

Operating System Security

Computer Security

Peter Reiher

January 28, 2021

Outline

- What does the OS protect?
- Authentication for operating systems
- Memory protection
 - Buffer overflows
- IPC protection
 - Covert channels
- Stored data protection
 - Full disk encryption

Introduction

- Operating systems provide the lowest layer of software visible to users
- Operating systems are close to the hardware
 - Often have complete hardware access
- If the operating system isn't protected, the machine isn't protected
- Flaws in the OS generally compromise all security at higher levels

Why Is OS Security So Important?

- The OS controls access to application memory
- The OS controls scheduling of the processor
- The OS ensures that users receive the resources they ask for
- If the OS isn't doing these things securely, practically anything can go wrong
- So almost all other security systems must assume a secure OS at the bottom

Single User Vs. Multiple User Machines

- The majority of today's computers usually support a single user
- Some computers are still multi-user
 - Often specialized servers
- Single user machines often run multiple processes, though
 - Often through downloaded code
- Increasing numbers of embedded machines
 - Effectively no (human) user

Trusted Computing

- Since OS security is vital, how can we be sure our OS is secure?
- Partly a question of building in good security mechanisms
- But also a question of making sure you're running the right OS
 - And it's unaltered
- That's called *trusted computing*

How Do We Achieve Trusted Computing?

- From the bottom up
- We need hardware we can count on
- It can ensure the boot program behaves
- The boot can make sure we run the right OS
- The OS will protect at the application level

TPM and Bootstrap Security

- Trusted Platform Module (TPM)
 - Special hardware designed to improve OS security
- Proves OS was booted with a particular bootstrap loader
 - Using tamperproof HW and cryptographic techniques
- Also provides secure key storage and crypto support

TPM and the OS Itself

- Once the bootstrap loader is operating, it uses TPM to check the OS
- Essentially, ensures that expected OS was what got booted
- OS can request TPM to verify applications it runs
- Remote users can request such verifications, too

Transitive Trust in TPM

- You trust the app, because the OS says to trust it
- You trust the OS, because the bootstrap says to trust it
- You trust the bootstrap, because somebody claims it's OK
- You trust the whole chain, because you trust the TPM hardware's attestations

Trust vs. Security

- TPM doesn't guarantee security
 - It (to some extent) verifies trust
- It doesn't mean the OS and apps are secure, or even non-malicious
- It just verifies that they are versions you have said you trust
- Offers some protection against tampering with software
- But doesn't prevent other bad behavior

Status of TPM

- Hardware widely installed
 - Not widely used
- Microsoft Bitlocker uses it
 - When available
- A secure Linux boot loader and OS work with it
- Some specialized software uses TPM

SecureBoot

- A somewhat different approach to ensuring you boot the right thing
- Built into the boot hardware and SW
- Designed by Microsoft
- Essentially, only allows booting of particular OS versions

Some Details of SecureBoot

- Part of the Unified Extensible Firmware Interface (UEFI)
 - Replacement for BIOS
- Microsoft insists on HW supporting these features
- Only boots systems with pre-arranged digital signatures
- Some issues of who can set those

Security Enclaves

- Many modern processors have trusted hardware components on the chip
- Typically intended to handle security-sensitive operations
 - Often by hiding crypto keys
- The approach has proven challenging
- Most such hardware has known flaws

Authentication and Authorization in Operating Systems

- The OS must authenticate all user requests
 - Otherwise, can't control access to critical resources
- Human users log in
 - Locally or remotely
- Processes run on their behalf
 - And request resources
- Once authenticated, requests must be authorized

In-Person User Authentication

- Authenticating the physically present user
- Most frequently using password techniques
- Sometimes biometrics
- To verify that a particular person is sitting in front of keyboard and screen

Remote User Authentication

- Many users access machines remotely
- How are they authenticated?
- Most typically by password
- Sometimes via public key crypto
- Sometimes at OS level, sometimes by a particular process
 - In latter case, what is their OS identity?
 - What does that imply for security?

Process Authentication

- Successful login creates a primal process
 - Under ID of user who logged in
- The OS securely ties a process control block to the process
 - Not under user control
 - Contains owner's ID
- Processes can fork off more processes
 - Usually child process gets same ID as parent
- Usually, special system calls can change a process' ID

For Example,

- Process X wants to open file Y for read
- File Y has read permissions set for user Bill
- If process X belongs to user Bill, system ties the open call to that user
- And file system checks ID in open system call to file system permissions
- Other syscalls (e.g., RPC) similar

Authorization in Operating Systems

- Operating systems allow user processes to perform system calls
 - Which generally do things that not all users/processes should do
- When operation requires permissions, we need to check those
- When is that?
- When should the OS perform authorization?

Authorization and Reference Monitors

- If an operation requires authorization, it should pass through a reference monitor
- Reference monitors add overhead
 - So we don't want to use them unnecessarily
- But when will it be necessary?
- A question for OS design and implementation

Protecting Memory

- What is there to protect in memory?
- Page tables and virtual memory protection
- Special security issues for memory
- Buffer overflows

What Is In Memory?

- Executable code
 - Integrity required to ensure secure operations
- Copies of permanently stored data
 - Secrecy and integrity issues
- Temporary process data
 - Mostly integrity issues

Mechanisms for Memory Protection

- Most general purpose systems provide some memory protection
 - Logical separation of processes that run concurrently
- Usually through virtual memory methods
- Originally arose mostly for error containment, not security

Paging and Security

- Main memory is divided into page frames
- Every process has an address space divided into logical pages
- For a process to use a page, it must reside in a page frame
- If multiple processes are running, how do we protect their frames?

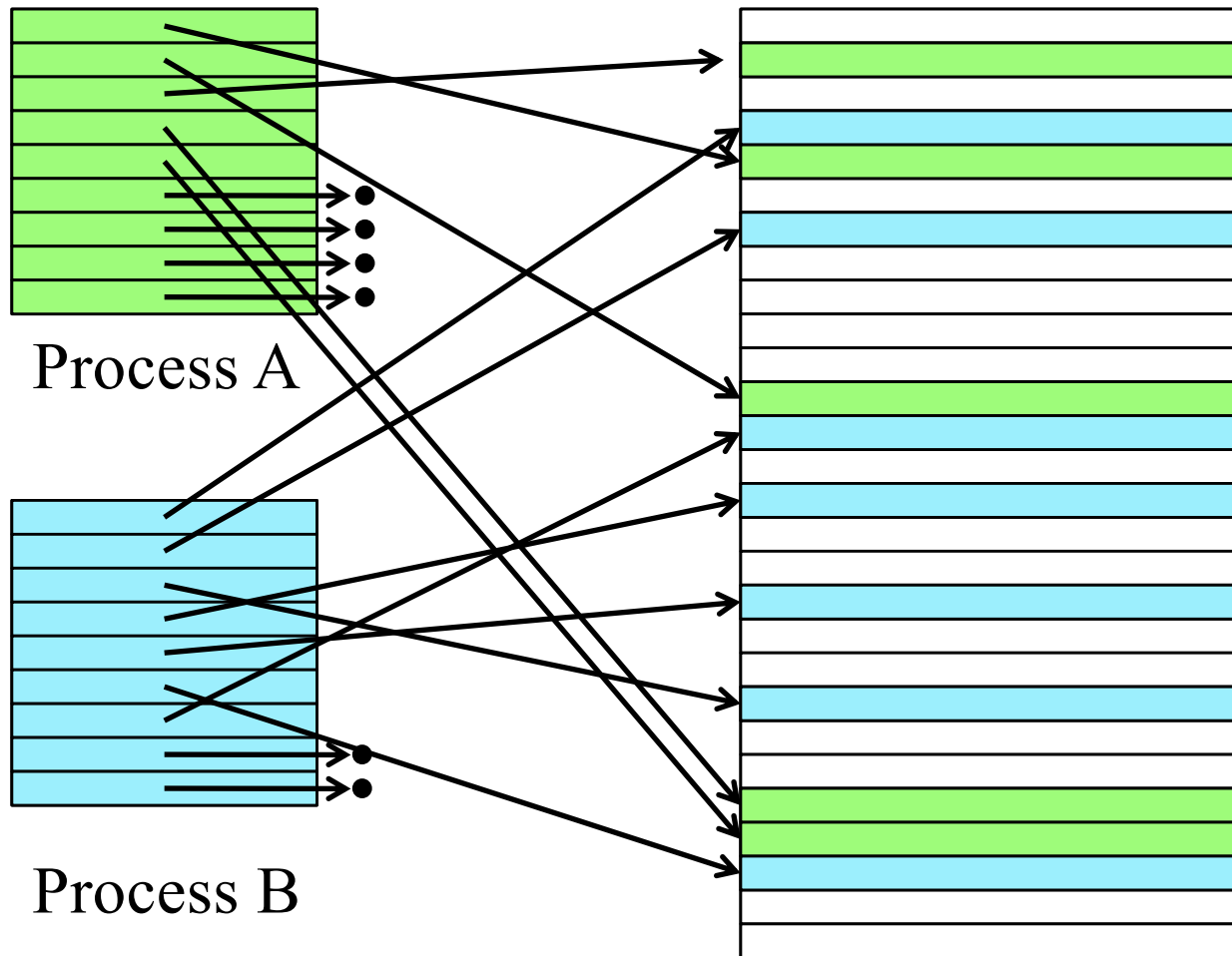
Protection of Pages

- Each process is given a page table
 - Translation of logical addresses into physical locations
- All addressing goes through page table
 - At unavoidable hardware level
- If the OS is careful about filling in the page tables, a process can't even name other processes' pages

Page Tables and Physical Pages

Process Page Tables

Physical Page Frames



Any address
Process A
names goes
through the
green table

Any address
Process B
names goes
through the
blue table

They can't
even name
each other's
pages

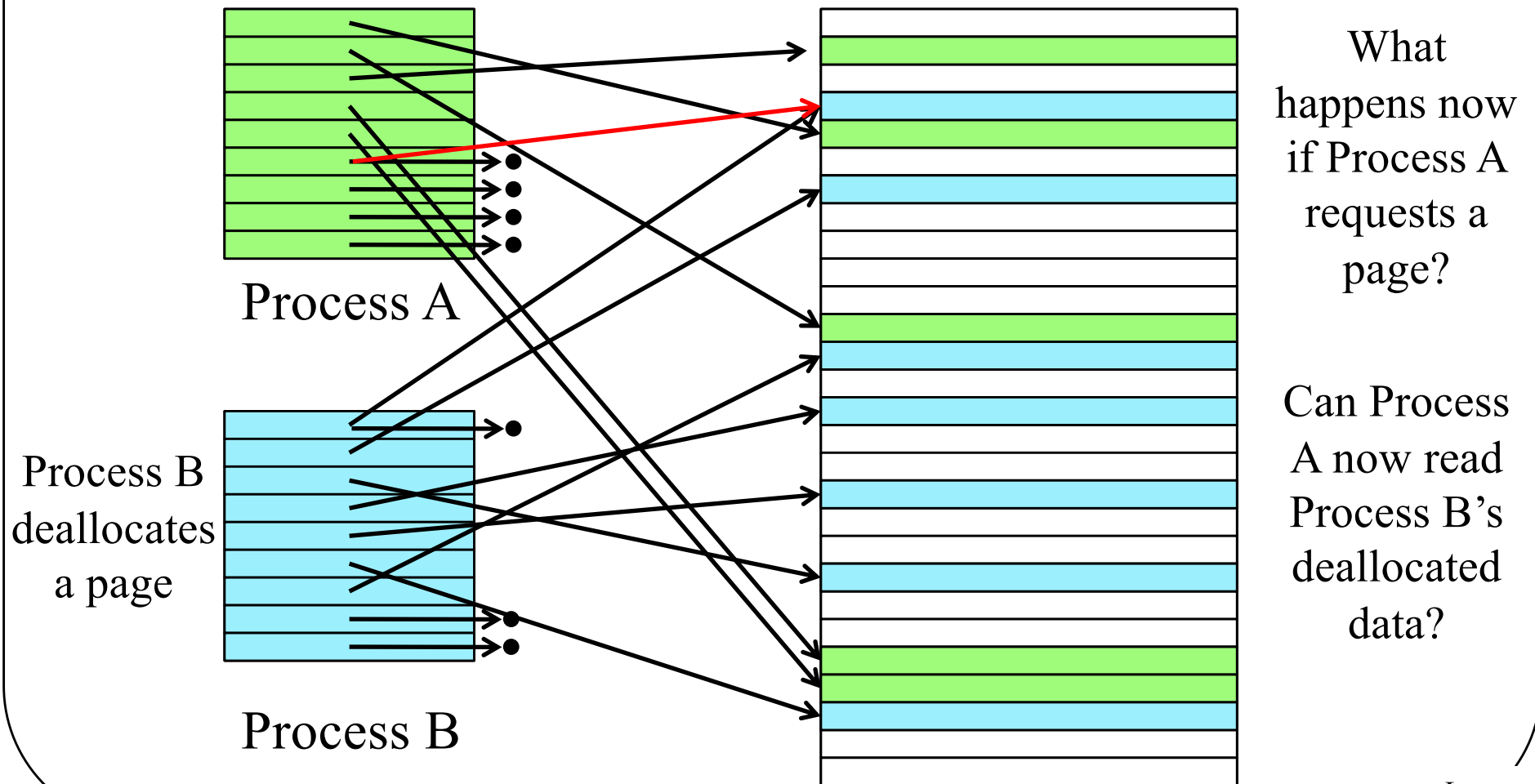
Security Issues of Page Frame Reuse

- A common set of page frames is shared by all processes
- The OS switches ownership of page frames as necessary
- When a process acquires a new page frame, it used to belong to another process
 - Can the new process read the old data?

Reusing Pages

Process Page Tables

Physical Page Frames



Strategies for Cleaning Pages

- Don't bother
 - Basic Linux strategy
- Zero on deallocation
- Zero on reallocation
- Zero on use
- Clean pages in the background
 - Windows strategy

Special Interfaces to Memory

- Some systems provide a special interface to memory
- If the interface accesses physical memory,
 - And doesn't go through page table protections,
 - Then attackers can read the physical memory
 - Letting them figure out what's there and find what they're looking for

Buffer Overflows

- One of the most common causes for compromises of operating systems
- Due to a flaw in how operating systems handle process inputs
 - Or a flaw in programming languages
 - Or a flaw in programmer training
 - Depending on how you look at it

What Is a Buffer Overflow?

- A program requests input from a user
- It allocates a temporary buffer to hold the input data
- It then reads all the data the user provides into the buffer, but . . .
- It doesn't check how much data was provided

For Example,

```
int main() {  
    char name[32];  
    printf("Please type your name:  ");  
    gets(name);  
    printf("Hello, %s", name);  
    return (0);  
}
```

- What if the user enters more than 32 characters?

Well, What If the User Does?

- Code continues reading data into memory
- The first 32 bytes go into `name` buffer
 - Allocated on the stack
 - Close to record of current function
- The remaining bytes go onto the stack
 - Right after `name` buffer
 - Overwriting current function record
 - Including the instruction pointer

Why Is This a Security Problem?

- The attacker can cause the function to “return” to an arbitrary address
- But all attacker can do is run different code than was expected
- He hasn’t gotten into anyone else’s processes
 - Or data
- So he can only fiddle around with his own stuff, right?

Is That So Bad?

- Well, yes
- That's why a media player can write configuration and data files
- Unless roles and access permissions set up very carefully, a typical program can write all its user's files

The Core Buffer Overflow Security Issue

- Programs often run on behalf of others
 - But using your identity
- Maybe OK for you to access some data
- But is it OK for someone who you're running a program for to access it?
 - Downloaded programs
 - Users of web servers
 - Many other cases

Using Buffer Overflows to Compromise Security

- Carefully choose what gets written into the instruction pointer
- So that the program jumps to something you want to do
 - Under the identity of the program that's running
- Such as, execute a command shell
- Usually attacker provides this code

Effects of Buffer Overflows

- A remote or unprivileged local user runs a program with greater privileges
- If buffer overflow is in a root program, it gets all privileges, essentially
- Can also overwrite other stuff
 - Such as heap variables
- Common mechanism to allow attackers to break into machines

Stack Overflows

- The most common kind of buffer overflow
- Intended to alter the contents of the stack
- Usually by overflowing a dynamic variable
- Usually with intention of jumping to exploit code
 - Though it could instead alter parameters or variables in other frames
 - Or even variables in current frame

Heap Overflows

- Heap is used to store dynamically allocated memory
- Buffers kept there can also overflow
- Generally doesn't offer direct ability to jump to arbitrary code
- But potentially quite dangerous

What Can You Do With Heap Overflows?

- Alter variable values
- “Edit” linked lists or other data structures
- If heap contains list of function pointers, can execute arbitrary code
- Generally, heap overflows are harder to exploit than stack overflows
- But they exist
 - E.g., one discovered in Google Chrome in 2020 (not Chrome’s first)

Some Recent Buffer Overflows

- Adobe Reader
- Cisco Integrated Management Controller
- Grub2 bootloader
- Instagram for Android
- sudo for Linux
- S3 CODESYS automation software

Fixing Buffer Overflows

- Write better code (check input lengths, etc.)
- Use programming languages that prevent them
- Add OS controls that prevent overwriting the stack
- Put things in different places on the stack, making it hard to find the return pointer (e.g., Microsoft ASLR)
- Don't allow execution from places in memory where buffer overflows occur (e.g., Windows DEP)
 - Or don't allow execution of writable pages
- Why aren't these things commonly done?
 - Sometimes they are, but not always effective
- When not, presumably because programmers and designers neither know nor care about security

Protecting Interprocess Communications

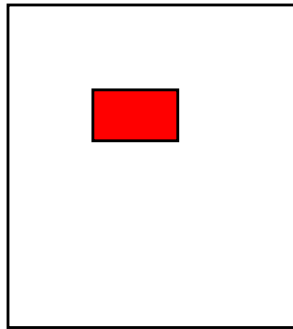
- Operating systems provide various kinds of interprocess communications
 - Messages
 - Semaphores
 - Shared memory
 - Sockets
- How can we be sure they're used properly?

IPC Protection Issues

- How hard it is depends on what you're worried about
- For the moment, let's say we're worried about one process improperly using IPC to get info from another
 - Process A wants to steal information from process B
- How would process A do that?

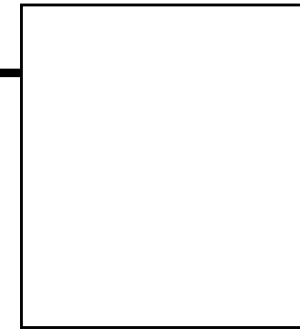
Message Security

Process A



Gimme your
secret

Process B



That's probably
not going to work

Can process B use message-
based IPC to steal the secret?

How Can B Get the Secret?

- He can convince the system he's A
 - A problem for authentication
- He can break into A's memory
 - That doesn't use message IPC
 - And is handled by page tables
- He can forge a message from someone else to get the secret
 - But OS tags IPC messages with identities
- He can “eavesdrop” on someone else who gets the secret

Can an Attacker Really Eavesdrop on IPC Message?

- On a single machine, what is a message send, really?
- A copy from a process buffer to an OS buffer
 - Then from OS buffer to another process' buffer
 - Sometimes optimizations skip some copies
- If attacker can't get at processes' internal buffers and can't get at OS buffers, he can't “eavesdrop”
- Need to handle page reuse (discussed earlier)
- Also an issue for properly checking authorization (discussed earlier)

Other Forms of IPC

- Semaphores, sockets, shared memory, RPC
- Pretty much all the same
 - Use system calls for access
 - Which belong to some process
 - Which belongs to some principal
 - OS can check principal against access control permissions at syscall time
 - Ultimately, data is held in some type of memory
 - Which shouldn't be improperly accessible

So When Is It Hard?

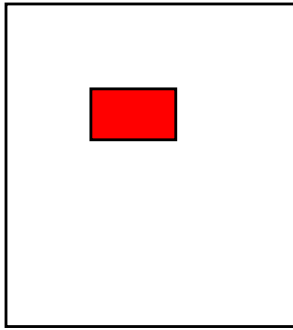
1. When there's a bug in the OS
 - E.g., not always checking authorization
 - Allowing masquerading, eavesdropping, etc.
 - Or, if the OS itself is compromised, all bets are off
2. What if it's not a single machine?
3. What if the OS has to prevent cooperating processes from sharing information?

Distributed System Issues

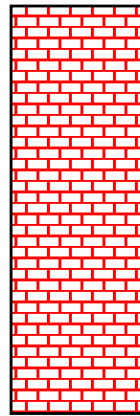
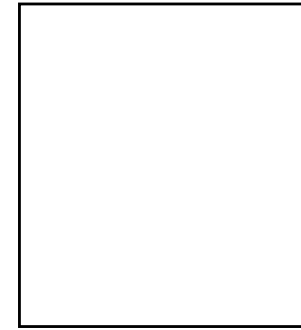
- What if your RPC is really remote?
- RPC tries to make remote access look “just like” local access
- The hard part is authentication
 - The call didn’t come from your OS
 - How do you authenticate its origin?
- With usual remote authentication and authorization mechanisms

The Other Hard Case

Process A



Process B



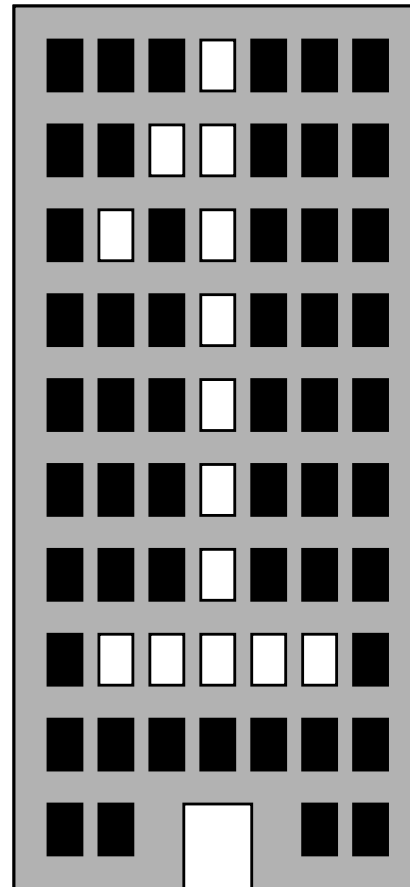
Process A wants to tell the secret to process B
But the OS has been instructed to prevent that
A necessary part of Bell-La Padula, e.g.
Can the OS prevent A and B from colluding
to get the secret to B?

OS Control of Interactions

- OS can “understand” the security policy
- Can maintain labels on files, process, data pages, etc.
- Can regard any IPC or I/O as a possible leak of information
 - To be prohibited if labels don’t allow it

Covert Channels

- Tricky ways to pass information
- Requires cooperation of sender and receiver
 - Generally in active attempt to deceive system
- Use something not ordinarily regarded as a communications mechanism



Covert Channels in Computers

- Generally, one process “sends” a covert message to another
 - But could be computer to computer
- How?
 - Disk activity
 - Page swapping
 - Time slice behavior
 - Use of a peripheral device
 - Limited only by imagination

Handling Covert Channels

- Relatively easy if you know details of how the channel is used
 - Put randomness/noise into channel to wash out message
- Hard to impossible if you don't know what the channel is
- Not most people's problem

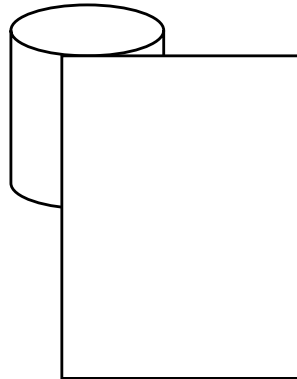
Stored Data Protection

- Files are a common example of a typically shared resource
- If an OS supports multiple users, it needs to address the question of file protection
- Simple read/write access control
- What else do we need to do?
- Protect the raw disk or SSD

Encrypted File Systems

- Data stored on disk is subject to many risks
 - Improper access through OS flaws
 - But also somehow directly accessing the disk
- If the OS protections are bypassed, how can we protect data?
- How about if we store it in encrypted form?

An Example of an Encrypted File System



K_s

**Sqamsédq
\$000 \$n
ihx
sauhmójs
abbotms**

Issues for
encrypted file
systems:

When does the
cryptography occur?

Where does the
key come from?

What is the
granularity of
cryptography?

When Does Cryptography Occur?

- Transparently when a user opens a file?
 - In disk drive?
 - In OS?
 - In file system?
- By explicit user command?
 - Or always, implicitly?
- How long is the data decrypted?
- Where does it exist in decrypted form?

Where Does the Key Come From?

- Provided by human user?
- Stored somewhere in file system?
- Stored on a smart card?
- Stored in the disk hardware?
- Stored on another computer?
- Where and for how long do we store the key?

What Is the Granularity of Cryptography?

- An entire disk?
- An entire file system?
- Per file?
- Per block?
- Consider both in terms of:
 - How many keys?
 - When is a crypto operation applied?

What Are You Trying to Protect Against With Crypto File Systems?

- Unauthorized access by improper users?
 - Why not just access control?
- The operating system itself?
 - What protection are you really getting?
 - Unless you're just storing data on the machine
- Data transfers across a network?
 - Why not just encrypt while in transit?
- Someone who accesses the device not using the OS?
 - A realistic threat in your environment?

Full Disk Encryption

- All data on the disk is encrypted
- Data is encrypted/decrypted as it enters/leaves disk
- Primary purpose is to prevent improper access to stolen disks
 - Designed mostly for portable machines (laptops, tablets, etc.)

HW Vs. SW Full Disk Encryption

- HW advantages:
 - Faster
 - Totally transparent, works for any OS
 - Setup probably easier
- HW disadvantages:
 - Not ubiquitously available today
 - More expensive (not that much, though)
 - Might not fit into a particular machine
 - Backward compatibility

Example of Hardware Full Disk Encryption

- Seagate's Momentus 7200 FDE line
- Hardware encryption for entire disk
 - Using AES
- Key accessed via user password, smart card, or biometric authentication
 - Authentication information stored internally on disk
 - Check performed by disk, pre-boot
- 3 Gbytes/sec maximum transfer rate (2021)
- Primarily for laptops

Example of Software Full Disk Encryption

- Microsoft BitLocker
- Doesn't encrypt quite the whole drive
 - Unencrypted partition holds bootstrap
- Uses AES for cryptography
- Key stored either in special hardware or USB drive
- Microsoft claims “single digit percentage” overhead
 - One independent study claims 12%