Lecture 15
October 30, 2023

Type Checking

- Lock is type, key is operation
  - Example: UNIX system call *write* won't work on directory object but does work on file
  - Example: split I&D space of PDP-11
  - Example: countering buffer overflow attacks on the stack by putting stack on non-executable pages/segments
    - Then code uploaded to buffer won't execute
    - Does not stop other forms of this attack, though …

More Examples

- LOCK system:
  - Compiler produces “data”
  - Trusted process must change this type to “executable” before program can be executed
- Sidewinder firewall
  - Subjects assigned domain, objects assigned type
    - Example: ingress packets get one type, egress packets another
  - All actions controlled by type, so ingress packets cannot masquerade as egress packets (and vice versa)

Sharing Secrets

- Implements separation of privilege
- Use (t, n)-*threshold scheme*
  - Data divided into n parts
  - Any t parts sufficient to derive original data
- Or-access and and-access can do this
  - Increases the number of representations of data rapidly as n, t grow
  - Cryptographic approaches more common

Shamir's Scheme

- Goal: use (t, n)-threshold scheme to share cryptographic key encoding data
  - Based on Lagrange polynomials
  - Idea: take polynomial $p(x)$ of degree t–1, set constant term ($p(0)$) to key
  - Compute value of p at n points, *excluding* x = 0
  - By algebra, need values of p at any t distinct points to derive polynomial, and hence constant term (key)

Reference Monitor

- *Reference monitor* is access control concept of an abstract machine that mediates all accesses to objects by subjects
- *Reference validation mechanism* (RVM) is an implementation of the reference monitor concept.
  - Tamperproof
  - Complete (always invoked and can never be bypassed)
  - Simple (small enough to be subject to analysis and testing, the completeness of which can be assured)
    - Last engenders trust by providing evidence of correctness
- Note: RVM is almost always called a reference monitor too

Examples (Or, What Should Be Examples)

- *Security kernel* combines hardware and software to implement reference monitor
- *Trusted computing base* (*TCB*) consists of all protection mechanisms within a system responsible for enforcing security policy
  - Includes hardware and software
  - Generalizes notion of security kernel

Policy and Reference Monitor

- Reference monitor implements a given policy
  - It has a tamperproof authorization database
  - Also maintains an audit trail (record of security-related events) for review

Example Problem

- Server balances bank accounts for clients
- Server security issues:
  - Record correctly who used it
  - Send *only* balancing info to client
- Client security issues:
  - Log use correctly
  - Do not save or retransmit data client sends

Generalization

- Client sends request, data to server
- Server performs some function on data
- Server returns result to client
- Access controls:
  - Server must ensure the resources it accesses on behalf of client include *only* resources client is authorized to access
  - Server must ensure it does not reveal client’s data to any entity not authorized to see the client’s data

Confinement Problem

- Problem of preventing a server from leaking information that the user of the service considers confidential

Total Isolation

- Process cannot communicate with any other process
- Process cannot be observed

Impossible for this process to leak information

  - Not practical as process uses observable resources such as CPU, secondary storage, networks, etc.

Example

- Processes *p*, *q* not allowed to communicate
  - But they share a file system
- Communications protocol:
  - *p* sends a bit by creating a file called *0* or *1*, then a second file called *send*
    - *p* waits until *send* is deleted before repeating to send another bit
  - *q* waits until file *send* exists, then looks for file *0* or *1*; whichever exists is the bit
    - *q* then deletes *0*, *1*, and *send* and waits until *send* is recreated before repeating to read another bit

Covert Channel

- A path of communication not designed to be used for communication
- In example, file system is a (storage) covert channel

Rule of Transitive Confinement

- If *p* is confined to prevent leaking, and it invokes *q*, then *q* must be similarly confined to prevent leaking
- Rule: if a confined process invokes a second process, the second process must be as confined as the first

Isolation

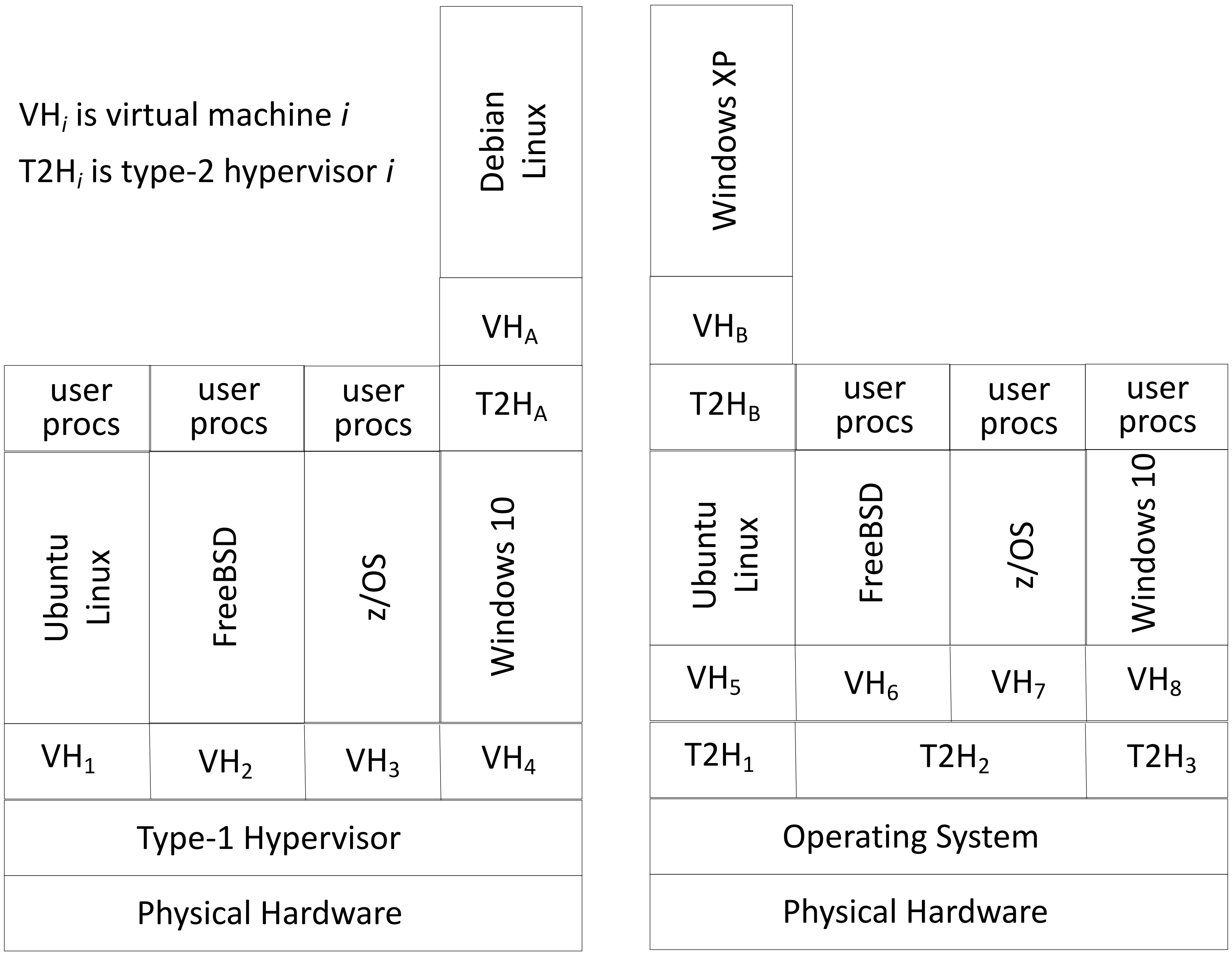
- Constrain process execution in such a way it can only interact with other entities in a manner preserving isolation
  - Hardware isolation
  - Virtual machines
  - Library operating systems
  - Sandboxes
- Modify program or process so that its actions will preserve isolation
  - Program rewriting
  - Compiling
  - Loading

Hardware Isolation

- Ensure the hardware is disconnected from any other system
  - This includes networking, including wireless
- Example: SCADA systems
  - 1st generation: serial protocols, not connected to other systems or networks; no security defenses needed, focus being on malfunctions
  - 2nd generation: serial networks connected to computers not connected to Internet
  - 3rd generation: TCP/IP protocol running on networks connected to Internet; need security defenses for attackers coming in over Internet
- Example: electronic voting systems
  - Physical isolation protects systems from attackers changing votes remotely
  - Required in many U.S. states, such as California: never connect them to any network

Virtual Machine

- Program that simulates hardware of a machine
  - Machine may be an existing, physical one or an abstract one
  - Uses special operating system, called *virtual machine monitor* (*VMM*) or *hypervisor*, to provide environment simulating target machine
- Types of virtual machines
  - Type 1 hypervisor: runs directly on hardware
  - Type 2 hypervisor: runs on another operating system
- Existing OSes do not need to be modified
  - Run under VMM, which enforces security policy
  - Effectively, VMM is a security kernel



VH$_i$ is virtual machine *i*
T2H$_i$ is type-2 hypervisor *i*
Debian Linux
Windows XP
VH$_A$
VH$_B$
user procs
user procs
user procs
T2H$_A$
T2H$_B$
user procs
user procs
user procs
Ubuntu Linux
FreeBSD
z/OS
Windows 10
Ubuntu Linux
FreeBSD
z/OS
Windows 10
VH$_5$
VH$_6$
VH$_7$
VH$_8$
VH$_1$
VH$_2$
VH$_3$
VH$_4$
T2H$_1$
T2H$_2$
T2H$_3$
Type-1 Hypervisor
Operating System
Physical Hardware
Physical Hardware

VMM as Security Kernel

- VMM deals with subjects (the VMs)
  - Knows nothing about the processes within the VM
- VMM applies security checks to subjects
  - By transitivity, these controls apply to processes on VMs
- Thus, satisfies rule of transitive confinement

Example: Xen Hypervisor

- Xen 3.0 hypervisor on Intel virtualization technology
- Two modes, VMX root and non-root operation
- Hardware-based VMs (HVMs) are fully virtualized domains, support unmodified guest operating systems and run in non-root operation mode
    - Xen hypervisor runs in VMX root mode
- 8 levels of privilege
    - 4 in VMX root operation mode
    - 4 in VMX root operation mode
    - No need to virtualize one of the privilege levels!

Xen and Privileged Instructions

- Guest operating system executes privileged instruction
  - But this can only be done as a VMX root operation
- Control transfers to Xen hypervisor (called *VM exit*)
- Hypervisor determines whether to execute instruction
- After, it updates HVM appropriately and returns control to guest operating system (called *VM entry*)

Problem

- Physical resources shared
  - System CPU, disks, etc.
- May share logical resources
  - Depends on how system is implemented
- Allows covert channels

Sandboxes

- An environment in which actions are restricted in accordance with security policy
  - Limit execution environment as needed
    - Program not modified
    - Libraries, kernel modified to restrict actions
  - Modify program to check, restrict actions
    - Like dynamic debuggers, profilers

Example: Capsicum

- Framework developed to sandbox an application
- *Capability* provides fine-grained rights for accessing, manipulating underlying file
- To enter sandbox *(capability mode*), process issues *cap_enter*
- Given file descriptor, create capability with *cap_new*
  - Mask of rights indicates what rights are to be set; if capability exists, mask must be subset of rights in that capability
- At user level, library provides interface to start sandboxed process and delegate rights to it
  - All nondelegated file descriptors closed
  - Address space flushed
  - Socket returned to creator to enable it to communicate with new process

Example: Capsicum (con't)

- Global namespaces not available
  - So system calls that depend on that (like *open*(2)) don't work
    - Need to use a modified *open* that takes file descriptor for containing directory
  - Other system calls modified appropriately
    - System calls creating memory objects can create anonymous ones, not named ones (as those names are in global namespace)
- Subprocesses cannot escalate privileges
  - But a privileged process can enter capability mode
- All restrictions applied in kernel, not at system call interface

Program Confinement and TCB

- Confinement mechanisms part of trusted computing bases
  - On failure, less protection than security officers, users believe
  - “False sense of security”
- Must ensure confinement mechanism correctly implements desired security policy

Covert Channels

- Shared resources as communication paths
- *Covert storage channel* uses attribute of shared resource
  - Disk space, message size, etc.
- *Covert timing channel* uses temporal or ordering relationship among accesses to shared resource
  - Regulating CPU usage, order of reads on disk

Example Storage Channel

- Processes *p*, *q* not allowed to communicate
  - But they share a file system!
- Communications protocol:
  - *p* sends a bit by creating a file called *0* or *1*, then a second file called *send*
    - *p* waits until *send* is deleted before repeating to send another bit
  - *q* waits until file *send* exists, then looks for file *0* or *1*; whichever exists is the bit
    - *q* then deletes *0*, *1*, and *send* and waits until *send* is recreated before repeating to read another bit

Example Timing Channel

- System has two VMs
  - Sending machine *S*, receiving machine *R*
- To send:
  - For 0, *S* immediately relinquishes CPU
    - For example, run a process that instantly blocks
  - For 1, *S* uses full quantum
    - For example, run a CPU-intensive process
- *R* measures how quickly it gets CPU
  - Uses real-time clock to measure intervals between access to shared resource (CPU)

Example Covert Channel

- Uses ordering of events; does not use clock
- Two VMs sharing disk cylinders 100 to 200
  - SCAN algorithm schedules disk accesses
  - One VM is *High* (*H*), other is *Low* (*L*)
- Idea: *L* will issue requests for blocks on cylinders 139 and 161 to be read
  - If read as 139, then 161, it’s a 1 bit
  - If read as 161, then 139, it’s a 0 bit

How It Works

- *L* issues read for data on cylinder 150
  - Relinquishes CPU when done; arm now at 150
- *H* runs, issues read for data on cylinder 140
  - Relinquishes CPU when done; arm now at 140
- *L* runs, issues read for data on cylinders 139 and 161
  - Due to SCAN, reads 139 first, then 161
  - This corresponds to a 1
- To send a 0, *H* would have issued read for data on cylinder 160