Laboratorio di Sistemi Operativi
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uMPS Introduction

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A simulator, why?

- **Modern hardware architectures:**
  - may be too complex to understand
  - may be not useful for teaching and demonstration purposes
  - may require additional costs for effective development (software development kit, test boards, etc.)
  - may add unnecessary complexities to the development cycle

A simulator, why?

- **A simulated hardware architecture:**
  - may be tailored to provide exactly the “right” features for teaching and demonstration purposes
  - may be provided with an integrated development kit, graphical user interface and debug tools
  - may be deployed on available CS lab equipment
  - will probably be a lot slower than the real one (not always a bad feature)

MIPS, MPS and uMPS

- **MIPS: Microprocessor (without) Interlocking Pipe Stages**
  - one of the original RISC processor architectures from the ’80s
  - with a lot of interesting features
  - still widely used (on embedded systems, but also …)
- **MPS:**
  - a complete (simulated) computer system integrating an (emulated) MIPS R3000 CPU
- **uMPS:**
  - a complete (simulated) computer system integrating an (emulated) MIPS R3000 CPU with physical and virtual memory addressing

A MIPS processor, why?

- **MIPS R3000 processor with MIPS I instruction set:**
  - is reasonably easy to understand
  - provides useful features and insights for instructional purposes
  - documentation is widely available
  - is supported by the GNU gcc compiler and development kit
  - does not impose a fixed devices interface
  - More info (and manuals too):

    http://en.wikipedia.org/wiki/MIPS_architecture

MPS and uMPS

- **MPS simulator provides:**
  - a complete emulation of MIPS R3000 main processor and CP0 (MIPS I instruction set)
  - RAM
  - ROM (for bootstrap and basic functions)
  - a basic set of devices:
    - TOD clock
    - disks
    - tapes
    - printers
    - tty-like terminals
  - an integrated development kit, with a graphical user interface, a cross-compiler (gcc) and debug tools

MPS and uMPS

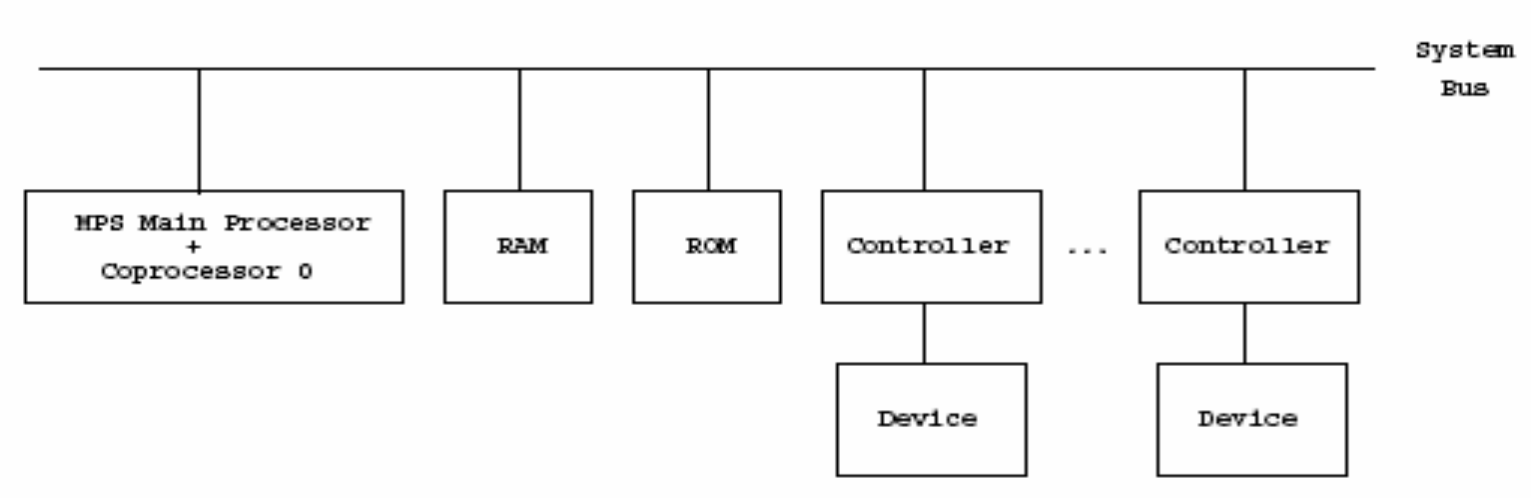
- **uMPS:**
  - (almost) “all of the above”
  - ethernet-like network interfaces
  - physical and virtual memory addressing
  - a streamlined user interface
- **Why use uMPS and not MPS?**
  - Because having virtual memory “right from the beginning” adds unnecessary complexities when writing an OS from scratch…

MPS and uMPS may be compiled on:

- FreeBSD, GNU/Linux distributions (x86 and PPC)
- Sun Solaris

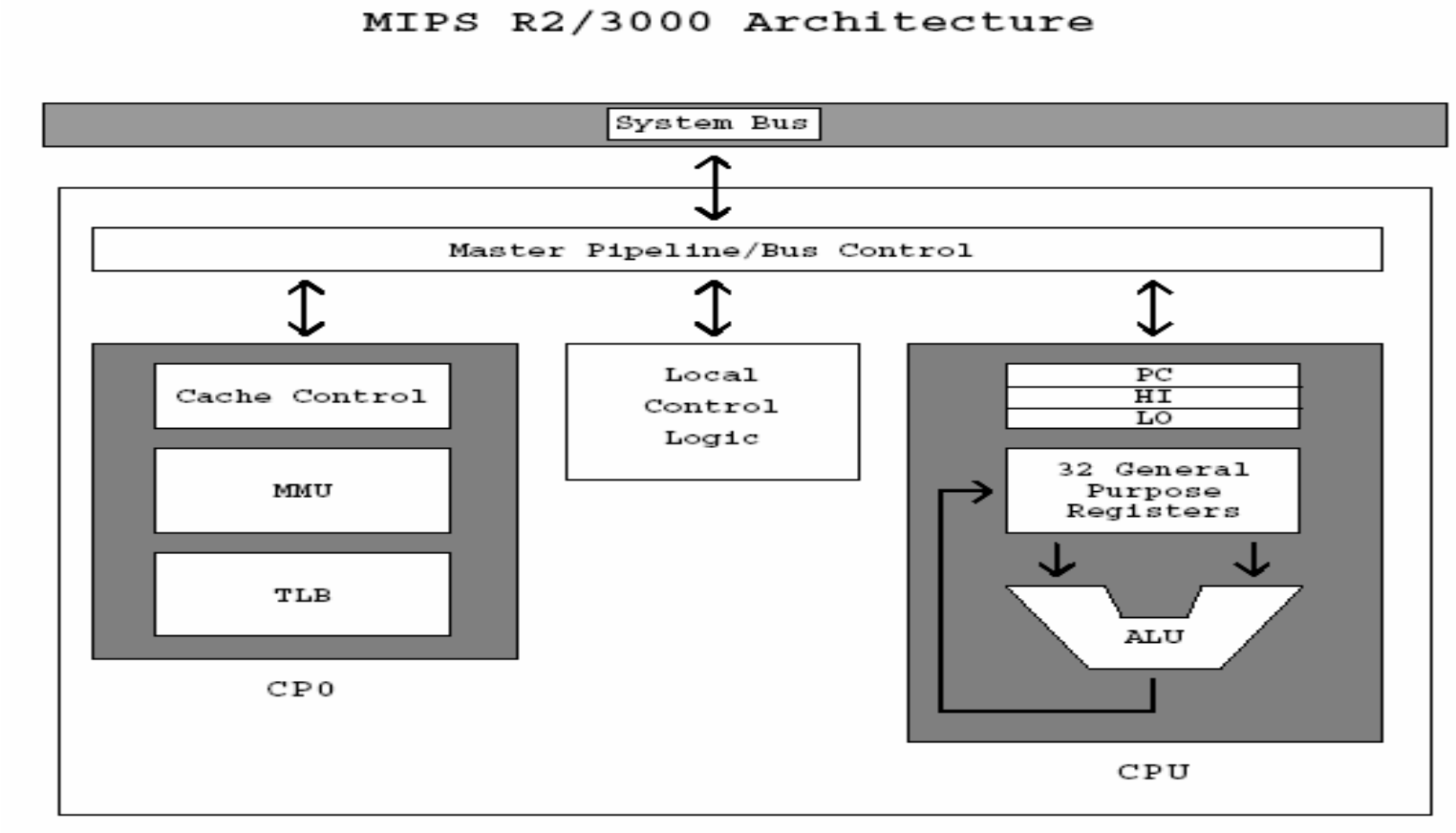
uMPS processor architecture

- **The uMPS architecture**



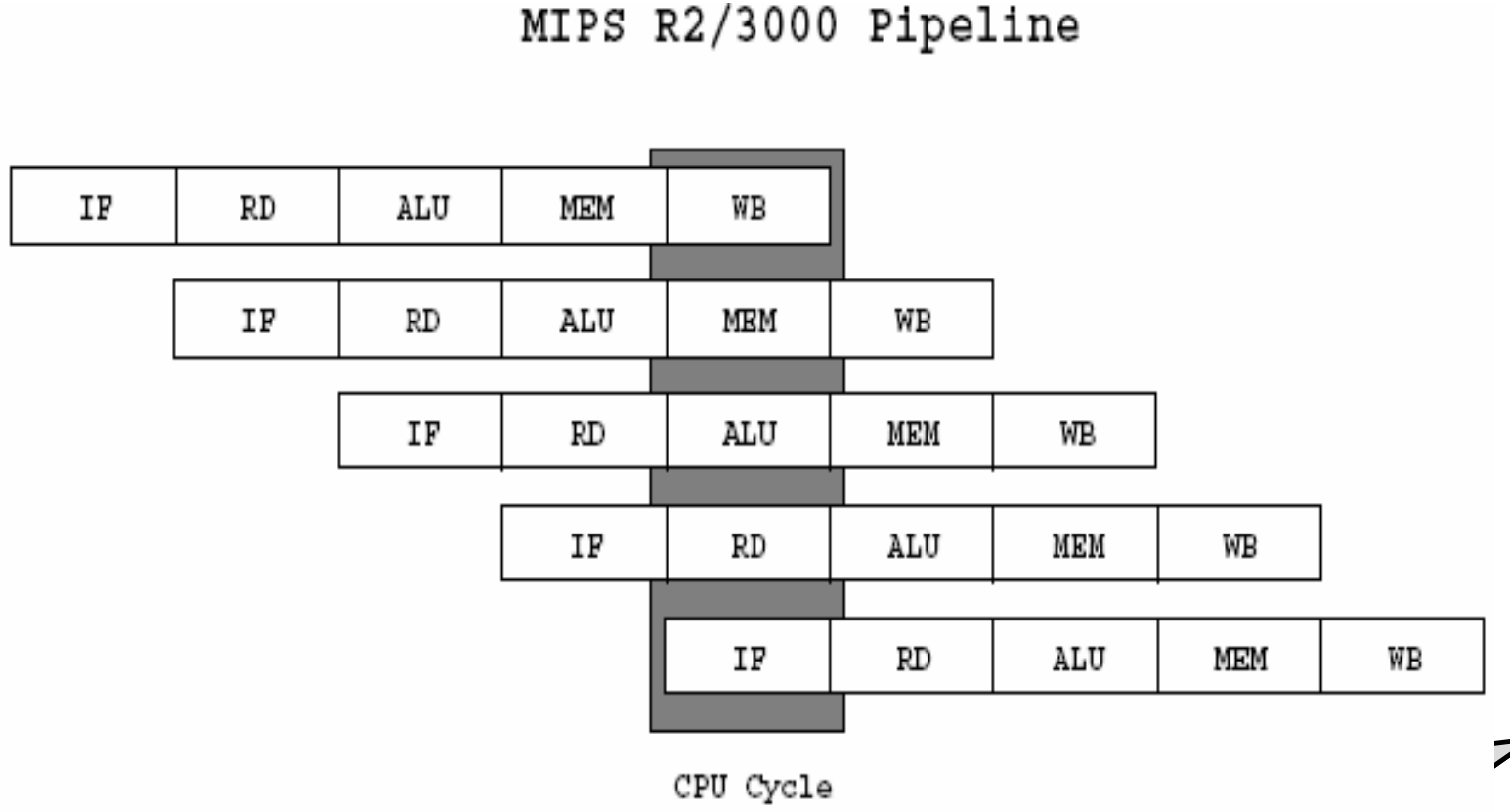
uMPS processor architecture

- **The MIPS processor architecture**



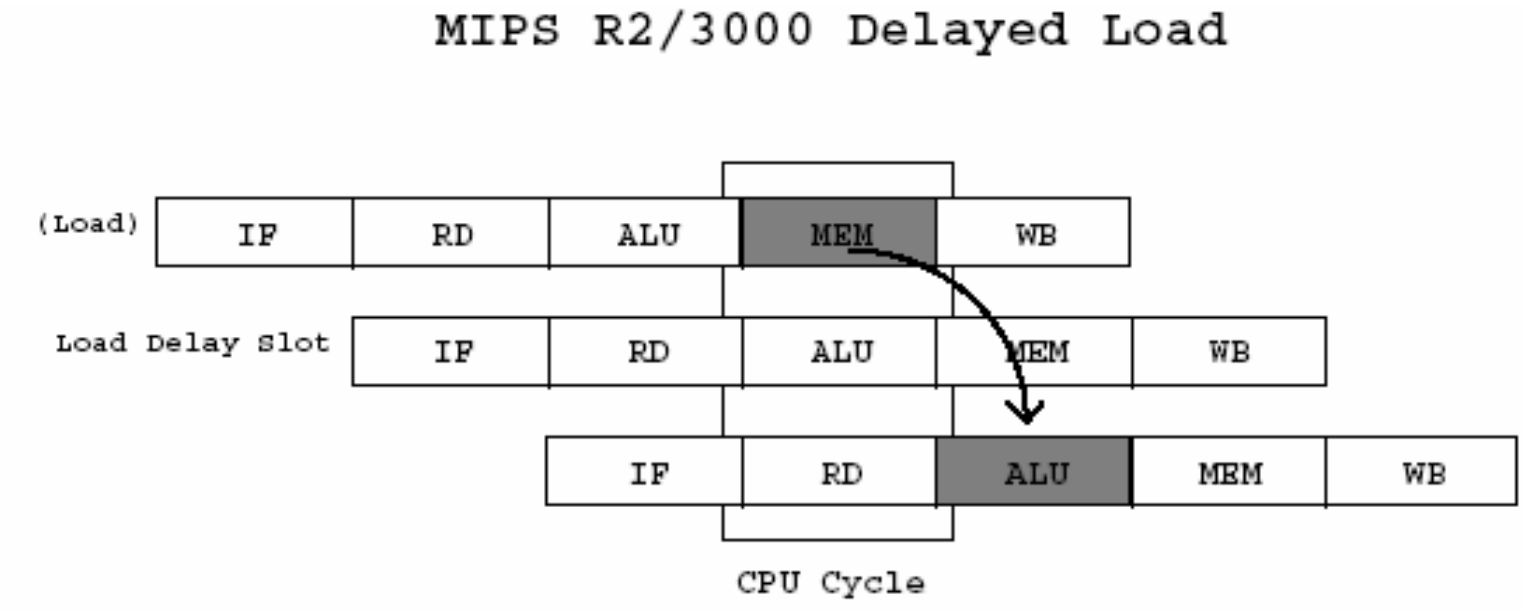
uMPS processor architecture

- **The MIPS processor architecture (cont'd)**



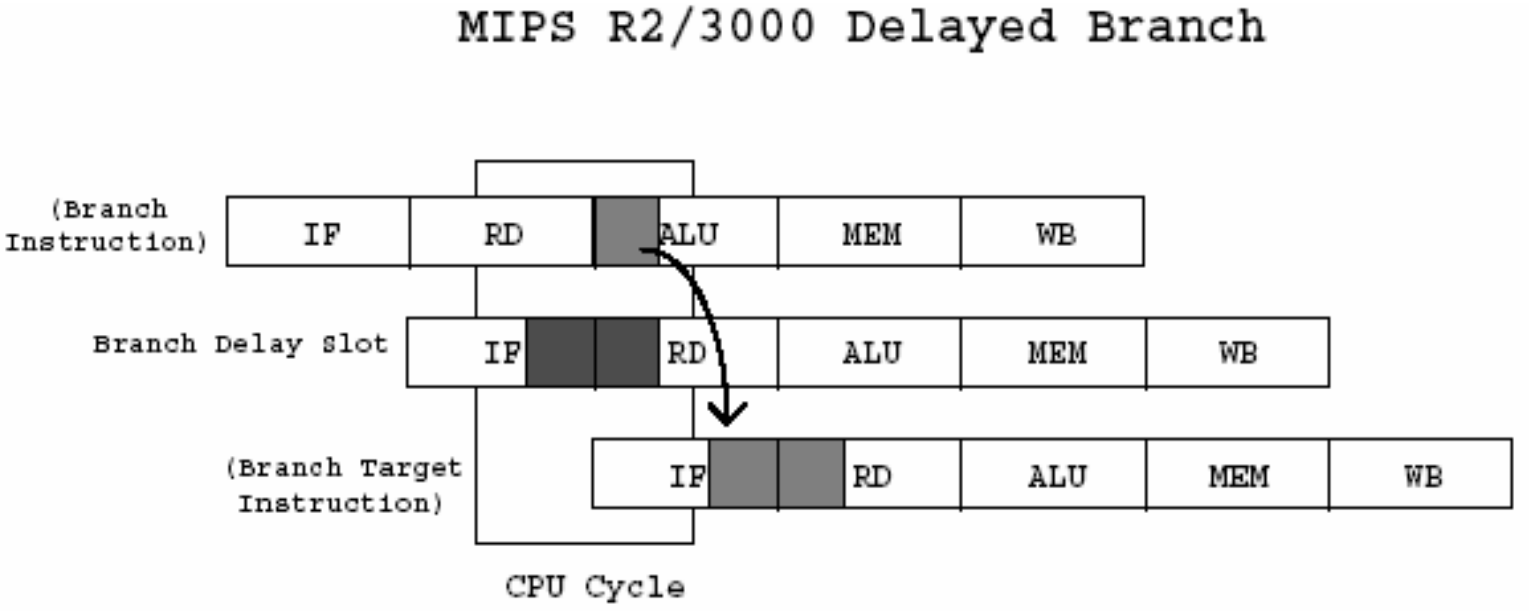
uMPS processor architecture

- **MIPS delayed load:**



uMPS processor architecture

- **MIPS delayed branch:**



uMPS processor architecture

- **uMPS processor features:**
  - RISC-type integer instruction set on a load-store architecture
  - 32-bit word for registers/instructions/addressing (4 GB physical address space)
  - Pipelined execution, delayed loads and branches
  - 32 general purpose registers (**GPR**) denoted **$0**. . .**$31**
    - Register **$0** is hardwired to zero (0)
    - Registers **$1**. . .**$31** (also with mnemonic designation)

uMPS processor architecture

- **uMPS processor features (cont'd):**
  - all of **$1**. . .**$31** registers may be used, but some conventions exist, for example:
    - **$26** and **$27** (**$k0** and **$k1**) are reserved to kernel use
  - **HI** and **LO,** special registers for holding the results from multiplication and division operations
  - **PC**, the program counter

uMPS processor architecture

- **uMPS processor features (cont'd):**
  - **CP0** (CoProcessor 0) is incorporated into the main CPU and provides:
    - two processor operation modes:
      - kernel-mode
      - user-mode
    - exception handling
    - virtual memory addressing

uMPS processor architecture

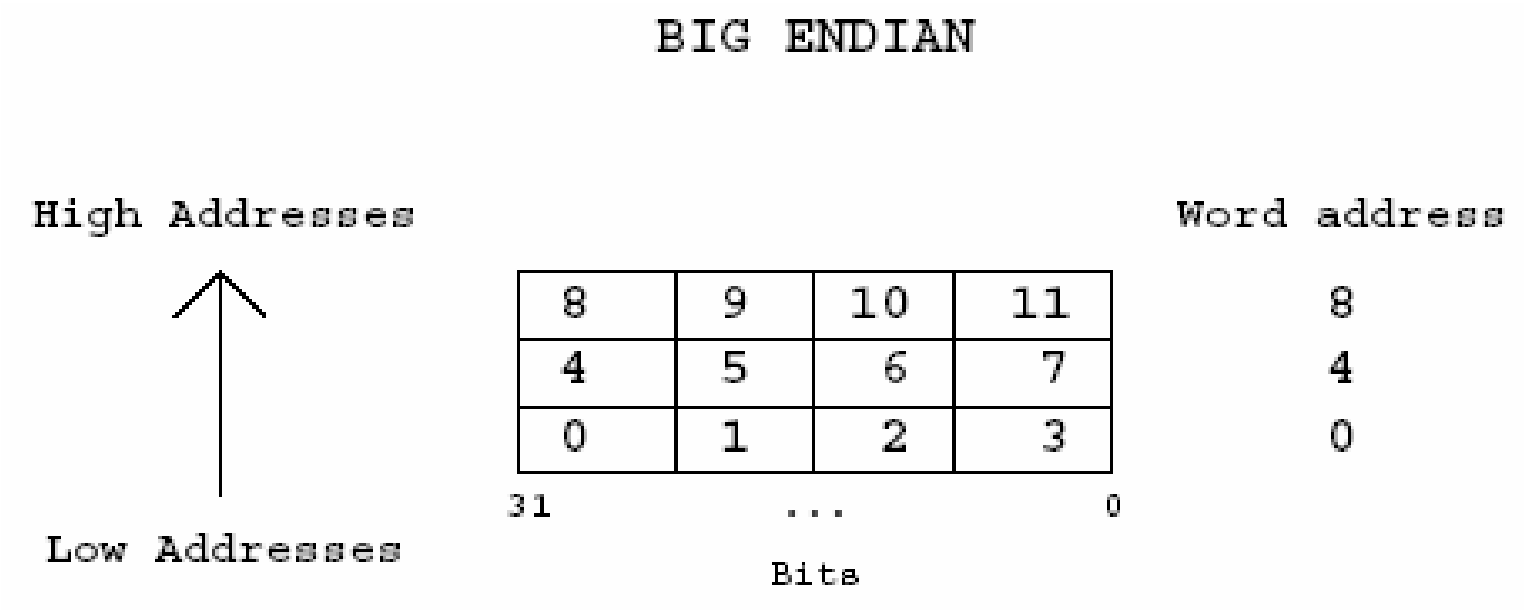
- **uMPS processor features (cont'd):**
  - **CP0** has 8 registers:
    - **Status** register
    - used for exception handling:
      - **Cause**
      - **EPC**
    - used for virtual memory addressing:
      - **Index**
      - **Random**
      - **EntryHi**
      - **EntryLo**
      - **BadVAddr**

uMPS processor architecture

- **Miscellaneous uMPS processor features:**
  - Endianness:
    - the uMPS processor may operate in big-endian and little-endian mode (the emulator uses the endianness of the host architecture)
    - a different cross-compiler set is required
  - CP1: optional coprocessor for floating point support
    - unimplemented
    - processor traps if floating point instructions are executed or CP1 access is attempted

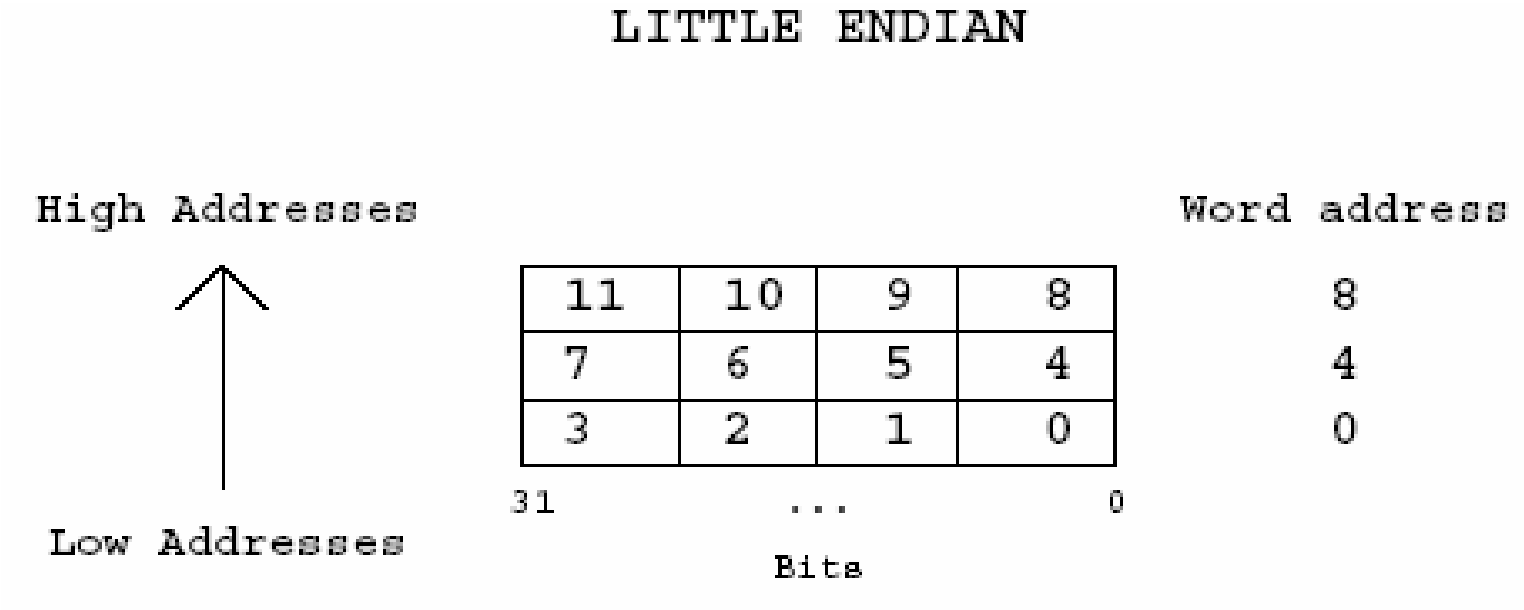
uMPS processor architecture

- **Big endianness:**



uMPS processor architecture

- **Little endianness:**

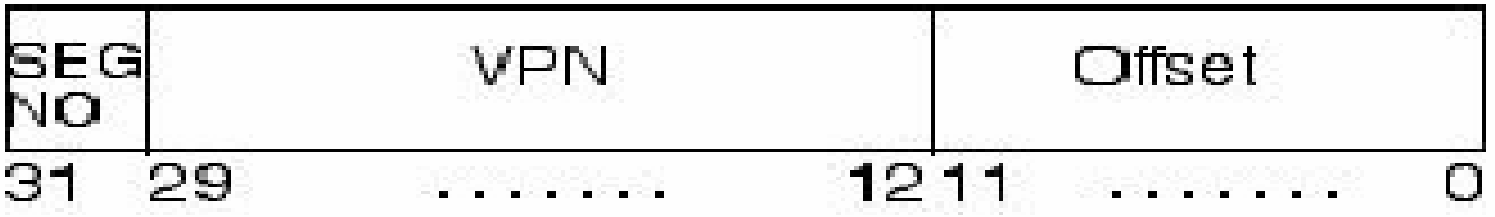


uMPS processor architecture

- **uMPS physical memory address format:**
  - **Physical Frame Number** and **Offset**

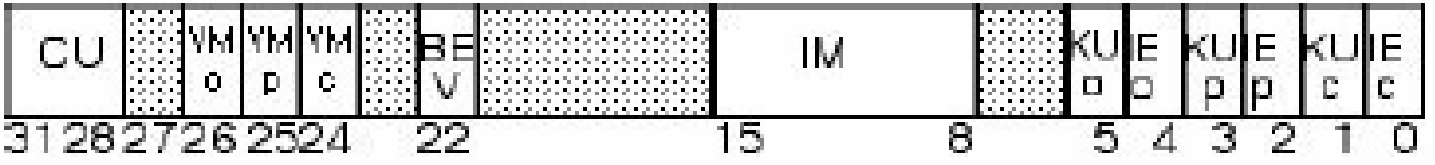
uMPS processor architecture

- **uMPS virtual memory address format:**
  - **Segment Number**, **Virtual Page Number** and **Offset**
  - **ASID** (Address Space IDentifier)**:** 0..63 (0 for Kernel)



uMPS processor architecture

- **Status register structure:**



uMPS processor architecture

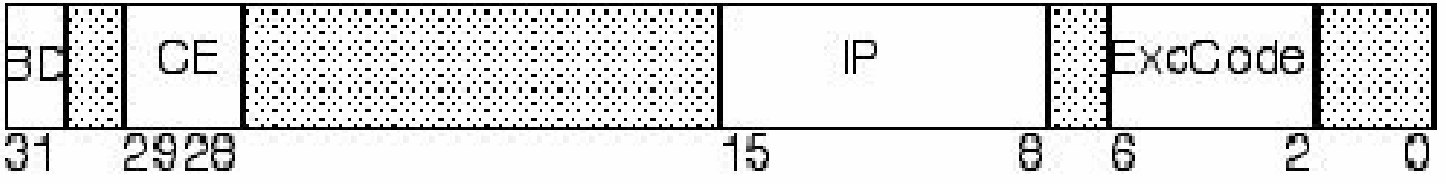
- **Status register structure:**
  - **IE**: Interrupt Enable
  - **KU**: Kernel/User mode (kernel = 0)
  - **IM**: Interrupt Mask
  - **VM**: Virtual Memory
  - **BEV**: Bootstrap Exception Vector
  - **CU**: Coprocessor Usable

uMPS processor architecture

- **uMPS processor status at bootstrap:**
  - CP0 is enabled
  - Virtual Memory is off
  - Bootstrap Exception Vector bit is on
  - Processor is in Kernel mode
  - **PC** = 0x1FC0.0000 (in boot ROM)

uMPS processor architecture

- **Exception handling:**
  - **EPC (**Exception PC): is automatically corrected by the CPU if **BD** bit is set, to allow re-execution of the branch
  - **Cause:**



uMPS processor architecture

- **Exception handling (cont'd):**
  - **Cause** explained:
    - **IP**: Interrupt Pending
    - **BD**: Branch Delay
    - **CE**: Coprocessor Error
    - **ExcCode**

uMPS processor architecture

- **ExcCode:**

Number	Code	Description
0	*Int*	External Device Interrupt
1	*Mod*	TLB-Modification Exception
2	*TLBL*	TLB Invalid Exception: on a Load instr. or instruction fetch
3	*TLBS*	TLB Invalid Exception: on a Store instr.
4	*AdEL*	Address Error Exception: on a Load or instruction fetch
5	*AdES*	Address Error Exception: on a Store instr.
6	*IBE*	Bus Error Exception: on an instruction fetch
7	*DBE*	Bus Error Exception: on a Load/Store data access
8	*Sys*	Syscall Exception
9	*Bp*	Breakpoint Exception
10	*RI*	Reserved Instruction Exception
11	*CpU*	Coprocessor Unusable Exception
12	*OV*	Arithmetic Overflow Exception
13	*BdPT*	Bad Page Table
14	*PTMs*	Page Table Miss

uMPS processor architecture

- **Exception handling (cont'd):**
  - Exception types:
    - *Program Traps* (PgmTrap)
    - *SYSCALL/Breakpoint* (SYS/Bp)
    - *TLB Management* (TLB)
    - *Interrupts* (Ints)

uMPS processor architecture

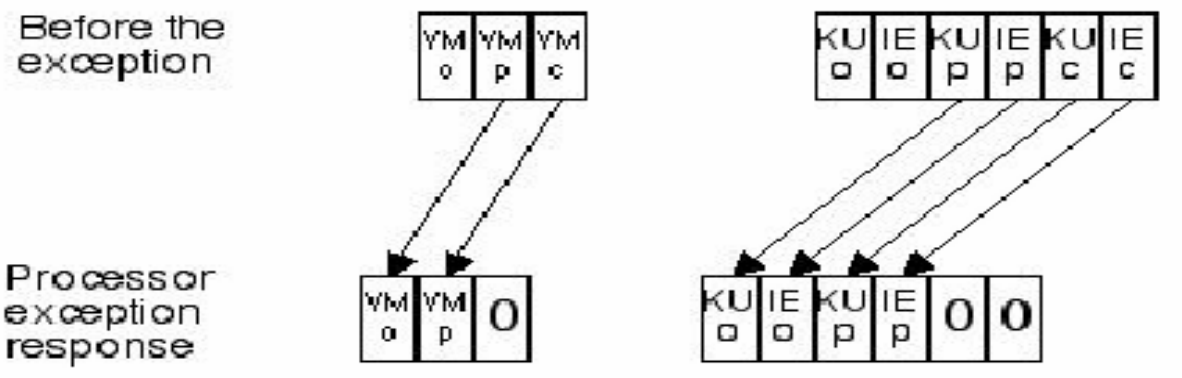
- **Exception handling (cont'd):**
  - *Program Traps* (PgmTrap)
    - Address Error (*AdEL* & *AdES*)
    - Bus Error (*IBE* & *DBE*)
    - Reserved Instruction (*RI*)
    - Coprocessor Unusable (*CpU*)
    - Arithmetic Overflow (*Ov*)
  - *SYSCALL/Breakpoint* (SYS/Bp)
    - SYSCALL instruction
    - BREAK instruction

uMPS processor architecture

- **Exception handling (cont'd):**
  - *TLB Management* (TLB)
    - TLB-Modification (*Mod*)
    - TLB-Invalid (*TLBL* & *TLBS*)
    - Bad-PgTbl (*BdPT*)
    - PTE-MISS (*PTMs*)
  - *Interrupts* (Ints)
    - remember **Status.IM** mask and **Status.IEc** bit
    - hardware and software interrupts

uMPS processor architecture

- **uMPS processor actions on exception:**
  - Basic operations:
    - **EPC** stores the current **PC**
    - **BD bit** is set if required
    - **Cause.ExcCode** is set
    - **Status.VM, KU** and **IE** stacks are pushed:



uMPS processor architecture

- **uMPS processor actions on exception (cont'd):**
  - Exception-specific operations:
    - Address Error (*AdEL* & *AdES*): set **BadVAddr**
    - Coprocessor Unusable (*CpU*): set **Cause.CE**
    - *Interrupts* (Ints): set **Cause.IP**
    - *TLB Management* (TLB):
      - set **BadVAddr**
      - load **EntryHi.SEGNO** and **EntryHi.VPN**

uMPS processor architecture

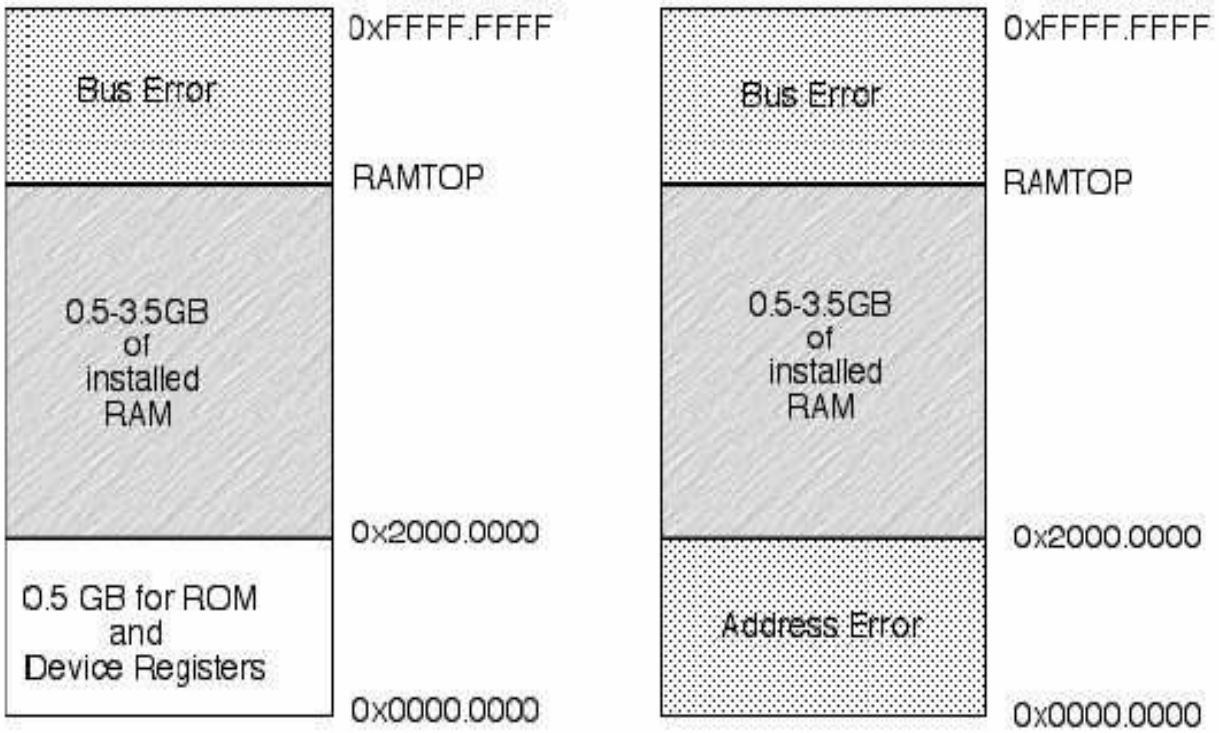
- **uMPS processor actions on exception (cont'd):**
  - At the end:
    - load **PC** with a fixed address in ROM:
      - 0x1FC0.0180 if **Status.BEV** is set
      - 0x0000.0080 if **Status.BEV** is not set
  - All this in *one atomic operation*
  - ROM exception handlers will perform specific actions and set some exception types:
    - Bad-PgTbl (*BdPT*)
    - PTE-MISS (*PTMs*)

uMPS processor architecture

- **ROM exception handler first task:**
  - to save the current processor state (the “old” one) and to load a new state (the “new” one)
  - A processor state contains:
    - 1 word for the **EntryHi CP0** register (contains the current ASID, **EntryHi.ASID**)
    - 1 word for the **Cause CP0** register
    - 1 word for the **Status CP0** register
    - 1 word for the **PC** (New) or **EPC** (Old)
    - 29 words for the **GPR** registers (**GPR** registers $0, $k0, and $k1 are excluded)

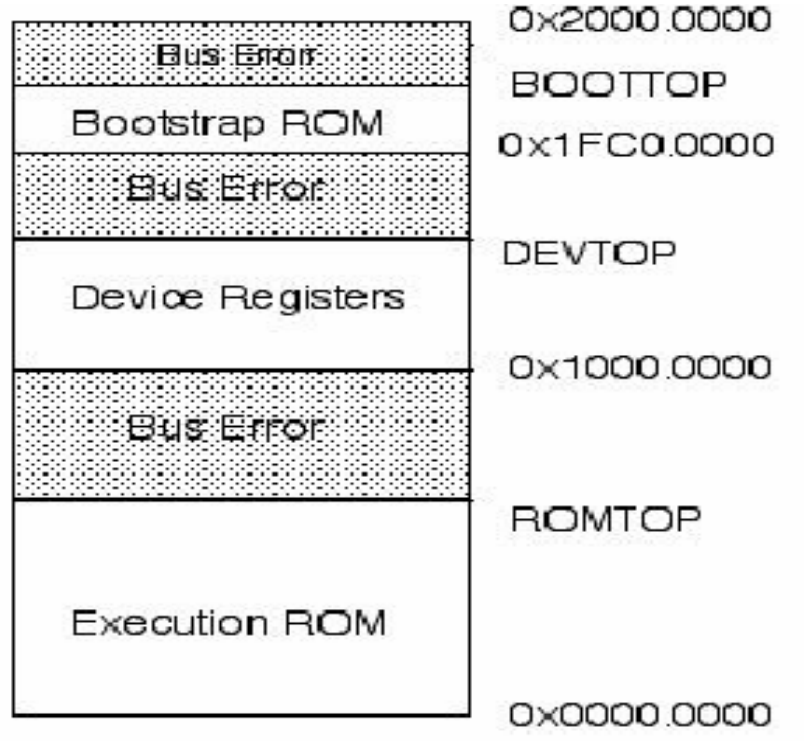
uMPS processor architecture

- **But where is the ROM?**
  - uMPS physical memory map (Kernel and User modes)



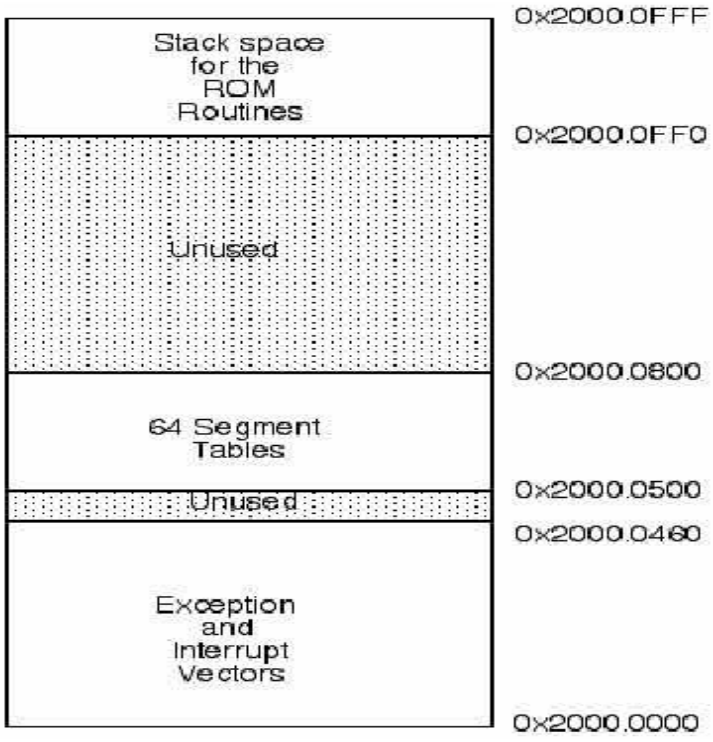
uMPS processor architecture

- **How it is mapped?**
  - ROM and device registers area:



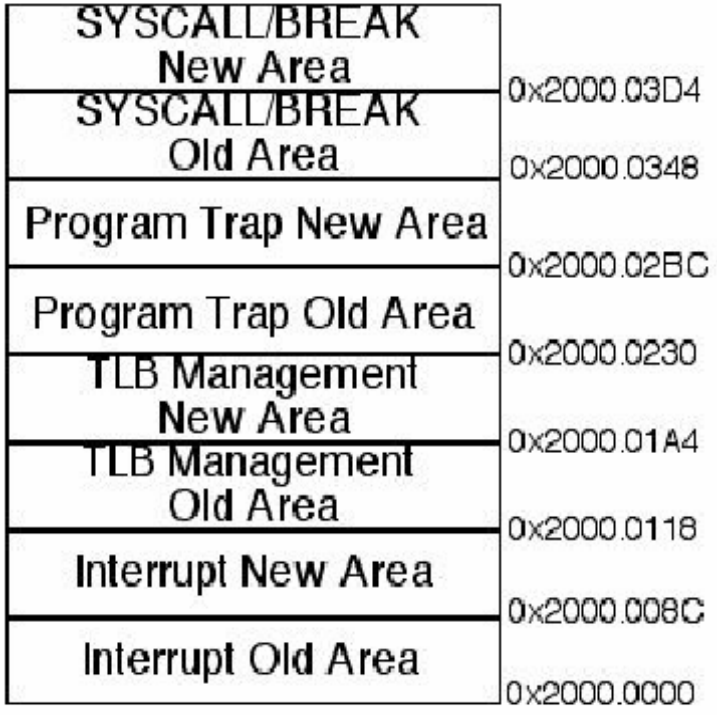
uMPS processor architecture

- **But where is the processor state stored?**
  - in the ROM reserved frame:



uMPS processor architecture

- **But where?**
  - in the bottom part of the ROM reserved frame:



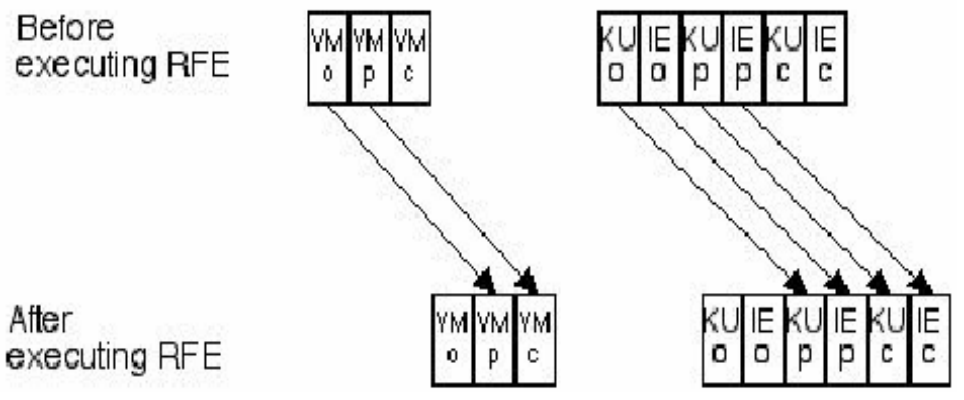
uMPS processor architecture

- **Ending the exception handling:**

  ROM handler (hopefully) will load a processor state and**:**

  jump to some address

  RFE (Return From Exception): pop the **KU**, **IE** and **VM** stacks



uMPS processor architecture

- **Beware…**
  - look at **Cause** in Old area for knowing exactly what happened
  - remember that **KU**, **IE** and **VM** stacks in **Status** were pushed before being stored, and will be popped when returning from the exception
  - remember that **EPC** will point to the correct address to jump to after having serviced the exception (the **BD** bit tells if it was the instruction at **EPC** or the instruction in a branch delay slot to cause the exception)