Protection and Security

CS 256/456

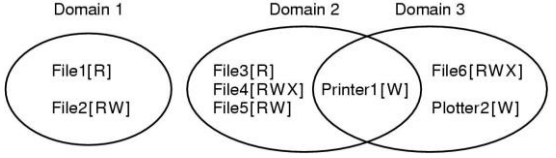
Dept. of Computer Science, University of Rochester

Security and Protection

- Goals:
  - Data confidentiality
  - Data integrity
  - System availability
- Threats:
  - Malicious intruders
  - Accidental data loss

Operating Systems Protection

- Operating system consists of a collection of objects, hardware or software (e.g., files, printers)
- Protection problem - ensure that each object is accessed correctly and only by those processes that are allowed to do so
  - a specific type of security problem
- Domain = set of (object, rights) pairs
  - what is a domain in traditional UNIX?
  - when do process domain switches occur in traditional UNIX?



How to Track Objects/Rights in Domains?

- View protection as a matrix (*protection matrix*)
  - Rows represent domains
  - Columns represent objects
  - *Access(i, j)* is the set of operations that a process executing in $Domain_i$ can invoke on $Object_j$
- Dynamic protection
  - Operations to add, delete access rights

Domain \ Object	File1	File2	File3	File4	File5	File6	Printer1	Plotter2
1	Read	Read Write						
2			Read	Read Write Execute	Read Write		Write	
3						Read Write Execute	Write	Write

Domain Structure

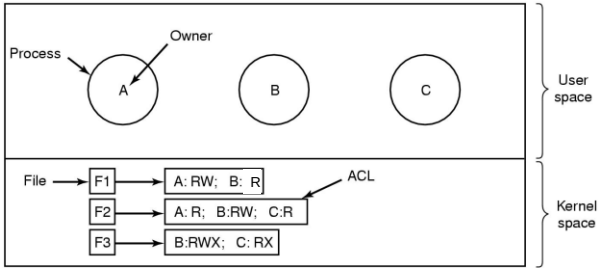
- Principle of protection: least privilege
- Alternatives for domain of protection:
  - Unix: users, groups
  - Multics (1960s): rings of capabilities/protection

Implementation of Protection

- The complete protection matrix consumes too much space and is usually very sparse.
  - two ways to condense it
- Each column = Access-control list for one object
  Defines who can perform what operation.
  Domain 1 = Read, Write
  Domain 2 = Read
  Domain 3 = Read
  ⋮
- Each Row = Capability List for each domain
  Define what operations allowed on what objects.
  Object 1 – Read
  Object 4 – Read, Write, Execute
  Object 5 – Read, Write, Delete, Copy
- Alternative: Lock-Key Mechanism

What does traditional UNIX do?

Access Control Lists



Use of access control lists to manage file access

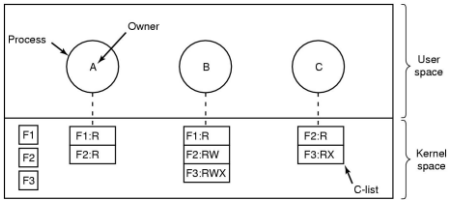
Revocation of access rights?

Capabilities

- Capability for a domain
  - abstraction that indicates access rights to objects for the domain
- Comparing against ACL
  - may be built-in with handle to objects (more efficient access right checking)
  - efficient mechanism to pass it around
- Important concern
  - a process should not be able to tamper with its capabilities

Implementing Capabilities

- Kernel-space capability list
  - user programs use handles (e.g., file descriptors) to refer to them



- Tagged architecture
  - memory words containing capabilities are tagged; user programs can only read those words; only kernel programs can change those words
  - the protection system kernel does not need to track capabilities and capabilities can be passed by memory sharing

Cryptographically-protected Capabilities

- Cryptographically-protected capability
  - a random number (called "check") is generated for each file at creation time and maintained in secrecy
  - capability is formed cryptographically

Server	Object	Rights	f(Object, Rights, Check)

- Function f() is a one-way function such that:
  - it is computationally infeasible to guess what "check" is even when object, rights, and f(object, rights, check) is known.
- Compared with tagged capabilities, cryptographically-protected capability
  - does not require new hardware support
  - can be passed around between distributed machines

Revocation of Access Rights

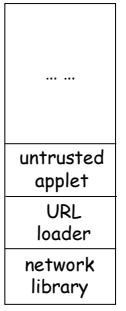
- Immediate or delayed
- *Selective vs. general*
  - *selective:* revoking rights to a select group of domains (e.g., all processes belonging to a particular user)
- Partial vs. total
  - Subset or all rights to object
- Temporary vs. permanent
- Access control lists: immediate, selective or general, total or partial, permanent or temporary
- Capabilities: distributed throughout the system; possible solutions
  - Reacquisition
  - Back-pointers
  - Indirection
  - Keys

Protection in UNIX

- Protection domains: users
- Access matrix for files:
  - a simplified access control list
- Protection commands for files:
  - each user can change protection on files it owns
  - superuser can do everything

Protection in Java

- A Java class can be loaded remotely; therefore can be dangerous
  - A class is assigned a protection domain when it is loaded by the JVM
  - The protection domain indicates what operations the class can (and cannot) perform
- If a library method is invoked that performs a privileged operation, the stack is inspected for access right violation
- Other techniques
  - Sandboxing
  - interpretation



The Security Environment

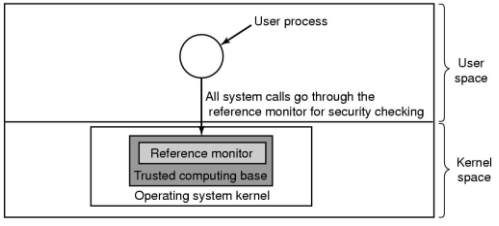
We focus on OS-related security issues …

Security goals:
- Authentication
- Data confidentiality
- Data integrity
- System availability

Threats of intruders or adversaries:
- Identity hijacking
- Exposing data
- Tampering with data
- Denial of service attacks

Trusted Systems

- Trusted Computing Base
  - hardware and software for enforcing security rules
- If the TCB works according to specification, the system security cannot be compromised
- A reference monitor-based TCB:



Formal Models of Secure Systems

Objects

	Compiler	Mailbox 7	Secret
Eric	Read Execute		
Henry	Read Execute	Read Write	
Robert	Read Execute		Read Write

(a)

Objects

	Compiler	Mailbox 7	Secret
Eric	Read Execute		
Henry	Read Execute	Read Write	
Robert	Read Execute	Read	Read Write

(b)

- Protection commands: operations that can change protection matrix
- TCB must ensure that protection commands do not move the protection matrix from an authorized state to an unauthorized state

Login Spoofing

- Login spoofing
  - A program running by the attacker displays a login screen (like the real one)
  - After a legitimate user types in username and password, it records those, kills itself, and a real login screen is shown
  - The user thinks she typed in a wrong password and tries again, which works
- Countermeasure?
  - Start each login session with a non-user-catchable key combination "Ctrl-Alt-Delete"

Leaking Unnecessary Information

LOGIN: ken
PASSWORD: FooBar
SUCCESSFUL LOGIN

(a)

LOGIN: carol
INVALID LOGIN NAME
LOGIN:

(b)

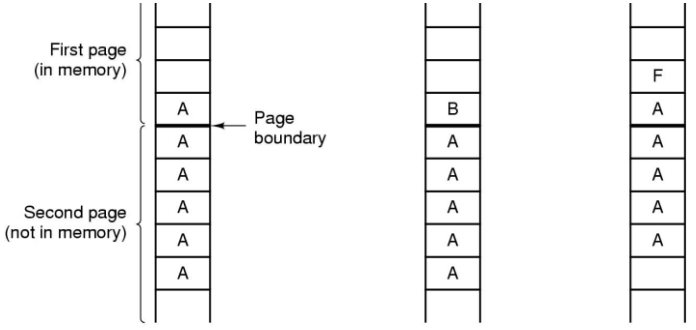
LOGIN: carol
PASSWORD: Idunno
INVALID LOGIN
LOGIN:

(c)

User authentication:
(a) A successful login
(b) Login rejected after name entered
(c) Login rejected after name and password typed

The TENEX Password Problem

- Files are accessed with passwords. At each access, the password is checked byte-by-byte and an error is returned as soon as a byte is mismatched.



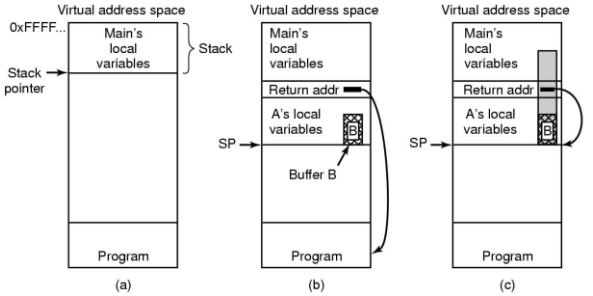
User Authentication

- UNIX user passwords were mapped using a one-way function "e()"; and then stored in a globally readable file "/etc/passwd"
  - Bobbie, e(Dog)
  - Tony, e(6%%TaeFF)
  - … …
- Attack:
  - used a precomputed common password list
- Countermeasure?
  - salt
  - Bobbie, 4238, e(Dog4238)
  - Tony, 2918, e(6%%TaeFF2918)

Improving Password Security

- One-time passwords
  - Challenge-response authentication
- Authentication using a physical object (e.g., ATM card)
- Authentication using biometrics

Buffer Overflow



(a) Situation when main program is running
(b) After program *A* called
(c) Buffer overflow shown in gray

Countermeasures:

- boundary checks, non-executable stack/data segment, …

The Morris Worm [1988]

- Three methods of infection
  - rsh from trusted machine
  - Buffer overflow attack in finger
  - Bug in sendmail
- Once a machine was infected, used password cracking for further proliferation
- If a copy of the worm already existed, 1 in 7 exited
  - Downfall since it brought the Internet down

Security Services

- Privacy (prevent others from obtaining information)
- Authentication (verify the identity of an object owner)
- Data integrity (make sure the data is not altered)

→ Cryptography as a Security Tool

Cryptographic Algorithms

- Encryption/decryption algorithms typically public knowledge
- Key shared between sender and receiver is the difference
  - Secret key – symmetric – both participants share a single key
  - Public key (e.g., RSA)
    - Public key published for all to know
    - Private key that is shared with no one
  - Hash or message digest (e.g., MD5) – no keys
    - Map a potentially large piece of data into a small fixed-length number
    - More efficient to compute than the above techniques

Encryption Algorithm Requirement

- Assumption – only the key is kept secret or you will have to keep re-inventing new encryption algorithms!
- Algorithm must be safe from chosen plain-text attacks (if the attacker knows both plaintext and ciphertext)
  - Make sure none of the structure of plaintext remains

→ Key distribution a central problem in security

DES – Date Encryption Standard

- Secret key algorithm
- Encrypts 64-bit blocks of plaintext using a 64-bit key
- Three distinct phases
  - Permute (shuffle bits in the block)
  - Perform 16 rounds of an identical operation
  - Perform the inverse of the original permutation
- Decryption – apply the same algorithm, except that the keys are applied in reverse

Encrypting Large Data

- Cipher block chaining (CBC) – XOR ciphertext for block i with plaintext for block i+1 before running it through DES
- Use initialization vector in lieu of non-existent ciphertext for block 0
- Use Triple-DES to increase security

RSA (Rivest, Shamir, and Adleman) Algorithm

- Public key for encryption, private key for decryption
- Grounded in number theory
- Encryption/decryption function requires enormous computational power

Key Selection

- Key length of 512 bits
- Choose two large prime numbers p and q, and multiply them together to get n
- Choose encryption key e such that e and (p-1)x(q-1) are relatively prime
- Compute decryption key d such that
- Public key constructed from the pair <e,n> and private key by the pair <d,n>

Authentication: Simple Three-Way Handshake

- Participants already share a secret key
- Client sends encrypted (using client handshake key) random number x along with clientId
- Server decrypts and responds with x+1, along with random number y, both encrypted with server handshake key
- Client validates legitimacy of server by checking return value x+1 and returns encrypted y+1
- Server validates legitimacy of client based on response and then sends encrypted session key

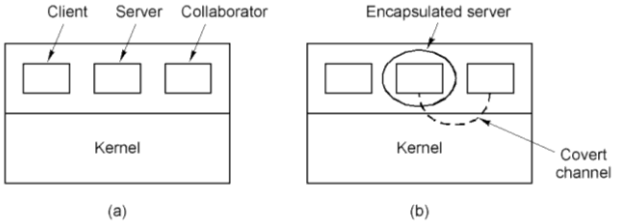
Authentication: Trusted Third Party (e.g., Kerberos)

- The authentication server S is trusted and shares a secret key with A and B, K_A and K_B respectively
- A identifies A and B to S
- S sends back a two-part message, encoding session key K and a timestamp T, using K_A and K_B
- A decodes first part of message and forwards second part to B along with timestamp encoded using K
- B decodes second part to recover K and T and uses K to decode second part and compare
- B replies with T+1 encoded using K

PGP – Pretty Good Privacy

- Provides privacy, authentication, integrity, compression
  - Hash message using MD5
  - Encrypt hash using private RSA key
  - Compress using ZIP
  - Use random key to encrypt message using IDEA (similar to DES)
  - Encrypt random key using receiver's public key

Covert Channels: Information leaking



Client, server, and collaborator processes

Encapsulated server can still leak to collaborator via covert channels

- Covert channels
  - Modulating CPU usage
  - Locking/unlocking files

Information Leaking Through Side Channels

- Side channels
  - performance observations
  - program execution signals (e.g., cache usage, memory bus usage)
- Side channel attack on hyper-threading processors [Percival 2005]
  - OpenSSH running DES encryption on one hyper-thread
  - attacker running on the other hyper-thread
  - attacker and OpenSSH share hardware cache, so attacker can monitor its own cache miss pattern to infer the execution of OpenSSH (and its DES encryption key)

Denial-of-Service Attack

- Attacker attempts to consume all available resources at the host so no resources are left to serve legitimate users
  - attacks often come from network and they are distributed
- TCP flooding:
  - attackers establish many bogus TCP connections
  - host allocates buffer space for each connection
  - host memory is exhausted eventually
- Countermeasure?
  - discard flooded requests: throws out good and bad ones
  - trace back to source of floods
    - sources are most likely an innocent, compromised machines
  - delayed processing/resource allocation
    - stateless TCP [Shieh et al., NSDI2005]

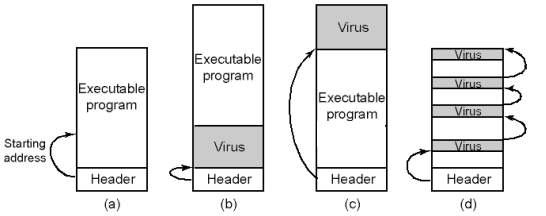
Virus

- Virus (fragment of code embedded in a legitimate program)
  - program can reproduce itself
    - e.g., when invoked, traverse the file system and attach it to randomly selected executables
  - additionally, do harm
    - steal your data
    - temporarily crash the system
    - permanently damage data or hardware
    - denial of service by using all available system resources

"Good" virus

- quickly spreading virus
- difficult to detect
- hard to get rid of

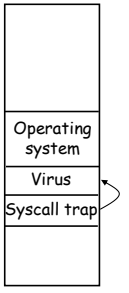
Infecting An Executable (Trojan Horses)



(a) An executable program
(b) With a virus at the front
(c) With the virus at the end
(d) With a virus spread over free space within program

Memory Resident Viruses

- Virus resides in memory; intercepting system calls
- Where in memory to put the virus?
  - known unused memory in OS kernel
  - make the OS believe the memory that virus uses is "legitimately used"
- How to load virus there in the first place?
  - boot sector viruses
  - device driver viruses



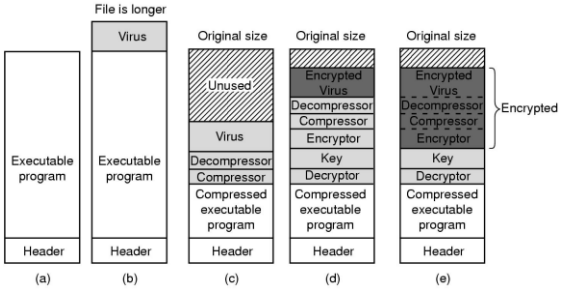
How Viruses Spread

- Try to infect programs on
  - networks: exploiting buffer overflow errors in network server daemons
  - floppy drives
- Attach to innocent looking email
  - when it runs, use mailing list to replicate

Antivirus Techniques

- Size checkers
  - keep a record of the size of disk files and scan them periodically for any size changes
  - apply on read-only executables
- Signature scanning
  - maintain a database of patterns of common viruses
  - scan disk files for these patterns

Anti-Antivirus Techniques



(a) A program
(b) Infected program
(c) Compressed infected program
(d) Encrypted virus
(e) Compressed virus with encrypted compression code

More Antivirus Techniques

- Integrity checkers
  - similar to size checkers, but this time we compute a checksum for file and store them somewhere; we periodically check all files to see whether the checksum still matches
- Behavioral checkers (memory-resident anti-virus program)
  - intercept system calls and detect suspicious activities: overwriting executables, …

Disclaimer

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So far …

- Login and password security
- Exploiting system weaknesses and worms
  - Login spoofing
  - Buffer overflow attack
  - Tenex password problem
- Today
  - Cryptography as a security tool
  - Viruses