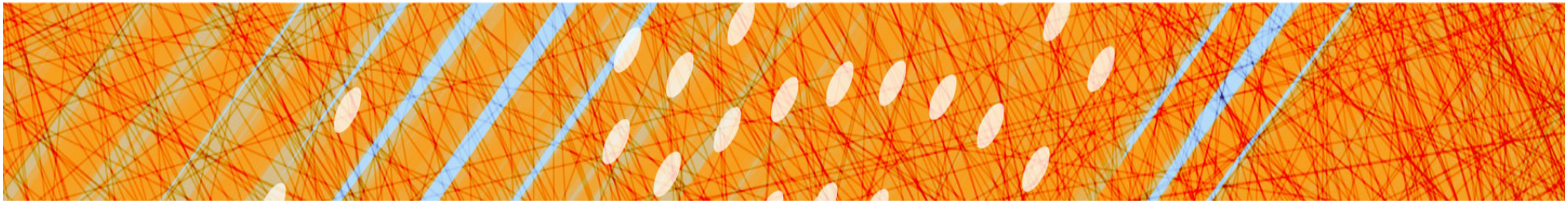
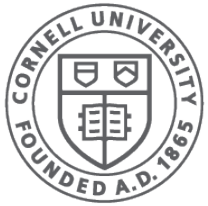


Security

CS 4410
Operating Systems



Cornell CIS
COMPUTING AND INFORMATION SCIENCE

References: Security Introduction and Access Control by Fred Schneider

Historical Context

1961

Compatible Time-Sharing System (CTSS) is Demonstrated

The increasing number of users needing access to computers in the early 1960s leads to experiments in timesharing computer systems. Timesharing systems can support many users – sometimes hundreds – by sharing the computer with each user. CTSS was developed by the MIT Computation Center under the direction of Fernando Corbató and was based on a modified IBM 7094 mainframe computer. Programs created for CTSS included RUNOFF, an early text formatting utility, and an early inter-user messaging system that presaged email. CTSS operated until 1973.

1969

Kenneth Thompson and Dennis Ritchie develop UNIX

AT&T Bell Labs programmers Kenneth Thompson and Dennis Ritchie develop the UNIX operating system on a spare DEC minicomputer. UNIX combined many of the timesharing and file management features offered by Multics, from which it took its name. (Multics, a project of the mid-1960s, represented one of the earliest efforts at creating a multi-user, multi-tasking operating system.) The UNIX operating system quickly secured a wide following, particularly among engineers and scientists, and today is the basis of much of our world's computing infrastructure.

1960's OSes begin to be shared. Enter:

- Communication
- Synchronization
- Protection
- Security: once a small OS sub-topic. *Not anymore!*

`http://www.computerhistory.org, https://en.wikipedia.org`

History of Discretionary Access Control (DAC)

1760+	early philosophical pioneers of private property (Blackston, Bastiat,+)
1965	"access control lists" coined @ MIT describing Multics (CTSS foreshadowed ACLs) (Daley & Neumann)
1966	"capability" coined and OS supervisor outlined @ MIT (Dennis & van Horn)
1974	early computer security: "the user gives access rights at his own discretion" (Walter+)
1983	DoD's Orange book coins the term "discretionary access control"

Security Properties: CIA

Confidentiality: *keeping secrets*

- who is allowed to learn what information

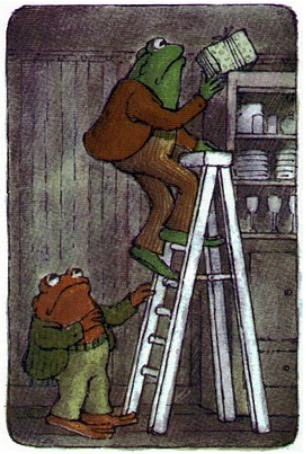
Integrity: *permitting changes*

- what changes to the system and its environment are allowed

Availability: *guarantee of service*

- what inputs must be read | outputs produced

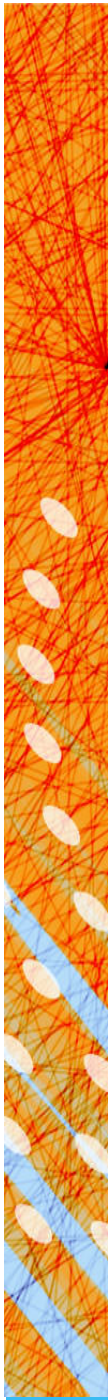
Are they orthogonal? Sadly, no…



Plan of Attack *(no pun intended!)*

- Protection / Discretionary Access Control
  - Authorization: *what are you permitted to do?*
  - Access Control Matrix

- Security – *Next lecture*
  - Authentication: *how do we know who you are?*
  - Threats and Attacks



Access Control Terminology

Operations: how one learns or updates information

Principals: executors (users, processes, threads, procedures)

Objects of operations: memory, files, modules, services

Access Control Policy:

- who may perform which operations on which objects
- enforces confidentiality & integrity

Reference Monitor:

- entity with the power to observe and enforce the policy
- consulted on operation invocation
- allows operation to proceed if invoker has required privileges

Goal: each object is accessed correctly and only by those principals that are allowed to do so

Principle of Least Privilege

"Every program and every privileged user of the system should operate using the least amount of privilege necessary to complete the job."

- Jerome Saltzer
(of the end-to-end argument)

Want to minimize:

- code running inside kernel
- code running as sysadmin

Challenge: Hard to know:

- what permissions are needed in advance
- what permissions should be granted

Access Control Matrix

- Abstract model of protection
- Rows: principals = users
- Columns: objects = files, I/O, *etc.*

Principals	OBJECTS		
	`prelim.pdf`	`jim-hw.tex`	`scores.xls`
egs (prof)	r, w	r	r, w
jim (student)		r, w	

Unordered set of triples <Principal,Object,Operation>

What does Principal of Least Privilege say about this?

Need Finer-Grained Principals

Protection Domains = new set of principals

- each thread of control belongs to a protection domain
- executing thread can transition from domain to domain

Example domain: user ▷ task

- task = program, procedure, block of statements
- task = started by user or in response to user's request
- user ▷ task: holds min. privilege to get task done for user

→ *task-specific privileges (PoLP is ☺)*

Access Matrix with Protection Domains

Principals	OBJECTS		
	`prelim.pdf`	`jim-hw.tex`	`scores.xls`
egs▷sh			
egs▷latex	r, w	r	
egs▷excel			r, w
jim▷sh			
jim▷latex		r, w	
jim▷excel			

When to transition protection-domains?

- invoking a program
- changing from user to kernel mode
- …

Need to explicitly authorize them in the matrix

Access Matrix with Domain Transitions

Principals	OBJECTS								
	prelim.pdf	jim-hw.tex	scores.xls	egs△sh	egs△latex	egs△excel	jim△sh	jim△latex	jim△excel
egs▷sh					e	e			
egs▷latex	r, w	r							
egs▷excel			r, w						
jim▷sh								e	e
jim▷latex		r, w							
jim▷excel									

e = enter

Implementation Needs

Must support:

- Determining if <*Principal,Object,Operation*> is in matrix
- Changing the matrix
- Assigning each thread of control a protection domain
- Transitioning between domains as needed
- Listing each principal's privileges (for each object)
- Listing each object's privileges (held by principals)

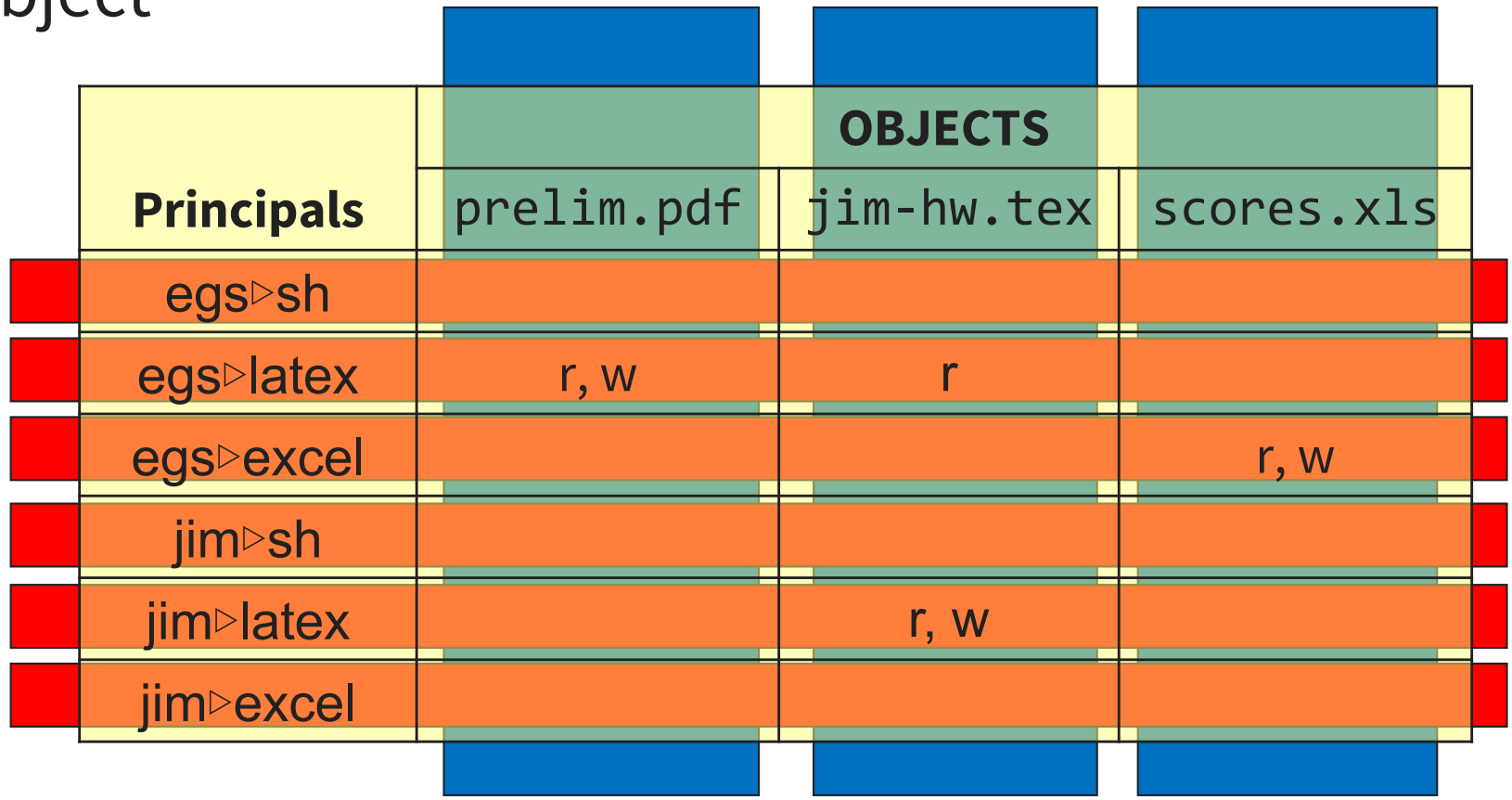
2D array? + looks good in powerpoint! – sparse

→ store only the non-empty cells

How shall we implement this?

Access Control List (ACL): column for each object stored as a list for the object

Capabilities: row for each subject stored as list for the subject

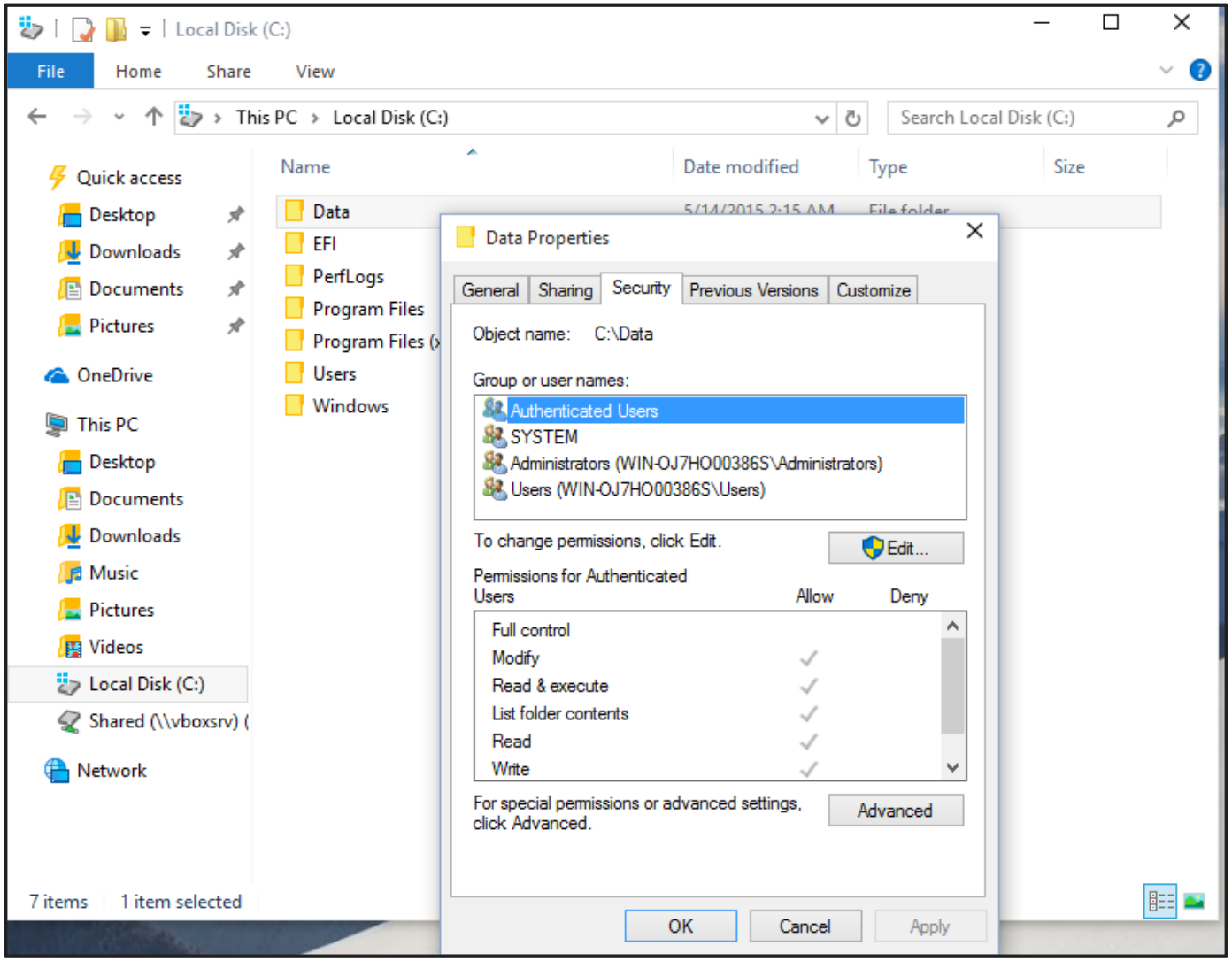


Same in theory; different in practice!

ACLs vs Capabilities

	ACLs	**Capabilities**
	For each Object: <P_1,$privs_1$> <P_2,$privs_2$>…	<Object,privs> held by a principal
Review rights for object O	Easy! Print the list.	Implementation Dependent. Single easy-to-find list for each principal? Or are capabilities scattered throughout memory?
Review rights for principal P across all objects	Hard. Need to scan all objects' lists.	
Revocation	Easy! Delete P from O's list.	

Access Control in Windows



Access Control in UNIX

UNIX: has user and group identifiers: `uid` and `gid`

Per process: protection domain = `egs|faculty▷sh`

Per file: ACL `owner|group|other` → stored in i-node

- Only owner can change these rights (using chmod)
- Each i-node has 12 mode bits for user, group, others
- Last 3 mode bits allow process to change across domains

(Hybrid!) Approximation of access control scheme:

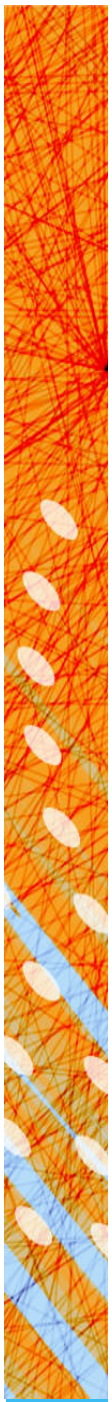
- Authorization (check ACL) performed at `open`
- Returns a file handle → essentially a capability
- Subsequent `read` or `write` uses the file handle

Good luck tonight!

Plan of Attack

- Protection
  - Authorization: *what are you permitted to do?*
  - Access Control Matrix

- Security
  - Authentication: *how do we know who you are?*
  - Threats and Attacks



Security in the real world

- Security decisions based on:
  - Value, Locks, Police

- Some observations:
  - Not all locks are the same
  - People pay for security they need
  - Police are critical to the picture
  - Security is only as good as the weakest link

Security in Computer Systems

- In computer systems, this translates to:
  - **Au**thorization
  - **Au**thentication
  - **Au**dit
- This is the Gold Standard for Security (Lampson)
- Some security goals:
  - Data confidentiality: secret data remains secret
  - Data integrity: no tampering of data
  - System availability: unable to make system unusable
  - Privacy: protecting from misuse of user's information

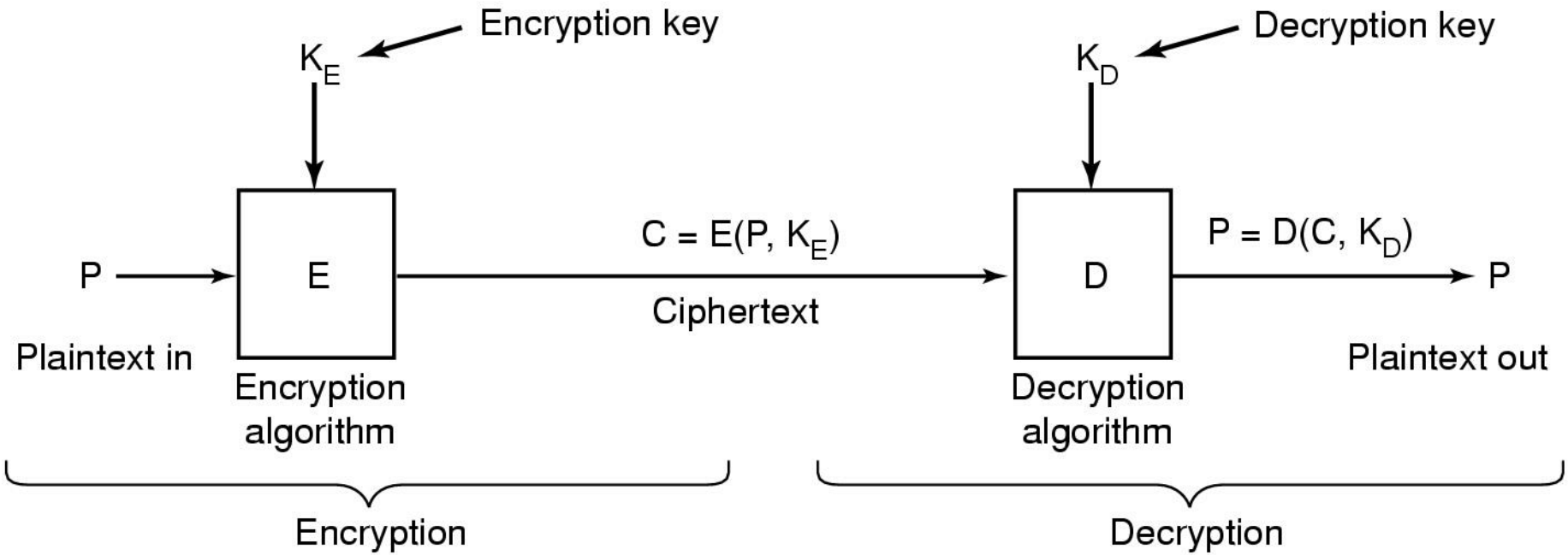
Security Threats

Identified by Defense Science Board:

- Incomplete, inquisitive and unintentional blunders.
- Hackers driven by technical challenges.
- Disgruntled employees or customers seeking revenge.
- Criminals interested in personal financial gain or stealing services.
- Organized crime with the intent of hiding something or financial gain.
- Organized terrorist groups attempting to influence U.S. policy by isolated attacks.
- Foreign espionage agents seeking to exploit information for economic, political, or military purposes.
- Tactical countermeasures intended to disrupt specific weapons or command structures.
- Multifaceted tactical information warfare applied in a broad orchestrated manner to disrupt a major U.S. military mission.
- Large organized groups / nation-states intent on overthrowing the US

Cryptography Overview

- Encrypt data so it only makes sense to authorized users
  - Input data is a message or file called plaintext
  - Encrypted data is called ciphertext
- Encryption and decryption functions should be public
  - Security by obscurity is not a good idea!



Secret-Key Cryptography

- Also called *symmetric cryptography*
  - Encryption algorithm is publicly known
  - E(message, key) = ciphertext D(ciphertext, key) = message
- Naïve scheme: monoalphabetic substitution
  - Plaintext : ABCDEFGHIJKLMNOPQRSTUVWXYZ
  - Ciphertext: QWERTYUIOPASDFGHJKLZXCVBNM
  - So, *attack* is encrypted to: *qzzqea*
  - 26! possible keys ~ 4×10^{26} possibilities
    - 1 μs per permutation ⇒ 10 trillion years to break
  - easy to break this scheme! How?
    - ‘e’ occurs 14%, ‘t’ 9.85%, ‘q’ 0.26%

Symmetric Key Cryptography

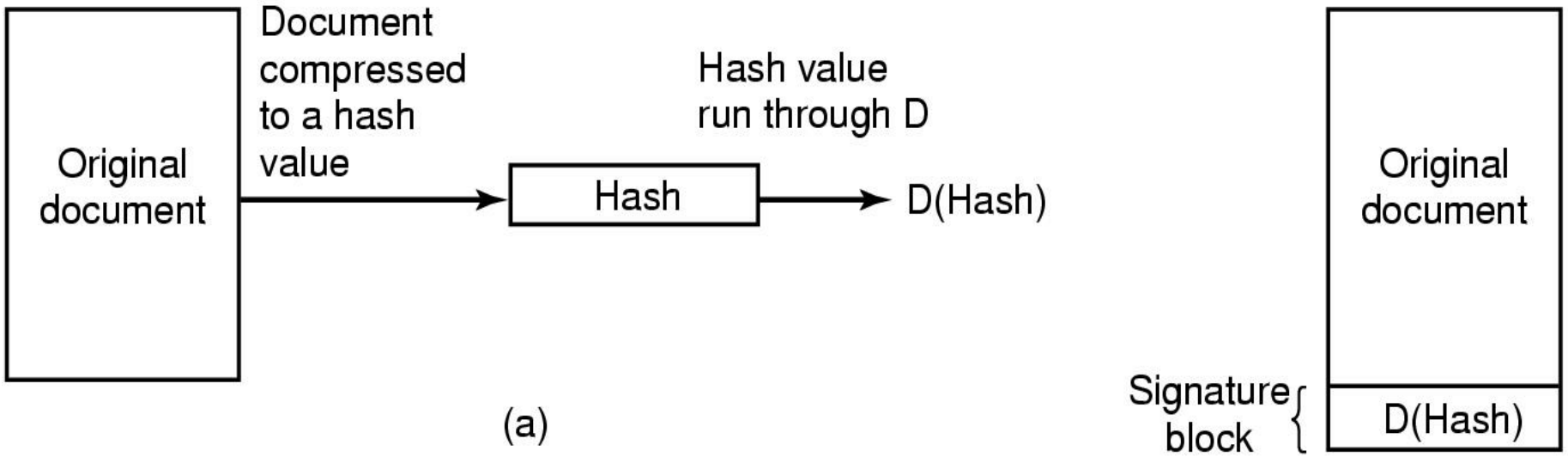
- Which encryption algorithm is good?
  - DES was proposed in the 1970s
    - Encrypts 64 bits of data with 56 bit key to give 64-bit ciphertext
    - Uses 16 rounds of substitution and permutation
    - EFF invested $250000 to break DES message in 56 hours
    - DES made powerful by encrypting message 3 times (DES3)
  - Current standard is AES
    - A result of 3-year competition with entries from 12 countries
    - Winning entry was from Belgium, called ‘Rijndael’
  - Strong algorithms, such as DES3, RC4 are used
    - WEP uses RC4

Public Key Cryptography

- Diffie and Hellman, 1976
- All users get a public key and a private key
  - Public key is published
  - Private key is not known to anyone else
- If Alice has a packet to send to Bob,
  - She encrypts the packet with Bob's public key
  - Bob uses his private key to decrypt Alice's packet
- Private key linked mathematically to public key
  - Make it computationally infeasible to derive (RSA)
- Pros: more security, convenient, digital signatures
- Cons: slower

Digital Signatures

- Hashing function hard to invert, e.g. MD5, SHA
- Apply private key to hash (decrypt hash)
  - Called signature block
- Receiver uses sender's public key on signature block
  - *E(D(x)) = x* should work (works for RSA)



Authentication

- Establish the identity of user/machine by
  - Something you know (password, secret)
  - Something you have (credit card, smart card)
  - Something you are (retinal scan, fingerprint)
- In the case of an OS this is done during login
  - OS wants to know who the user is
- Passwords: secret known only to the subject
  - Simplest OS implementation keeps (login, password) pair
  - Authenticates user on login by checking the password
  - Try to make this scheme as secure as possible!
    - Display the password when being typed? (Windows, UNIX)

Online passwords attacks

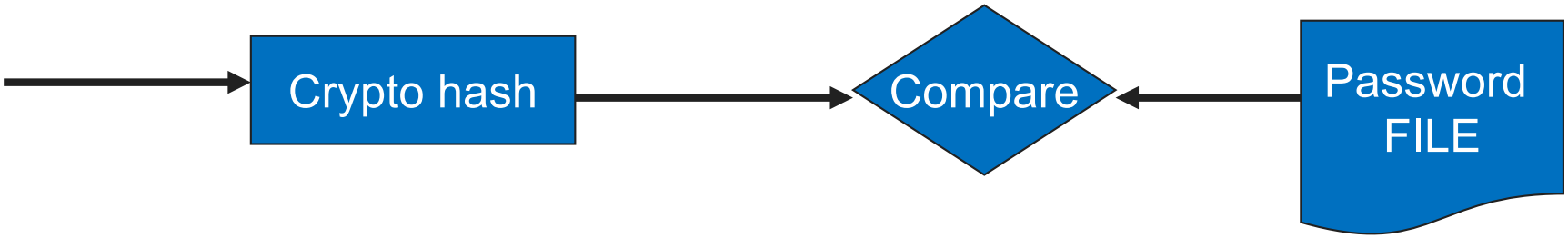
- Online attacks: system used to verify the guesses
  - How someone broke into LBL

```
LBL> telnet elxsi
ELXSI AT LBL
LOGIN: root
PASSWORD: root
INCORRECT PASSWORD, TRY AGAIN
LOGIN: guest
PASSWORD: guest
INCORRECT PASSWORD, TRY AGAIN
LOGIN: uucp
PASSWORD: uucp
WELCOME TO THE ELXSI COMPUTER AT LBL
```

  - Thwart these attacks:
    - limit the number of guesses
    - better passwords

Offline password attacks

- Depends on how passwords are stored
- Approach 1: store username/password in a file
  - Attacker only needs to read the password file
  - Security of system now depends on protection of this file!
- Approach 2: store username/encrypted password in file



- Properties of the one-way hash function *h*:
  - *h* is not invertible: *h(m)* easy to compute, $h^{-1}(m)$ difficult
  - It is hard to find *m* and m' s.t. *h(m) = h(m')*
- Should use standard functions, such as SHA, MD5, etc.

More offline attacks

- Previous scheme can be attacked: Dictionary Attack
  - Attacker builds dictionary of likely passwords offline
  - At leisure, builds hash of all the entries
  - Checks file to see if hash matches any entry in password file
  - There will be a match unless passwords are truly random
  - 20-30% of passwords in UNIX are variants of common words
    - Morris, Thompson 1979, Klein 1990, Kabay 1997
- Solutions:
  - Shadow files: move password file to /etc/shadow
    - This is accessible only to users with root permissions
  - Salt: store *(user name, salt, E(password+salt))*
    - Simple dictionary attack will not work. Search space is more.

Salting Example

Bobbie, 4238, e(Dog4238)
Tony, 2918, e(6%%TaeFF2918)
Laura, 6902, e(Shakespeare6902)
Mark, 1694, e(XaB@Bwcz1694)
Deborah, 1092, e(LordByron,1092)

- If the hacker guesses Dog, he has to try Dog0001, …
- UNIX adds 12-bit of salt
- Passwords should be made secure:
  - Length, case, digits, not from dictionary
  - Can be imposed by the OS! This has its own tradeoffs

One time passwords

- Password lasts only once
  - User gets book with passwords
  - Each login uses next password in list

  - UNBREAKABLE..

Challenge Response Scheme

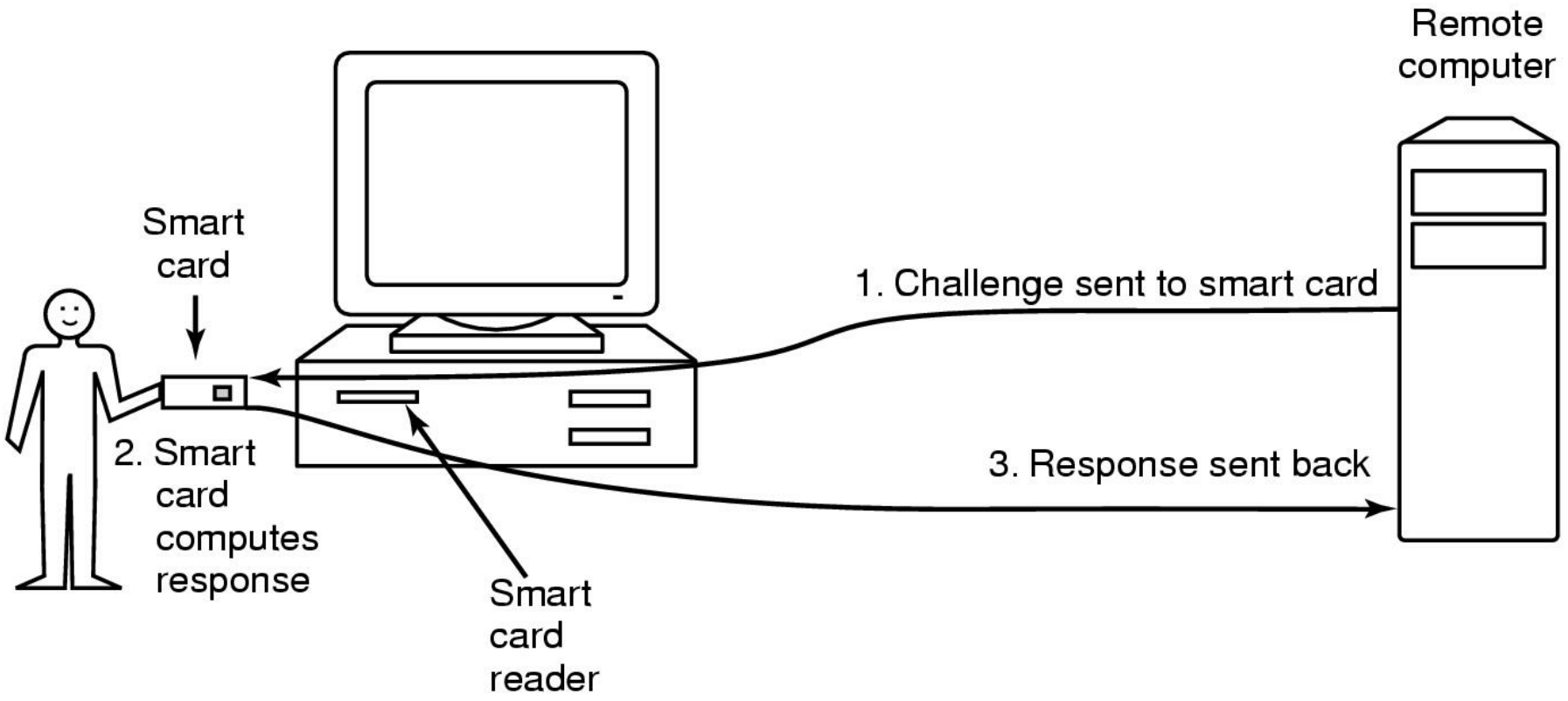
- New user provides server with list of ques/ans pairs
  - Server asks one of them at random
  - Requires a long list of question answer pairs
- Prove identity by computing a secret function
  - User picks an algorithm, e.g. x^2
  - Server picks a challenge, e.g. x=7
  - User sends back 49
  - Should be difficult to deduce function by looking at results
- In practice
  - Algorithm is fixed, e.g. one-way hash, but user selects a key
  - The server's challenge is combined with user's key to provide input to the function

Auth. Using Physical Objects

- Door keys have been around long
- Plastic card inserted into reader associated with comp
  - Also a password known to user, to protect against lost card
- Magnetic stripe cards: ~140 bytes info glued to card
  - Is read by terminal and sent to computer
  - Info contains encrypted user password (only bank knows key)
- Chip cards: have an integrated circuit
  - Stored value cards: have EEPROM memory but no CPU
    - Value on card can only be changed by CPU on another comp
  - Smart cards: 4 MHz 8-bit CPU, 16 KB ROM, 4 KB EEPROM, 512 bytes RAM, 9600 bps comm. channel

Smart Cards

- Better security than stored value cards
  - Card sends a small encrypted msg. to merchant, who can later use it to get money from the bank
  - Pros: no online connection to bank required
- Perform local computations, remember long passwords



Biometrics: something you are

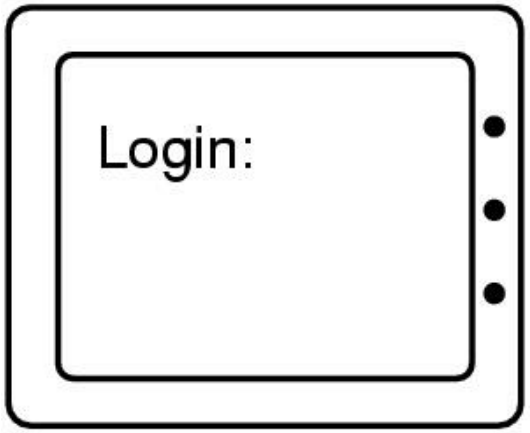
- System has 2 components:
  - Enrollment: measure characteristics and store on comp
  - Identification: match with user supplied values
- What are good characteristics?
  - Finger length, voice, hair color, retinal pattern, voice, blood
- Pros: user carries around a good password
- Cons: difficult to change password, can be subverted

Trojan Horse

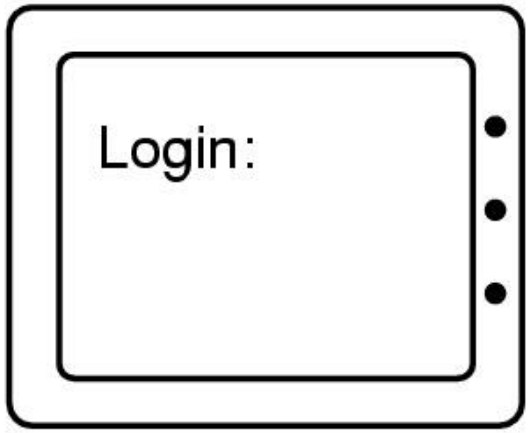
- Malicious program disguised as an innocent one
  - Could modify/delete user's file, send important info to cracker, etc
- The program has to get to the computer somehow
  - Cracker hides it as a new game, e-card, windows update site, etc.
- When run, Trojan Horse executes with user's privileges
- Examples:
  - Hide program in path directory as a common typo: *la* for *ls*
  - Malicious user puts malicious *ls* in directory, and attracts superuser
    - Malicious *ls* could make user the superuser
    - Denning's paper 1999

Login Spoofing

- Specialized case of Trojan Horse
  - Attacker displays a custom screen that user thinks belong to the system
  - User responds by typing in user name and password



(a)



(b)

  - Can be circumvented by key sequence that user programs cannot catch: e.g. CTRL+ALT+DEL in Windows

Logic Bombs

- Piece of code, in the OS or app, which is dormant until a certain time has elapsed or event has occurred
  - Event could be missing employee record from payroll
- Could act as a Trojan Horse/virus once triggered
- Also called “slag code” or “time bomb”
- Recovery options for a firm include:
  - Calling the police
  - Rehiring the programmer

Trap Doors

- Code in system inserted by programmer to bypass normal check
- Ken Thompson “Reflections on Trusting Trust”
  - Hole in UNIX system utility; enforced by C compiler

```
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);
```

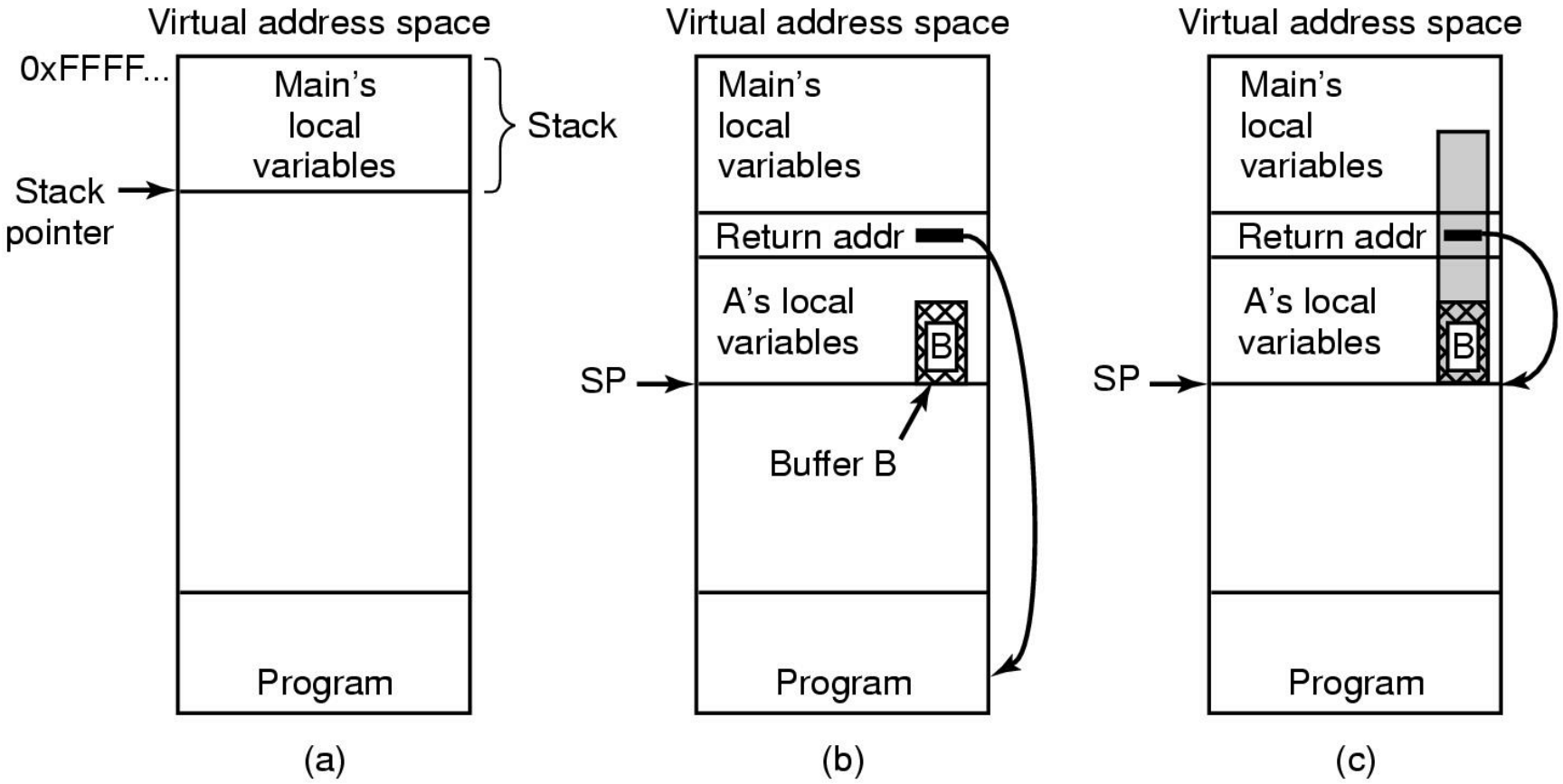
(a)

```
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)

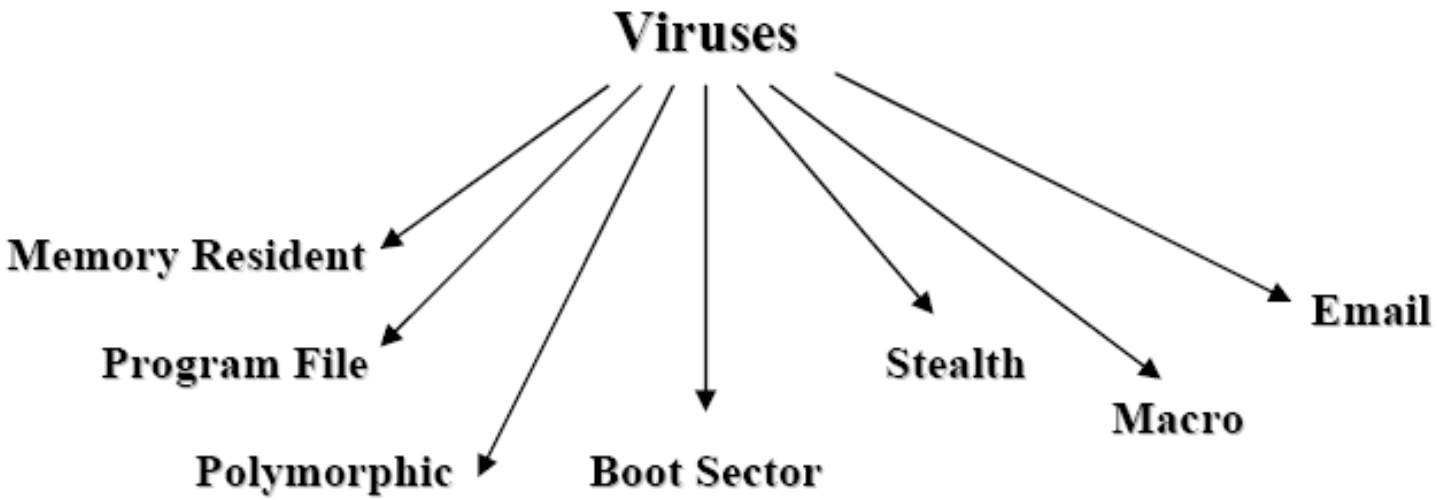
Buffer Overflow

- C compiler does no array bounds checking
  - A number of programs a written in C
  - Cracker can force his routine to run by violating array bounds



Viruses and Worms

- Virus is a program that reproduces itself by attaching its code to another program
  - They require human intervention to spread
  - Melissa, I LOVE YOU spread by e-mail
- Worms actively replicate without a helper program
  - Is a subclass of virus, but does not require user intervention
  - Sasser and Blaster targeted machines with out of date software



Denial of Service

- Client sends a legitimate-looking request for service to a service provider
- Service provider commits the necessary resources to provide the service
  - Ports, buffer space, bandwidth
- The resources are wasted, legitimate users get diminished service
  - Usually launched from many computers controlled by attackers
- Possible whenever the cost to ask for service is far cheaper than the cost of providing it
  - Challenge-response mechanism, selective packet tagging

Other Network Attacks

- Protocol attacks:
  - E.g. IEEE 802.11 WEP
- Brute force attacks
- Use Network Firewalls to reduce security risk

Trusted Systems

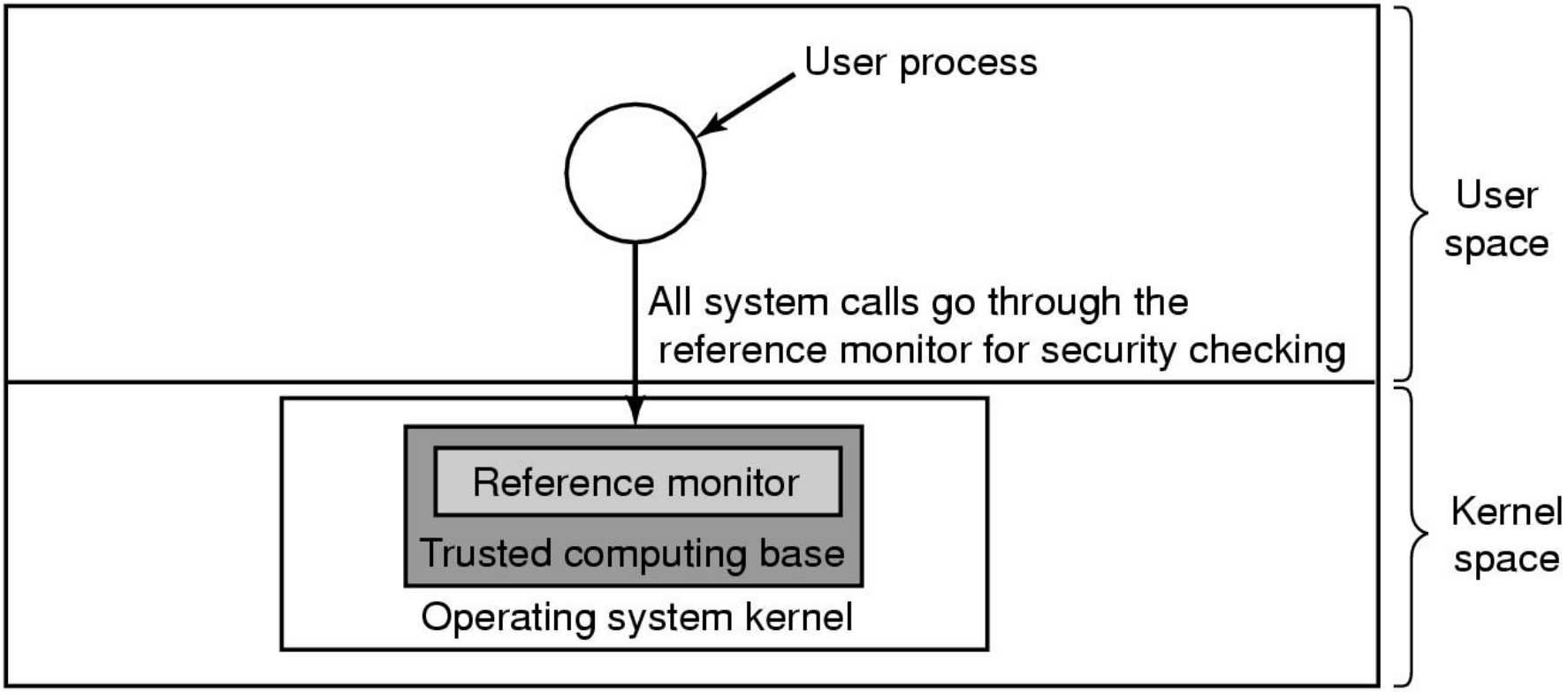
- The computer world is full of security problems
- Can we build a secure computer system?
  - Yes!
- Then why has it not been built yet?
  - Users unwilling to throw out existing systems
  - New systems have more features, so:
    - more complexity, code, bugs and security errors
- Examples: e-mail (from ASCII to Word), web (applets)
- Trusted Systems: formally stated security requirements, and how they are met

Trusted Computing Base (TCB)

- Heart of every trusted system has a small TCB
  - Hardware and software necessary for enforcing all security rules
  - Typically has:
    - most hardware,
    - Portion of OS kernel, and
    - most or all programs with superuser power
- Desirable features include:
  - Should be small
  - Should be separable and well defined
  - Easy to audit independently

Reference Monitor

- Critical component of the TCB
  - All sensitive operations go through the reference monitor
  - Monitor decides if the operation should proceed
  - Not there in most OSes



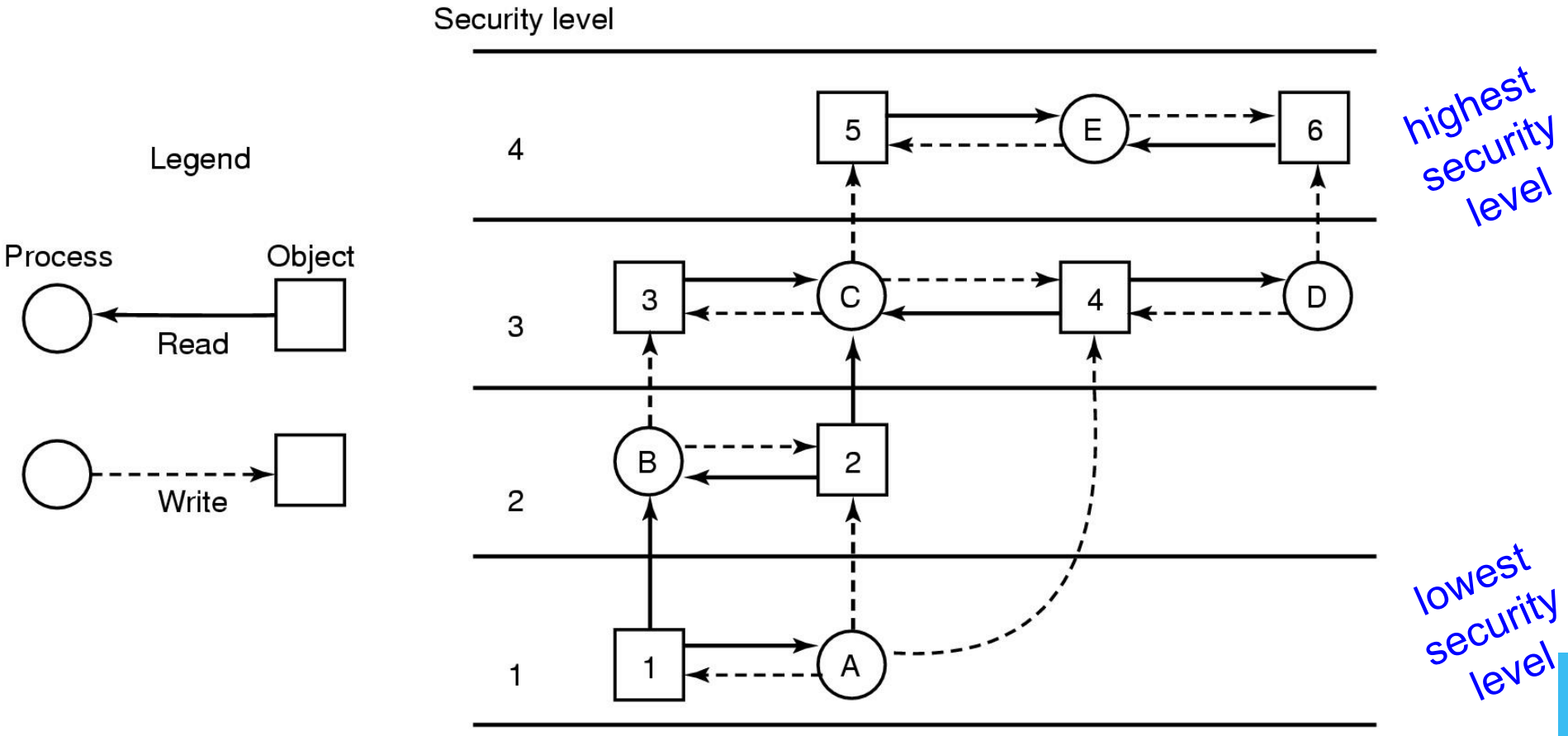
Access Control

- Discretionary Access Control (DAC)
  - Subjects can determine who has access to their objects
  - Commonly used, for example in Unix File System
  - Is flawed for tighter security, since program might be buggy
- Mandatory Access Control (MAC)
  - System imposes access control policy that object owner's cannot change
  - Multi-level Security as an example of MAC
    - MLS is environment where there are various security levels
      - Eg. Classify info as unclassified, confidential, secret, top secret
      - General sees all documents, lieutenant can only see below confidential
    - Restrict information flow in environments where various levels interact

Bell-La Padula Model

"no read up, no write down"

- Properties to satisfy for information flow
  - user at level 'k' can read objects at level j <= k
  - user at level 'k' can can write objects at level j >= k



Biba Model

"No write up, no read down"

- Integrity property: A user at security level k can write only objects at level j, j <= k
- The integrity * property: A user at level k can read only objects at level j, j >= k
- Want Bell-La Padula and Biba in the same system, for different types of objects
  - But Bell-La Padula and Biba are in direct conflict (Confidentiality vs. Data Integrity)
- In practice, a mix of DAC and MAC

Covert Channels

- Do these ideas make our system completely secure?
  - No. Security leaks possible even in a system proved secure mathematically. Lampson 1973
- Model: 3 processes. The client, server and collaborator
  - Server and collaborator collude
  - Goal: design a system where it is impossible for server to leak to the collaborator info received from the client (Confinement)
- Solution: Access Matrix prevents server to write to a file that collaborator has read access; no IPC either
- BUT: Covert Channel => compute hard for 1, sleep for a 0
- Others: paging, file locking with ACKs, pass secret info even though there is censor

Steganography

- Pictures appear the same

- Picture on right has text of 5 Shakespeare plays
  - encrypted, inserted into low order bits of color values

Orange Book

Dept. of Defense Standards DoD 5200.28 in 1985

- Known as Orange Book for the color of its cover

Categorizes OSes based on security property

- **D** – Minimal security.
- **C** – Provides discretionary protection through auditing. Divided into **C1** and **C2**. **C1** identifies cooperating users with the same level of protection. **C2** allows user-level access control.
- **B** – All the properties of **C**, however each object may have unique sensitivity labels. Divided into **B1**, **B2**, and **B3**.
- **A** – Uses formal design and verification techniques to ensure security.