

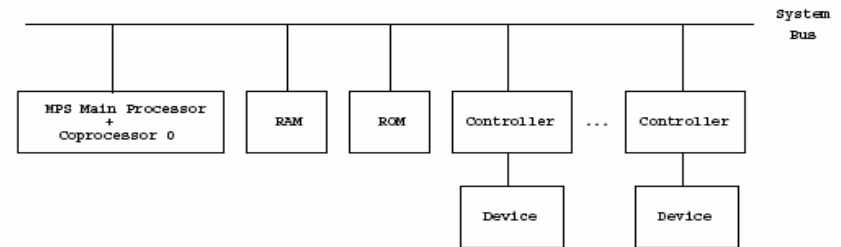
*Laboratorio di Sistemi Operativi*  
*Anno Accademico 2006-2007*

**uMPS Introduction**  
**Part 2**  
Mauro Morsiani

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## uMPS processor architecture

### The uMPS architecture



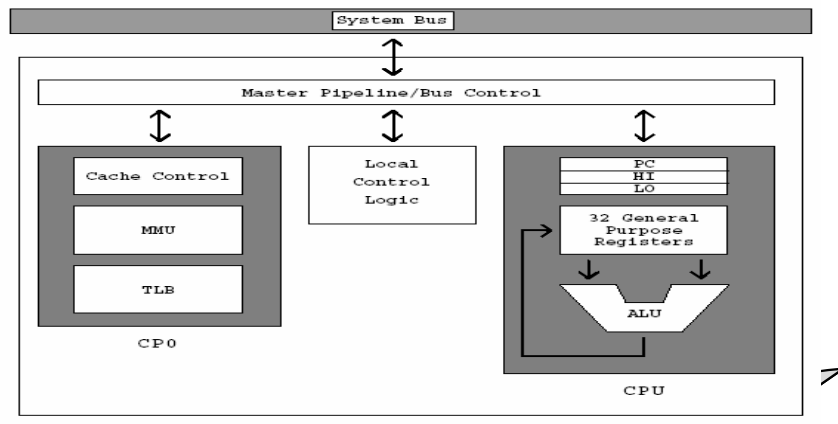
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# uMPS processor architecture

## The MIPS processor architecture

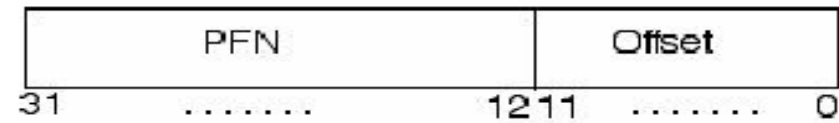
MIPS R2/3000 Architecture



# uMPS memory management

## uMPS physical memory address format

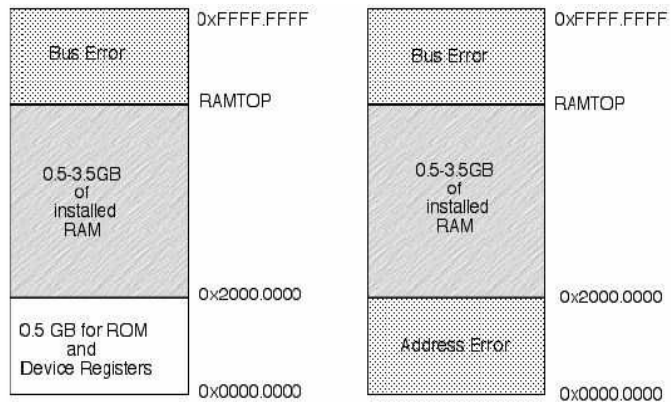
Physical Frame Number and Offset



# uMPS memory management

## uMPS physical memory map

Kernel and User modes

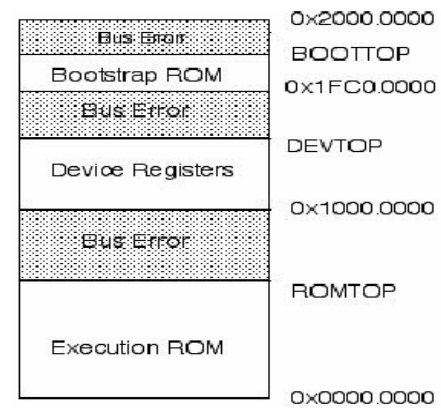


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# uMPS memory management

## ROM and Device Registers Area

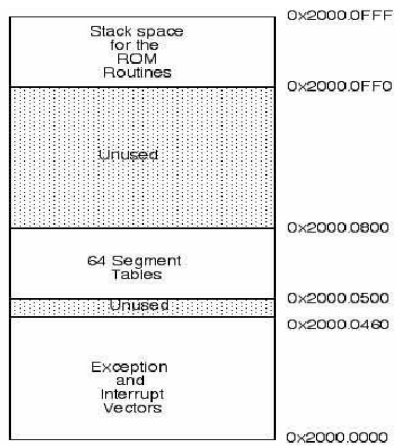


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## uMPS memory management

### ROM reserved frame (first RAM frame)



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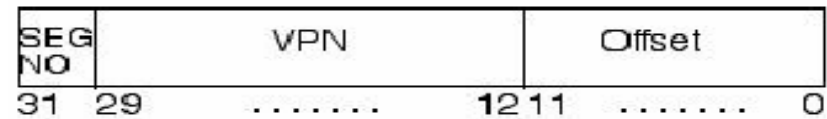
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## uMPS memory management

### uMPS virtual memory address format

**Segment Number, Virtual Page Number and Offset**

**ASID (Address Space Identifier): 0..63 (0 for Kernel)**

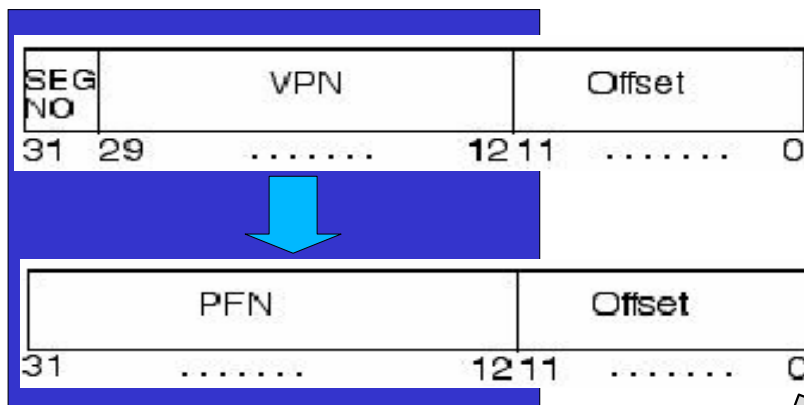


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# uMPS memory management

## Mapping virtual memory to physical memory



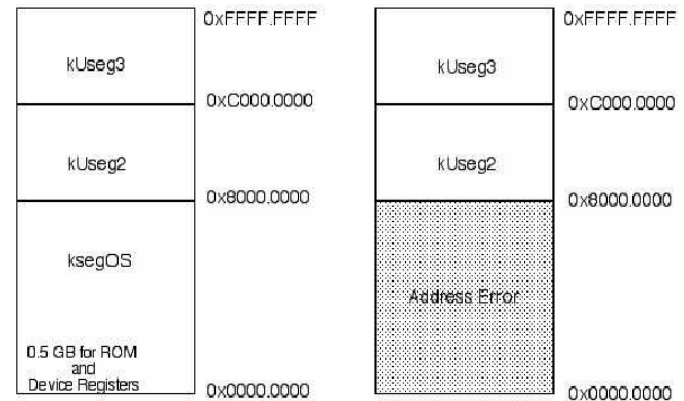
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# uMPS memory management

## uMPS virtual memory map

### Kernel and User modes



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## uMPS memory management

### uMPS virtual memory segment description

*ksegOS* (**SEGNO 00** and **01**: 2 GB)

is protected by User mode access:

completely (2 GB) when virtual memory is on (that is, when

**Status.VMc = 1**)

partially (0,5 GB) when virtual memory is off (that is, when

**Status.VMc = 0**)

holds ROM, device registers (the first 0,5 GB) and will hold kernel *text*, *data*, *stack* areas (the remaining 1,5 GB)

## uMPS memory management

### uMPS virtual memory segment description (cont'd)

*kUseg2* (**SEGNO 10**: 1 GB)

may be accessed in Kernel mode and User mode  
will hold user mode process *text*, *data*, *stack* areas  
user processes will be identified using **ASIDs**

*kUseg3* (**SEGNO 11**: 1 GB)

may be accessed in Kernel mode and User mode  
is typically used for data sharing among processes  
here, too, user processes will be identified using **ASIDs**

## uMPS memory management

### uMPS virtual memory management scheme

Problem: each process running in a virtual memory space requires the management of the list of the page frames it employs, and the mapping of virtual page addresses to these page frames (**Offsets** are the same)

Solution: to use *Page Tables (PgTbl)*, one for each segment

Problem 1: **PgTbls** could become very large (1 GB RAM = 256K pages)

Problem 2: Kernel and ROM handlers will need to access these tables

Solution: to use a *Segment Table*: put the **PgTbl** addresses into ROM reserved frame, and **PgTbls** themselves somewhere else

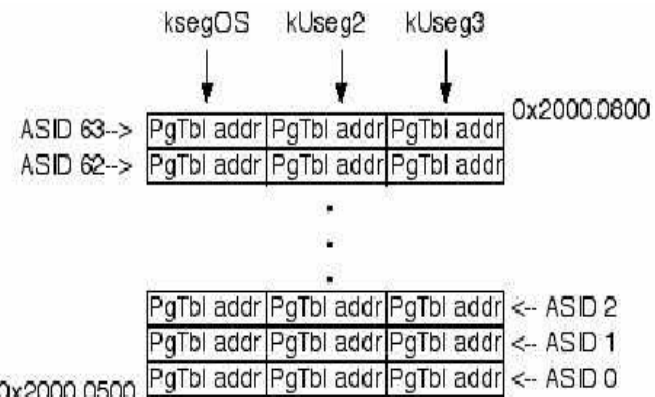
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## uMPS memory management

### Segment Table format:

All **PgTbl** addresses are *physical memory addresses*

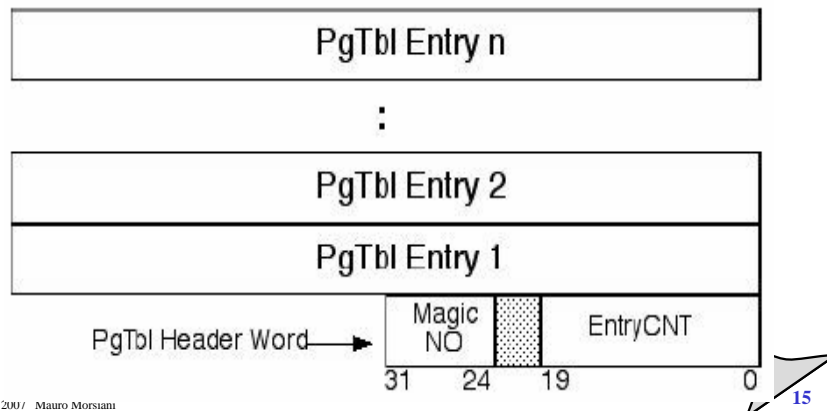


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## uMPS memory management

### PgTbl format:



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## uMPS memory management

### PgTbl format (cont'd):

**MagicNO:** Magic number = 0x2A

**EntryCNT:** number of entries

**PTE (Page Table Entry):** holds the virtual -> physical address translation rule for one (**ASID**, **SEGNO**, **VPN**) to one **PFN**

Which format to use?

Who does the job of translating the addresses?

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## uMPS memory management

### Enter the TLB (Translation Lookaside Buffer):

- is located in the uMPS main CPU
- performs the virtual address translation
- caches the most recent translations
- has a finite number of entries (**TLBSIZE**: 4-64 entries)
- entry #0 is protected by accidental overwriting
- somebody has to (re)fill it

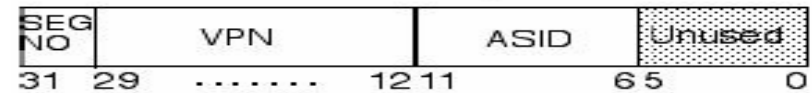
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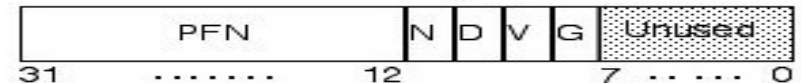
## uMPS memory management

### PTE and TLB entry format:

#### TLB EntryHi



#### TLB EntryLo



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## uMPS memory management

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### EntryLo flags explained:

**N** (Non-cacheable) bit: unused

**D** (Dirty) bit: trying to write to a virtual memory address with **D** bit = 0 raises a TLB-Modification (*Mod*) exception (allows to define read-only virtual memory areas and memory protection schemes)

**V** (Valid) bit: trying to read at or write to a virtual memory address with **V** bit = 0 raises a TLB-Invalid (*TLBL* & *TLBS*) exception (allows to build memory paging schemes)

**G** (Global) bit: if **G** bit = 1, the TLB entry will match for any **ASID** with the same **VPN** (allows to define memory sharing schemes)

## uMPS memory management

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### CP0 registers used for virtual memory addressing:

**BadVAddr**: employed in exception management

**EntryHi**: employed for defining the ASID of the current process and in TLB refilling operations (same format as TLB **EntryHi**)

**EntryLo**: employed in TLB refilling operations (same format as TLB **EntryLo**)

**Index**: employed in TLB refilling operations

**Random**: employed in TLB refilling operations

## uMPS memory management

### Putting all together

A process running with virtual memory on is identified by **CP0.EntryHi.ASID**; its current status is described in **CP0.Status**

For each access in virtual memory, the CPU:

checks if the process has been granted the access to the **SEGNO** requested (that is, if the **KUc** bit in **CP0.Status** enables it to access)

if access is denied, an exception is raised:

Address Error (*AdEL* or *AdES*) (also raised if the address is ill-formed)

if access is granted...

## uMPS memory management

### Putting all together (cont'd)

(if access is granted) ... the CPU scans the TLB looking for a match for the (**ASID**, **SEGNO**, **VPN**) requested

if a match is found *and* it is valid, the **PFN** is paired with the **Offset** to form the physical address, and physical memory is finally accessed (raising a *IBE* or *DBE* exception if something goes wrong)

if a match is found but it is *not* valid, an exception is raised:

TLB-Modification (*Mod*) on writing with **D** bit = 0

TLB-Invalid (*TLBL* or *TLBS*) on **V** bit = 0

but if the match is not found? A *TLB-Refill* exception is raised and the ROM TLB-refill handler kicks in...

## uMPS memory management

### Putting all together (final)

the ROM TLB-refill handler looks at the Segment Table, finds the **PgTbl** and scans it, looking for the first **PTE** matching the request

if a match is found: the ROM handler refills the TLB with the **PTE** needed, and returns from the exception: the CPU starts re-executing the access to the virtual memory again, *as if the exception never happened*; this time, the match in the TLB will be found, and the CPU will continue as required

if a match is *not* found, it could be for two reasons:

the Segment Table or the **PgTbl** is corrupted somehow: the ROM handler “raises” a Bad-PgTbl (*BdPT*) exception

the **PgTbl** does not contain any match: the ROM handler “raises” a PTE-MISS (*PTMs*) exception

## uMPS memory management

### The ROM strikes again

To refill the TLB, the ROM TLB-refill handler uses the following **CP0** registers:

**EntryHi**

**EntryLo**

**Index**

**Random**

and may use some special **CP0** instructions:

**TLBWI** (*TLB Write Indexed*)

**TLBWR** (*TLB Write Random*)

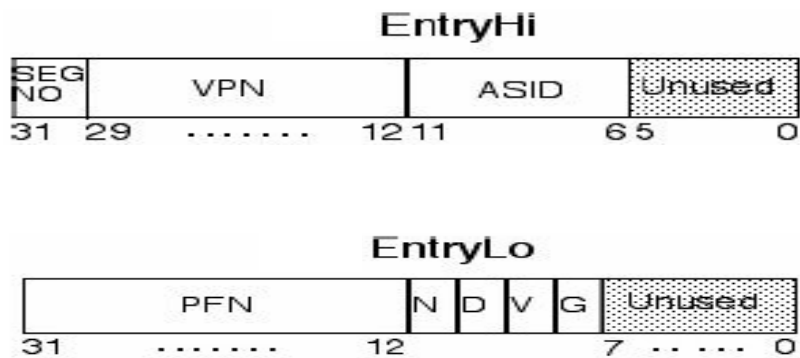
**TLBP** (*TLB Probe*)

**TLBR** (*TLB Read*)

**TLBCLR** (*TLB Clear*)

## uMPS memory management

### CP0 registers for VM management:

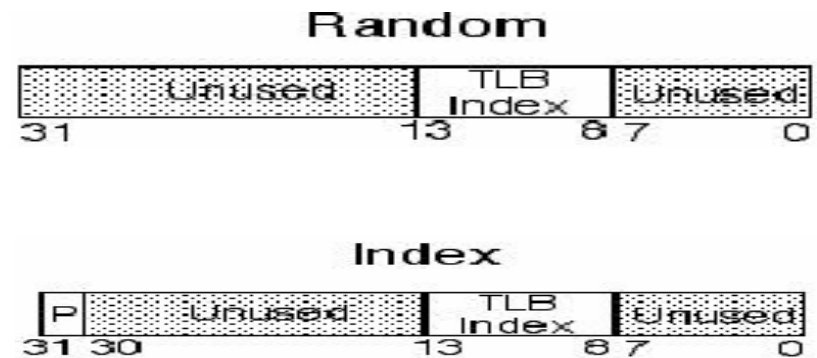


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## uMPS memory management

### CP0 registers for VM management (cont'd):



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## uMPS memory management

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### CP0 registers for VM management (cont'd):

#### Index:

**P** (Probe failure) bit: becomes 0 if a **TLBP** is successful, 1 otherwise

#### TLB Index:

tells which TLB entry matches in a **TLBP**  
sets which TLB entry gets read (in a **TLBR**) or written (in a **TLBWI**)

**Random:** cycles its **TLB Index** field in the range [1..**TLBSIZE**-1]  
(one step forward each clock cycle)

## uMPS memory management

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### The ROM TLB-Refill algorithm, part 1

The ROM TLB-refill handler:

looks up the **PgTbl** position in the segment table, looking at **CP0.EntryHi**

accesses the **PgTbl** performing some basic checks (address alignment, magic number, size vs. **RAMTOP**)

if something is not ok, then the **PgTbl** is not good: the handler saves the "Old" processor state, sets **Cause.ExcCode** in the "Old" area to indicate a Bad-PgTbl (*BdPT*) exception, and loads a "New" processor state to handle the exception

if all is ok, performs a linear scan of the **PgTbl** looking for a match...

## uMPS memory management

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### The ROM TLB-Refill algorithm, part 2

if, scanning the **PgTbl**, a match is found:

the matching **PTE** gets loaded (a **TLBWR** is performed)

a **RFE** is executed, and the processor restarts execution

if a match is not found: the handler saves the “Old” processor state in the appropriate area, sets **Cause.ExcCode** in the “Old” area to indicate a PTE-MISS (*PTMs*) exception, and loads a “New” processor state to handle the exception

## uMPS memory management

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### Some interesting questions:

How does the ROM detect a TLB-Refill exception?

Could the ROM TLB-refilling algorithm be made smarter?

Who fills the Segment Tables and the **PgTbls**?

Why the kernel should start with virtual memory off?

Could the kernel be started with virtual memory on?

Is another memory management scheme possible?

If so, how to implement it?

Why the TLB size can be made smaller or larger?

Why TLB entry #0 is protected from TLBWR?

Will AMIKaya project phase2 require the virtual memory management?

## uMPS memory management

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### Some interesting answers (1 of 3):

How does the ROM detect a TLB-Refill exception?

Because the CPU jumps to a different address if a TLB-Refill exception is raised:

0x1FC0.0100 if **Status.BEV** is set

0x0000.0000 if **Status.BEV** is not set

Could the ROM TLB-refilling algorithm be made smarter?

yes, by defining different specifications (eg. using an ordered list for the **PgTbIs**)

Who fills the Segment Tables and the **PgTbIs**?

the kernel itself (or some part of it, eg. a specialized VM process)

## uMPS memory management

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### Some interesting answers (2 of 3):

Why the kernel should start with virtual memory off?

because it's easier to manage the VM by starting with it off

Could the kernel be started with virtual memory on?

yes (in MPS, it was the only way); in that case, the Bootstrap ROM needs to be more sophisticated

Are other memory management schemes possible?

yes: they could be simpler or more complex, and they could be more or less efficient, depending on hardware/software interaction

If other memory management schemes are possible, how to implement them?

by changing the ROMs



## uMPS memory management

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### Some interesting answers (3 of 3):

Why the TLB size can be made smaller or larger?

to allow testing for more frequent or infrequent TLB-Refill exceptions, that is, to allow testing the performance of different memory management schemes

Why TLB entry #0 is protected from TLBWR?

To have a place where to put a "safe" TLB entry (eg. if kernel starts with VM on, such a TLB entry is quite useful)

Will AMIKaya project phase2 require virtual memory management?

*NO*