A Comparison of Software and Hardware Techniques for x86 Virtualization

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VMWare

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The Renaissance of Virtualization

- 1970s: virtual machines first used
- 1990s:
  - x86 becomes prominent server platform
  - No vertical integration in x86
  - Lack of enterprise features in commodity OSs
- 1999: VMWare first product to virtualize x86
- 2006: AMD and Intel offer hardware support

Outline

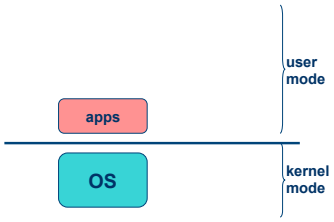
- Classic Virtualization
- Software Virtualization
- Intel/AMD Hardware Virtualization
- Comparison and Results
- Discussion

Classic Virtualization

- Popek and Goldberg's Criteria:
  1. ***Fidelity*** **–** run any software
  2. ***Performance*** **–** run it fairly fast
  3. ***Safety*** **–** VMM manages all hardware
- **Trap-and-Emulate** only real solution until recently

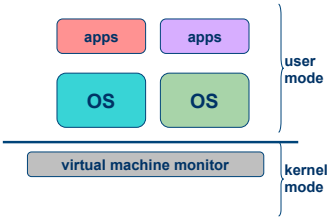
Trap-and-Emulate Virtualization

1. De-Privilege OS



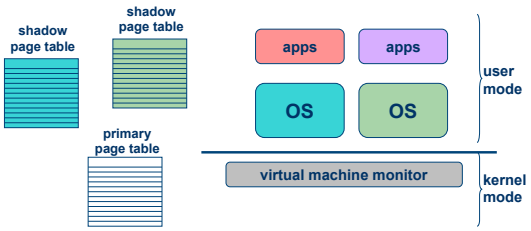
Trap-and-Emulate Virtualization

1. De-Privilege OS



Trap-and-Emulate Virtualization

1. De-Privilege OS
2. Shadow structures and memory tracing



Trap-and-Emulate cont.

- Traps are expensive (~3000 cycles)
- Many traps unavoidable
  - E.g., page faults
- Important enhancements
  - "Paravirtualization" to reduce traps (e.g., Xen)
  - Hardware VM modes (e.g., IBM s370)

Can x86 Trap and Emulate?

- No
  - Even with 4 execution modes!
  - Key problem: dual-purpose instructions don't trap
- Classic Example: ***popf*** instruction
  - Same instruction behaves differently depending on execution mode
  - User Mode: changes ALU flags
  - Kernel Mode: changes ALU **and** system flags
  - **Does not generate a trap in user mode**

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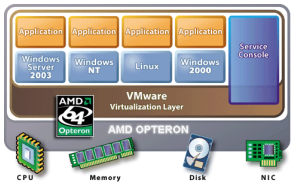
Software Virtualization with VMWare

- **Binary translation!**



VMWare's Binary Translation

- On-the-fly
- Only need to translate OS code
  - Makes SPEC run fast by default
- Most instruction sequences don't change
- Instructions that **do change:**
  - Indirect control flow: call/ret, jmp
  - PC-relative addressing
  - Privileged instructions
- Adaptive Translation
  - ***"Innocent until proven guilty"***

Performance Advantages of BT

- Translation sequences can be faster than native:
  - ***cli*** *vs.* vpu.flags.IF := 0
- Avoid privilege instruction traps
  - Example: rdtsc
    - Trap-and-emulate: 2030 cycles
    - Callout-and-emulate: 1254 cycles
    - BT emulation: 216 cycles (but TSC value is stale)

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AMD SVM and Intel VT

- Extensions to x86-32 and x86-64
  - Allows classic **trap-and-emulate**!
  - Hardware VM modes to reduce traps
  - Details:
    - VMCB – virtual machine control block
    - VMX mode for running guest OSs
    - ***Vmrun*** instruction to enter VMX mode
    - Many instructions and events cause VMX **exits**
    - Control fields in VMCB can change VMX exit behavior

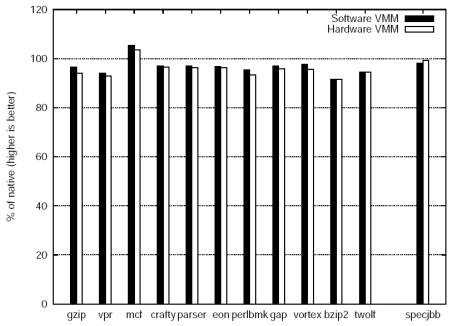
Hardware VM Example: syscall

1. VMM fills in VMCB exception table for Guest OS
   - Sets bit in VMCB ***not*** **exit on syscall exception**
2. VMM executes ***vmrun***
3. Application invokes ***syscall***
4. CPU → CPL #0, ***does not trap***, vectors to VMCB exception table

Software BT vs. Hardware VM

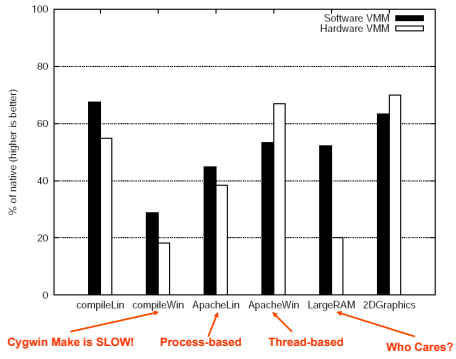
- Binary Translation VMM:
  - Converts traps to callouts
    - Callouts faster than trapping
  - Faster emulation routine
    - VMM does not need to reconstruct state
  - Avoids callouts entirely
- Hardware VMM:
  - Preserves code density
  - No precise exception overhead
  - Faster system calls

Compute-bound Benchmarks



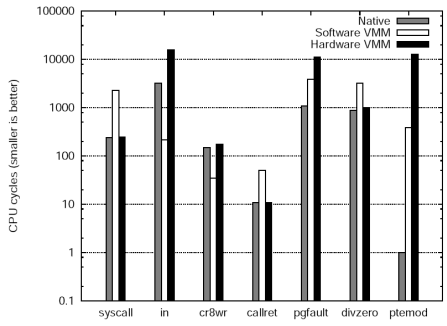
Bottomline: little difference for SPEC

Mixed Benchmarks

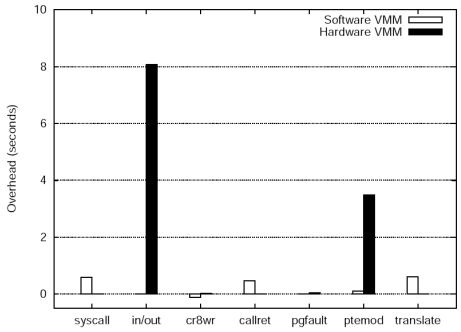


Would Hardware VM do better for multithreaded database?

Costs of Operations



Nanobenchmarks



VMWare Nanobenchmarks

- ***syscall***
  - Native/Hardware VMM: same
  - Software VMM: +2000 cycles
- ***in***
  - Native: 3209 cycles
  - Hardware VMM: 15826 cycles
  - Software VMM: 15x faster?
- ***call/ret***
  - Native/Hardware VMM: 11 cycles
  - Software VMM: 51 cycles

Opportunities

- Faster Microarchitecture implementations
  - Intel Core Duo already much faster than P4
- Hardware VMM algorithms
- Software/Hardware Hybrid VMM
- Hardware MMU
  - Virtualize DMA

Catalysts for Discussion

- Is BT really faster for things that matter?
  - Process-based Apache on Linux?
  - Who configures a system to constantly page?
- VMWare is done, why bother with Hardware VM support?
  - Simplicity of VMM w/ Hardware support
  - New applications
- Will next-gen hardware make binary translation unnecessary?