

COMP5900 OS SECURITY

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1 Introduction

- trusted computing base
 - applications that are essential to functioning of the OS
 - e.g., passwd
 - these would probably be okay to talk about for OS vuln. but kernelspace code is preferred

1.1 Bloom's Taxonomy

- course targets top 3 sections (for evaluation)
 - create
 - evaluate
 - analyze
 - (some understanding)

1.2 What is an OS?

- kernel
- essential applications (systemd, passwd, etc.)
- what does it do?
 - scheduling
 - network stack
 - file systems
 - block I/O on disk
 - hardware interrupts (e.g. I/O)
 - at least basic access control (memory protection, etc.)
 - often runs in supervisor mode (apparently not necessarily? But I don't agree with this...)

1.3 What is the Most Secure OS?

- probably something task-specific

1.4 Group Activity: Come up with an OS-less implementation for a word processor

- interrupt handling for keyboard
 - need at least some basic scheduler that can pause and resume main execution
- interface with monitor for graphical display
- block I/O driver for disk
 - filesystem to organize data
- hmm... this is starting to feel like we just implemented our own task-specific OS
 - that's the main takeaway here!

2 Secure OS

2.1 Van Oorschot Chapter 5.0 - 5.2

2.1.1 Intro

- early security had same challenges we face today
 - protecting programs from others
 - restricting access to resources
 - “protection” means mostly memory access control
- memory is important
 - holds data
 - holds programs
 - I/O devices through memory address and files
 - files -> both main memory and secondary storage
- early protection
 - virtual addresses
 - access control lists
 - limited process address space
 - these fundamentals are still used today
- Multics
 - security very influential in its early design
 - original UNIX was heavily based on Multics

2.1.2 Memory protection, supervisor mode, and accountability

- batch processing
 - prepare jobs ahead of time and submit them together as a batch job
- time-sharing systems
 - allowed shared use of a single computer
 - (preferable to batch jobs from a usability standpoint)
 - same way single-user computers work today with one user running many programs
- resource conflicts
 - processes running simultaneously can try to access the same resources

- ▶ intentionally or otherwise
- ▶ if a program could access full memory of the machine, errors could corrupt OS data or code
- supervisor
 - ▶ runs with higher permissions in the protection CPU (ring 0, 1, 2)
 - ▶ no other program can alter the privileged bit
 - ▶ a special machine instruction immediately transfers control to the supervisor
- privileged bit
 - ▶ process is running in supervisor mode
- descriptor register
 - ▶ holds a memory descriptor that describes base and upper bound
 - ▶ lowest addressable memory by a process and a number of words from that point that are addressable
- limitations of memory-range based protection
 - ▶ all-or-nothing mode of control
 - ▶ either you have full access or no access
 - ▶ allows full isolation, but not fine-grained sharing
- segment addressing with access permissions
 - ▶ segment = collection of words representing a logical unit of information
 - ▶ descriptor segment per process maintained by OS
 - holds segment descriptors that define addressable memory and permissions
 - ▶ descriptor base register points to memory descriptor of active process
- permissions on virtual segments
 - ▶ R non-supervisor can read
 - ▶ W can be written to
 - ▶ X can be executed
 - ▶ M run in supervisor mode (if X)
 - ▶ F all access attempts trap to supervisor
 - ▶ now the same physical segment can be given different access for different processes
- accountability, UIDs, and principals
 - ▶ UID (maps users to a unique identifier)
 - ▶ “principal” -> abstracts the entity responsible for code execution from the actual user or program actions
 - ▶ UID is the primary basis for granting permissions
- roles
 - ▶ assign distinct UIDs to distinct privileges
 - ▶ should follow principle of least privilege

2.1.3 Reference monitor, access matrix, security kernel

- reference monitor
 - ▶ concept that “all references by any program to any other program, data, or device are validated”
 - ▶ conceptualized as one reference monitor, but in practice, would be a lot of reference monitors working together

- access matrix
 - 2D matrix of subjects, objects
 - taking a row (subject) gives a capabilities list
 - taking a column (object) gives an access control list
 - each intersection in this matrix defines a set of permissions
- security kernel
 - reference validation
 - audit trails via audit logs (user X did Y at time Z)
 - these might not necessarily need to be tamper-proof, depends on needs
 - needs to be:
 - tamper-proof
 - always invoked (not circumventable)
 - verifiable (needs to be minimal / small enough to make this possible)
- protection mechanisms
 - ticket-oriented (capabilities)
 - access token allows entry to an event, as long as ticket is authentic
 - id-based
 - authorization lists based on ID

2.2 Jaeger Chapter 1

- general-purpose -> complex
- task-specific -> not so complex
- general purpose OS are hard to secure because of their complexity
- ensuring security depends on securing
 - resource mechanisms
 - scheduling mechanisms

2.2.1 Secure OS

- enforce security goals despite the threats faced by the system
 - implement security mechanisms to do this
- secure OS possible?
 - probably not
 - a modern OS by definition can probably never be 100% secure
 - security as a negative goal
- understanding secure OS requires understanding
 - security goals
 - trust model
 - threat model

2.2.2 Security Goals

- define operations that can be executed by a system while remaining in a secure state
 - i.e. prevent unauthorized access

- high level of abstraction
- define a requirement that the system's design can then satisfy
- we want to maintain: secrecy, integrity, availability
 - secrecy = limit read access for objects by subjects
 - integrity = limit the write access for objects by subjects
 - availability = limit the resources that a subject may consume (i.e. no DoS)
- subjects
 - users, processes, etc.
- objects
 - resources of the system that subjects may or may not access in various ways
 - e.g. files, sockets, memory
- security goals can be
 - defined by function (e.g. principle of least privilege)
 - defined by requirements (e.g. simple-security property)

2.2.3 Trust Model

- trust model
 - defines the set of software and data we trust to help us enforce our security goals
 - we depend on this model to correctly enforce our security goals
- trusted computing base
 - trust model for an operating system
- TCB should **ideally** be minimal to the extent that we require
 - in practice, this is a wide variety of software
- TCB includes
 - all OS code (assuming no boundaries as in a monolithic kernel)
 - other software that defines our security goals
 - other software that enforces our security goals
 - software that bootstraps the above
 - software like Xorg that performs actions on behalf of all other processes
- a secure OS developer needs to prove their system has a viable trust model
 - (1) TCB must mediate all sensitive operations
 - (2) verification of the TCB software and data
 - (3) verification of TCB tamper-resistance
- identifying and verifying TCB is a complex and non-trivial task

2.2.4 Threat Model

- defines a set of operations that an attacker may use to compromise the system
- assume a powerful attacker who
 - can inject operations from the network
 - may be in control of non-TCB applications
- if the attacker finds a vulnerability that violates secrecy or integrity goals, the system is compromised
- highlights a critical weakness in commercial OSes

- ▶ assume that all software running on behalf of a subject is trusted by the subject
- our task? protect the TCB from threats
 - ▶ easier said than done
 - ▶ user interacts with a variety of processes
 - ▶ users are untrusted
 - ▶ TCB interacts with a variety of untrusted processes

2.3 Jaeger Chapter 2

2.3.1 Protection System

- protection system consists of
 - ▶ protection state
 - ▶ protection state operations
- protection state
 - ▶ what operations can subjects perform on objects
- protection state operations
 - ▶ what operations can modify the protections state
 - ▶ (this is distinct from the operations that the protection state describes)

Lampson's Access Matrix.

- protection state
 - ▶ rows = subjects
 - ▶ cols = objects
 - ▶ select row -> capability list
 - ▶ select col -> access control list
 - ▶ each entry specified privileges subject -> object
- protection state operations
 - ▶ determine which processes can modify cells

Mandatory Protection Systems.

- we don't want untrusted processes tampering with the protection system's state by adding subjects, objects, operations
- discretionary access control system (DAC)
 - ▶ an access control system that permits untrusted modification
 - ▶ *safety problem*
 - how do we ensure that all possible states deriving from initial state will not provide unauthorized access
- mandatory protection systems / mandatory access control (MAC)
 - ▶ protection system can only be modified by trusted administrators via trusted software
 - ▶ mandatory protection state -> subjects and objects are represented by labels
 - state describes operations subject labels -> object labels
 - ▶ labeling state

- state for mapping subjects and objects to labels
- transition state
 - describes legal ways subjects and objects may be relabeled
- set of labels being fixed in MAC doesn't mean that set of subjects/objects are fixed
 - we can dynamically assign labels to created subjects and objects (labeling state)
 - we can dynamically relabel subjects and objects/resources (transition state)

2.3.2 Reference Monitor

- classical access enforcement mechanism
- takes request as input
- outputs binary response -> is the request authorized or not?
- main components?
 - interface
 - authorization module
 - policy store

Reference Monitor Interface.

- defines queries to the reference monitor
- provides an interface for checking security-sensitive operations
 - (security-sensitive means it may violate security policy)
- e.g., consider the **open** system call in UNIX (reference monitor decides what is allowed / disallowed)

Authorization Module.

- takes interface inputs, converts to a query for the policy store
- this query is used to check authorization
- authorization module needs to map PID to subject label and object references to an object label
- needs to determine the actual operation(s) to authorize

Policy Store.

- database that holds protection state, labeling state, transition state
- answers queries from the authorization module
- has specialized queries for each of the three states

2.3.3 Secure Operating System Definition

- a secure operating system's access enforcement satisfies the reference monitor model
- the reference monitor model defines the necessary and sufficient properties of a system that securely enforces MAC
- three guarantees:
 - (1) complete mediation -> ensure access enforcement for all security-sensitive operations

- (2) tamper proof -> cannot be tampered with from outside the TCB (untrusted processes)
- (3) verifiable -> small enough to be subject to testing, analysis

2.3.4 Assessment Criteria

Complete Mediation.

- how does the reference monitor interface ensure that all security-sensitive operations are mediated correctly
- does the reference monitor mediate security-sensitive operations on all system resources
- how do we verify complete mediation?

Tamper Proof.

- how does the system protect the reference monitor and its protection system from modification?
- does the protection system protect TCB programs?

Verifiable.

- what is the basis for TCB correctness?
- does the protection system enforce security goals?

3 Multics

3.1 Jaeger Chapter 3

- Multics = the first modern OS
- invented many fundamental OS concepts
 - segmented virtual memory
 - shared memory for multiprocessors
 - hierarchical filesystems
 - online reconfiguration
 - (many others)
- invented many fundamental *secure OS* concepts
 - reference monitor
 - ring protection model
 - protection systems
 - protection domain transactions
 - multilevel security policies
 - (many others)

3.1.1 Jaeger 3.1

- Multics emerged from the CTSS (Compatible Timesharing System) system

- Early timesharing systems could support a few jobs at a time
 - vs batch processing could only do one at a time
- Project MAC (Multi-Access Computer) aims to create a general-purpose timesharing service to support large number of users simultaneously
 - This would require several functions such as multiplexing of devices for different processes, scheduling processes, communications between processes, and protection from other processes
- IBM wasn't interested in the idea, so GE took over
- Although it was considered a failure (bigger, slower, not reliable), it brought important OS and security features that would lead to UNIX
- Multics cost around \$7 million initially (only 80 licenses sold)
- Last department to use Multics was the Canadian Department of Defense (LOL we got issues boi)

3.1.2 Jaeger 3.2

3.1.3 Jaeger 3.3

3.2 Virtual Memory in Multics (Video)

Generating Address.

- 36 bits in total
 - 18 bit segment number
 - 18 bit word number
- i.e. 2^{18} segments and within each segment 2^{18} words

Instruction Format.

- segment tag
 - has segment number and word number
- address
- operation code
- external flag
- addressing mode (2 bits)
 - corresponds to one of four pointers
 - (1) argument pointer
 - (2) base pointer (bottom of stack frame)
 - (3) linkage pointer
 - (4) stack pointer (top of stack [frame])

Segment Number.

- can only be changed by ring 0 (supervisor mode) program

Word Number.

- can be changed by user mode programs

Switching Processes.

- all the kernel does is substitute a new descriptor base register (with a different segment number)

Apple II and Stuff (1982).

- introduced copy protection on memory / disks
- no virtual memory (they didn't need it, hobbyists didn't need to care about security)

3.3 Protection in an information processing utility (Graham 1968)

Challenges of Protecting an IPU.

- lots of users
- many users using the system simultaneously