Introduction to Malware*

Murat Kantarcioglu

Slides are based on Chapter 22 of the
"Computer Security" book by Bishop and the book's slides

Malicious Logic

- What is malicious logic
- Types of malicious logic
- Defenses

Overview

- Defining malicious logic
- Types
  - Trojan horses
  - Computer viruses and worms
  - Other types
- Defenses
  - Properties of malicious logic
  - Trust

Malicious Logic

- Set of instructions that cause site security policy to be violated

Example

- Shell script on a UNIX system:

```
cp /bin/sh /tmp/.xyzzy
chmod u+s,o+x /tmp/.xyzzy
rm ./ls
ls $*
```

- Place in program called “ls” and trick someone into executing it
- You now have a setuid-to-*them* shell!

Trojan Horse

- Program with an *overt* purpose (known to user) and a *covert* purpose (unknown to user)
  - Often called a Trojan
  - Named by Dan Edwards in Anderson Report
- Example: previous script is Trojan horse
  - Overt purpose: list files in directory
  - Covert purpose: create setuid shell

Example: NetBus

- Designed for Windows NT system
- Victim uploads and installs this
  - Usually disguised as a game program, or in one
- Acts as a server, accepting and executing commands for remote administrator
  - This includes intercepting keystrokes and mouse motions and sending them to attacker
  - Also allows attacker to upload, download files

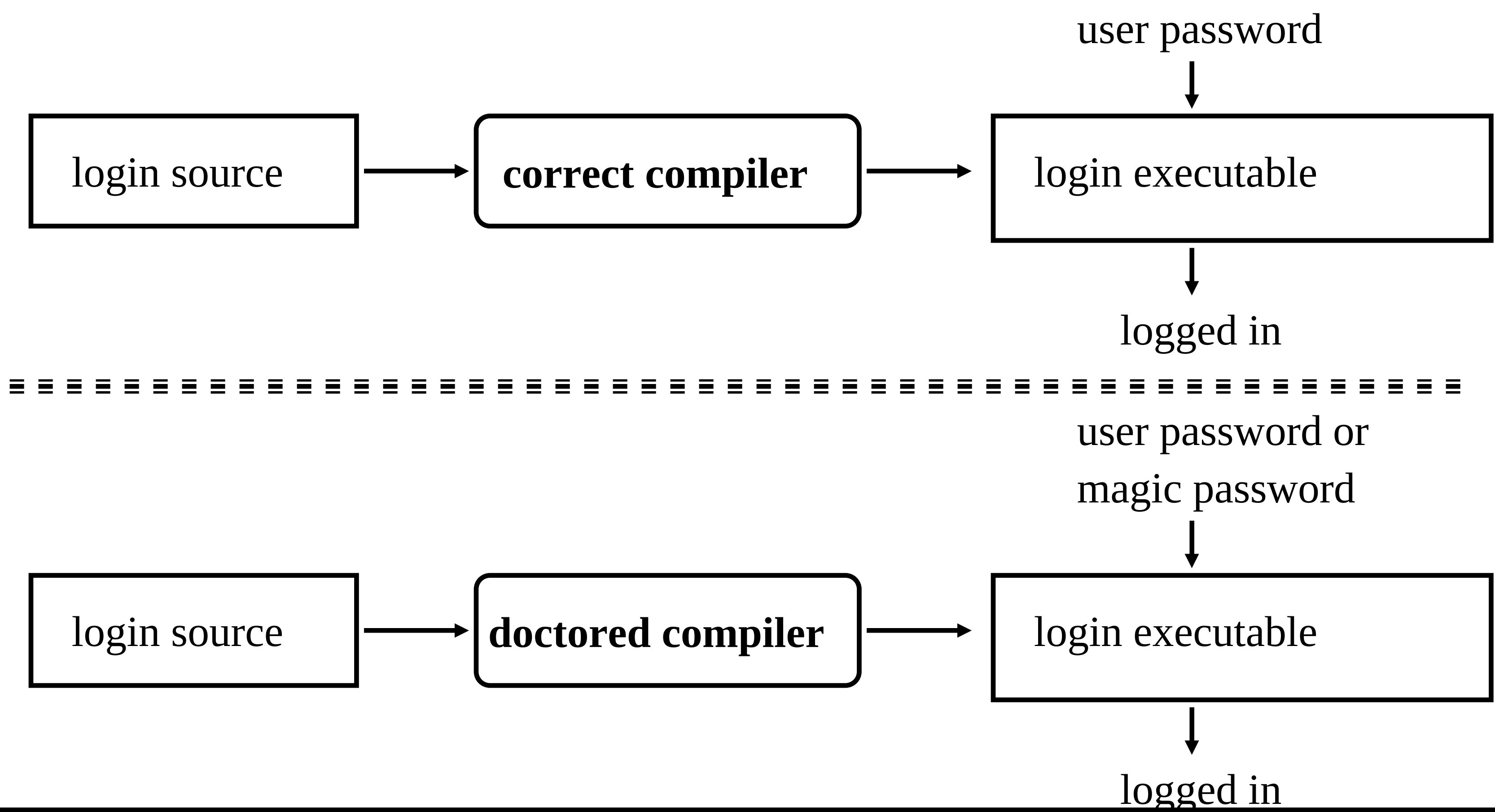
Replicating Trojan Horse

- Trojan horse that makes copies of itself
  - Also called *propagating Trojan horse*
  - Early version of *animal* game used this to delete copies of itself
- Hard to detect
  - 1976: Karger and Schell suggested modifying compiler to include Trojan horse that copied itself into specific programs including later version of the compiler
  - 1980s: Thompson implements this

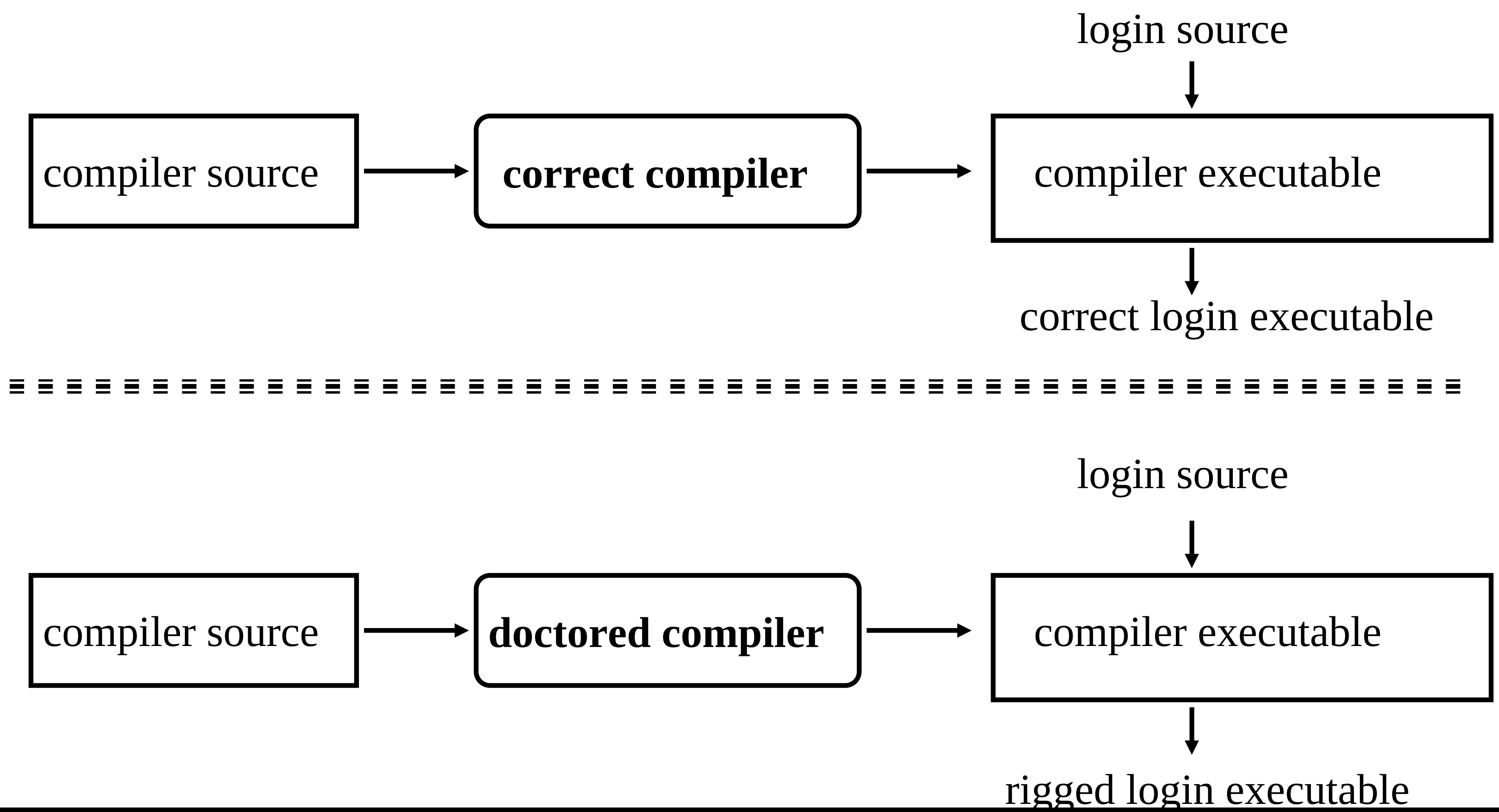
Thompson's Compiler

- Modify the compiler so that when it compiles *login* , *login* accepts the user's correct password or a fixed password (the same one for all users)
- Then modify the compiler again, so when it compiles a new version of the compiler, the extra code to do the first step is automatically inserted
- Recompile the compiler
- Delete the source containing the modification and put the undoctored source back

The Login Program



The Compiler



Comments

- Great pains taken to ensure second version of compiler never released
  - Finally deleted when a new compiler executable from a different system overwrote the doctored compiler
- The point: *no amount of source-level verification or scrutiny will protect you from using untrusted code*
  - Also: having source code helps, but does not ensure you’re safe

Computer Virus

- Program that inserts itself into one or more files and performs some action
  - *Insertion phase* is inserting itself into file
  - *Execution phase* is performing some (possibly null) action
- Insertion phase *must* be present
  - Need not always be executed
  - Lehigh virus inserted itself into boot file only if boot file not infected

Pseudocode

```
beginvirus:
  if spread-condition then begin
    for some set of target files do begin
      if target is not infected then begin
        determine where to place virus instructions
        copy instructions from beginvirus to endvirus
          into target
        alter target to execute added instructions
      end;
    end;
  end;
  perform some action(s)
  goto beginning of infected program
endvirus:
```

Trojan Horse Or Not?

- Yes
  - Overt action = infected program's actions
  - Covert action = virus' actions (infect, execute)
- No
  - Overt purpose = virus' actions (infect, execute)
  - Covert purpose = none
- Semantic, philosophical differences
  - Defenses against Trojan horse also inhibit computer viruses

History

- Programmers for Apple II wrote some
  - Not called viruses; very experimental
- Fred Cohen
  - Graduate student who described them
  - Teacher (Adleman) named it “computer virus”
  - Tested idea on UNIX systems and UNIVAC 1108 system

Cohen's Experiments

- UNIX systems: goal was to get superuser privileges
  - Max time 60m, min time 5m, average 30m
  - Virus small, so no degrading of response time
  - Virus tagged, so it could be removed quickly
- UNIVAC 1108 system: goal was to spread
  - Implemented simple security property of Bell-LaPadula
  - As writing not inhibited (no *-property enforcement), viruses spread easily

First Reports

- Brain (Pakistani) virus (1986)
  - Written for IBM PCs
  - Alters boot sectors of floppies, spreads to other floppies
- MacMag Peace virus (1987)
  - Written for Macintosh
  - Prints "universal message of peace" on March 2, 1988 and deletes itself

More Reports

- Duff's experiments (1987)
  - Small virus placed on UNIX system, spread to 46 systems in 8 days
  - Wrote a Bourne shell script virus
- Highland's Lotus 1-2-3 virus (1989)
  - Stored as a set of commands in a spreadsheet and loaded when spreadsheet opened
  - Changed a value in a specific row, column and spread to other files

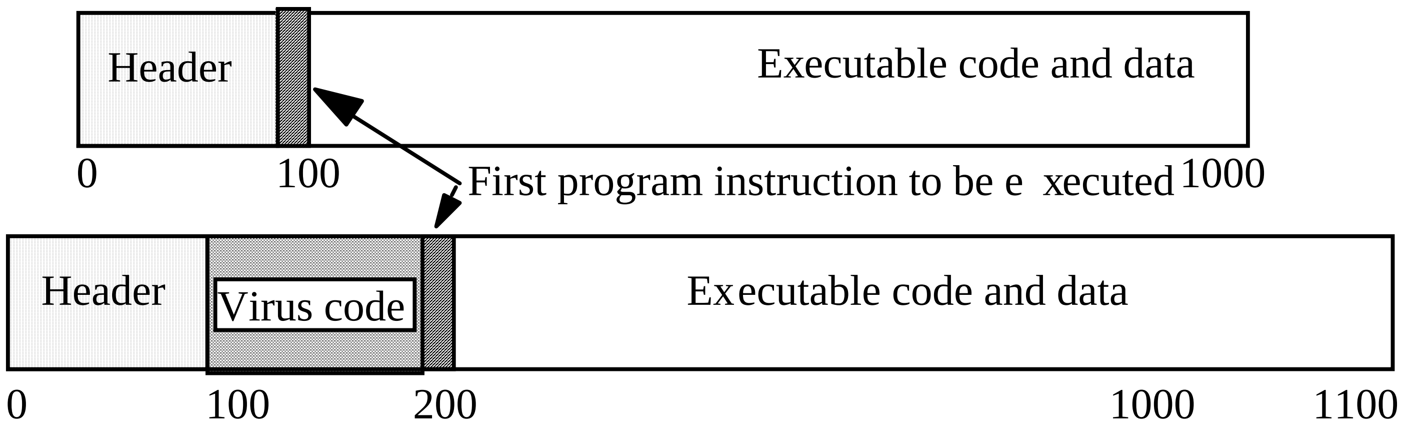
Types of Viruses

- Boot sector infectors
- Executable infectors
- Multipartite viruses
- TSR viruses
- Stealth viruses
- Encrypted viruses
- Polymorphic viruses
- Macro viruses

Boot Sector Infectors

- A virus that inserts itself into the boot sector of a disk
  - Section of disk containing code
  - Executed when system first “sees” the disk
    - Including at boot time …
- Example: Brain virus
  - Moves disk interrupt vector from 13H to 6DH
  - Sets new interrupt vector to invoke Brain virus
  - When new floppy seen, check for 1234H at location 4
    - If not there, copies itself onto disk after saving original boot block

Executable Infectors



- A virus that infects executable programs
  - Can infect either .EXE or .COM on PCs
  - May prepend itself (as shown) or put itself anywhere, fixing up binary so it is executed at some point

Executable Infectors (*con't*)

- Jerusalem (Israeli) virus
  - Checks if system infected
    - If not, set up to respond to requests to execute files
  - Checks date
    - If not 1987 or Friday 13th, set up to respond to clock interrupts and then run program
    - Otherwise, set destructive flag; will delete, not infect, files
  - Then: check all calls asking files to be executed
    - Do nothing for COMND.COM
    - Otherwise, infect or delete
  - Error: doesn't set signature when .EXE executes
    - So .EXE files continually reinfected

Multipartite Viruses

- A virus that can infect either boot sectors or executables
- Typically, two parts
  - One part boot sector infector
  - Other part executable infector

TSR Viruses

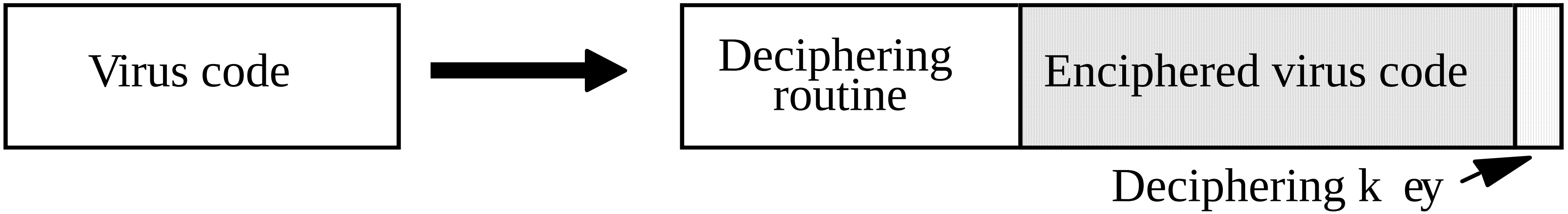
- A virus that stays active in memory after the application (or bootstrapping, or disk mounting) is completed
  - TSR is “Terminate and Stay Resident”
- Examples: Brain, Jerusalem viruses
  - Stay in memory after program or disk mount is completed

Stealth Viruses

- A virus that conceals infection of files
- Example: IDF virus modifies DOS service interrupt handler as follows:
  - Request for file length: return length of *uninfected* file
  - Request to open file: temporarily disinfect file, and reinfect on closing
  - Request to load file for execution: load infected file

Encrypted Viruses

- A virus that is enciphered except for a small deciphering routine
  - Detecting virus by signature now much harder as most of virus is enciphered



Example

```
(* Decryption code of the 1260 virus *)
(* initialize the registers with the keys *)
rA = k1; rB = k2;
(* initialize rC with the virus;
   starts at sov, ends at eov *)
rC = sov;
(* the encipherment loop *)
while (rC != eov) do begin
      (* encipher the byte of the message *)
      (*rC) = (*rC) xor rA xor rB;
      (* advance all the counters *)
      rC = rC + 1;
      rA = rA + 1;
end
```

Polymorphic Viruses

- A virus that changes its form each time it inserts itself into another program
- Idea is to prevent signature detection by changing the "signature" or instructions used for deciphering routine
- At instruction level: substitute instructions
- At algorithm level: different algorithms to achieve the same purpose
- Toolkits to make these exist (Mutation Engine, Trident Polymorphic Engine)

Example

- These are different instructions (with different bit patterns) but have the same effect:
  - add 0 to register
  - subtract 0 from register
  - xor 0 with register
  - no-op
- Polymorphic virus would pick randomly from among these instructions

Macro Viruses

- A virus composed of a sequence of instructions that are interpreted rather than executed directly
- Can infect either executables (Duff’s shell virus) or data files (Highland’s Lotus 1-2-3 spreadsheet virus)
- Independent of machine architecture
  - But their effects may be machine dependent

Example

- Melissa
  - Infected Microsoft Word 97 and Word 98 documents
    - Windows and Macintosh systems
  - Invoked when program opens infected file
  - Installs itself as “open” macro and copies itself into Normal template
    - This way, infects any files that are opened in future
  - Invokes mail program, sends itself to everyone in user’s address book

Computer Worms

- A program that copies itself from one computer to another
- Origins: distributed computations
  - Schoch and Hupp: animations, broadcast messages
  - Segment: part of program copied onto workstation
  - Segment processes data, communicates with worm's controller
  - Any activity on workstation caused segment to shut down

Example: Internet Worm of 1988

- Targeted Berkeley, Sun UNIX systems
  - Used virus-like attack to inject instructions into running program and run them
  - To recover, had to disconnect system from Internet and reboot
  - To prevent re-infection, several critical programs had to be patched, recompiled, and reinstalled
- Analysts had to disassemble it to uncover function
- Disabled several thousand systems in 6 or so hours

Example: Christmas Worm

- Distributed in 1987, designed for IBM networks
- Electronic letter instructing recipient to save it and run it as a program
  - Drew Christmas tree, printed “Merry Christmas!”
  - Also checked address book, list of previously received email and sent copies to each address
- Shut down several IBM networks
- Really, a macro worm
  - Written in a command language that was interpreted

Rabbits, Bacteria

- A program that absorbs all of some class of resources
- Example: for UNIX system, shell commands:

```
while true
do
    mkdir x
    chdir x
done
```

- Exhausts either disk space or file allocation table (inode) space

Logic Bombs

- A program that performs an action that violates the site security policy when some external event occurs
- Example: program that deletes company's payroll records when one particular record is deleted
  - The "particular record" is usually that of the person writing the logic bomb
  - Idea is if (when) he or she is fired, and the payroll record deleted, the company loses *all* those records

Defenses

- Distinguish between data, instructions
- Limit objects accessible to processes
- Inhibit sharing
- Detect altering of files
- Detect actions beyond specifications
- Analyze statistical characteristics

Data vs. Instructions

- Malicious logic is both
  - Virus: written to program (data); then executes (instructions)
- Approach: treat “data” and “instructions” as separate types, and require certifying authority to approve conversion
  - Keys are assumption that certifying authority will *not* make mistakes and assumption that tools, supporting infrastructure used in certifying process are not corrupt

Example: LOCK

- Logical Coprocessor Kernel
  - Designed to be certified at TCSEC A1 level
- Compiled programs are type “data”
  - Sequence of specific, auditable events required to change type to “executable”
- Cannot modify “executable” objects
  - So viruses can’t insert themselves into programs (no infection phase)

Example: Duff and UNIX

- Observation: users with execute permission usually have read permission, too
  - So files with “execute” permission have type “executable”; those without it, type “data”
  - Executable files can be altered, but type immediately changed to “data”
    - Implemented by turning off execute permission
    - Certifier can change them back
      - So virus can spread only if run as certifier

Limiting Accessibility

- Basis: a user (unknowingly) executes malicious logic, which then executes with all that user's privileges
  - Limiting accessibility of objects should limit spread of malicious logic and effects of its actions
- Approach draws on mechanisms for confinement

Information Flow Metrics

- Idea: limit distance a virus can spread
- Flow distance metric $fd(x)$:
  - Initially, all info x has $fd(x) = 0$
  - Whenever info y is shared, $fd(y)$ increases by 1
  - Whenever $y_1, \ldots, y_n$ used as input to compute z, $fd(z) = \max(fd(y_1), \ldots, fd(y_n))$
- Information x accessible if and only if for some parameter V, $fd(x) < V$

Example

- Anne: $V_A = 3$; Bill, Cathy: $V_B = V_C = 2$
- Anne creates program P containing virus
- Bill executes P
  - P tries to write to Bill's program Q
    - Works, as $fd(P) = 0$, so $fd(Q) = 1 < V_B$
- Cathy executes Q
  - Q tries to write to Cathy's program R
    - Fails, as $fd(Q) = 1$, so $fd(R)$ would be 2
- Problem: if Cathy executes P, R can be infected
  - So, does not stop spread; slows it down greatly, though

Implementation Issues

- Metric associated with *information*, not *objects*
  - You can tag files with metric, but how do you tag the information in them?
  - This inhibits sharing
- To stop spread, make V = 0
  - Disallows sharing
  - Also defeats purpose of multi-user systems, and is crippling in scientific and developmental environments
    - Sharing is critical here

Reducing Protection Domain

- Application of principle of least privilege
- Basic idea: remove rights from process so it can only perform its function
  - Warning: if that function requires it to write, it can write anything
  - But you can make sure it writes only to those objects you expect

Example: ACLs

- s_1 owns file f_1 and s_2 owns program p_2 and file f_3
  - Suppose s_1 can read, write f_1, execute p_2, write f_3
  - Suppose s_2 can read, write, execute p_2 and read f_3
- s_1 needs to run p_2
  - p_2 contains Trojan horse
    - So s_1 needs to ensure p_{12} (subject created when s_1 runs p_2) can't write to f_3
  - Ideally, p_{12} has capability { (s_1, p_2, x) } so no problem
    - In practice, p_{12} inherits s_1's rights—bad! Note s_1 does not own f_3, so can't change its rights over f_3
- Solution: restrict access by others

Authorization Denial Subset

- Defined for each user s_i
- Contains ACL entries that others cannot exercise over objects s_i owns
- In example: $R(s_2) = \{ (s_1, f_3, w) \}$
  - So when p_{12} tries to write to f_3, as p_{12} owned by s_1 and f_3 owned by s_2, system denies access
- Problem: how do you decide what should be in your authorization denial subset?

Karger's Scheme

- Base it on attribute of subject, object
- Interpose a knowledge-based subsystem to determine if requested file access reasonable
  - Sits between kernel and application
- Example: UNIX C compiler
  - Reads from files with names ending in ".c", ".h"
  - Writes to files with names beginning with "/tmp/ctm" and assembly files with names ending in ".s"
- When subsystem invoked, if C compiler tries to write to ".c" file, request rejected

Lai and Gray

- Implemented modified version of Karger's scheme on UNIX system
  - Allow programs to access (read or write) files named on command line
  - Prevent access to other files
- Two types of processes
  - Trusted (no access checks or restrictions)
  - Untrusted (valid access list controls access)
    - VAL initialized to command line arguments plus any temporary files that the process creates

File Access Requests

1. If file on VAL, use effective UID/GID of process to determine if access allowed
2. If access requested is read and file is world-readable, allow access
3. If process creating file, effective UID/GID controls allowing creation
   – Enter file into VAL as NNA (new non-argument); set permissions so no other process can read file
4. Ask user. If yes, effective UID/GID controls allowing access; if no, deny access

Example

- Assembler invoked from compiler

  `as x.s /tmp/ctm2345`

  and creates temp file /tmp/as1111
  - VAL is

    `x.s /tmp/ctm2345 /tmp/as1111`
- Now Trojan horse tries to copy x.s to another file
  - On creation, file inaccessible to all except creating user so attacker cannot read it (rule 3)
  - If file created already and assembler tries to write to it, user is asked (rule 4), thereby revealing Trojan horse

Trusted Programs

- No VALs applied here
  - UNIX command interpreters
    - csh, sh
  - Program that spawn them
    - getty, login
  - Programs that access file system recursively
    - ar, chgrp, chown, diff, du, dump, find, ls, restore, tar
  - Programs that often access files not in argument list
    - binmail, cpp, dbx, mail, make, script, vi
  - Various network daemons
    - fingerd, ftpd, sendmail, talkd, telnetd, tftpd

Guardians, Watchdogs

- System intercepts request to open file
- Program invoked to determine if access is to be allowed
  - These are *guardians* or *watchdogs*
- Effectively redefines system (or library) calls

Trust

- Trust the user to take explicit actions to limit their process' protection domain sufficiently
  - That is, enforce least privilege correctly
- Trust mechanisms to describe programs' expected actions sufficiently for descriptions to be applied, and to handle commands without such descriptions properly
- Trust specific programs and kernel
  - Problem: these are usually the first programs malicious logic attack

Sandboxing

- Sandboxes, virtual machines also restrict rights
  - Modify program by inserting instructions to cause traps when violation of policy
  - Replace dynamic load libraries with instrumented routines

Example: Race Conditions

- Occur when successive system calls operate on object
  - Both calls identify object by name
  - Rebind name to different object between calls
- Sandbox: instrument calls:
  - Unique identifier (inode) saved on first call
  - On second call, inode of named file compared to that of first call
    - If they differ, potential attack underway …

Inhibit Sharing

- Use separation implicit in integrity policies
- Example: LOCK keeps single copy of shared procedure in memory
  - Master directory associates unique owner with each procedure, and with each user a list of other users the first trusts
  - Before executing any procedure, system checks that user executing procedure trusts procedure owner

Multilevel Policies

- Put programs at the lowest security level, all subjects at higher levels
  - By *-property, nothing can write to those programs
  - By ss-property, anything can read (and execute) those programs
- Example: DG/UX system
  - All executables in “virus protection region” below user and administrative regions

Detect Alteration of Files

- Compute manipulation detection code (MDC) to generate signature block for each file, and save it
- Later, recompute MDC and compare to stored MDC
  - If different, file has changed
- Example: tripwire
  - Signature consists of file attributes, cryptographic checksums chosen from among MD4, MD5, HAVAL, SHS, CRC-16, CRC-32, etc.)

Assumptions

- Files do not contain malicious logic when original signature block generated
- Pozzo & Grey: implement Biba's model on LOCUS to make assumption explicit
  - Credibility ratings assign trustworthiness numbers from 0 (untrusted) to *n* (signed, fully trusted)
  - Subjects have risk levels
    - Subjects can execute programs with credibility ratings ≥ risk level
    - If credibility rating < risk level, must use special command to run program

Antivirus Programs

- Look for specific sequences of bytes (called “virus signature” in file
  - If found, warn user and/or disinfect file
- Each agent must look for known set of viruses
- Cannot deal with viruses not yet analyzed
  - Due in part to undecidability of whether a generic program is a virus

Detect Actions Beyond Spec

- Treat execution, infection as errors and apply fault tolerant techniques
- Example: break program into sequences of nonbranching instructions
  - Checksum each sequence, encrypt result
  - When run, processor recomputes checksum, and at each branch co-processor compares computed checksum with stored one
    - If different, error occurred

N-Version Programming

- Implement several different versions of algorithm
- Run them concurrently
  - Check intermediate results periodically
  - If disagreement, majority wins
- Assumptions
  - Majority of programs not infected
  - Underlying operating system secure
  - Different algorithms with enough equal intermediate results may be infeasible
    - Especially for malicious logic, where you would check file accesses

Proof-Carrying Code

- Code consumer (user) specifies safety requirement
- Code producer (author) generates proof code meets this requirement
  - Proof integrated with executable code
  - Changing the code invalidates proof
- Binary (code + proof) delivered to consumer
- Consumer validates proof
- Example statistics on Berkeley Packet Filter: proofs 300–900 bytes, validated in 0.3 –1.3 ms
  - Startup cost higher, runtime cost considerably shorter

Detecting Statistical Changes

- Example: application had 3 programmers working on it, but statistical analysis shows code from a fourth person—may be from a Trojan horse or virus!
- Other attributes: more conditionals than in original; look for identical sequences of bytes not common to any library routine; increases in file size, frequency of writing to executables, etc.
  - Denning: use intrusion detection system to detect these

Key Points

- A perplexing problem
  - How do you tell what the user asked for is *not* what the user intended?
- Strong typing leads to separating data, instructions
- File scanners most popular anti-virus agents
  - Must be updated as new viruses come out