Advanced virtualization techniques for FAUmachine

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September 2004

Outline

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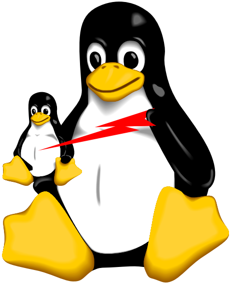
Many Different Virtualization Projects

- Commercial: VMware, Virtual PC, Simics, ...
- Open Source: bochs, plex86, QEMU, PearPC, FAUmachine, ...
- partial virtualization: UML, VServer, ...

History of FAUmachine



- Motivation: Fault injection
- UMLinux started as a user mode Linux (different to UML)
- Moved to a hardware simulator with minimal changes in the guest system
- Now called FAUmachine

Goals of FAUmachine

- Complete simulation of a PC
- Simulator runs in user mode
- No need to patch host kernel
- Efficient

CPU: Direct Execution

- No performance penalty
- Privileged instructions and privilege level changes need special care
- Examples: Hardware support in S390, vm86

Memory: Mapped Files

- Files to represent the physical memory
- Process' address space to represent virtual memory
- mmap(2) to simulate MMU
- Only 3GB are available in Linux

Peripherals: Simulated

- Hardware is represented by software
- Input/output is mapped to function calls
- Simulated hardware can interact with the host system:
  - hard disk content is stored in a file
  - video signal is displayed in a window
  - sound is sent to real sound card

Differences Between User And Kernel Mode

- Different memory mappings
  - Only the kernel can access all the physical memory
- Some instructions are only available in kernel mode
  - All hardware access
  - Processor configuration
- Some instructions behave differently on i386

Virtualization of User Mode Code

- Code consists of unprivileged instructions
- Simulator has to handle user/kernel mode transitions
- Traps either provoke a signal or a real host system call
  - Can be detected by ptrace(2) or a special kernel extension

Virtualization of Kernel Mode Code

- Code contains many privileged instructions
- Those cannot be executed in user mode
- A JIT compiler is used to generate code that can be executed directly

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Kernel Mode Code

- Direct execution of kernel code not possible in user mode
- C implementation of every instruction
- Simulator works on a shadow copy of the CPU state

`inb` *imm8* $\Rightarrow$ `regs->al = host_bus_inb(instp->imm8);`

Switching Between Simulation And Direct Execution

- Direct execution is not possible all the time
- Simulation is slow

Solution:

- Only use simulation when it is necessary
- Switch back to direct execution as soon as possible

Problems:

- Real CPU state and the shadow copy have to stay in sync
- How/when to activate the simulator?

pushf / popf

0	0	0	0	0	0	0	0
0	0	ID	VIP	VIF	AC	VM	RF
0	NT	IOPL		OF	DF	IF	TF
SF	ZF	0	AF	0	PF	0	CF

- available both in user and kernel mode
- but with different semantics

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- available both in user and kernel mode
- but with different semantics
- some bits only available to kernel

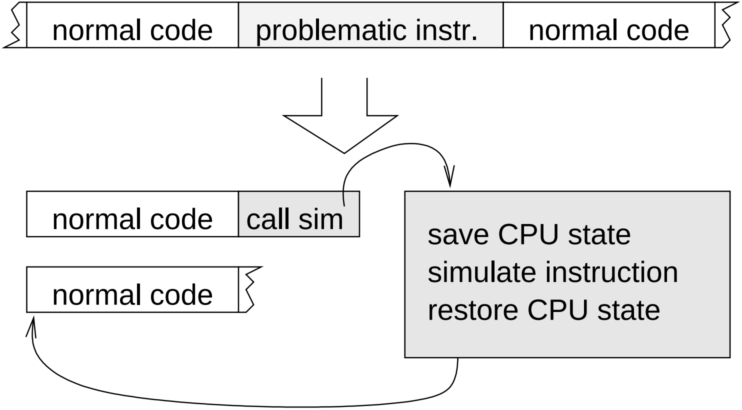
Detecting Instructions That Need To Be Simulated

- No hardware support to detect problematic instructions on i386
- Every instruction has to be checked before it is executed
- But: every instruction has to be checked only once
- The result can be stored in a cache

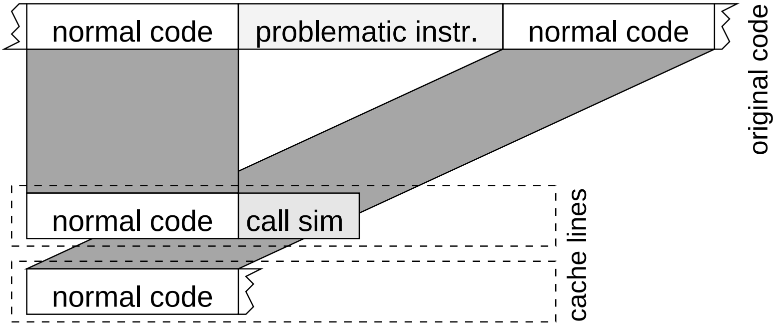
Cache

- Executable code in the cache
- Problematic instructions are replaced with special simulator calls
- Cache is filled instruction by instruction by a JIT compiler
- A special "compile-next-instruction" call is appended to the cached code

Code Transformation



Cache Lines



- Cache is split into several cache lines
- Direct mapping between original and cached code inside of each cache line
- Hash tables to map real address to cache line

More Code Modifications

- Execution in a separate cache influences Instruction Pointer (`%eip`)

→ `call` and `ret` have to be simulated, too

- Layout of code is changed

→ Jump targets may have to be represented using more bits

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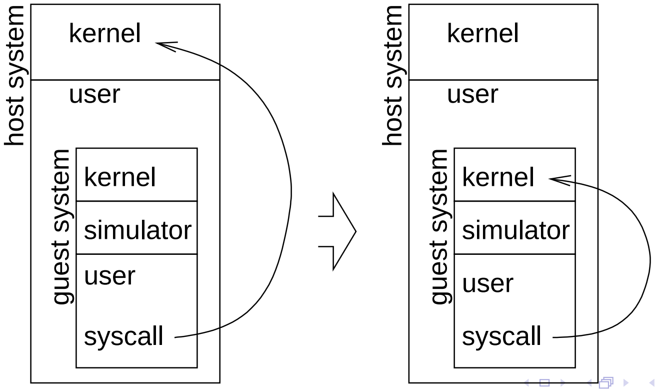
Handling of a System Call

- System calls in the guest user mode code will be executed directly, too
- The simulator has to intercept these system calls and redirect them to the guest kernel



Redirection of a System Call

- A signal is delivered instead of executing the system call
- The signal handler of the simulator fakes the system call in the guest system
- The simulator code residing in the CPU process still has to be able to execute system calls to the host kernel
- System calls coming from the simulator address space must not be redirected

ptrace(2)

- A special process ("tracer") uses PTRACE_SYSCALL to trace system calls executed by the CPU process
- It gets notified on system call entry and exit
- If the system call is coming from a guest process:
  - System call entry: redirect system call number to getpid(2)
  - System call exit: restore system call number, send signal to CPU process
- Total: four context switches, several system calls

Kernel Support For Redirection

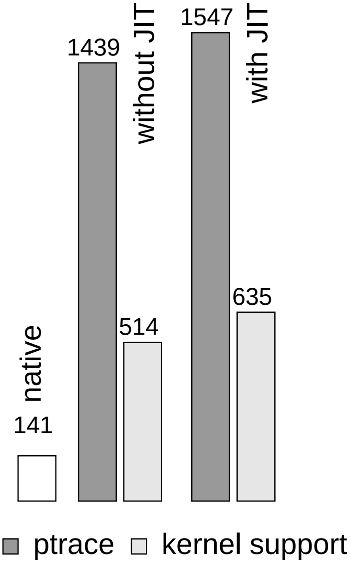
- Conversion of a system call to a signal is trivial in kernel space
- Only system calls from a guest process inside a FAUmachine CPU process have to be converted
- New system call to register FAUmachine CPU processes
- The address range of the simulator is given as parameter

Address Space

- Real machine has a 4GB address space
- User space processes only have a 3GB address space
- 4G patch has two problems:
  - extra TLB flush on every system call $\longrightarrow$ slowdown for all processes.
  - needs a fixed 16MB area for switching
- We are working on a conditional 4GB patch with a dynamic switching zone

$\Rightarrow$ Should allow us to efficiently run unmodified kernels in the future

Performance



- Benchmark: Kernel compilation
- JIT compiler has a performance impact
- Host kernel support can increase performance

Conclusion

- Direct execution to increase speed
- JIT to convert kernel to user mode code
- Host kernel support can increase performance

More information is available on faumachine.org.

Thank you!

Questions?

Thank you!

Have a nice time at LinuxKongress!

Cache Line Usage