Virtualization

- Virtualization: extend or replace an existing interface to mimic the behavior of another system.
  - Introduced in 1970s: run legacy software on newer mainframe hardware
- Handle platform diversity by running apps in VMs
  - Portability and flexibility
Types of Interfaces

- Different types of interfaces
  - Assembly instructions
  - System calls
  - APIs
- Depending on what is replaced /mimiced, we obtain different forms of virtualization

Types of Virtualization

- Emulation
  - VM emulates/simulates complete hardware
  - Unmodified guest OS for a different PC can be run
    - Bochs, VirtualPC for Mac, QEMU
- Full/native Virtualization
  - VM simulates “enough” hardware to allow an unmodified guest OS to be run in isolation
    - Same hardware CPU
    - IBM VM family, VMWare Workstation, Parallels,…
Types of virtualization

- Para-virtualization
  - VM does not simulate hardware
  - Use special API that a modified guest OS must use
  - Hypercalls trapped by the Hypervisor and serviced
  - Xen, VMware ESX Server
- OS-level virtualization
  - OS allows multiple secure virtual servers to be run
  - Guest OS is the same as the host OS, but appears isolated
    - apps see an isolated OS
  - Solaris Containers, BSD Jails, Linux Vserver
- Application level virtualization
  - Application is gives its own copy of components that are not shared
    - (E.g., own registry files, global objects) - VE prevents conflicts
  - JVM

Examples

- Application-level virtualization: “process virtual machine”
- VMM /hypervisor
The Architecture of Virtual Machines

J Smith and R. Nair
IEEE Computer, May 2005

Slides courtesy of Bhuvan Urgaonkar

Goal of Paper

• Provide a taxonomy of virtual machines
  – Different goals
  – Different implementations
Early Computers

- Hardware designed
  - Software written for hardware
- Each system crafted with own instruction set
  - Software had to made specifically for each instruction set
- Eventually instruction sets became more standardized
  - However, software still requires a certain instruction set architecture and operating system that meets strict standards.

Virtual Machines

- Eliminate real machine constraint
  - Increases portability and flexibility
- Virtual machine adds software to a physical machine to give it the appearance of a different platform or multiple platforms.
- Benefits
  - Cross platform compatibility
  - Increase Security
  - Enhance Performance
  - Simplify software migration
Initial Hardware Model

- All applications access hardware resources (i.e., memory, i/o) through system calls to operating system (privileged instructions)

- Advantages
  - Design is decoupled (i.e. OS people can develop OS separate of Hardware people developing hardware)
  - Hardware and software can be upgraded without notifying the Application programs

- Disadvantage
  - Application compiled on one ISA will not run on another ISA.
    - Applications compiled for Mac use different operating system calls then application designed for windows.
  - ISA’s must support old software
    - Can often be inhibiting in terms of performance
  - Since software is developed separately from hardware.
    - Software is not necessarily optimized for hardware.

Virtual Machine Basics

- Virtual software placed between underlying machine and conventional software
  - Conventional software sees different ISA from the one supported by the hardware

- Virtualization process involves:
  - Mapping of virtual resources (registers and memory) to real hardware resources
  - Using real machine instructions to carry out the actions specified by the virtual machine instructions
System/Process Virtual Machines

• Can view virtual machine as:
  – System virtual machine (i.e. think cygwin)
    • Full execution environment that can support multiple processes
    • Support I/O devices
    • Support GUI
  – Process virtual machine
    • Virtual machines can be instantiated for a single program (i.e. think Java)
    • Virtual machine terminates when process terminates.

Standard Interfaces

• When implementing virtual machines there are two standard interfaces
  – Deal with Process and System Level virtual machines
    • ISA -> has both user and system instructions
      – User instructions available to both the application programs and to the operating system
    • Application Binary Interface (ABI)
      – Composed of two components
        » First all user instructions
        » System call interface -> allows to work with OS privileged instructions
Process Level Virtual Machines

- Provide user with application level virtual ABI environment
  - Examples
    - Multiprogramming
      » Provide end users with illusion of having a complete machine to itself
      » Each process given own address space and access to file structure
    - Emulation and Binary Translators
      » Use interpretation to allow a program to be emulated on an ISA that is different then the ISA it was compiled on. (translate instruction when called into foreign ISA)
      » Can also use translation to put foreign code in to the current machines ISA.
  - High Level VMS
    » When process VM at the same time you design the high level language.
      » First done in Pascal. Take high level code and translates it into intermediary language.
      Intermediary language is then translated to the specific ISA.

System Level Virtual Machines

- Provide complete environment in which many processes, possibly belonging to multiple users can exist.
  - Virtual machine is the interface to the ISA
- Divide a single set of hardware among multiple guest Operating Systems.
  - Reason -> different people want different operating systems.
  - Provides security
  - Can configure hardware by monitoring performance
    - Statistics allow it to configure hardware
Virtualization

• The computational function carried out by a computer system is specified in terms of:
  – architected state (registers, memory)
  – instructions
    • cause changes in the architected state.
• Today often more implementation state then architecture state
• How do you virtualize a foreign ISA
  – E.x. A foreign architecture maybe have 32 registers but your architecture only has 8 registers.
  – This means that a virtual machine may not map to an ISA efficiently.

Operating System Support for Virtual Machines

• Samuel T. King, George W. Dunlap and Peter M. Chen
• Proceedings of the 2003 USENIX Technical Conference

• Slides: courtesy of Bhuvan Urgaonkar
Outline

- Introduction
- Review of Virtual Machines
- UMLinux - an evaluated Type II VMMs
- Host OS Support for Type II VMMs
- Performance Results
- Conclusions

Introduction

- About Virtual Machine Monitor (VMM)
  - A layer of software emulating hardware of a complete computer system.
  - Provide an abstraction - virtual machine (VM).
  - Could provide a VM identical to underlying hardware platform running VMM or totally different hardware platform.
- Uses of VMMs
  - To create illusion of multiple machines on a single physical machines.
  - To provide software environment for OS debugging.
  - To provide means of isolation that untrusted applications run separately.
Introduction

- Two types of VMMs
  - Type I
    - guest application
    - guest operating system
    - virtual-machine monitor (VMM)
    - host hardware
  - Type II
    - guest application
    - guest operating system
    - virtual-machine monitor (VMM)
    - host operating system
    - host hardware

Virtual Machines

- The classification of VMMs can be based on whether the VM created by a VMM emulates the same underlying hardware.
  - VMs emulating the underlying hardware (homogeneous)
    - Some performance problems due to enumeration overheads, additional complexity in term of frequent task switches and memory mapping.
  - VMs emulating different hardware (heterogeneous)
    - Various degree of compatibility:
      - Denali supports only some instructions.
      - Microkernel provides high-level services that are not provided by hardware.
      - Java VM is completely hardware independent.
Virtual Machines

- Another classification based on Type I/II VMMs
- This paper focuses on homogeneous Type II VMMs:
  - Pros:
    - Run as a process that system developers/administrators can have an easier control on it.
    - As a debugging platform
  - Cons:
    - Undesirable performance due to lack of sufficiently powerful interfaces provided by underlying operating systems.
    - That's work to be presented in this paper.

UMLinux

- What is UMLinux?
  - UMLinux is a Type II VMM, a case Type II VMM studied in this paper
  - It runs upon Linux and the guest operating systems and guest applications run as a single process.
  - Note: The interfaces provided by UMLinux is similar but not identical to underlying hardware, so modifications on both guest OS and VMM are needed.
  - It makes use of functionality supplied by underlying OS, e.g.
    - process as CPU,
    - Host memory mapping and protection as virtual MMU
    - Memory files as file systems etc.
    - files and devices as virtual devices,
    - TUN/TAP devices as virtual network,
    - host signal as virtual interrupts,
UMLinux

- **UMLinux system structure**
  - A VMM process and a guest-machine process
    
    | guest application | guest application |
    |-------------------|-------------------|
    | guest operating system | guest-machine process |
    
    - **VMM process**
    - Redirects operating signal and system calls
    - Restricts the set of system calls allowed by guest OS
    - VMM uses "ptrace" to mediate access between guest machine process and host OS.

  - ptrace is a system call to observe and control another process, and examine and change its core image and registers. It is primarily used to implement breakpoint debugging and system call tracing.

- **UMLinux operations**
  - Example:
    
    - System call intercepted by VMM process via ptrace
    - guest SIGUSR1 handler calls mmap to access guest kernel data; intercepted by VMM process
    - guest application
    - host operating system
Host OS support for Type II VMMs

- Three bottlenecks in running a Type II VMM
  - Inordinate number of context switches between processes.
  - A large number of memory protection operations.
  - A large number of memory mapping operations.

- This paper proposed possible modifications to VMM and in general, the modifications involves only a few number of lines of code.