Advanced Systems Security: Virtual Machine Systems

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Two Directions

- OS Security from Reference Monitor perspective
  - Mediation
    - LSM
  - Tamperproof
    - Linux and TCB
  - Simple enough to verify
    - Correct code
    - Correct policy

Basis for OS Security

- Isolation
  - A protection domain defines a boundary of isolation
- Based on
  - Rings
  - Address spaces
  - Access control policy
- Do these work in modern OSes?

Virtual Machine Systems

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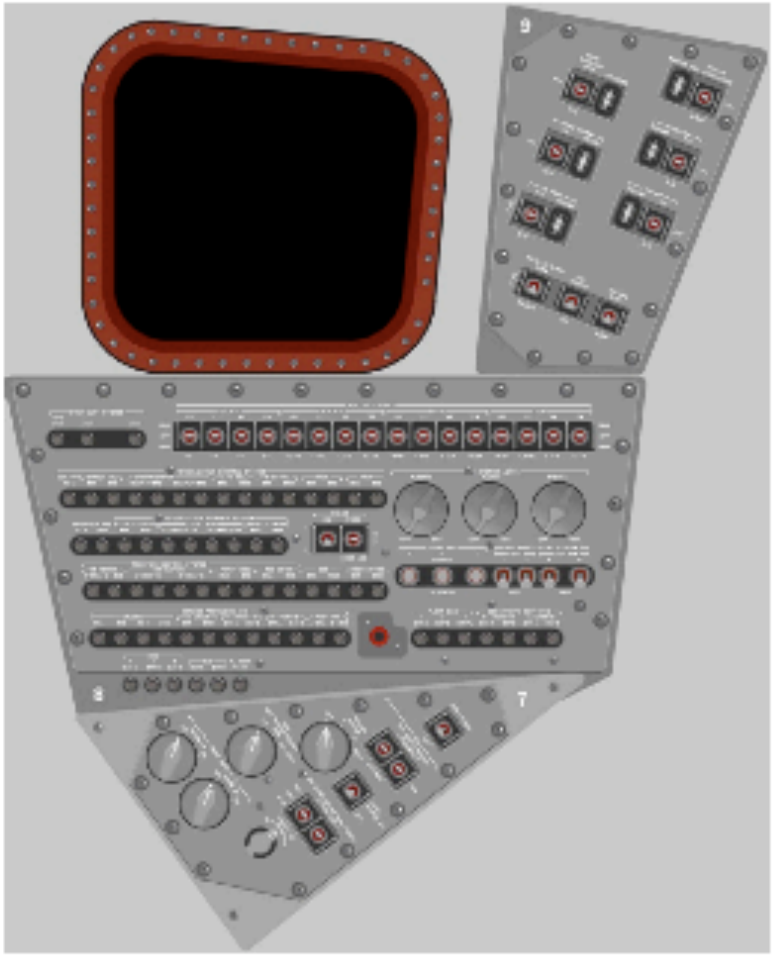
- Protection domain is extended to operating systems on one physical platform
  - Invented for resource utilization
- But, also provide a potential security benefit due to default
  - ISOLATION
- How does VM isolation differ from OS isolation?

Virtual Machines

- Instead of using system software to enable sharing, use system software to enable ***isolation***
- Virtualization
  - "a technique for hiding the physical characteristics of computing resources from the way in which others systems, applications, and end users interact with those resources"
- Virtual Machines
  - Single physical resource can appear as multiple logical resources



Virtual Machine Architectures

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- ***Full system simulation***
  - CPU can be simulated
- ***Paravirtualization (Xen)***
  - VM has a special API
  - Requires OS changes
- ***Native virtualization (VMWare)***
  - Simulate enough HW to run OS
  - OS is for same CPU
- ***Application virtualization (JVM)***
  - Application API

Virtual Machine Types

- ***Type I***
  - Lowest layer of software is VMM
  - E.g., Xen, VAX VMM, etc.
- ***Type II***
  - Runs on a host operating system
  - E.g., VMWare, JVM, etc.

- Q: What are the trust model issues with Type II compared to Type I?

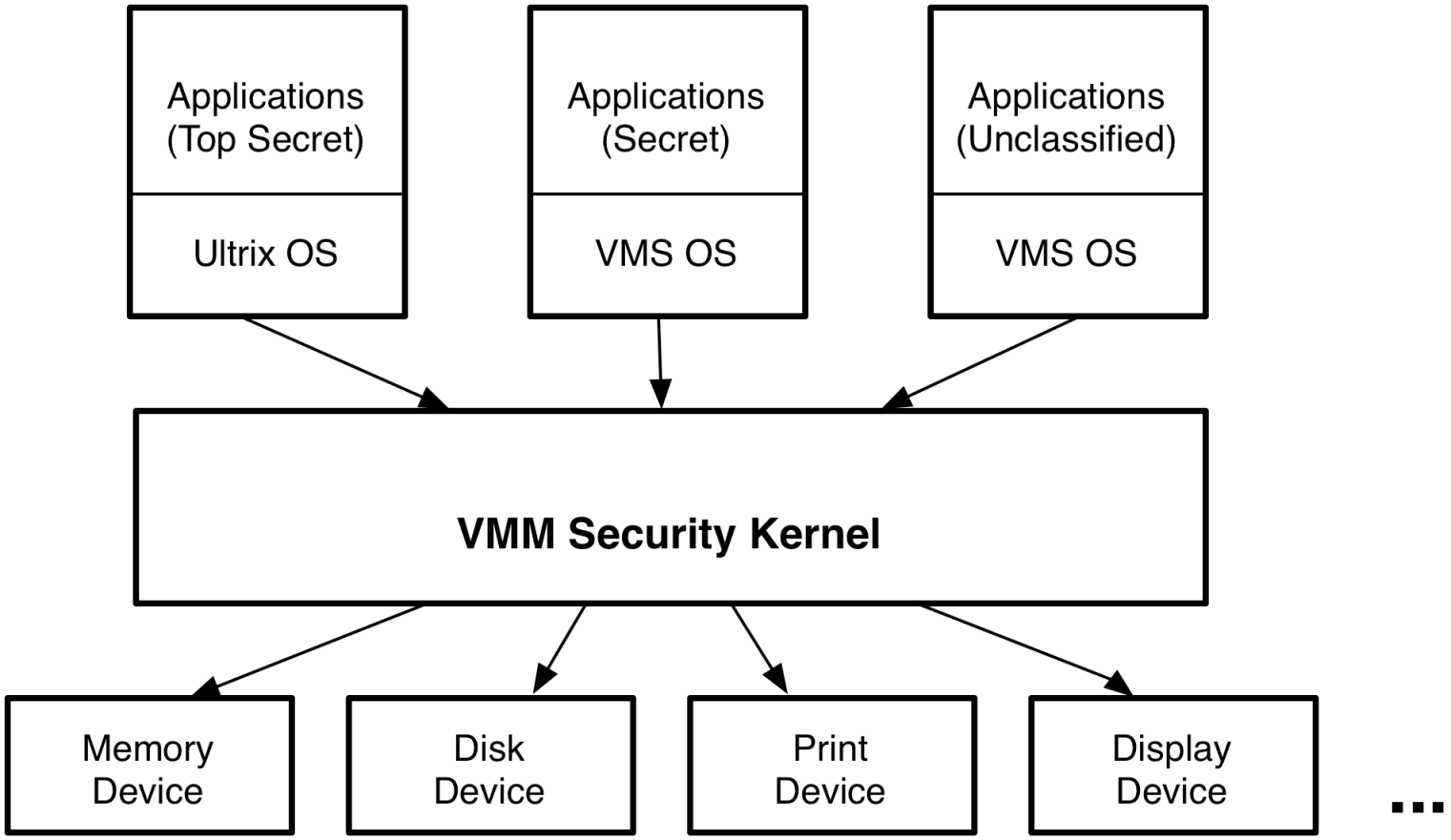
VM Systems and Ref Monitor

- How does a VM System improve ability to achieve reference monitor guarantees?
- Mediation
  - Mediation between VM interactions
- Tamperproof
  - Protection boundaries between OS
- Simple Enough to Verify
  - Code that needs to be correct?
  - Policy

VAX VMM

- A1-assured VMM system
- Carefully crafted VMM
- Mediation
  - VM interaction
- Tamperproof
  - Minimal TCB
- Simple enough to verify
  - Code assurance
  - Policy assurance: MLS policy, Biba policy, privileges

VAX VMM Design



VAX VMM Reference Monitor

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- Key design tasks
  - Virtualize processor
    - Make all sensitive instructions privileged
  - More rings
    - Need a new ring for the VMM
  - I/O emulation
  - Self-virtualizable
- What components constitute the VAX VMM reference monitor?

VAX VMM Policy

- MLS
  - Control secrecy
- Biba
  - Control integrity
- Privileges
  - Exceptional accesses
  - Audited
  - There are more of these than meets the eye!
- How is the protection state modified?

VAX VMM Evaluation

- **Mediation**: ensure all security-sensitive operations are mediated?
  - Virtualizing instructions, I/O emulation
  - VM-level operations? Privileges
- **Mediation**: mediate all resources?
  - VMM level
- **Mediation**: verify complete mediation?
  - A1-assured at VMM level

VAX VMM Evaluation

- **Tamperproof**: protect VMM?
  - Similar to Multics (no gatekeepers, but some kind of filters); authentication in VMM; protection system ops in VMM; fixed system?
- **Tamperproof**: protect TCB?
  - All trusted code at ring 0; trusted path from VMs for admin;
- **Verification**: verify code?
  - A1-assured at VMM level
- **Verification**: verify policy?
  - MLS and Biba express goals and policy; Privileges are ad hoc

VAX VMM Tasks

- Despite A1 assurance still several challenges in VAX VMM system
  - Device driver management; no network
  - Amount of assembler code
  - Covert channel countermeasures
  - Implications of 'privileges'
- Nonetheless, interesting mechanisms
  - Trusted path administration
  - Architecture of VMM
  - Virtualization for security

Modern VM Systems

- The development of a virtual machine monitor for x86 systems unleashed VMs on the masses
  - Why did this take so long?
- VMware, Xen, KVM, NetTop, …
  - Everyone is a virtual machine monitor now
- How do we implement a reference validation mechanism for these systems?
  - What granularity of control?

Isolation and Network

- VMware and NetTop assume that the VMM (and privileged VM) will isolate guest VMs
- Then, the problem is to control inter-VM communication
  - Only other communication is via the network
- VMware uses firewall
- NetTop is built on VMware where only VMs of the same label may communicate

VMs as Processes

- Type II VM systems can treat VMs as processes
- KVM uses SELinux to control access of VMs as if they are a process
  - VMs are processes to the host OS
  - VMs can access host OS resources (files)
- Uses SELinux to control VM access

Control of VMM Resources

- There are many virtual machine monitor resources that may be used to communicate
  - Memory, devices, IPC, …
- sHype adds reference monitor for some objects (IPC) and the privileged VM uses for networking
- Xen Security Modules (XSM) adds reference validation on the Xen hypervisor's distribution of these resources
  - Less trust in privileged VMs, so finer-grained policy results
- Minimizing TCB versus simplicity

Xen as a Reference Monitor?

- Reference Monitor
  - XSM in Xen
  - Scope includes dom0 Linux and user-level
- Mediation
  - XSM to control VMM operations
  - SELinux in dom0; use network to communicate
- Tamperproof
  - Xen has a much larger TCB, and more flexible
- Verification
  - Code – lots
  - Policy – SELinux style

Trusted VMs

- VMware and NetTop assume that the privileged VM (there is only one in these systems) prevents information flow (like a kernel)
- Thus, the only information flows between VMs are via networking
  - Privileged VM controls inter-VM communication via networking
- sHype controls IPC and networking at hypervisor level
  - Privileged VM uses hypervisor as policy store

Take Away

- VM Systems provide isolation
  - Between OSes/apps that may be untrusted
- VM Systems enable a small TCB
  - Type I VMMs
  - A1-Assured, like VAX VMM
- VM Systems can mediate inter-VM actions
  - Virtualized operations
  - Inter-VM operations