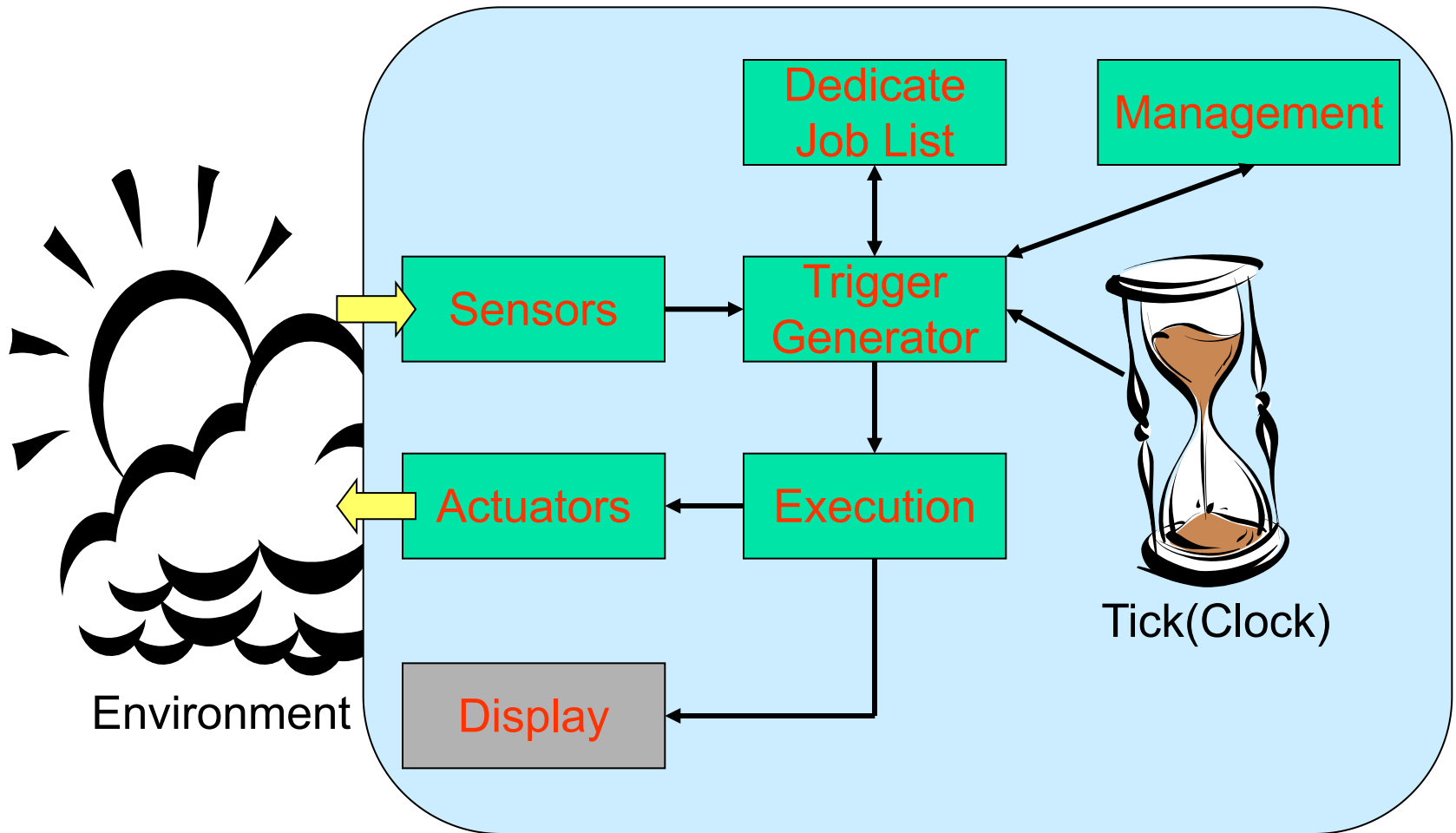
Keep in mind

- 即使在同一个实时系统内，对不同事件处理的实时性要求也是不同的

  如何处理？

- 事件的分类：
  - **Synchronous Events** – 周期性的，系统可预见下一次同类事件发生的时刻
  - **Asynchronous Events** – 非周期性的，事件发生的时间不可预测

RT mission in a car
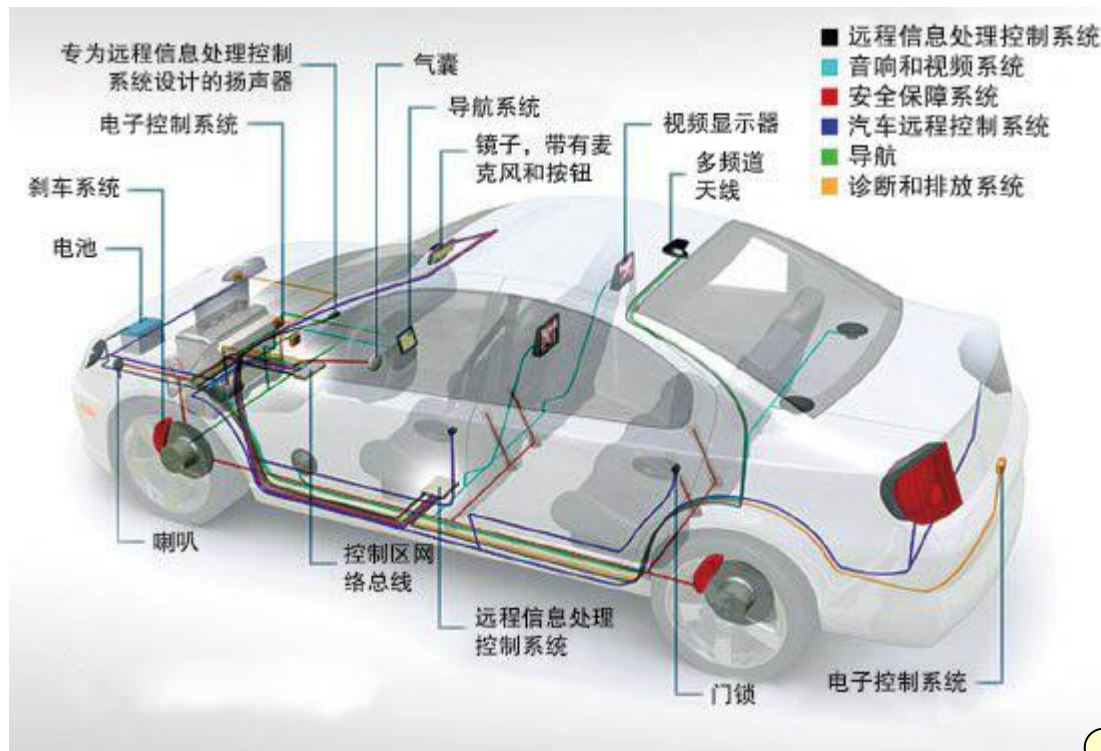
Steering

brakes

Radio

lights

Doors

Windows

…

这些功能的实时性如何？

典型的实时嵌入式系统（1）

- ## XW-1卫星无线电存储转发系统软件
  - 资源紧凑型(128K Flash + 64K RAM)高可靠、高稳定性通信协议星载软件(2009年12月发射)
  - 支持AX.25及PACSAT两个通信协议的多实例运行，C代码约12000行
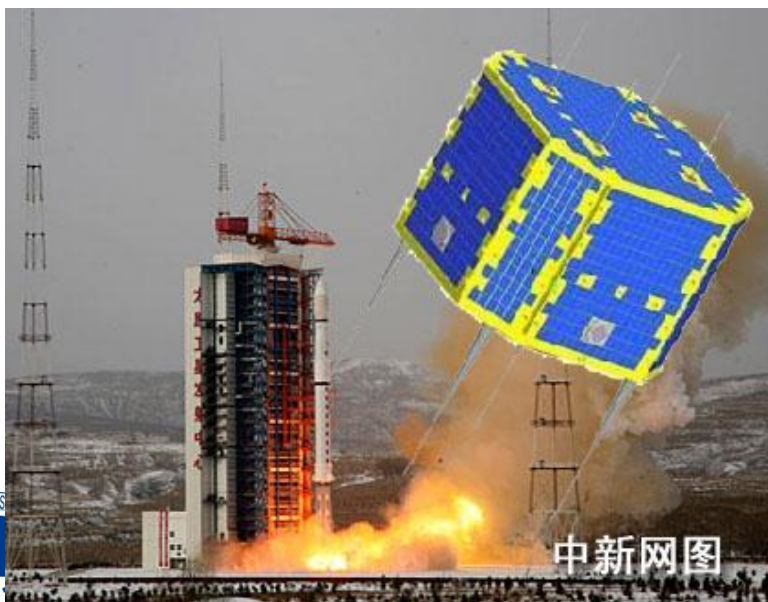
典型的实时嵌入式系统（2）

- ## 大型地震数据采集记录系统（2007-2008）
  - ### 数据密集型高可靠多协议强实时嵌入式系统

MPC82XX+ VxWorks + GBit Switch

PMU

DAU

LMU

测线仿真器

数据协议

控制协议

交叉站

TU (TMS)

LMU/FCU

交叉线仿真

FCU

主机接口
主机系统
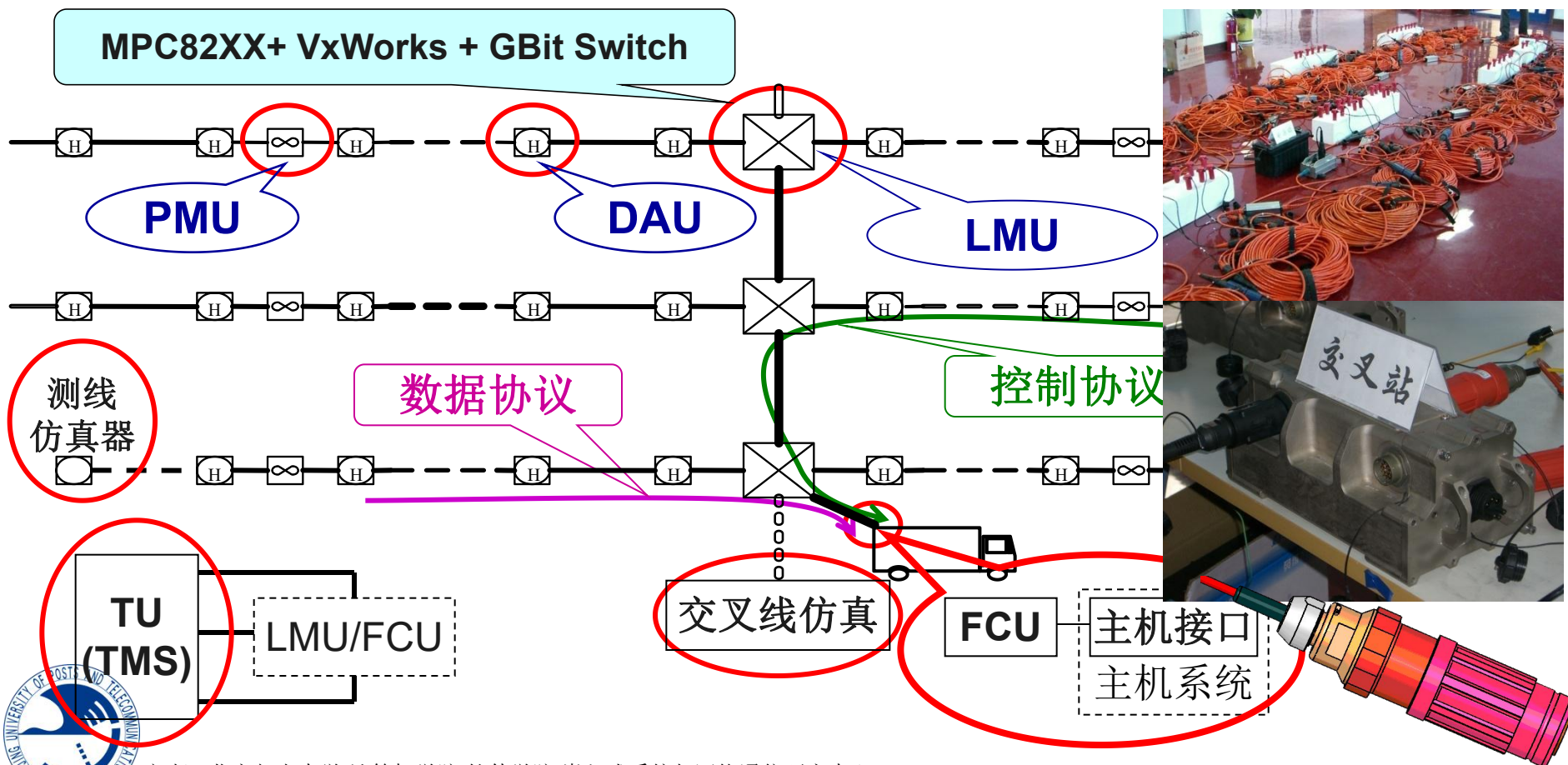
- 40万门ATM宽带话音交换系统
  - 多处理机、多通信协议、大量协议实例的大型实时嵌入式系统
  - 采用SDL形式化语言自动代码生成工具

**X86 + M68K
pSOS+
C + SDL**

实时嵌入式系统特征

- 给定功能的专用计算机系统，不同系统的差异性大，软硬件协同设计要求强烈。对用户，相对封闭性强；

- 不同功能的实时性要求各异，难点一：强实时处理；

- "嵌入"并不意味着一定是小(微)型系统；

- "弱交互"、"固化代码"普遍存在；

- "低功耗 + 资源紧凑"条件下的系统实现，要求OS及应用软件具有：精简、高效、深度优化特征（难点二）；

- 无人值守、长时间无间断工作、(极)低故障率需求，使系统研制具有"抗恶劣环境 + 高稳定性 + 高可靠性"的超强挑战性（难点三）；

- 开发环境相对桌面平台的弱，但在逐渐完备。

- 商业因素：成本，芯片、工具选型，时效 …

THE GOAL OF EVERY EMBEDDED SYSTEMS ENGINEER IS TO RETIRE WITHOUT GETTING BLAMED FOR A MAJOR CATASTROPHE.
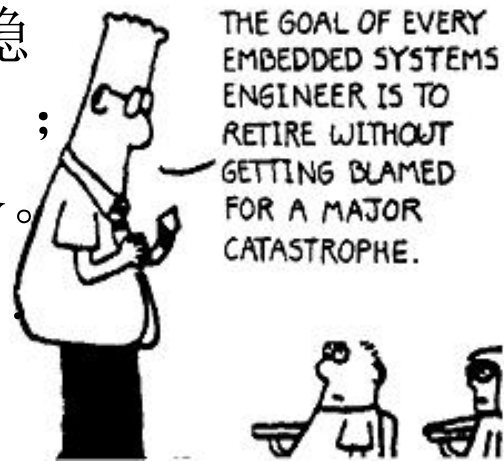
实时嵌入式系统基础

1. Embedded System
2. Real Time
3. HW Core - Architectures
4. SW Core

Embedded Microprocessor

What is Embedded Microprocessor?

A programmable processor whose programming interface is not accessible to end-user of the product.

The only user-interaction is through the actual application.
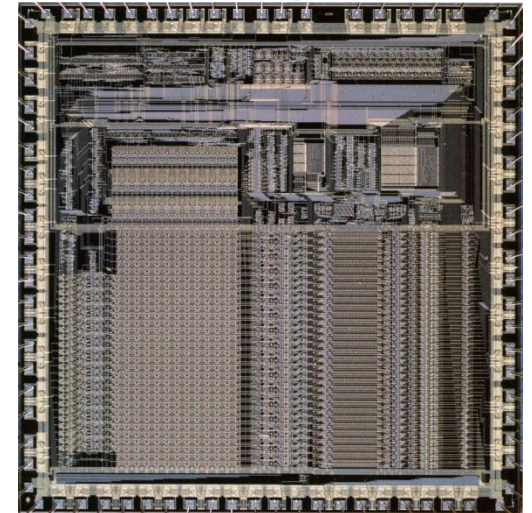
Something interesting

- **Intel 4004** – 计算器 **(1970, 4-bit CPU, 46 instructions)**
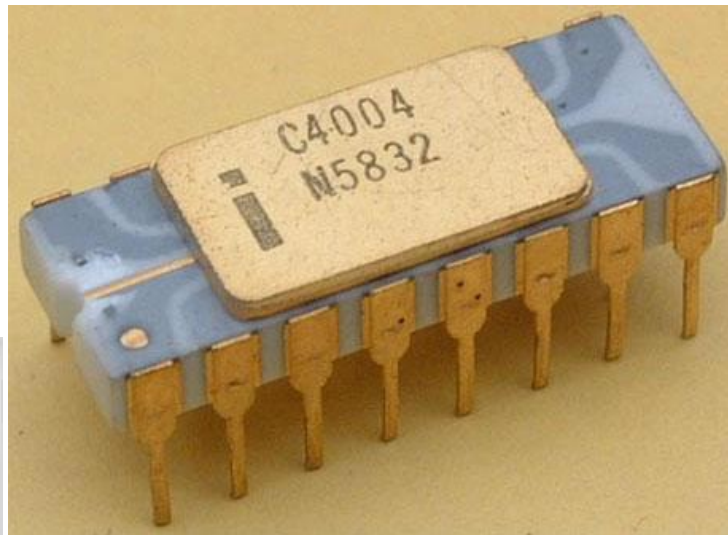
- 当今的处理器中有**90%**以上是用于嵌入式设备**(**以百亿计**/**年**)**

不应该只知道或只了解**X86**！

- **Embedded Processor focuses on:**
  - <u>**Performance that not achievable with GP-processor**</u> – **Network & Telecom equipment.**
  - <u>**Size, Power and Price**</u> – **PAD – interactive and display intensive, rather then computation intensive.**
  - <u>**Special**</u> – **DSPs, Graphics Processors, Media Processors …**

Categories

- **MPU** – **Microprocessor Unit**
- **MCU** – **Microcontroller Unit**
- **DSP** – **Digital Signal Processor**
- **SoC** – **System On Chip**
- **Muiti-Core**
  - **RISC+DSP**
  - **CSIC+RISC+DSP**
  - **DSC (DSP+MCU, Digital Signal Controller)**
  - **RISC*n**

BIG Family - Embedded Processors (wikipedia)

- Embedded processors can be broken into two(*) broad categories: ordinary **microprocessors (μP) and microcontrollers (μC)**, which have **many more peripherals on chip**, **reducing cost and size**.

- A long but still not exhaustive list of common architectures are: 65816, 65C02, 68HC08, 68HC11, **68k**, 78K0R/78K0, **8051**, **ARM**, **AVR**, AVR32, Blackfin, C167, Coldfire, COP8, Cortus APS3, eZ8, eZ80, FR-V, H8, HT48, M16C, M32C, **MIPS**, MSP430, PIC, **PowerPC**, R8C, RL78, SHARC, **SPARC**, ST6, **SuperH**, TLCS-47, TLCS-870, TLCS-900, TriCore, V850, x86, XE8000, Z80, AsAP etc.

作为嵌入式系统从业者，不应该只知道或只了解**ARM**！

Freescale MPC8260

EC603e PowerPC Core ①

16 KB I-Cache / **IMMU**

16 KB D-Cache / **DMMU**

SYSTEM INTERFACE UNIT

60x Bus Interface Unit
PowerPC-to-Local Bridge ②
Local Bus Interface Unit
Memory Controller
Time Counter/PIT
Bus Arbiter
L2 Cache Controller
System Functions

③ **COMM. PROCESSOR MODULE**

Four Timers	Interrupt Controller	Internal Memory Space	Serial DMAs
Parallel I/O			
Baud Rate Generators	Timers	32-bit RISC and Program ROM	Virtual IDMAs

MCC1	MCC2	FCC1	FCC2	FCC3	SCC1	SCC2	SCC3	SCC4	SMC1	SMC2	SPI	I²C

Time Slot Assigner	Serial Interface

8 TDMs 3 MII 2 UTOPIA

邝坚 北京邮电大学 计算机学院/软件学院 嵌入式系统与网络通信研究中心

CS8xx Evaluation Board BUPT

TI OMAP5430 SoC

TI OMAP5430 SoC block diagram

- **External memory/storage:** LPDDR2, LPDDR2, NAND/NOR Flash, SD, eMMC, SSD, USB SS/HS host/target
- **Memory interfaces:** EMIF 1, EMIF 2, GPMC, MMC/SD, SATA 2.0
- **USB:** USB 3.0 OTG, 3x USB 2.0 host (ULPI/TLL/HSIC) → USB HS target
- **3G/4G modem:** 2x MIPI HSI, MIPI LLI, TI C2C, USB/HSIC, UART/SPI, SDIO, McBSP
- **MIPI LLI/UniPort-M → Companion device**
- **Cameras:** MIPI CSI-3, 3x MIPI CSI-2 + CPI, Camera control — Up to four cameras
- **DIG MIC**

OMAP5430

| Dynamic memory manager | ARM Cortex-M4 | ARM Cortex-M4 |
| L2 cache | | |

| ARM® Cortex™-A15 MPCore (up to 2 GHz) | ARM Cortex-A15 MPCore (up to 2 GHz) | POWERVR™ SGX544-MPx 3D graphics | C64x DSP | IVA-HD video accelerator |
| | | TI 2D graphics | Image signal processor | |

L3 Network-on-chip interconnect

| Timers, Int Controller, Mailboxes, System DMA | Audio processor |
| Boot/Secure ROM, L3 RAM | |

M-Shield™ system security technology: SHA-1/SHA-2/MD5, DES/3DES, RNG, AES, PKA, secure WDT, keys, crypto DMA

| L4 peripherals | Multi-pipe display sub-system (DSS) |

- **WiLink™ wireless connectivity:** I²C/SPI, SDIO, UART, McBSP
- **TWL Power/Monitor — Main battery:** I²C
- HDQ/1-Wire
- REF/CLK — Clocks
- (4) UARTs — Serial devices
- **Debug & trace cJTAG/STP/PTM** → Emulator pod, Trace analyzer
- UART, GPIO, Keypad, I²C/SPI → Fast IrDA, GPIO, Keypad, Touch screen controller
- **TWL6040:** Audio, Headset, Speakers, Vibrators, Amplifiers, Micro — 32 kHz Crystal, In/Out, HF speakers, Handset microphone
- I²C, PDM, SLIMbus®
- MIPI DSI → LCD, MIPI DSI → LCD, MIPI DBI-B/DPI → LCD — Up to four displays
- HDMI 1.4a → TPD12S015 → 3D HDTV

国产CPU状况

- 全新自主指令系统
  - Unicore - 北大众志；
  - C*Core - 浙江大学、苏州国芯、杭州中天，M*CORE + PowerPC；
  - 申威 -上海高性能集成电路设计中心；

- 兼容国际主流、自主指令系统
  - 龙芯2/3(MIPS32/MIPS64) - 中国科学院计算所；
  - FT(SPARC) - 国防科技大学；
  - Xburst(MIPS32) - 北京君正。
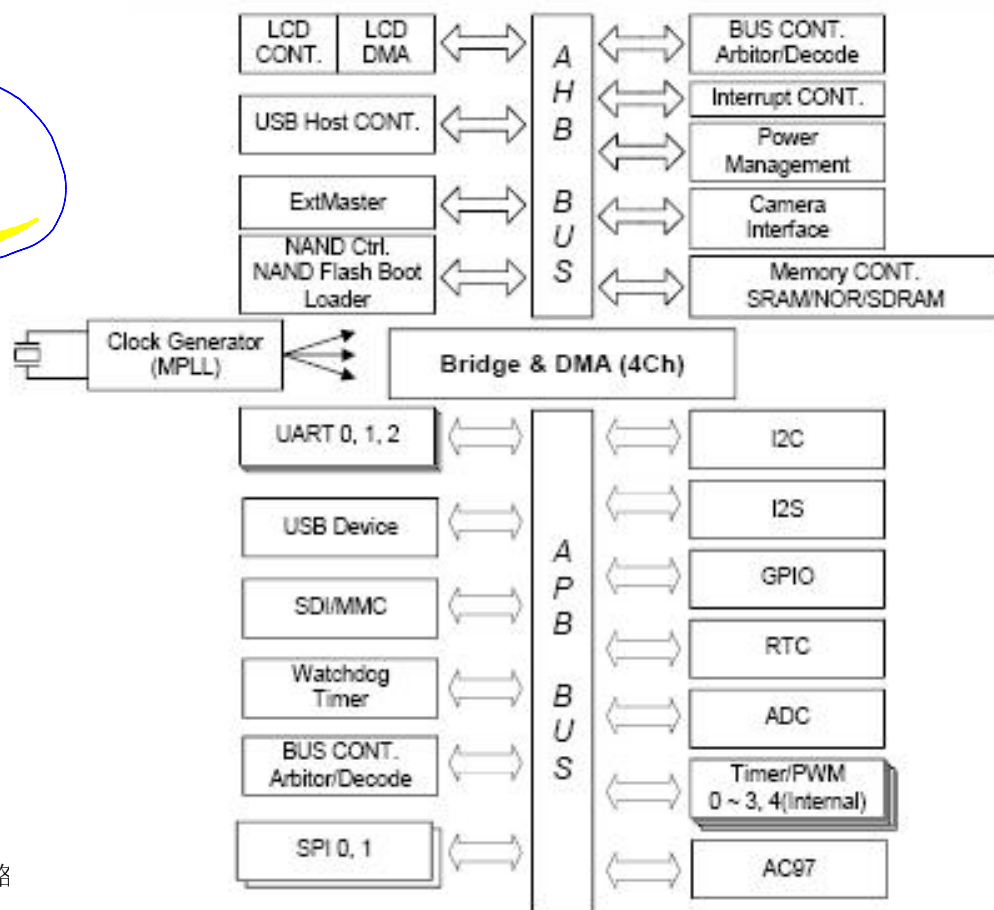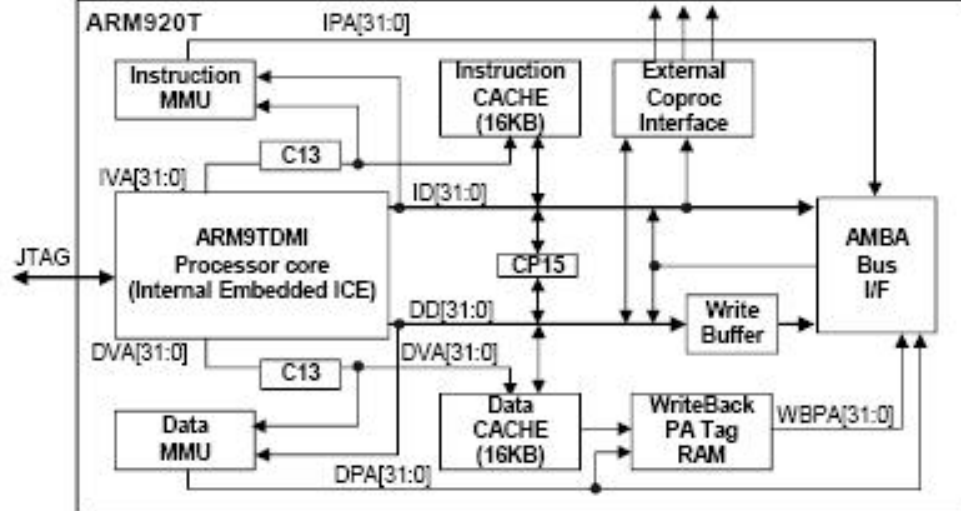
Our HW Target

- ## S3C2440
  - ### 体系结构具有代表性
    - RISC
    - MMU/Cache
    - Harvard architecture
  - ### 片上I/O经典
  - ### 教学资源丰富
  - ### 应用广泛

实时嵌入式系统基础

1. Embedded System
2. Real Time
3. HW Core
4. SW Core - RTOS

RTOS

- An OS that schedule execution in a strong timely manner, manage system resources, and provide a consistent foundation for developing application code.

- An RTOS that can usually or generally meet a deadline is a soft real-time OS, but if it can meet a deadline deterministically it is a hard real-time OS.

- KEY − Real time (**less jitter, definitely determined**), Highly modularized, MultiTasking, High performance, compact and scalable.

RTOS vs GPOS

- **专业化强** – 每一种实时嵌入式操作系统通常面向特定类型或几种相近类型应用。某些操作系统会根据不同的应用对象采用不同的模块搭配。有些操作系统甚至是自行研制的内部产品。

- **实时性** – 大多数嵌入式系统工作在实时性要求很高的环境中，对外部事件的响应，包括数据的获取、处理和数据的输出都必须在deadline规定的时间内完成。这就要求实时嵌入式操作系统必须将实时性作为一个重要指标。

- **强稳定性** – 与桌面系统不同，大多数嵌入式系统一旦开始运行就不需要人过多的干预。在这种条件下，要求作为系统资源总管的操作系统具有较高的稳定性。

RTOS vs GPOS

- **固化代码 –** 在嵌入式系统中，操作系统与应用软件代码通常被固化在嵌入式系统的ROM中。目前辅助存储器（如磁盘）在嵌入式系统中很少使用，因此，实时嵌入式操作系统的文件管理功能应该能够很容易裁减，取而代之的是各种内存文件系统。

- **弱交互性 –** 除消费类电子设备以外，大多数嵌入式系统的工作过程不需要人的干预。因此多数实时嵌入式操作系统所提供用户操作接口相对简单，主要通过系统调用命令向用户程序提供服务。

评价指标

- **任务切换时间（Task switch time）**。系统中两个具有相同优先级任务之间切换所需要的平均时间。

- **抢占时间（Preemption time）时间**。系统中某个高优先级任务抢占低优先级的任务花费的平均时间。

- **中断等待时间（Interrupt latency time）**。从CPU收到中断请求到执行中断服务程序的第一条指令所用的时间。

- **信号量延迟时间（Semaphore-shuffle time）**。从一个任务释放信号量到另一个等待信号量的任务被激活的时间延迟。

- **死锁解脱时间（Deadlock break time）**。指系统解开死锁所需的平均时间，造成死锁的原因是高优先级任务抢占某一低优先级任务后，进而需要刚刚被抢占任务所拥有的资源。

- **任务间消息传递延迟（Intertask message latency）**。非零长度消息在任务间传递的操作系统内部延迟时间。

- **数据报吞吐量（Datagram throughput time）**。任务间利用操作系统通信原语传递数据，每秒所传送的字节数。

…

Some RTOS maybe you know

哪个你知道？

Huge Family - RTOS List

- Abassi, AMX RTOS, ARTOS, Atomthreads, AVIX, BeRTOS, BRTOS, CapROS, ChibiOS/RT, ChorusOS, CMX RTOS, cocoOS,Concurrent CP/M, Concurrent DOS, Contiki, COS, Deos, DioneOS, DNIX, GEC DOS, DrRtos, DSPnano RTOS, DSOS, eCos, eCosPro, embOS, Embox, ERIKA, Enterprise, EROS, Femto OS, FlexOS, FreeOSEK, FreeRTOS, FunkOS, Fusion RTOS, HeartOS, Helium, HP-1000/RTE, Hybridthreads, IBM 4680 OS, IBM 4690 OS, INTEGRITY, IntervalZero RTX, ITRON, uITRON, microITRON, ioRTOS, iRTOS, LynxOS, MaRTE OS, MAX II,IV, MenuetOS, Milos, MP/M, MQX, MERT, Multiuser DOS, Nano-RK, Neutrino, Nokia OS, Nucleus OS, NuttX RTOS, On Time RTOS-32, OS20, OS21, OS4000, OPENRTOS, OSA, OSE, OS-9, OSEK, Phar Lap ETS, PaulOS, PICOS18, picoOS, Phoenix-RTOS, PikeOS, Portos, POK, PowerTV, Prex, Protothreads, pSOS, QNX, Q-Kernel, QP, RDOS, ReaGOS, REAL/32, Real-time Linux, REX OS, RMX, RSX-11, RT-11, RTAI, RTEMS, rt-kernel, RTLinux, RT-Thread, RTXC Quadros, SAFERTOS, Salvo, SCIOPTA, scmRTOS, SDPOS, SHaRK, SimpleAVROS, SINTRAN III, Sirius RTOS, SMX RTOS, SOOS Project, Symbian, Talon DSP RTOS, TargetOS, T-Kernel, THEOS, ThreadX, Trampoline Operating System, TNKernel, Transaction Processing Facility, TRON ProjectTUD:OS, Unison RTOS, μC/OS-II, μC/OS-III, UNIX-RTR, uSmartx, μTasker, u-velOSity, velOSity, VRTX, VxWorks, Windows CE, Xenomai, xPC Target, Y@SOS, MontaVista Linux, μnOS, uOS
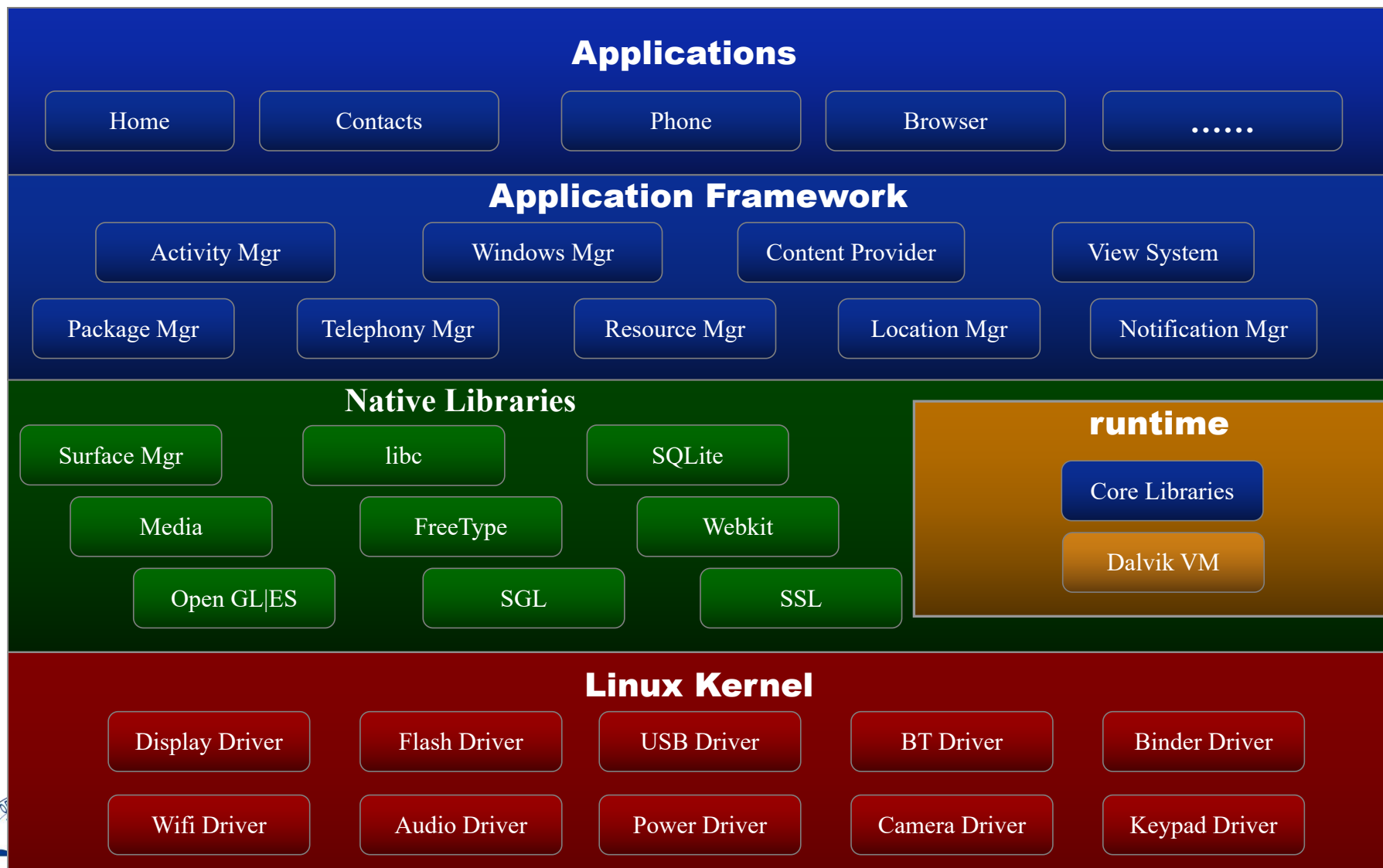
List of real-time operating systems - wikipedia

哪些个你知道？

VxWorks 6.9

Wind River Workbench			
Wireless Ethernet	Mobile IPv4/IPv6	802.1Q VLAN	Media Library Graphics
SSL & SSH	IPsec & IKE	NAT/Firewall	IGMP/MLD
RADIUS and Diameter Client	Wireless Security	Crypto Libraries	EAP
SNMP v1/v2/v3	Web Server	CLI/MIBway	Learning Bridge
VRRP	Web Svcs-Interop/SEC	DCOM	CAN/OPC
TIPC MIPC	Distributed Shared Memory	USB 1.1, 2.0	
dosFs	Flash Support (TrueFFS)	Highly Reliable FS	
IPv4/IPv6 Network Stack		PPP	

VxWorks/VxWorks Multiprocessing (SMP/AMP)

Android Architecture

Applications

Home	Contacts	Phone	Browser	......

Application Framework

Activity Mgr	Windows Mgr	Content Provider	View System
Package Mgr	Telephony Mgr	Resource Mgr	Location Mgr	Notification Mgr

Native Libraries

Surface Mgr	libc	SQLite
Media	FreeType	Webkit
Open GL|ES	SGL	SSL

runtime

Core Libraries

Dalvik VM

Linux Kernel

Display Driver	Flash Driver	USB Driver	BT Driver	Binder Driver
Wifi Driver	Audio Driver	Power Driver	Camera Driver	Keypad Driver

Our OS Target

- **uC/OS-II** (uC/OS-III)
  - Hard Real-Time RTOS内核
  - 源码公开
  - 结构小巧 (5-24KB)
  - 资源丰富
  - 稳定性强，可靠性高 – FAA (Federal Aviation Administration，联邦航空局)DO-178B认证，
  - 应用广泛
    - Avionics
    - Medical equipment/devices
    - Data communications equipment
    - White goods (appliances)
    - Mobile Phones, PDAs
    - Industrial controls
    - Consumer electronics
    - Automotive

µC/OS-II™
The Real-Time Kernel

实时嵌入式系统入门者的最佳选择之一