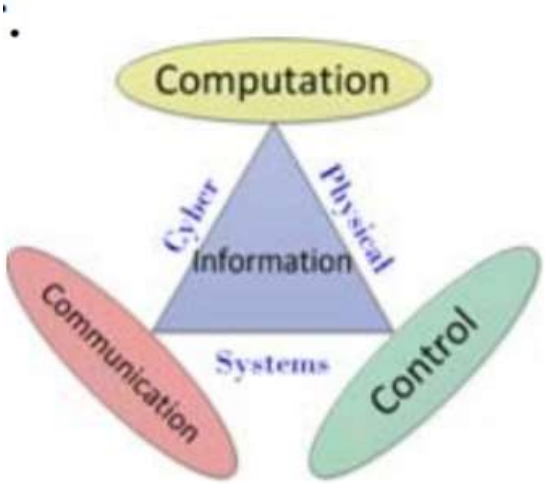
Embedded System

Lecture Note 1. Fundamentals

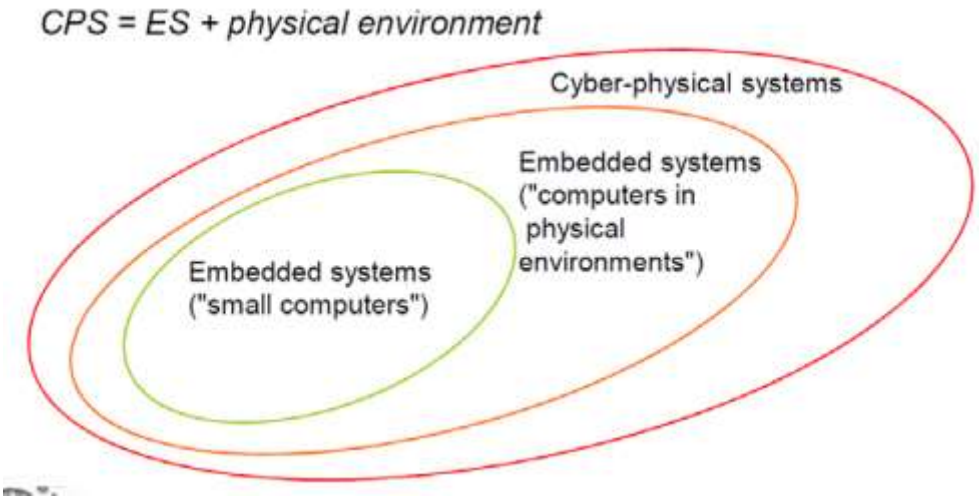
I. Control Applications

1. Common feature: Control functionality（註：這裡的控制與我們所學控制系統不同）
   (1) Event Control：Real-time system/applications, Dedicated function
      Ex：motor/engine control, indicator
   (2) Data Control：Data processing, Data formatting, I/O control
      Ex：image processing, graphics



II. CPS and Embedded Systems

1. 嵌入式系統就是 Computer as Component
2. CPS



III. IoT is embedded system?

1. 既然嵌入式系統是構成物聯網系統的主要元素，是否稱之為「嵌入式-物聯網」或是「e-IoT」更為貼切?這裡給出一個答案，物聯網的 I，表示萬物皆可連，Networked Embedded System。

2. 物聯網在 1995 年就被 Kevin Ashton 提出，不過隨後幾年卻沒被受到重視。
原因有二：

(1) 嵌入於「物件」中的感測器與致動器(Actuator)成本當時仍然相對地高。然而，在 2012 到 2013 的 18 個月當中，用於監測及追蹤物件的 RFID 晶片的成本急速地下降了 40%，這些標籤(Tag)現在的價格已低於 10 分錢美元，至於 MEMS 的價格，包括陀螺儀、加速感測器、及壓力感測器在內，也已在過去的 5 年當中下滑了 80%到 90%。

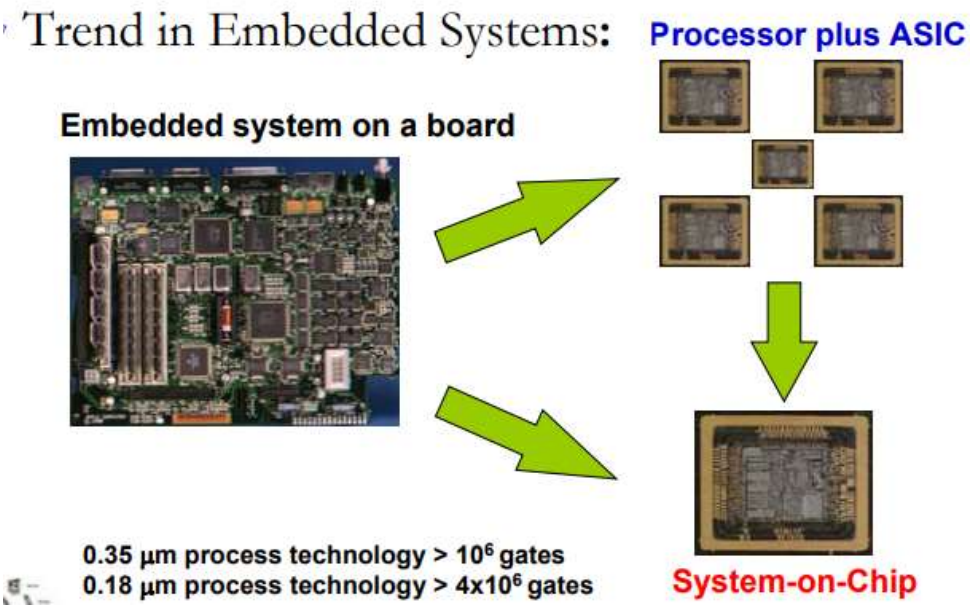
(2) 網際網路協定 IPv4(使用 32 位元做為其網際網路位址)只能容納 43 億(2^32)組唯一位址於其網際網路上，而由於其中大部分的 IP 位址都已被超過 20 億連接於網際網路上的人口搶用掉，只剩下極少的位址可供數百萬(最終還將增加到數兆)的「物件」連接上網際網路。

IV. Embedded Systems in Post-PC Era

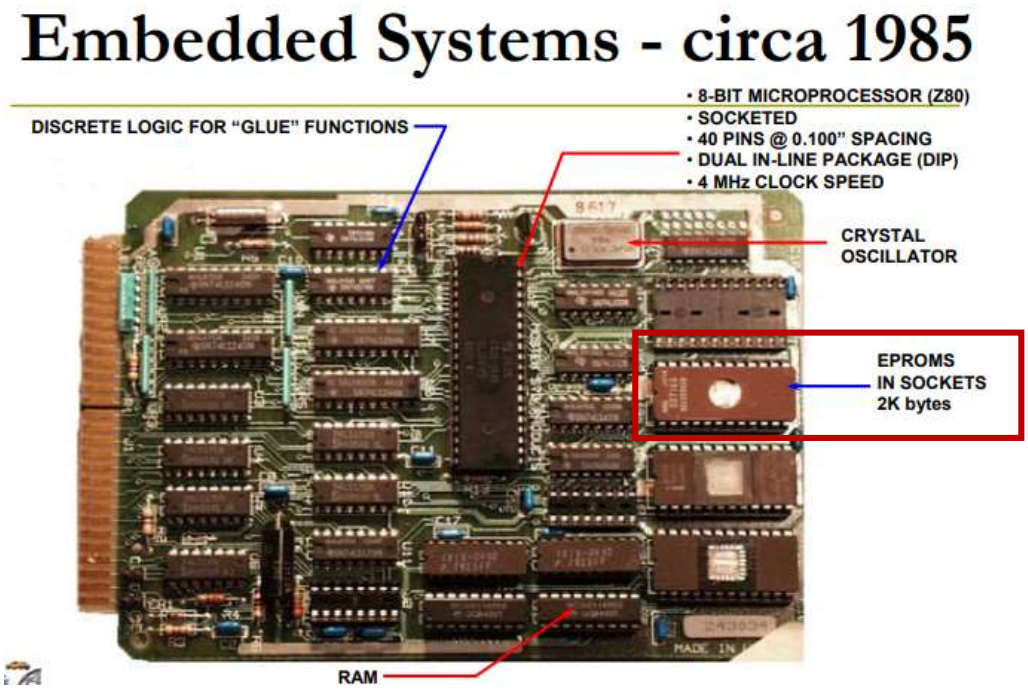
後 PC 時代曾經在計算機組織聽過，這裡給出幾個特點。

1. Moore's Law means "The complexity of integrated circuits will double every 18 months".
=> Process technology is able to put more and more functionality on the same chip as the CPU.

2. Originally, Design of Embedded system on a board is Processor plus ASIC, after revolution, it becomes to System on chip SoC which means "An IC that integrates all components of a computer or other electronic system into a single chip".



早期的嵌入式系統，有個明顯特徵 EPROMS



However, there are new types of memories, such as electrically erasable programmable ROM (EEPROM) and non-volatile RAM (NVRAM). Both can be read and write and do not lose its contents even if power is switched off. Flash memory is the best example of NVRAM. It is high-density, low-cost, fast, and electrically programmable. Flash memory is being extensively used for embedded systems that contain embedded operating systems and the application program.

(1) PROMS，像光碟機概念，只能寫一次，成本高
(2) EPROMS，E 表示 Erasable，改的方法是透過上面的透明壓克力版照射紫外光，將資料全部清除，1 cycle 約 30mins
(3) EEPROMS，E 表示 Electrical，表示已經可以用電清除資料
(4) FLASH，現代記憶體，如隨身碟、儲存卡，具有 EEPROMS+硬碟的效果，不過動態抗震性比硬碟強

現代 SoC，補充一點，ARM 的 A 系列表示可以跑 Linux, Android

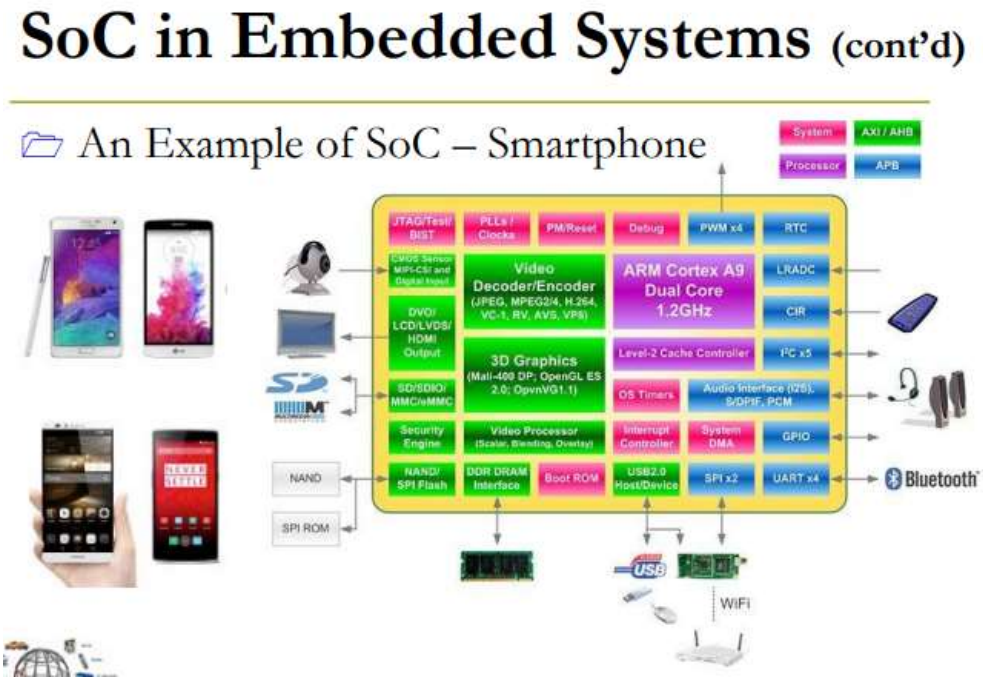
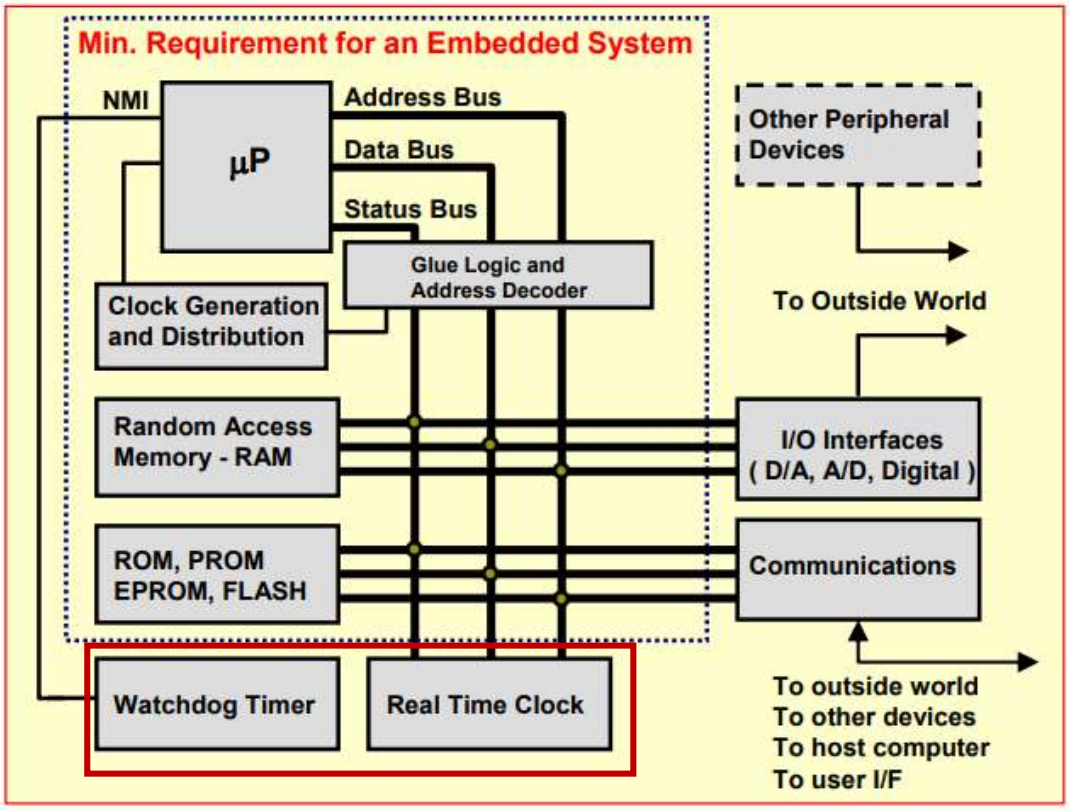


Table 1.1 ARM® architecture categories

Application	Real-time	Microcontroller
32-bit and 64-bit	32-bit	32-bit
A32, T32, and A64 instruction sets	A32 and T32 instruction sets	T32 / Thumb® instruction set only
Virtual memory system	Protected memory system (optional virtual memory)	Protected memory system
Supporting rich operating systems	Optimized for real-time systems	Optimized for microcontroller applications

V. Typical Embedded System

1. 典型的嵌入式系統架構



(1) **Real time clock**：不一定與數位手錶電路相同，電腦關機仍然供電給 Real time clock

(2) **Watchdog timer**：讓 Embedded System 更 Robust，更有操作性，設計一段時間(e.g. 1~2mins)倒數，時間到發訊息給 Processor，NMI 或 Reset 接腳。

(3) NMI：Non-Maskable Interrupt，是一種不能藉由 mask 機制來關閉的硬體中斷，NMI 可用來通報一個不可復原的硬體錯誤(如 system hung)以作即時的反應處理，可以直接交給 ISR(Interrupt Service Routine)讓系統重開機或是先保存資料再重新開機，軟體每 1~2mins 需 reset Watchdog Time，例如：網頁自動登出、巡邏箱。

在某些系統，NMI 可由外部硬體拉 NMI pin (如按特定 hot key)，或者是由其他 processor 來觸發產生，SoC 系統內，某一 processor 無法 handle 一般 interrupt 時，由其它 processor 觸發 NMI。

當 NMI 收到後,進入到 NMI handler，就可在 handler 作一些 debug 機制，如 cache flush 以利開發者之後分析 memory dump，或用 real time debug(i.e. Jtag)機制 break 在此 handler 來即時分析。

VI. Microprocessors

1. Why use Microprocessors?

像是 FPGA 通常在需要產量小才會使用，而且體積也較大。

Microprocessors are often very efficient：

(1) Same logic for different functions => programmable

(2) Flexible

(3) Simplify the design of families of products

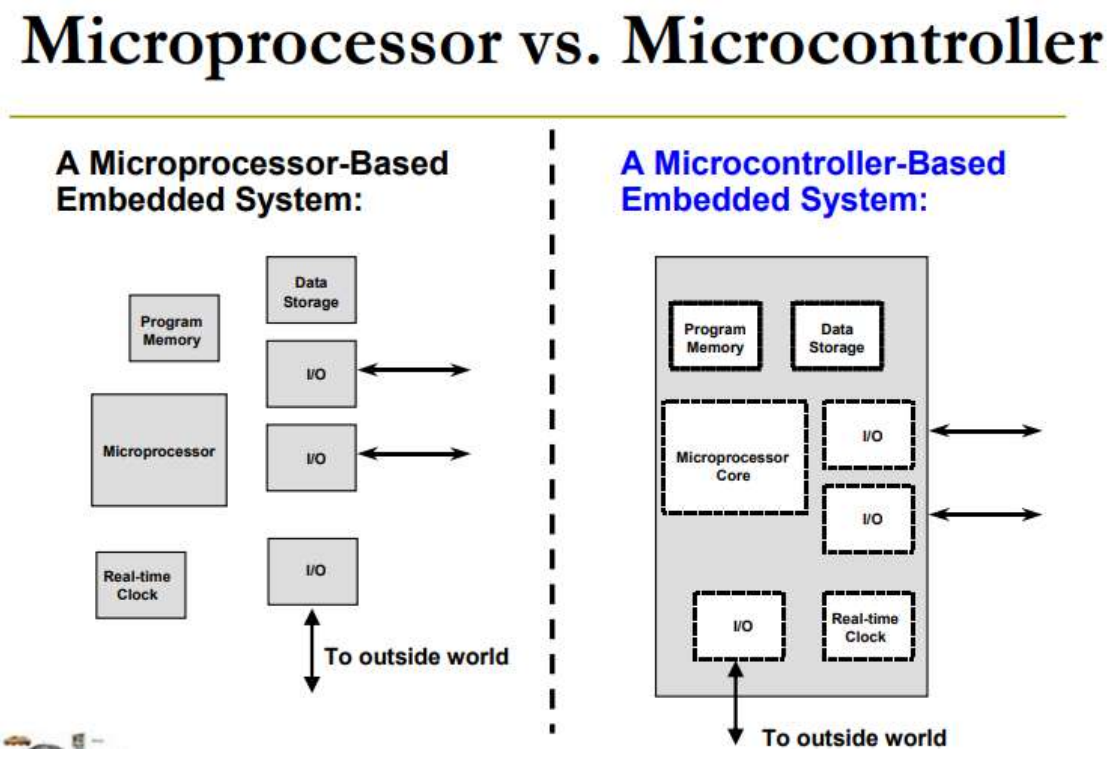
2. Microprocessor Varieties

(1) **Microcontroller**：A microprocessor with I/O devices (or interfaces) and on-board memory.

(2) **Digital signal processor (DSP)**：A microprocessor optimized for digital signal processing.

像是大量硬體支援向量運算指令，VLIW

(3) **Embedded Processor**：No precise definition，可以看成功能更強的 Microcontroller，例如：Intel 80186/88EB, 386EX, ARM, MIPS, PPC。



A typical microcontroller contains a central processing unit (CPU), interrupts, timer/counter, memory, and other peripherals, all in a single integrated circuit (IC).

A microcontroller is a true computer on a chip or system-on-a-chip (SoC).

Microcontrollers are ideal for control applications because you can use them to build an embedded system with little additional circuitry.

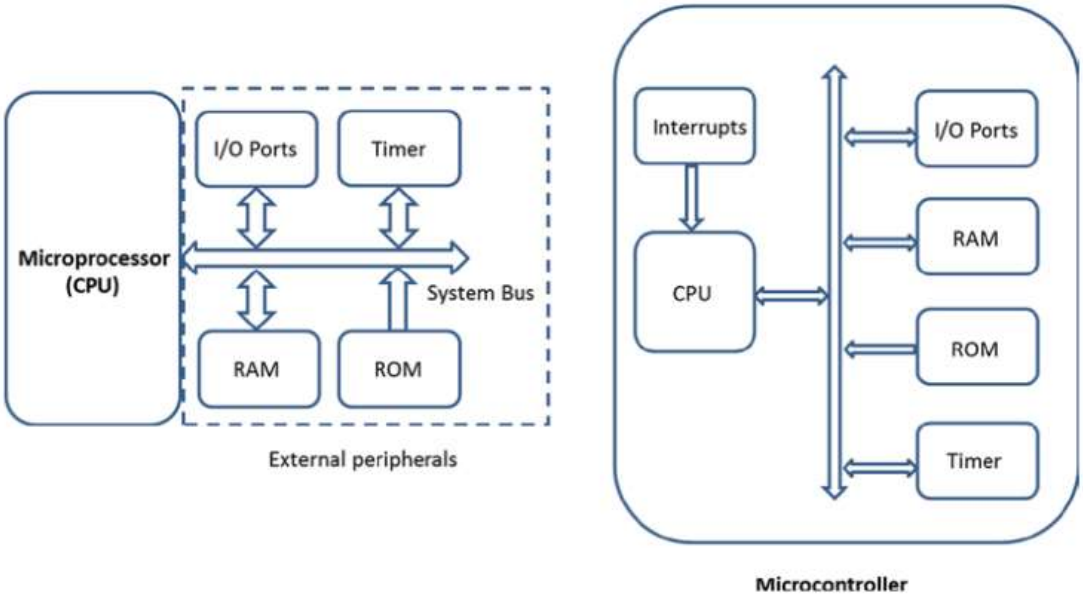


Figure 1.2 Comparison between a microprocessor and a microcontroller.

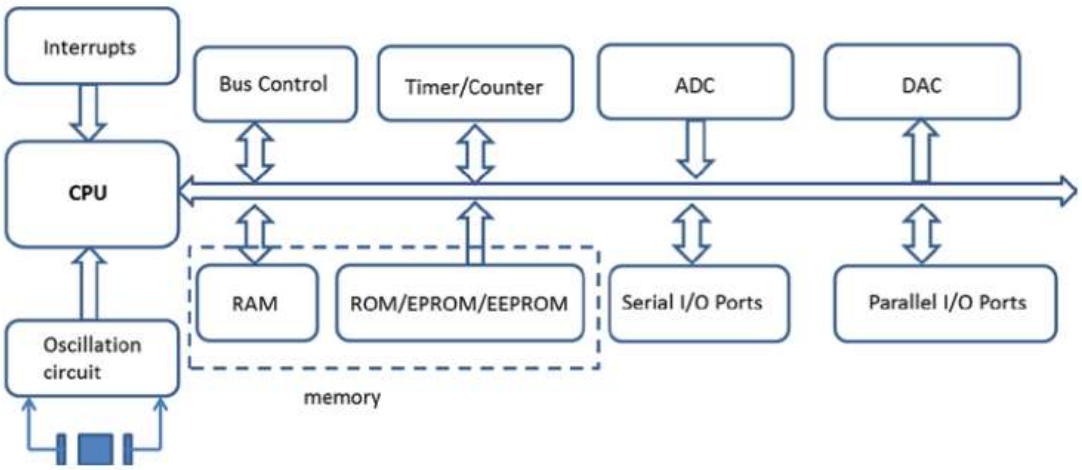
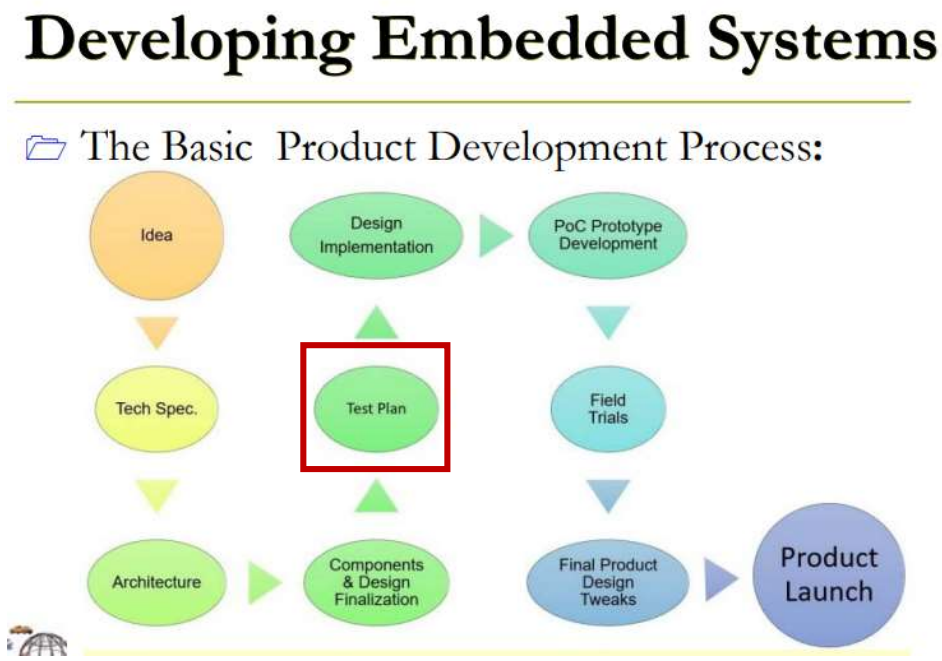


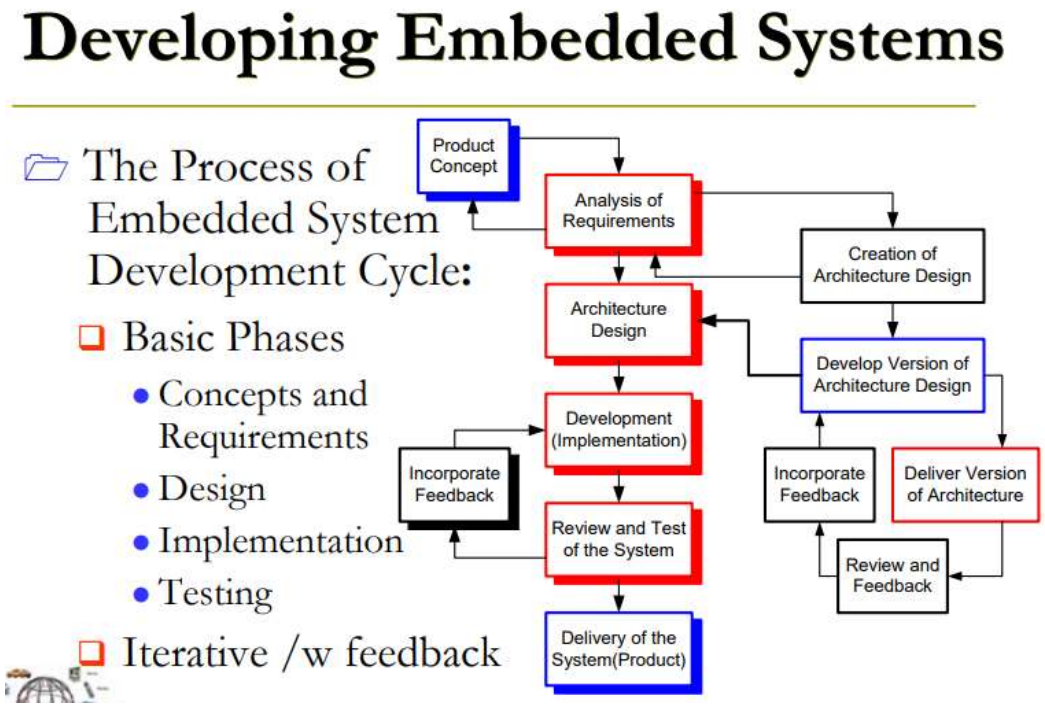
Figure 1.3 Detailed schematic diagram of a microcontroller.

To put it simply, you can imagine that a microprocessor is just a CPU on a single IC, while a microcontroller is a small computer with CPU, memory, and other peripherals.

VII. Developing Embedded Systems and Trends

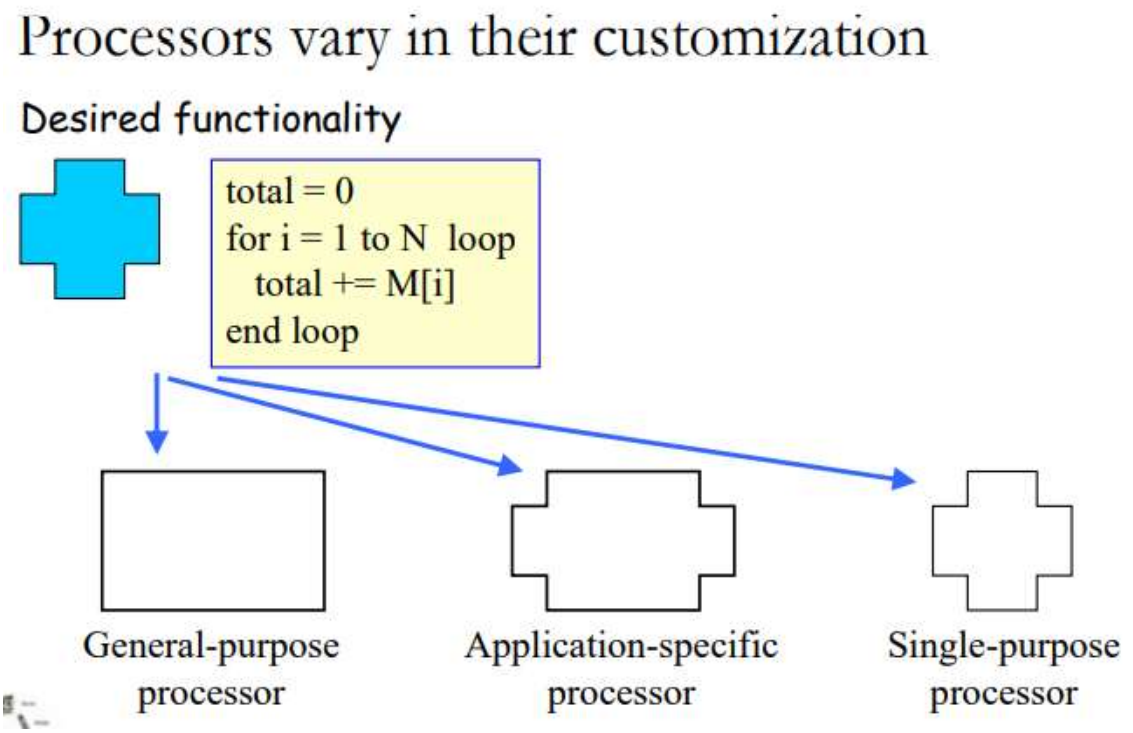
1. 開發嵌入式系統流程，下一章節會說明的更詳細





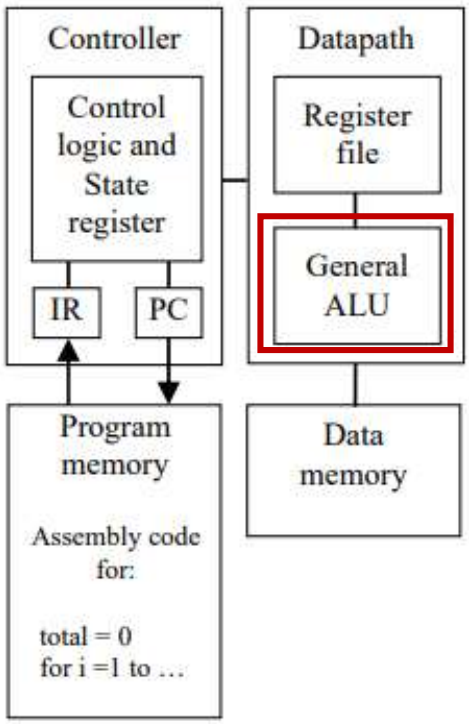
3. Design Processor

"Processor" not equal to general-purpose processor, Processor does not have to be programmable.



(1) **General-Purpose Processors (GPP)**

a. Also known as "microprocessor", Programmable device used in a variety of applications



b. Features：

(i) General datapath with large

(ii) register file & general ALU

program memory

c. User benefits：

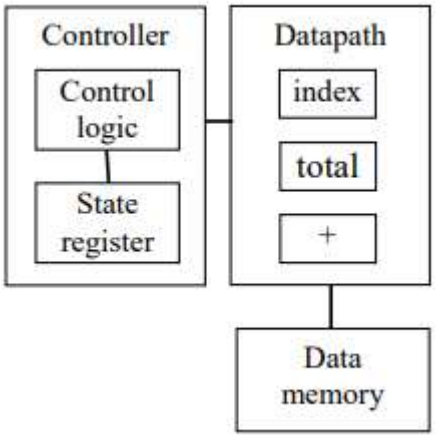
(i) Low time-to-market & NRE costs

NRE 指一次性工程費用

(ii)高彈性

(2) **Single-Purpose Processors (SPP)**

a. a.k.a. coprocessor, accelerator or peripheral, Digital circuit designed to execute one program



b. Features：

(ii) Contains only the components needed to execute the program

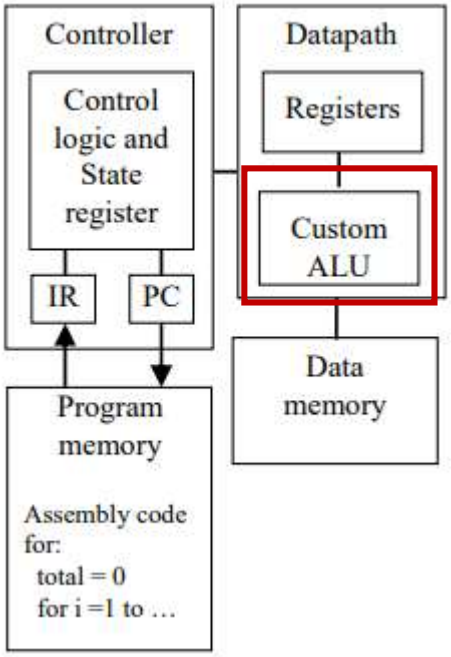
(ii) No program memory

(iii) User benefits：

Fast, Low power, Small size

(3) **Application-Specific Processors**

a. Compromise between GPP & SPP, Programmable processor optimized for particular class of applications of common characteristics.



b. Features：

(i) Program memory

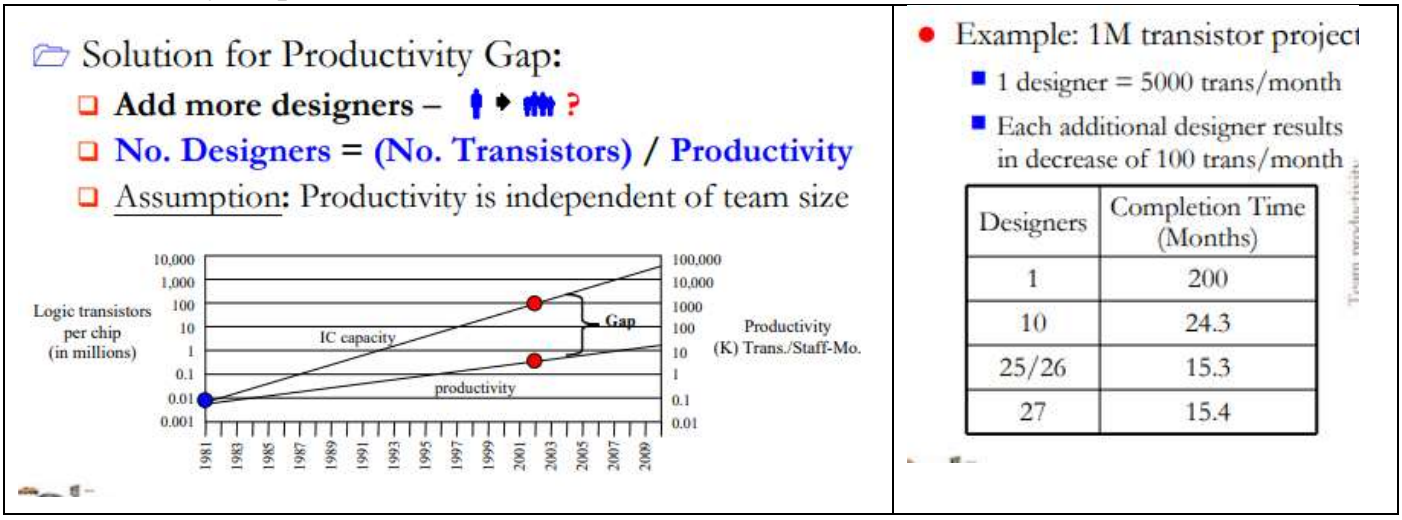
(ii) Optimized datapath

(iii) Special functional units

c. User benefits：

Some flexibility, Good performance, size and power

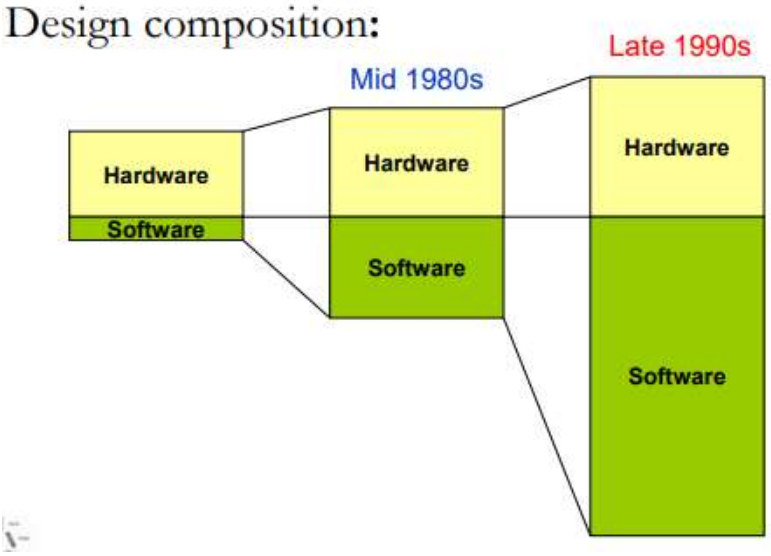
4. Productivity Gap



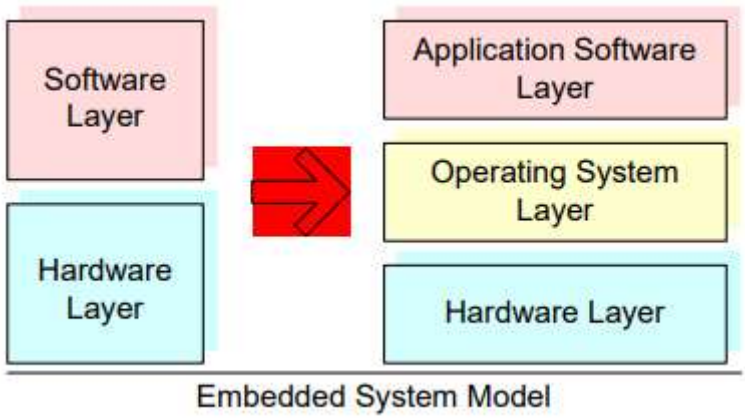
人的數量是有 Upper limit 的，人越多會有些溝通上的問題等等。

5. Design composition

因為軟體開發較為容易，故軟體所占比重越來越大。硬體盡量用現成或虛擬機，軟體部份若使用有 OS 的系統，撰寫更為容易，且軟體運作更 stable, secure。另外 HW 與 SW 開發是需要 co-design 的。



題外話，Embedded OS 不一定有 MMU，故有人開發出 *μCLinux* 。電視若裝上 Android 就能與手機一樣下載 APP。



VIII. Development Challenges

1. **Stability**

Uniform behaviors under all circumstances

2. **Safety**

Protected from harm or undesirable outcome

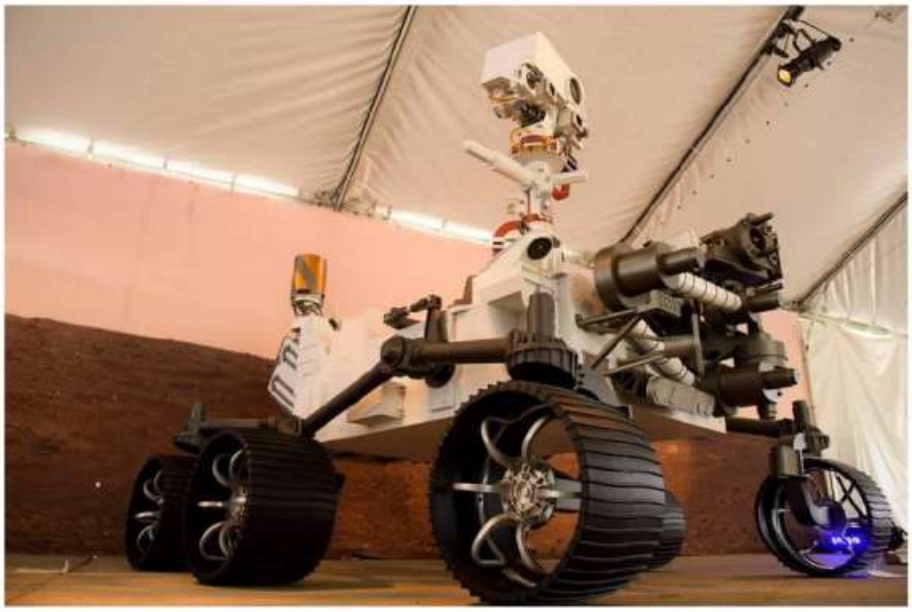
3. **Security**

Networking prone to the risk of hacking

4. **Limitation of resources and design**, ex:登月

考慮成本等問題，毅力號的晶片不再重新開發

尖端火星探測器「毅力號」 晶片竟和23年前iMac同款



5. **Timing**

(1) Correct execution has nothing to do with how long, 正確就好，與花多久無關

(2) Timing behavior is not part of software semantics, 與 Hardware 有關

6. **Compatibility and Integrity**

7. **Pace of changes - technologies are changing faster**