

# Memory Virtualization

# Memory Virtualization

- Memory management in OS
  - Traditionally, OS fully controls all physical memory space and provide a continuous addressing space to each process.
  - In server virtualization, VMM should make all virtual machines share the physical memory space without knowing the fact.
- Goals of memory virtualization :
  - Address Translation
    - Control table-walking hardware that accesses translation tables in main memory.
  - Memory Protection
    - Define access permission which uses the Access Control Hardware.



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# Memory Architecture

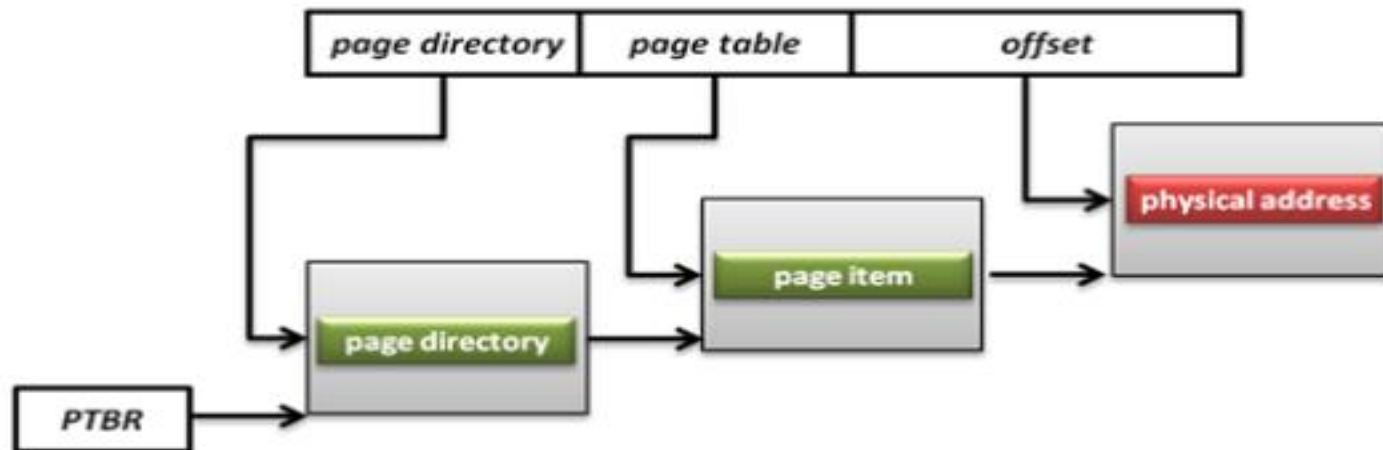
- Memory Management Unit (MMU)

- What is MMU ?

- A computer hardware component responsible for handling accesses to memory requested by the CPU.
    - Its functions include translation of virtual addresses to physical addresses, memory protection, cache control, bus arbitration and etc.

- What is PTBR ?

- Page Table Base Register (PTBR) is a register point to the base of page table for MMU.

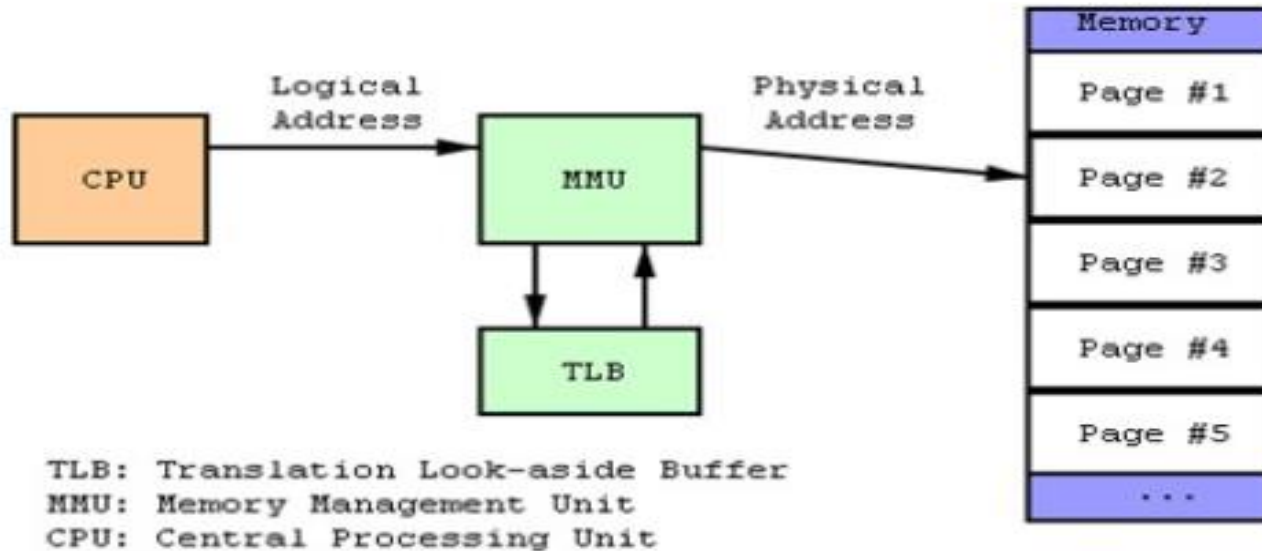


# Memory Architecture

- Translation Lookaside Buffer (TLB)

- What is TLB ?

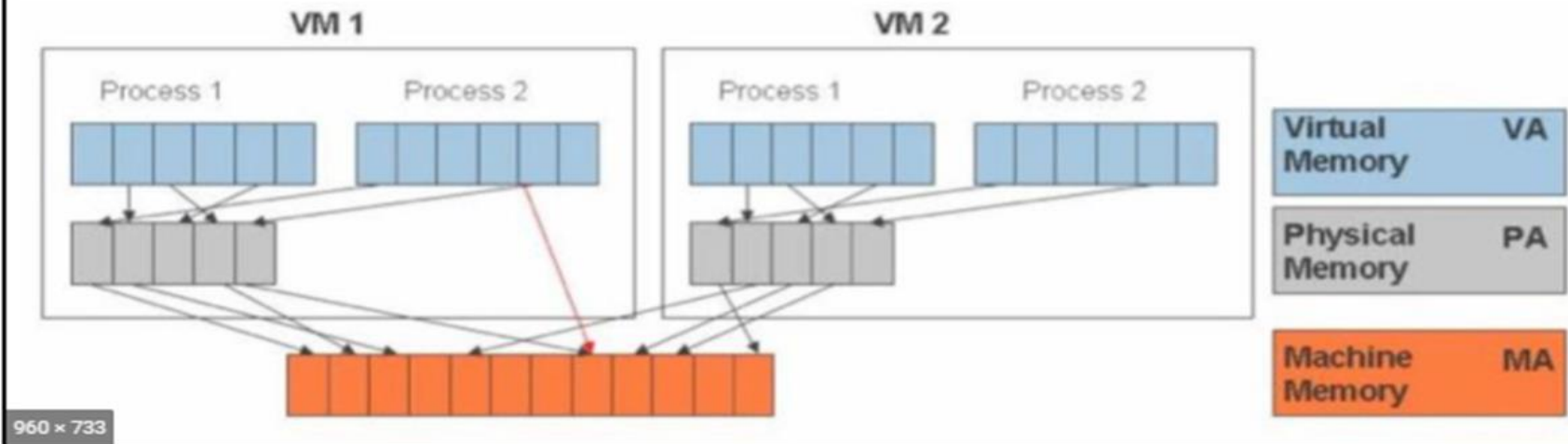
- A CPU cache that memory management hardware uses to improve virtual address translation speed.



# Memory Virtualization



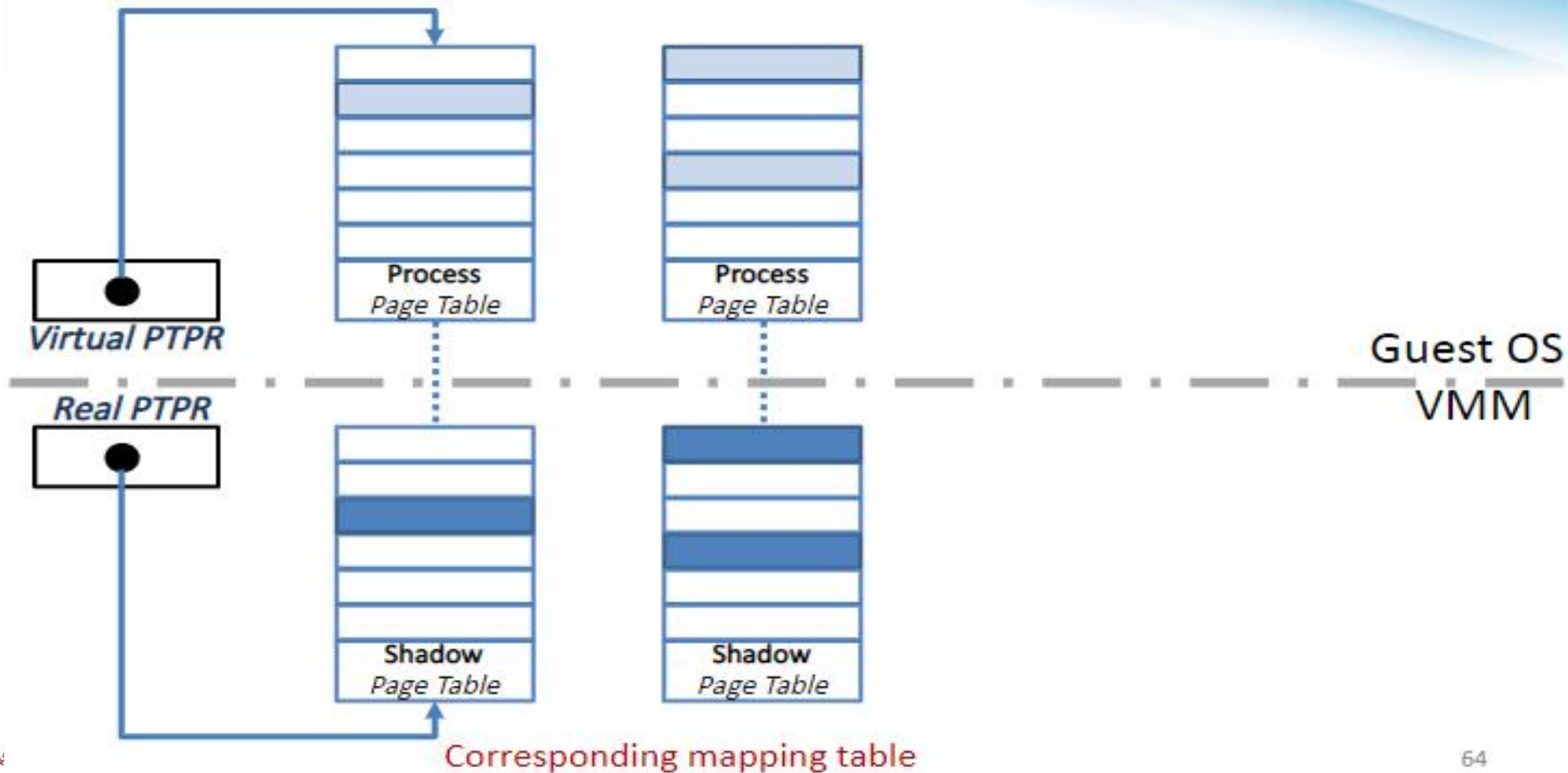
- The guest OS continues to control the mapping of virtual addresses to the guest memory physical addresses, but the guest OS cannot have direct access to the actual machine memory.
- The VMM is responsible for mapping guest physical memory to the actual machine memory, and it uses shadow page tables to accelerate the mappings.
- The VMM uses TLB hardware to map the virtual memory directly to the machine memory to avoid the two levels of translation on every access.





# Shadow Page Table

- Shadow page table operations :



# How does shadow Page Table works?

- VMM should make MMU virtualized
- VMM manages the real PTBR and a virtual PTBR for each VM
- When the guest OS is activated, the real PTBR points to a shadow page table
- When guest OS modifies the virtual PTBR, it is trapped by VMM
- VMM will walk the page table of the guest and modify the related shadow page table to make MMU get host physical address

# Hardware Solution

- Difficulties of shadow page table technique :
  - Shadow page table implementation is extremely complex.
  - Page fault mechanism and synchronization issues are critical.
  - Host memory space overhead is considerable.
- But why we need this technique to virtualize MMU ?
  - MMU do not first implemented for virtualization.
  - MMU is knowing nothing about two level page address translation.
- Now, let us consider hardware solution.

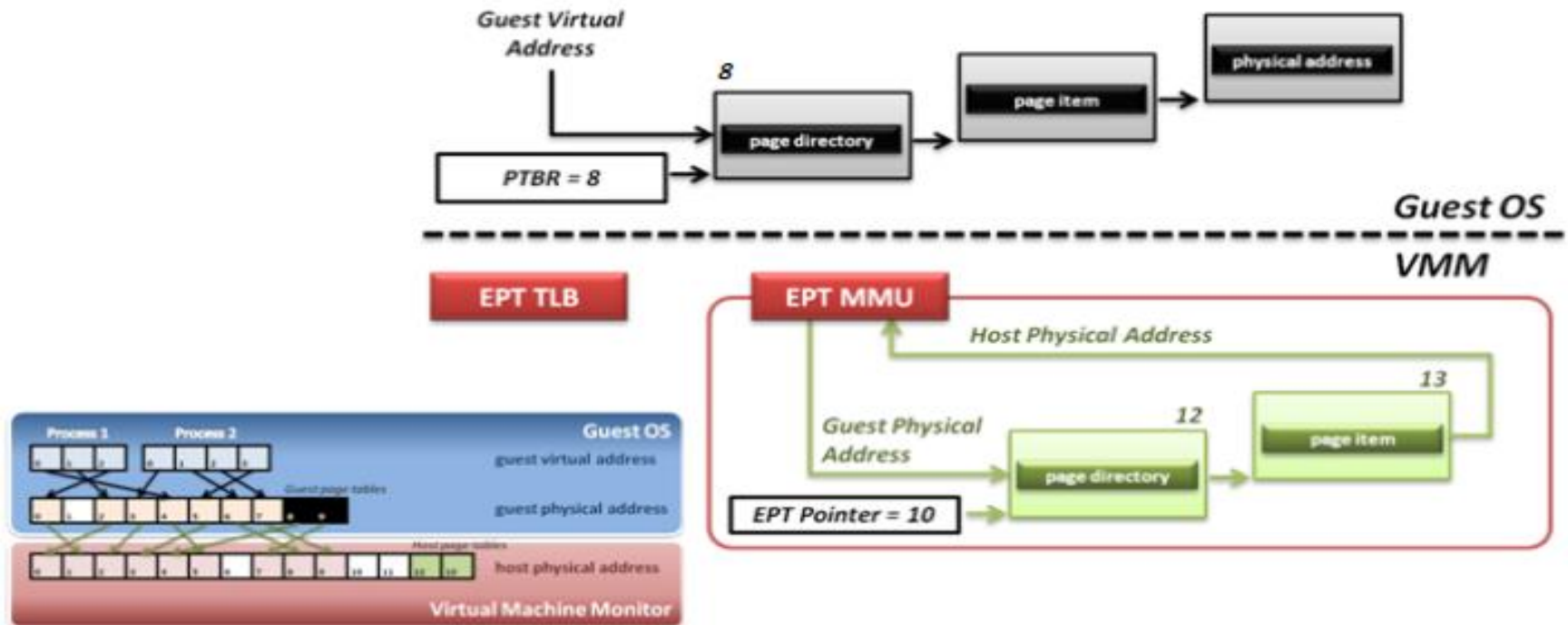


# Extended Page Table

- Concept of Extended Page Table (EPT) :
  - Instead of walking along with only one page table hierarchy, EPT technique implement one more page table hierarchy.
    - One page table is maintained by guest OS, which is used to generate guest physical address.
    - The other page table is maintained by VMM, which is used to map guest physical address to host physical address.
  - For each memory access operation, EPT MMU will directly get guest physical address from guest page table, and then get host physical address by the VMM mapping table automatically.

# Extended Page Table

- Memory operation :



# Memory Virtualization Summary

- Software implementation
  - Memory architecture
    - MMU (memory management unit)
    - TLB (translation lookaside buffer)
  - Shadow page table
    - MMU virtualization by virtual PTBR
    - Shadow page table construction
    - Page fault and page table protection
- Hardware assistance
  - Extended page table
    - Hardware walk guest and host page table simultaneously

# Memory Virtualization

## Summary

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- SW-based memory virtualization has been the most complex part in VMM
  - Before HW support, Xen continued optimizing its shadow page tables up to ver3
  - Virtual memory itself is already complicated, but virtualizing virtual memory is horrible
- HW-based memory virtualization significantly reduces VMM complexity
  - The most complex and heavy part is now offloaded to HW

# References

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- Virtualization and Cloud Computing Lecture 6:  
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- Server Virtualization:  
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