Recent Advances in VMM Support for Security

David Lie
University of Toronto

Talk Outline

1. What is a VMM?
   - VMM basics
   - What strengths does a VMM have?

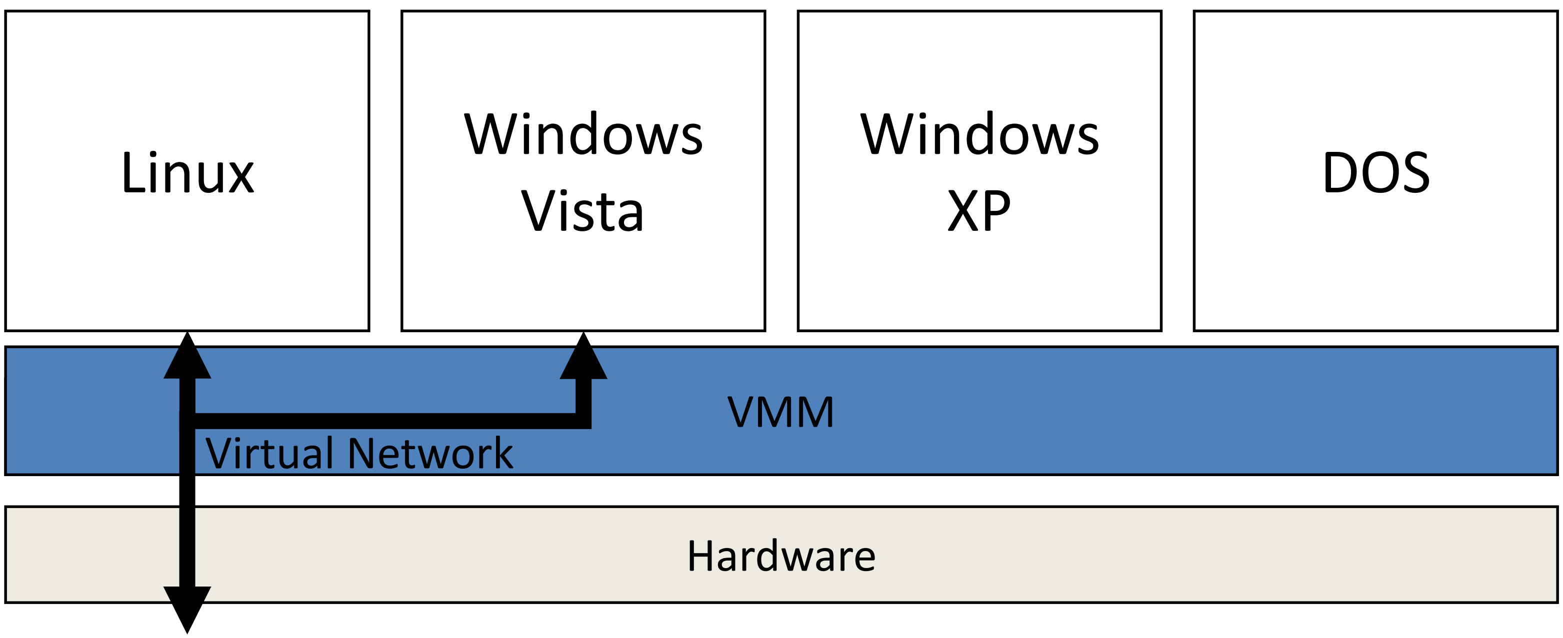
2. VMM Security Solutions Overview

3. Improved Monitoring and Detection

4. Secure Isolation of System Components

What is a VMM?

- A Virtual Machine Monitor (VMM) is a thin software layer between OS and hardware
  - Virtualizes the hardware interface so you can run multiple *Guest OSs*
  - Virtual Machines strongly isolated, can only communicate via network
  - VMM = hypervisor



Impact of VMMs

- VMMs are increasingly becoming common place:
  - Estimated billion dollar market, by 2010, it is estimated that 15% of servers will be running on a VMM
  - Many companies offering technologies (VMware, Microsoft, Virtual Iron, Parallels, XenSource/Citrix, IBM, HP, Sun, SGI…)
- VMMs virtualize the hardware/OS interface:
  - Decoupling the OS from the underlying hardware
  - This allows OS images to be cloned, moved, suspended and restarted
  - Allows multiple OS images to be run on a single hardware instance

Security Strengths of VMMs

- VMMs have two characteristics that are beneficial for security:
  1. **Simpler and Smaller**:
     - Operating systems have millions of lines of code (LOC). (Windows XP = ~ 40M LOC, Linux 2.6.18 kernel = ~5M LOC).
     - VMMs can be as small as several 100k lines (Xen 3.1 = ~200K LOC)
     - VMMs also provide less functionality: mimic hardware interface and provide decent performance.
     - Fewer bugs: flaws have been found in VMMs, but they are far fewer in number than in OS code.
  2. **Provide Strong Isolation between VMMs:**
     - VMMs isolate software in different VMMs without having to incur costs of extra hardware
     - VMMs provide ***stronger isolation guarantees between VMs than OSs do between processes***.

Talk Outline

1. What is a VMM?

2. VMM Security Solutions Overview
   – Why might VMMs be good for enhancing security?

3. Improved Monitoring and Detection
   – ISIS: VMM-based IDS
   – Patagonix: Detecting Root-kits and other hiddan malware

4. Secure Isolation of System Components

Can VMMs improve security?

- Much concern these days over the security of VMMs:
  - VMM companies like to claim their product is secure
  - While no software is bug-free, some evidence seems to support this:

	VMware ESX	Xen	Windows XP
CVE vulns since 2003	13	215	6

- On the other hand, VMMs can also increase security:
  1. Better monitoring:
     - VMMs have complete visibility, but good isolation from Guest OSs.
     - Good for intrusion detect, auditing, etc.…
  2. Component isolation:
     - Better protection for sensitive data and programs

- VMMs have the potential to take back the advantage from attackers

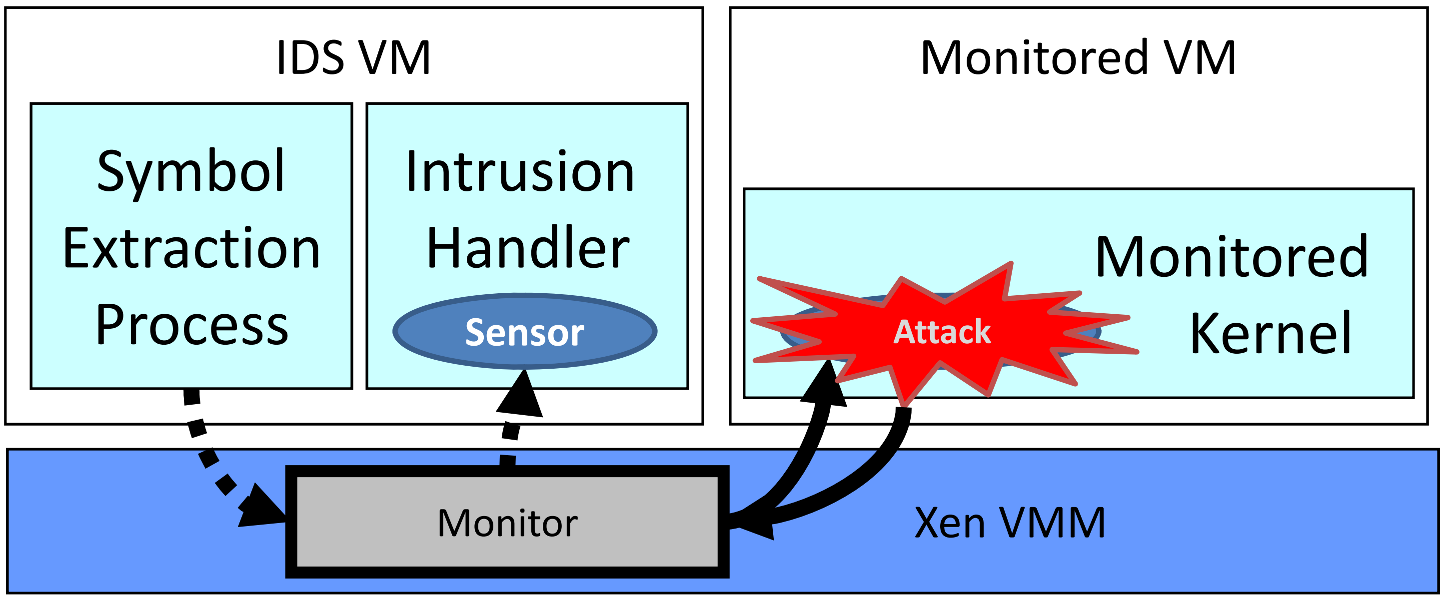
Who's going to win?

– Instead of all-powerful VMM-based malware, how about all-power VMM-based security solutions?
    - Lets use our unfair advantage!

Better Monitoring

- "One-way mirror":
  - The VMM is at a *higher privilege* level than the guest OS.
  - Thus the VMM may monitor the guest OS, but unaffected by malware in the guest OS.
  - Can monitor from a secure position.

ISIS: VMM-based IDS



- ISIS is a system that implements a monitor in the Xen VMM
  - Allows specific "triggers" to be inserted into the monitored kernel
  - When trigger is executed, it triggers a sensor that can inspects the state of the kernel
  - Inspecting the state of the VM kernel is called ***introspection***

Writing Sensors

Linux Source Code:

```
798 long sys_open(const char
   *filename, int flags, int mode)
799 {
...
806 tmp = getname(filename);
```

Sensor Code:

```
tmp_addr = get_value("tmp", vm_id, regs);
tmp = read_str(vm_id, tmp_addr);
flags = get_value("flags", vm_id, regs);
if (!strcmp(tmp, "/etc/passwd") &&
    ((flags & O_RDWR) || (flags &
   O_WRONLY))) {
  return COMPROMISED;
}
```

- Sensors are easy to write. Example:
  - Check if password file opened for writing
- Use symbol names from Linux source code in sensor:
  - Symbol names are resolved by monitor by examining kernel symbol table
  - Kernel symbol table is delivered securely from copy of kernel image in IDS VM

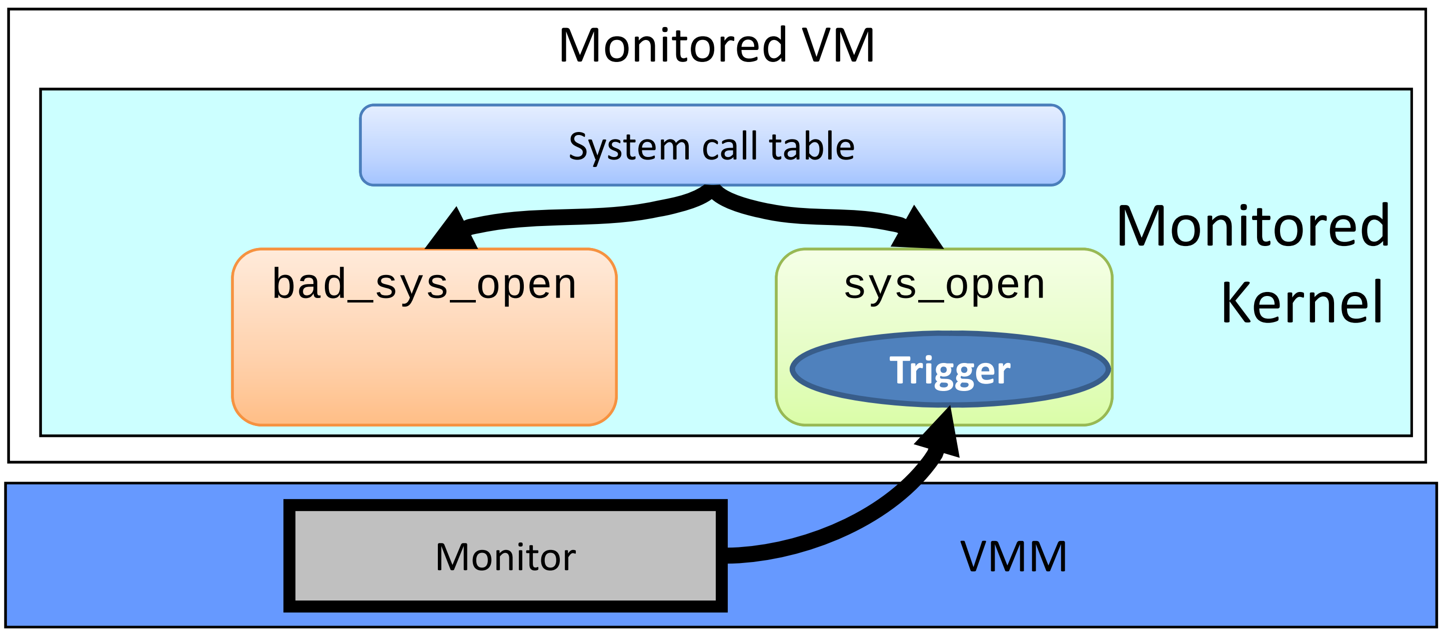
Other IDS systems

- Many other university research projects taking a similar approach:
  - Introvirt (U. of Michigan)
  - Livewire (Stanford University)

- Difficulties with VMM-based IDS:
  - Attacker cannot disable or tamper with the IDS
  - However, attacker may be able to evade or trick the IDS…

Evading Detection

- The in sensor-based VMM-IDS systems:
  - The attacker can trick the VMM into *misinterpreting* the state of the VMM
  - Example, attacker makes another copy of the sys_open function and redirects open calls to that instead. The trigger then is never executed.



Semantic Gap

- Attacker can evade detection by IDS because:
  - IDS doesn't know everything about the state of the OS, so it must make *assumptions* about the internal structure of the OS and the *semantics* of OS operation
    - Of course the attacker is not bound to these assumptions!

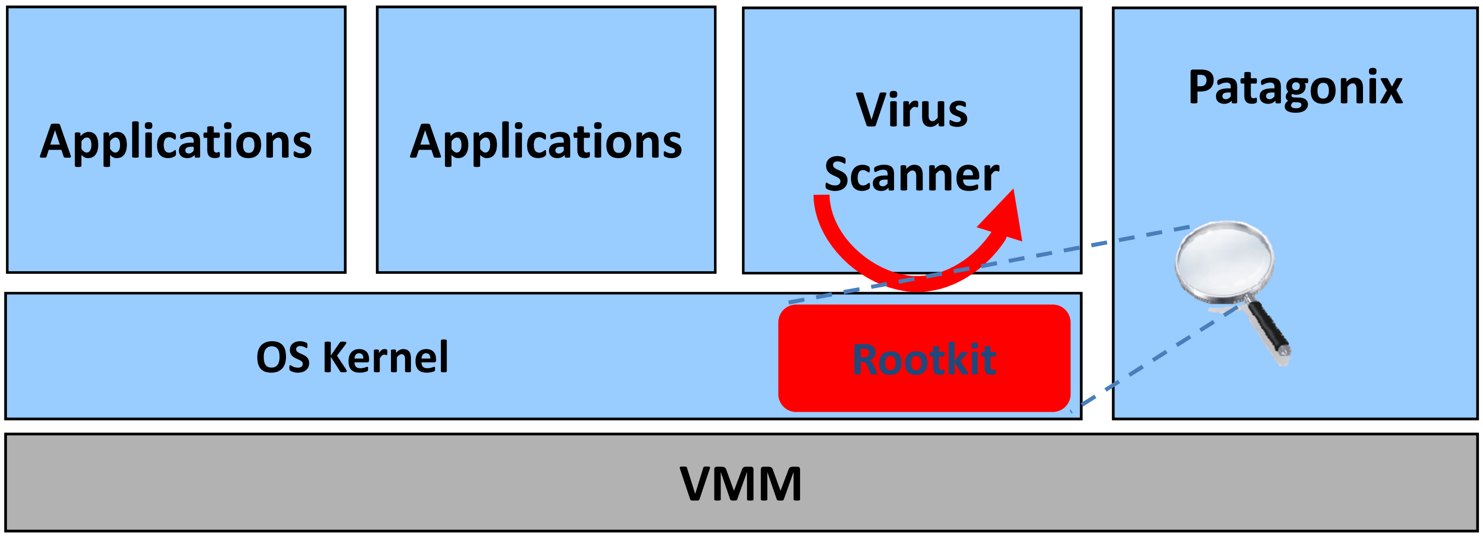
- VMM-IDS must make these assumption because there is a *semantic gap*:
  - This gap exists because the VMM operates *below* the abstractions offered by the OS. The VMM does not know how to *interpret* OS state.
  - In our example, the VMM does not know the true location of the `sys_open` handler. It has to assume the handler is where it would be in a pristine kernel.

Patagonix: Avoiding Assumptions

- We can avoid making assumptions about OS structure by only relying on what can be observed across the OS/hardware interface:

- Example: Patagonix
  - Attacker's frequently use root-kits to hide executing processes from the sys admin.
  - Patagonix can detect and identify all executing binaries on a system even if the OS is compromised (i.e. controlled by a rootkit)
  - Patagonix does not make assumptions about the OS kernel structure, instead Patagonix only relies on requests between the OS and the hardware that the VMM intercepts

Patagonix: Detecting Rootkits



- Patagonix uses the NX-bit in hardware to detect code execution:
  - Processor will invoke Patagonix whenever code is executed
  - Patagonix can then inspect the executing code and see if it can match it against either known legitimate code, or a known rootkit
  - Patagonix can also perform anomaly detection by comparing what the OS reports as running with the executing code pages that Patagonix observes

Patagonix

- Problem is that it is difficult to identify code sometimes:
  - Windows has relocations which mean that the code in memory depends on run-time state of the OS
- Solution is that Patagonix uses an OS agent to provide Patagonix with “hints” about the OS state:
  - These hints are then verified against the running code.
  - Example: the agent provides Patagonix with information about the locations of DLLs
  - Patagonix can then verify that these hints are truthful, any deviation indicates that the OS is not functioning properly (possible compromise)
- Enforcement of white lists:
  - VMM can also enforce what code can execute in the kernel and on the system, even if OS is compromised

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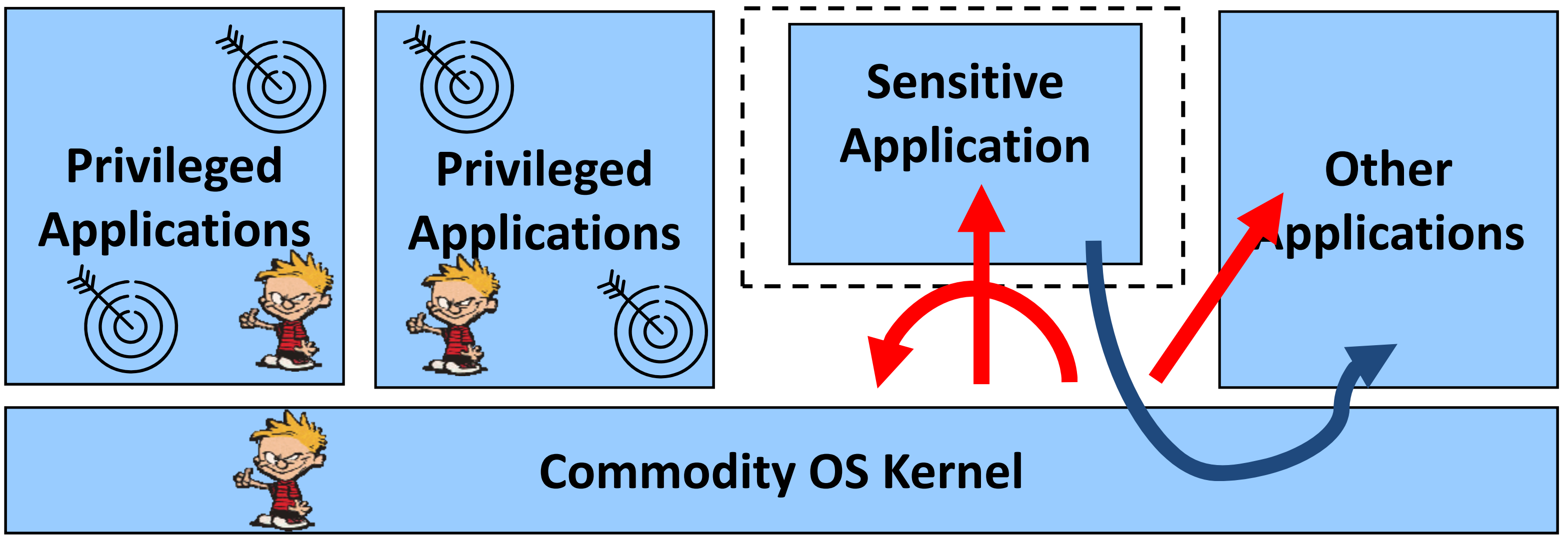
   - Terra: VMM-level isolation
   - Proxos: Using VMMs to control application isolation

Poor isolation

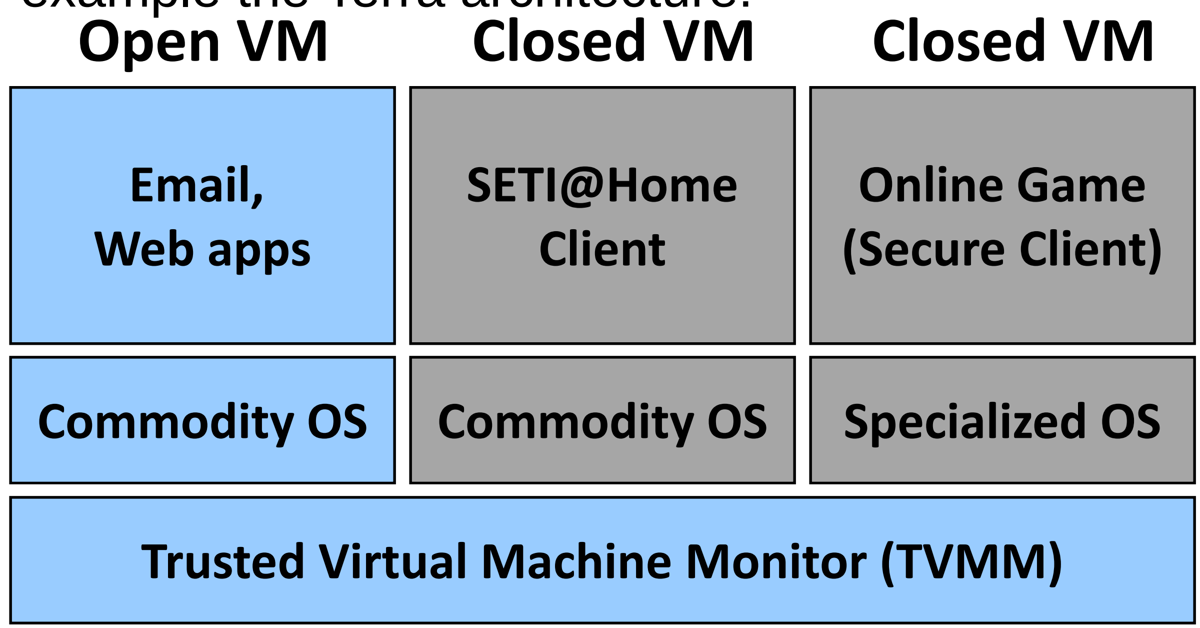
- In current OSs, a sensitive application depends on the OS and every other privileged application on the commodity OS



- Ideally, we would like to protect sensitive applications from unrelated applications on the same OS

Using Isolation

- Another use of VMMs is to isolate insecure applications from secure ones. For example the Terra architecture:



- Secure applications run along side legacy applications:
  - Secure applications are attested, restrictions are placed upon them to maintain their security
  - VMM strongly isolates the VMMs from each other. Vulnerabilities in the Open VM cannot affect the Closed VMs

Isolation and Communication

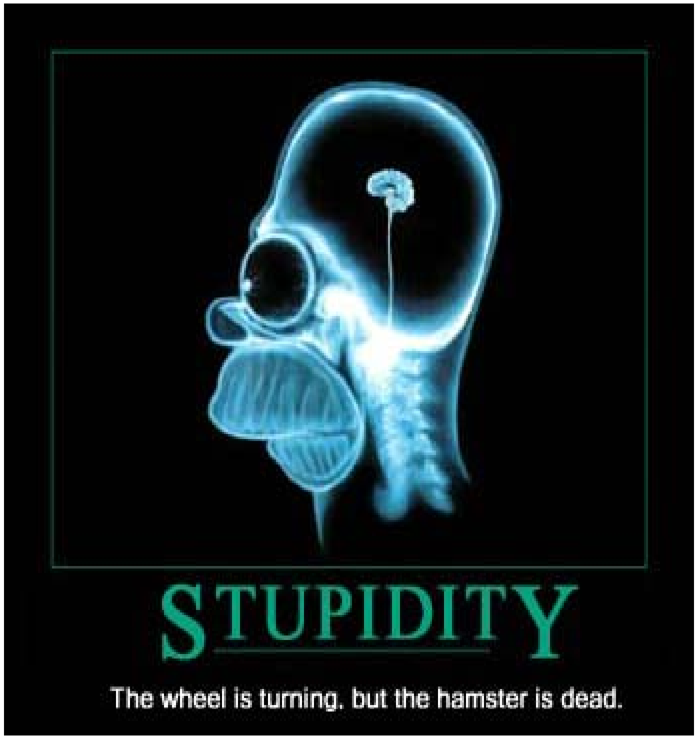
- This works if the various applications are independent of each other.
  - However, you may have interaction between applications in the same OS that have different security needs:
  - Examples:

1. A sensitive program like the remote terminal server (i.e. SSH, RD) invokes a shell and other applications:
   - SSH server has access to keys, password files
   - A shell can be used to do arbitrarily risky things
2. Web browser needs to invoke a helper application to view a file:
   - The web browser has access to sensitive information like cookies, passwords and browsing history
   - The application may not be secure enough to accept remote content.

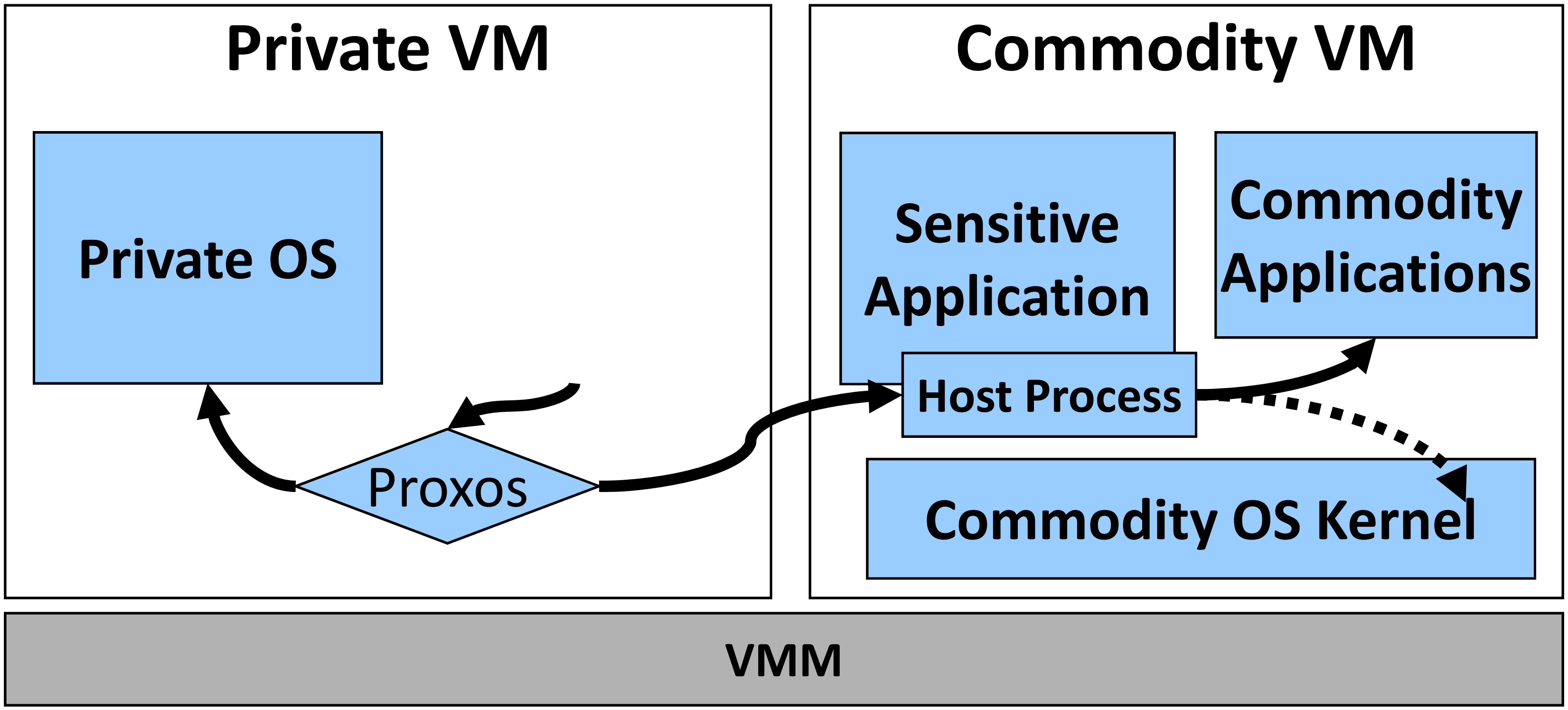
Isolation and Communication

3. A web server creates and SSL connection:
    - The web server needs access to SSL certificates to authenticate itself
    - Afterwards, it may invoke vulnerable scripts to generate dynamic content

- Problem:
  – You can't take these services and put them in different VMs because the applications need to talk to each other on the same OS
  – For example, putting your remote terminal service on a different VM than your applications makes your remote terminal service useless!!



Solution: Proxos



Proxy **O**perating **S**ystem (Proxos) routes system calls based on their sensitivity to attack

[Ta-Min et al. OSDI 2006]

Specifying System Call Routing Rules

- Proxos routes system calls based on the name of the resource, and the type of resource being accessed:

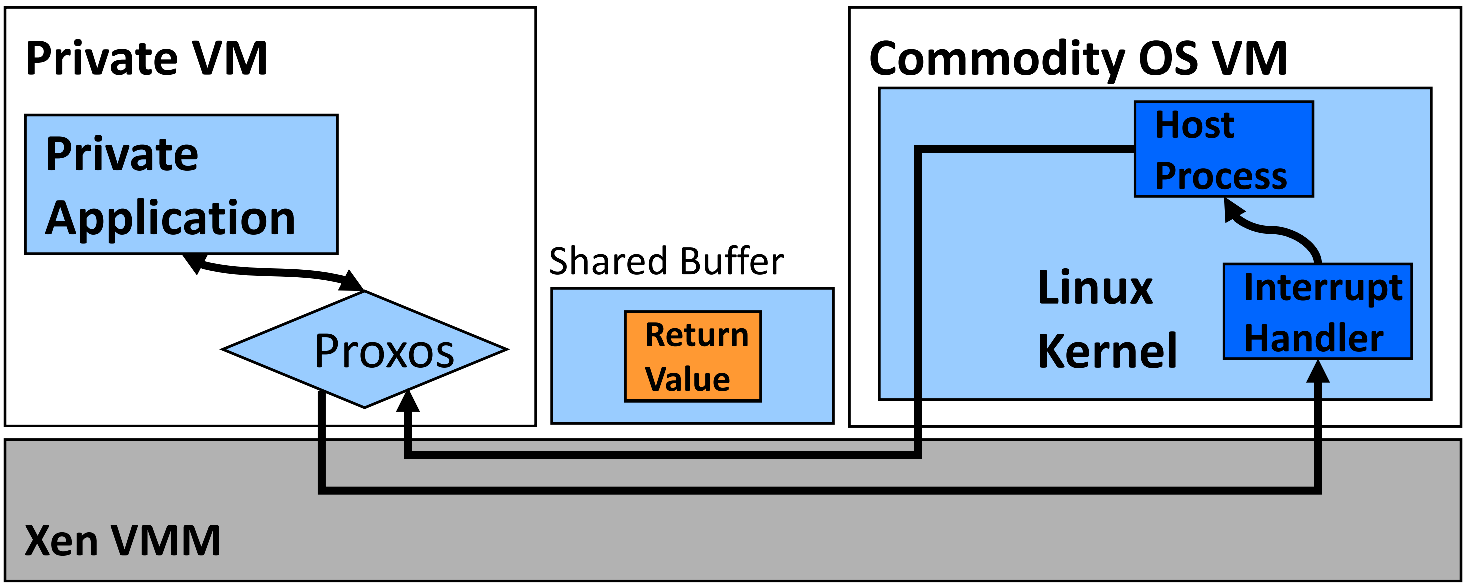
```
DISK:("/etc/shadow", priv_fs)
…
priv_fs = {
   .open = priv_open,
   .close = priv_close,
   .read = priv_read,
   .write = priv_write
}
```

Example Routing Rules

- Rules link a method table (`priv_fs`) with name of resource (`/etc/shadow`)
- Method table has pointers to system call handlers in the private OS
- Resources not named in the rules are routed to commodity OS by default

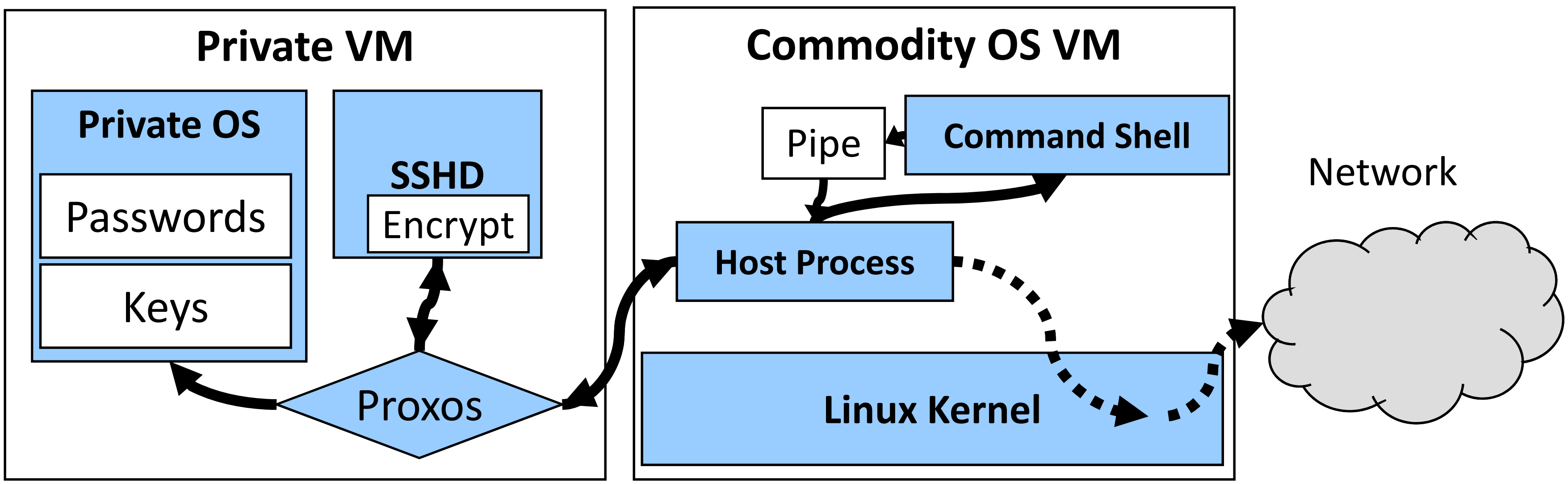
Interface is partitioned into accesses to sensitive and non-sensitive resources

Routing System Calls



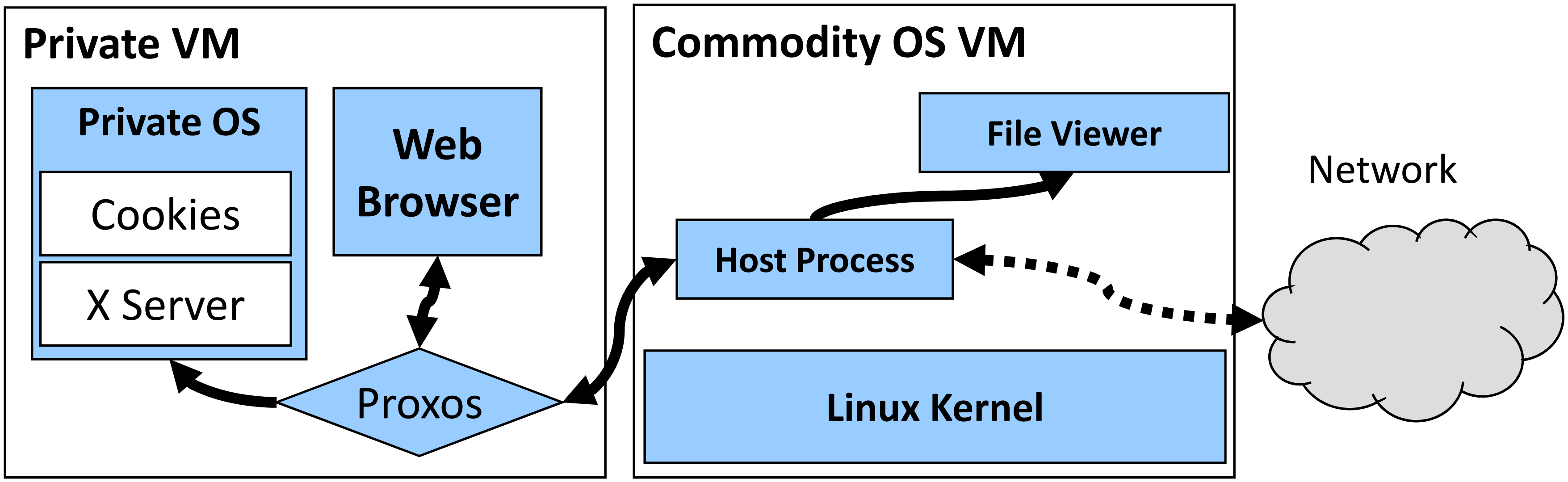
- System calls routed to commodity OS using RPC's:
  - During startup, a shared memory region between the commodity OS and Proxos is created

Application: SSH



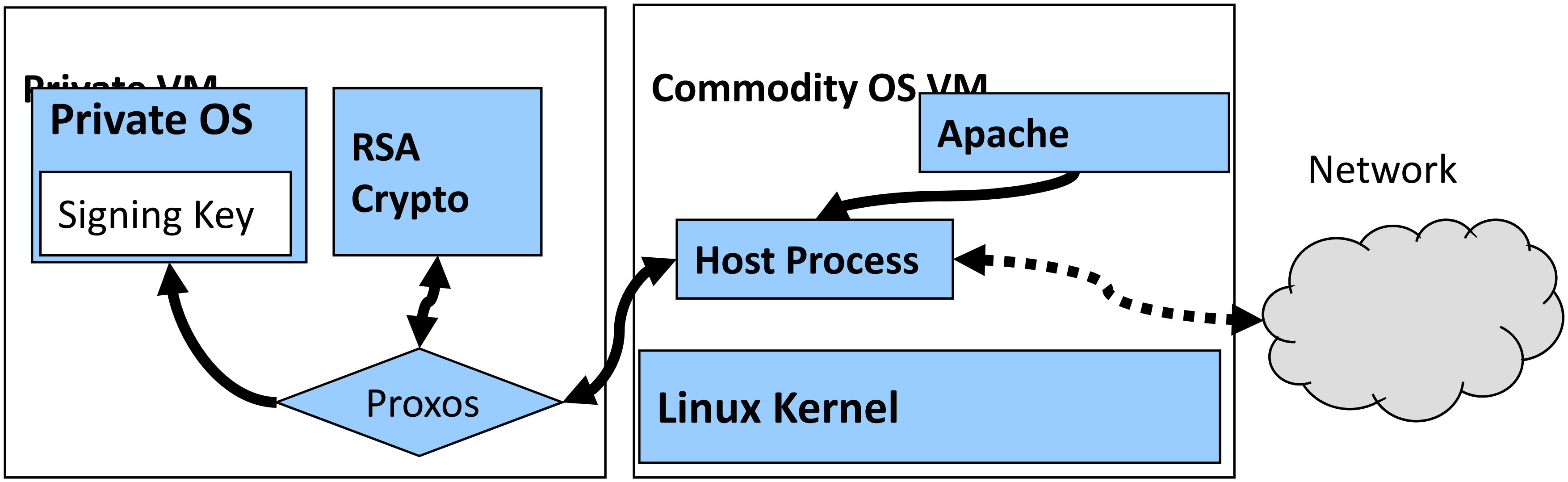
- Proxos allows applications to have access to commodity OS, but isolated sensitive resources at the same time. Ex SSHD Server:
  - Sensitive data such as user passwords and the host key stored in private OS
  - All network packets decrypted in private app before sent to command shell. Command shell is in Commodity OS.

Application: Graphical Web Browser



- Graphical Web Browser:
  - Sensitive user data and user interface is isolated from commodity OS
  - Dillo can save downloaded files and invoke file viewers on the commodity OS

Application: Apache & SSL



- Server Application: Apache & SSL extension
  - Private signing key isolated from commodity OS
  - To maintain performance, minimize private VM startup/shutdown by making host process persistent

Patch Conflicts

- Proxos can also be used to resolve conflicting applications:
  - We all know that applying patches can result in configuration and application conflicts
  - Proxos can separate conflicting applications so that:
  1. Applications the patch does not conflict with can get patched
  2. Applications that conflict with the patch are isolated from the patch.

Conclusions

- VMMs can be used for security:
  - Natural advantages:
  1. Higher privilege leve
  2. Small, and simple = Fewer vulnerabilities
  3. Stronger isolation between protection domains

- Many potential uses:
  - VMM-based IDS (ISIS)
  - VMM monitoring for hidden malware (Patagonix)
  - VMM enforcement of white-lists (Patagonix)
  - VMM-based protection of sensitive applications and Data (Proxos)
  - Transparent patch and configuration conflict resolution (Proxos)