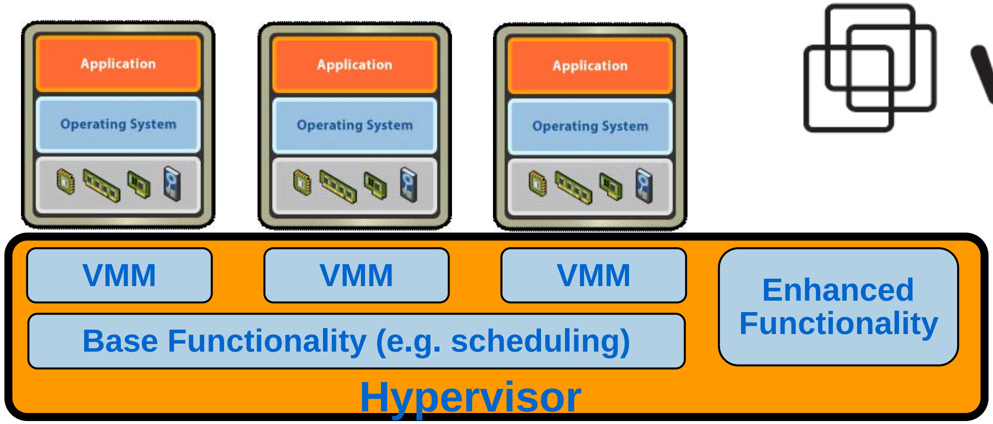
Virtualization

Part 2 – VMware

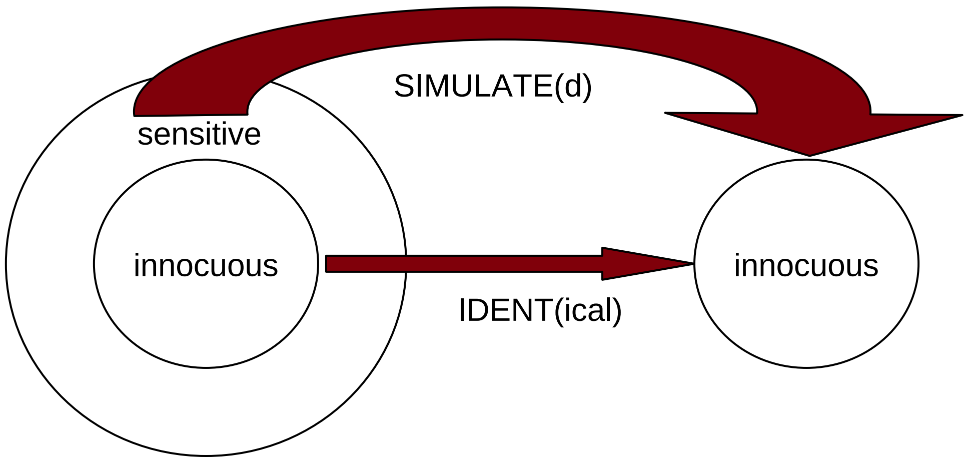
VMware: *binary translation*



References and Sources

- Carl Waldspurger, "Memory Resource Mangement in VMware ESX Server" Proceedings, 5th Symposium on Operating Systems Design and Implementation, Boston, Massachusetts, December 9-11, 2002, 14 pages.
- Keith Adams, and Ole Agesen, "A Comparison of Software and Hardware Techniques for x86 Virtualization," Proceedings, ASPLOS'06, San Jose, California, October 21, 2006, 12 pages.

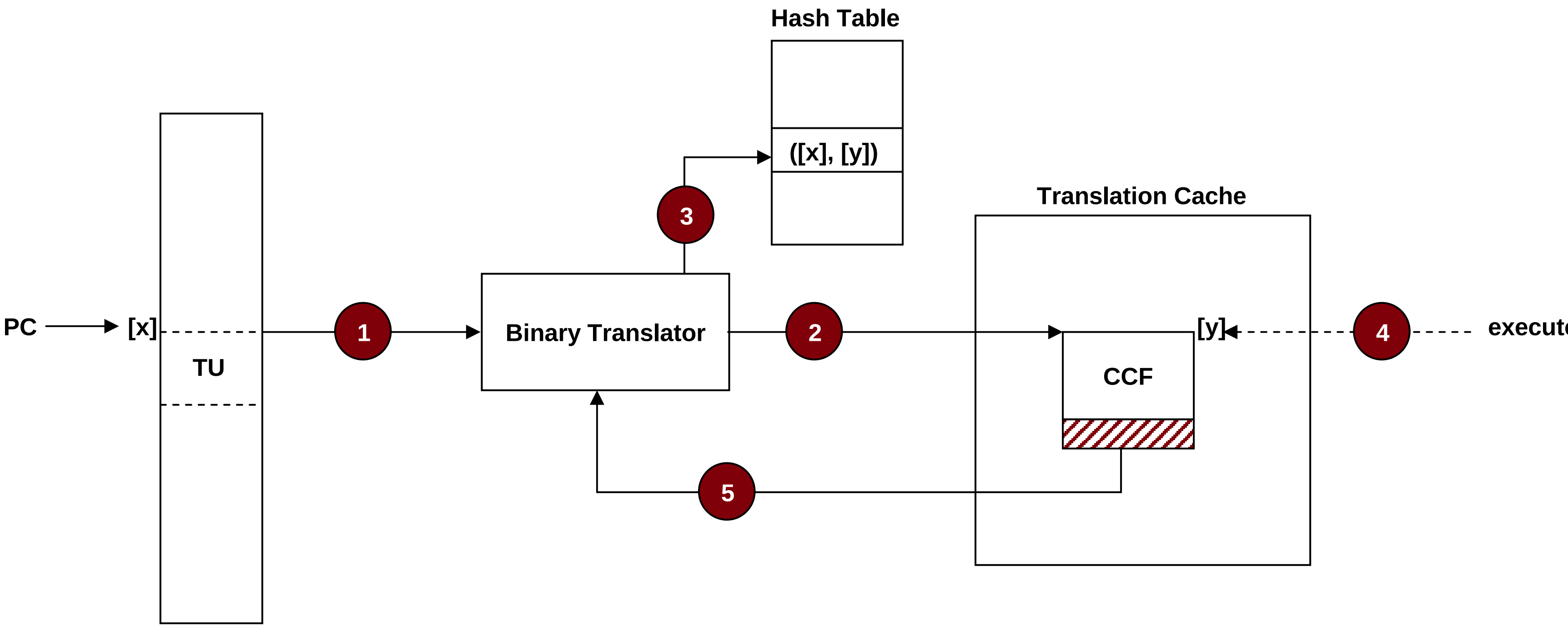
Binary Translation



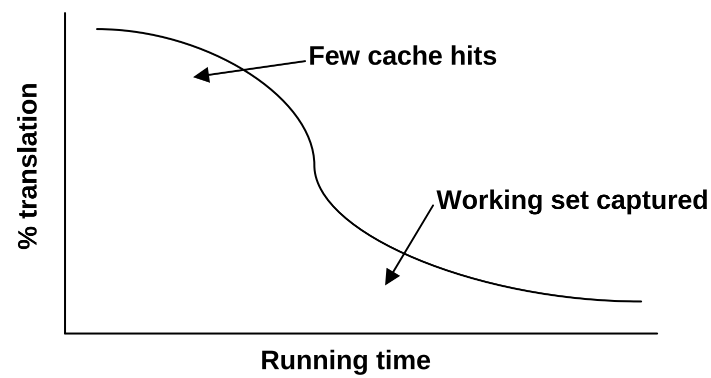
Characteristics

- Binary – input is machine-level code
- Dynamic – occurs at runtime
- On demand – code translated when needed for execution
- System level – makes no assumption about guest code
- Subsetting – translates from full instruction set to safe subset
- Adaptive – adjust code based on guest behavior to achieve efficiency

Binary Translation

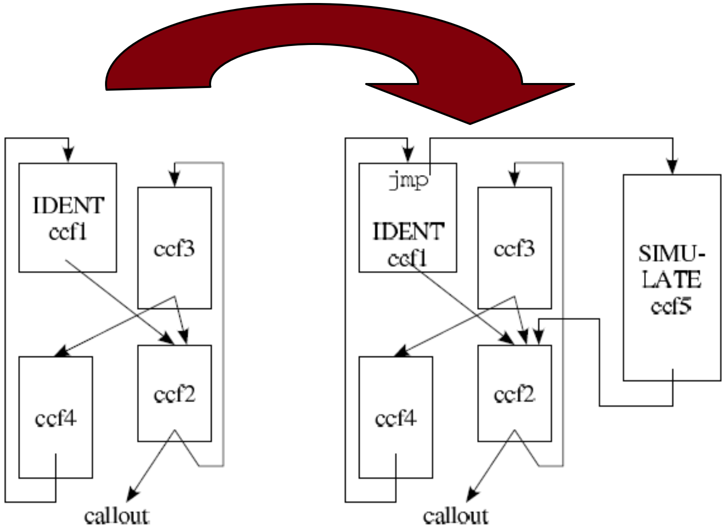


TU: translation unit (usually a basic block)
CCF: compiled code fragment
: continuation



Eliminating faults/traps

- Expensive traps/faults can be avoided
- Example: Pentium privileged instruction (rdtsc)
  - Trap-and-emulate: 2030 cycles
  - Callout-and-emulate: 1254 cycles
  - In-TC emulation: 216 cycles
- Process
  - Privileged instructions – eliminated by simple binary translation (BT)
  - Non-privileged instructions – eliminated by adaptive BT
    - (a) detect a CCF containing an instruction that trap frequently
    - (b) generate a new translation of the CCF to avoid the trap (perhaps inserting a call-out to an interpreter), and patch the original translation to execute the new translation

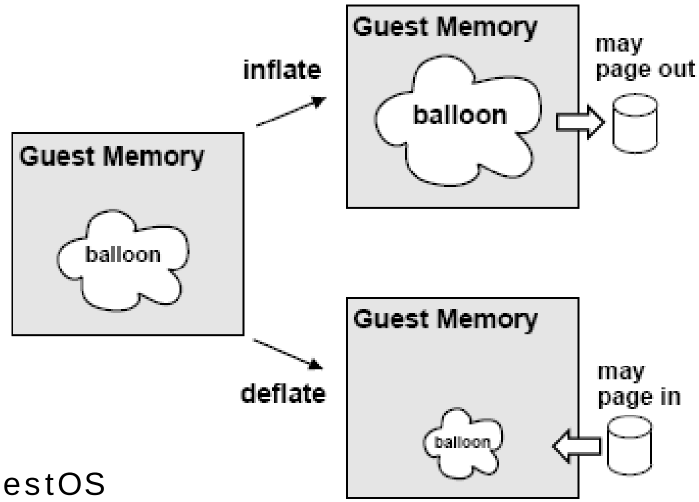


Memory resource management

- VMM (meta-level) memory management
  - Must identify both VM and pages within VM to replace
  - VMM replacement decisions may have unintended interactions with GuestOS page replacement policy
  - Worst-case scenario: double paging

- Strategies
  - "ballooning" –
    - add memory demands on GuestOS so that the GuestOS decides which pages to replace
    - Also used in Xen
  - Eliminating duplicate pages – even identical pages across different GuestOSs.
    - VMM has sufficient perspective
    - Clear savings when running numerous copies of same GuestOS
  - Allocation algorithm
    - Balances memory utilization vs. performance isolation guarantees
    - "taxes" idle memory

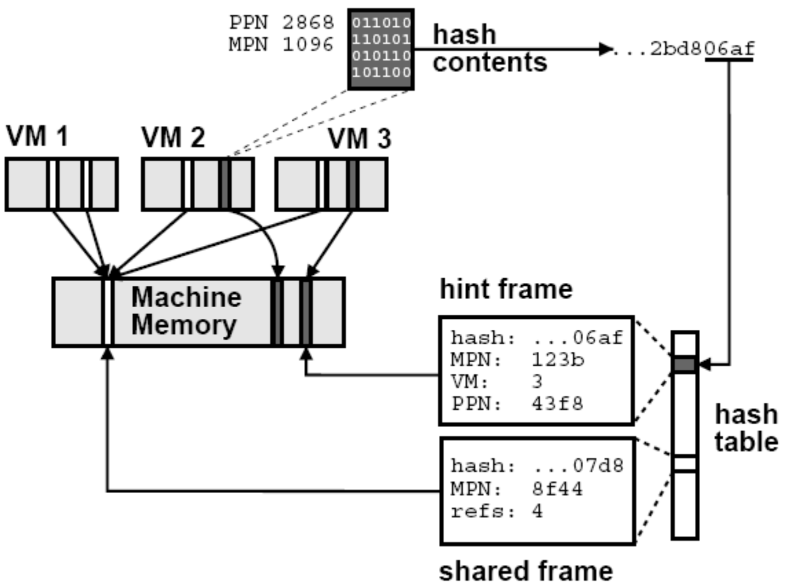
Ballooning



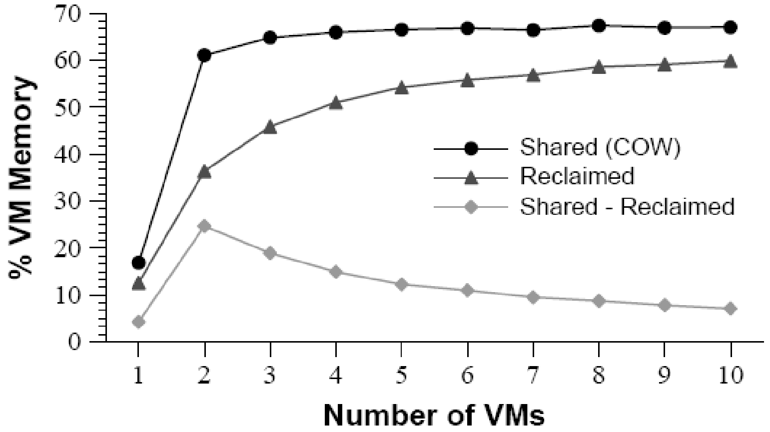
- "balloon" – module inserted into GuestOS as pseudo-device driver or kernel service
- Has no interface to GuestOS or applications
- Has a private channel for communication to VMM
- Polls VMM for current "balloon" size
- Balloon holds number of "pinned" page frames equal to its current size
- Inflating the balloon
  - Balloon requests additional "pinned" pages from GuestOS
  - Inflating the balloon causes GuestOS to select pages to be replaced using GuestOS page replacement policy
  - Balloon informs VMM of which physical page frames it has been allocated
  - VMM frees the machine page frames s corresponding to the physical page frames allocated to the balloon (thus freeing machine memory to allocate to other GuestOSs)
- Deflating the balloon
  - VMM reclaims machine page frames
  - VMM communicates to balloon
  - Balloon unpins/ frees physical page frames corresponding to new machine page frames
  - GuestOS uses its page replacement policy to page in needed pages

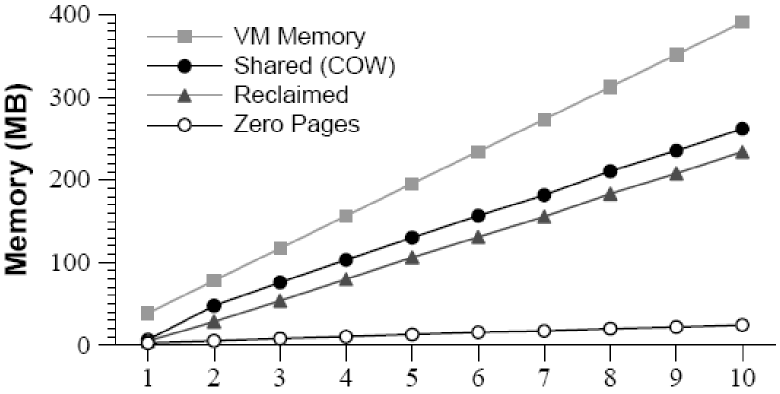
Content-based page sharing

- A hash table contains entries for shared pages already marked “copy-on-write”
- A key for a candidate page is generated from a hash value of the page’s contents
- A full comparison is made between the candidate page and a page with a matching key value
- Pages that match are shared – the page table entries for their VMMs point to the same machine page
- If no match is found, a “hint” frame is added to the hash table for possible future matches
- Writing to a shared page causes a page fault which causes a separate copy to be created for the writing GuestOS



Page sharing performance





- Identical Linux systems running same benchmark
- "best case" scenario
- Large fraction (67%) of memory sharable
- Considerable amount and percent of memory reclaimed
- Aggregate system throughput essentially unaffected

Measuring Cross-VM memory usage

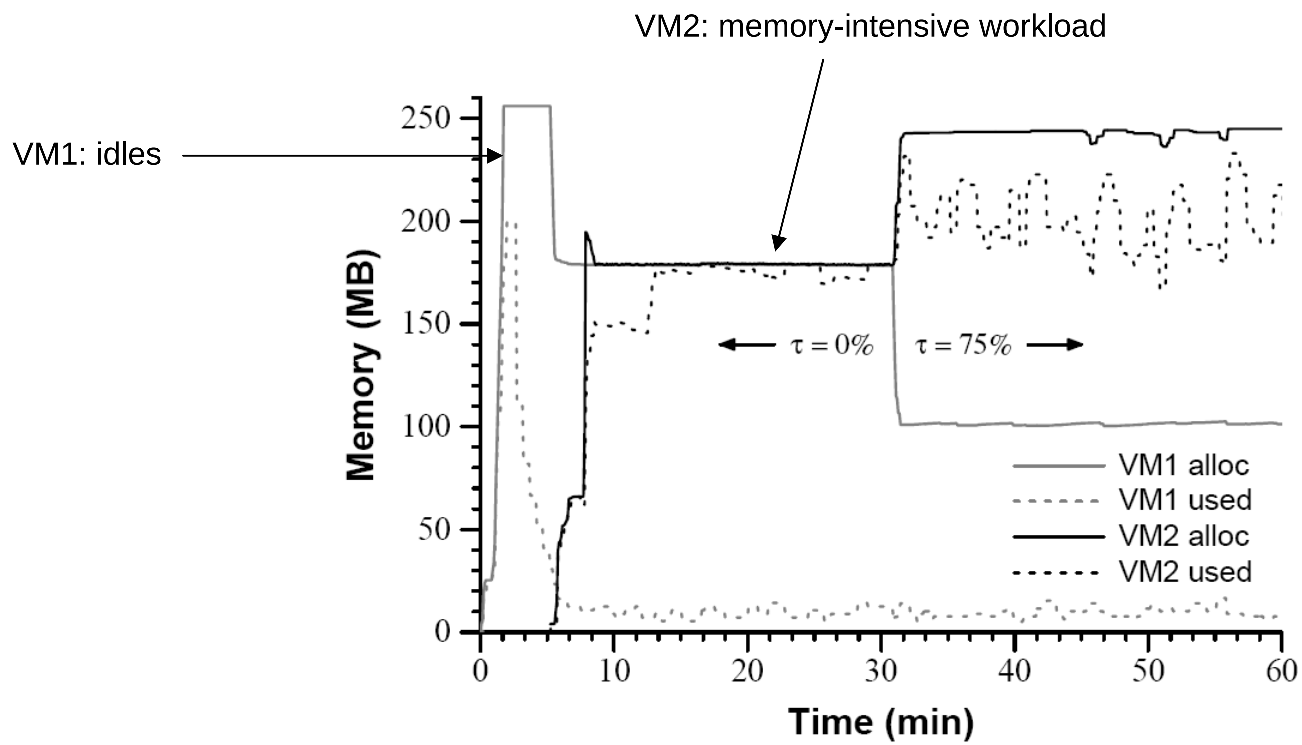
- Each GuestOS is given a number of shares, S, against the total available machine memory.
- The shares-per-page represents the "price" that a GuestOS is willing to pay for a page of memory.
- The price is determined as follows:

$$\rho = \frac{S}{P \cdot (f + k \cdot (1 - f))}$$

shares
price
page allocation
idle page cost
fractional usage

- The idle page cost is $k = 1/(1-\tau)$ where $0 \leq \tau < 1$ is the "tax rate" that defaults to 0.75
- The fractional usage, f, is determined by sampling (what fraction of 100 randomly selected pages are accesses in each 30 second period) and smoothing (using three different weights)

Memory tax experiment



- Initially, VM1 and VM2 converge to same memory allocation with τ=0 (no idle memory tax) despite greater need for memory by VM2
- When idle memory tax applied at default level (75%), VM1 relinquishes memory to VM2 which improves performance of VM2 by over 30%