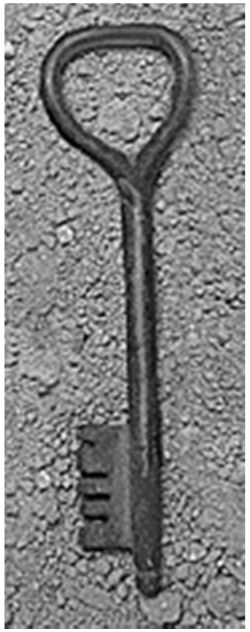
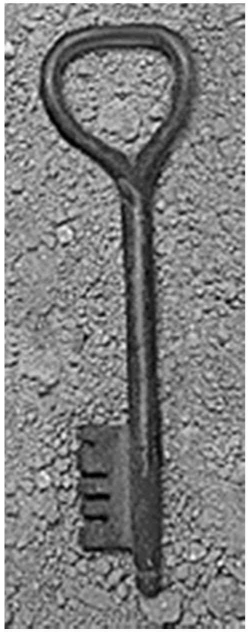
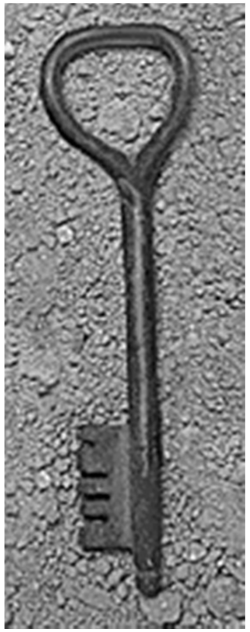


Malicious Code/Logic



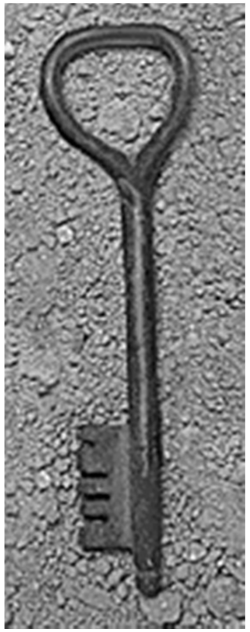
Overview

- 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

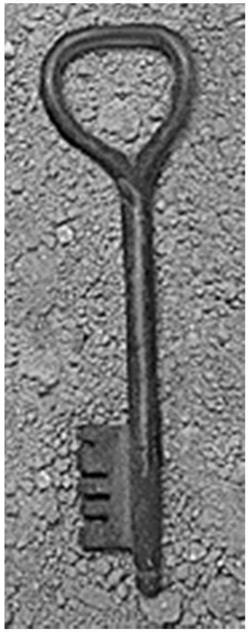


Example

- 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!



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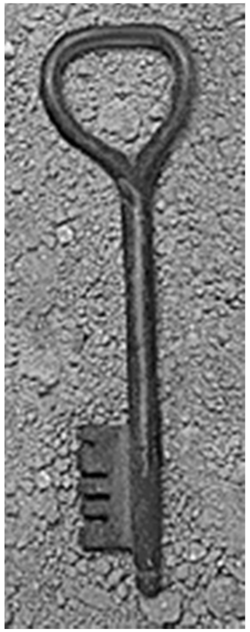
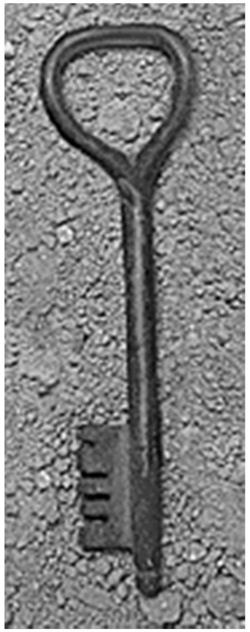


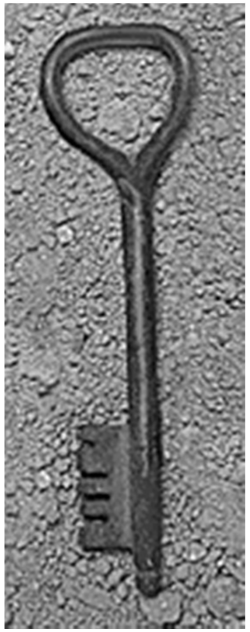
Trojan Horse

- Program with an *overt* purpose (known to user) and a *covert* purpose (unknown to user)
  - Often called a Trojan
  - Named by Dan Edwards in 1974 Anderson Report
- Example: previous script is Trojan horse
  - Overt purpose: list files in directory
  - Covert purpose: create setuid shell



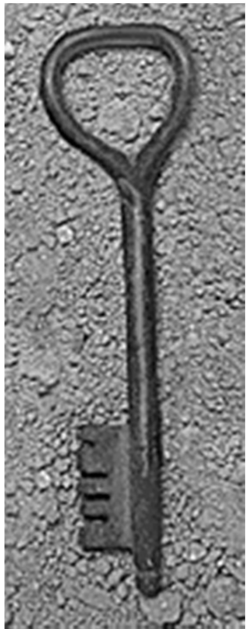
Example: NetBus

- 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



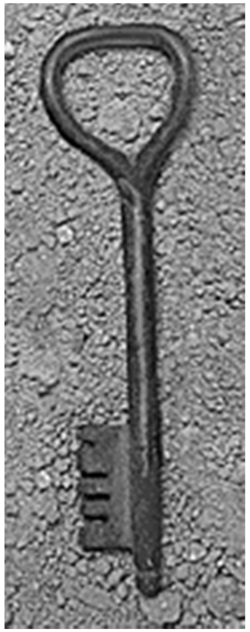
Replicating Trojan Horse

- Trojan horse that makes copies of itself
  - Also called *propagating Trojan horse*
- 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

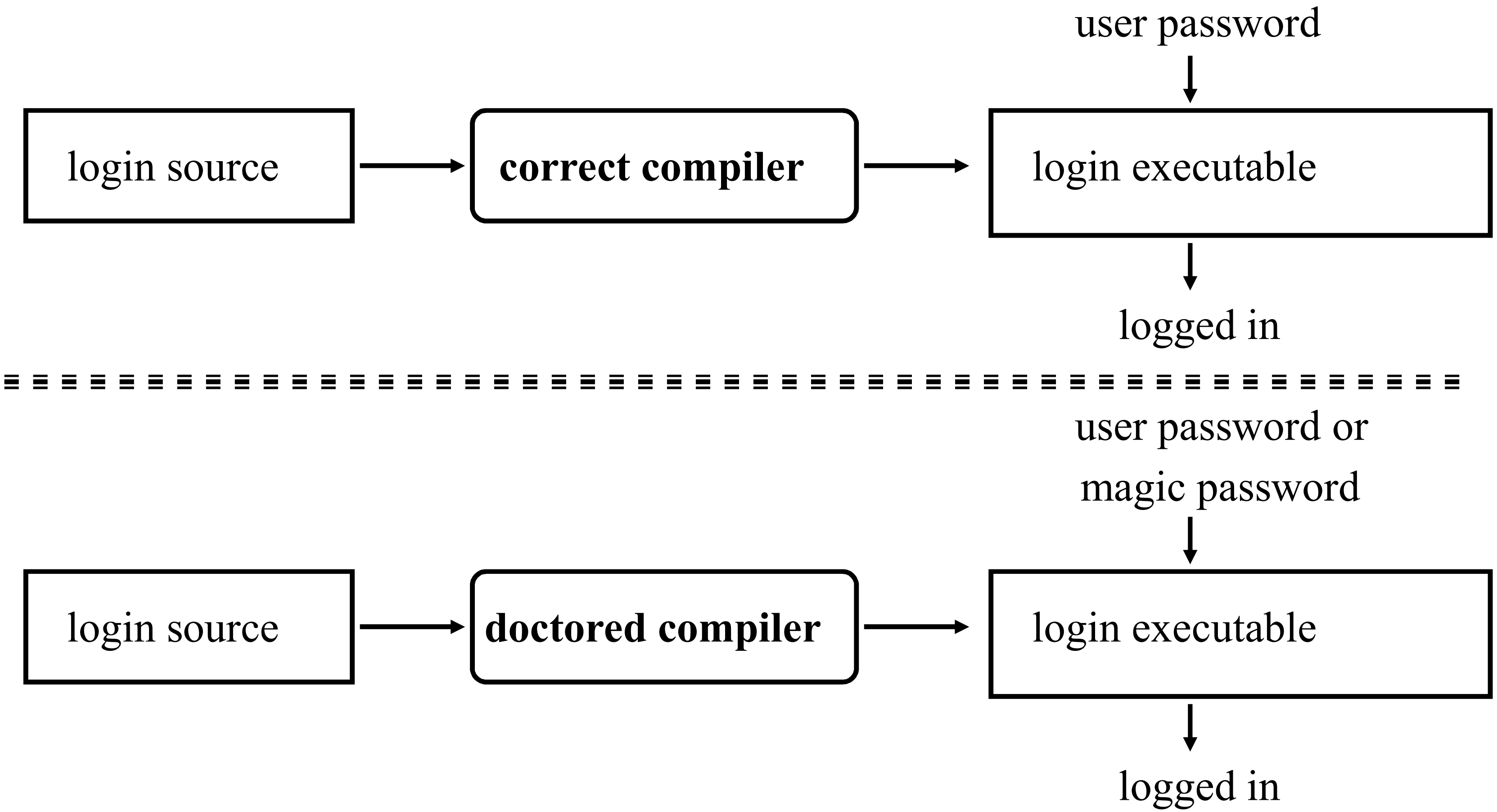


Thompson's Compiler

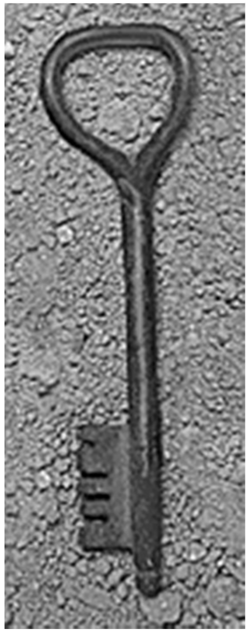
- Modify the compiler so that when it compiles *login* , *login* accepts the user's correct password or a fixed password (the same one for all users)
- Then modify the compiler again, so when it compiles a new version of the compiler, the extra code to do the first step is automatically inserted
- Recompile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

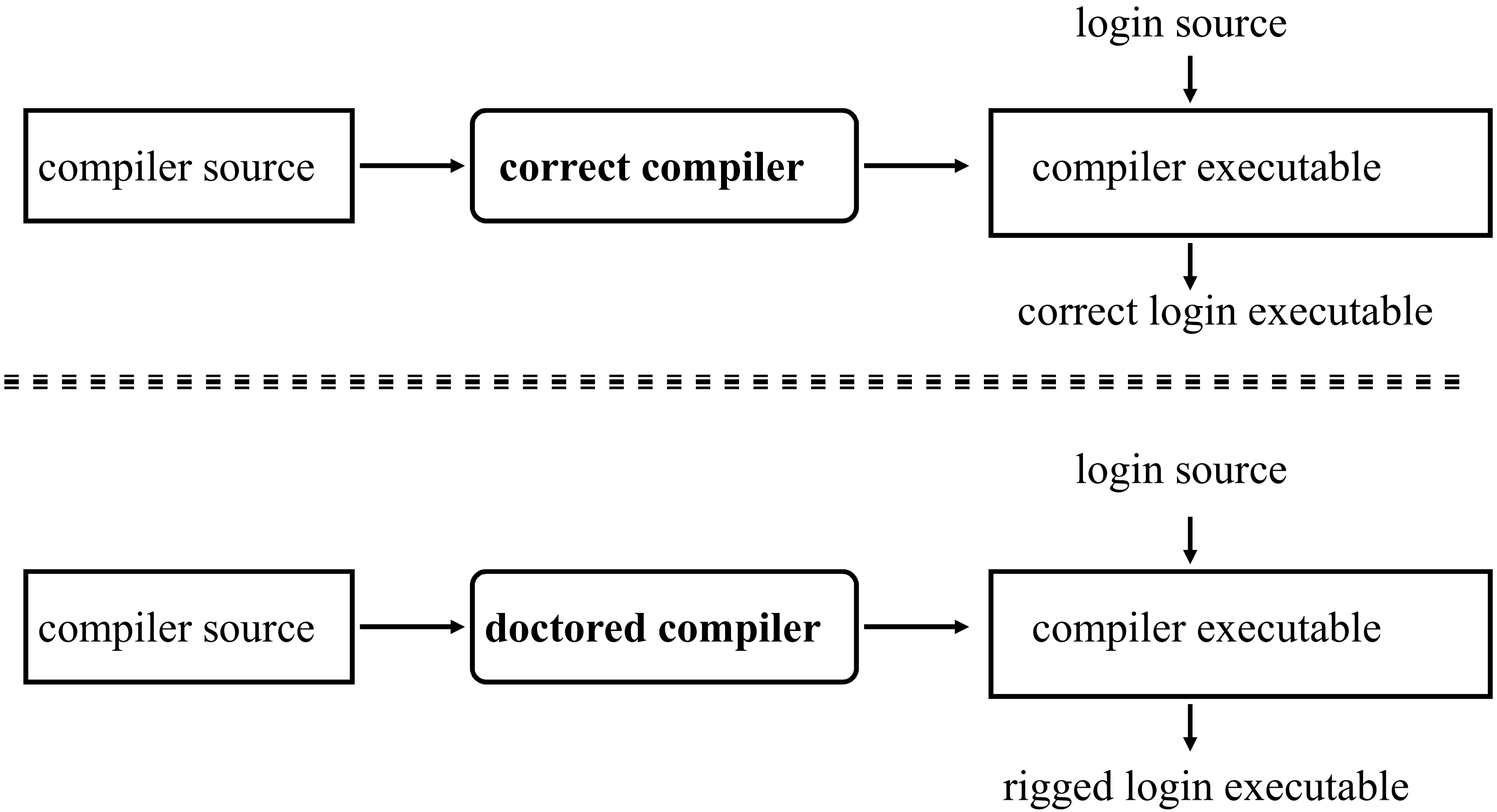


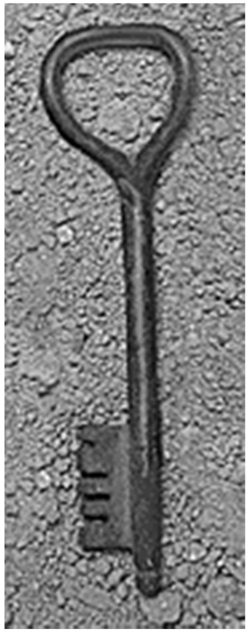
The Login Program



The Compiler

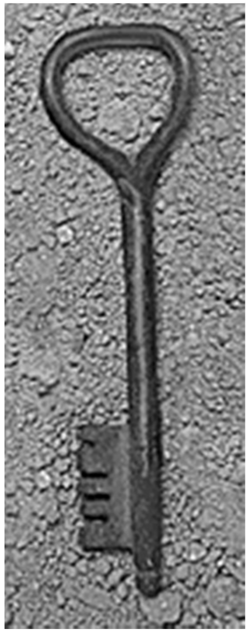






Comments

- 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



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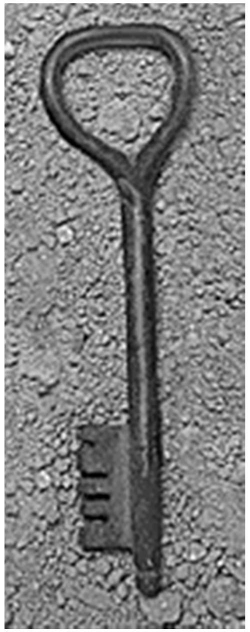
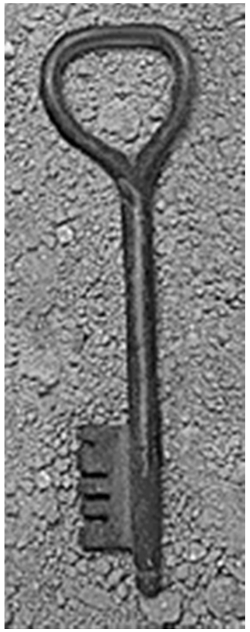


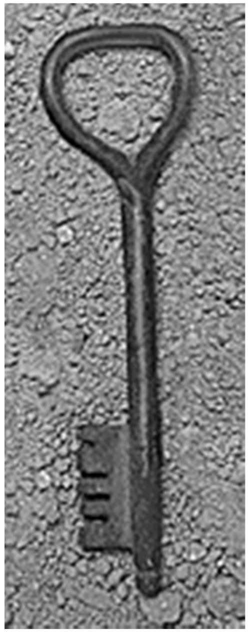
Computer Virus

- 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



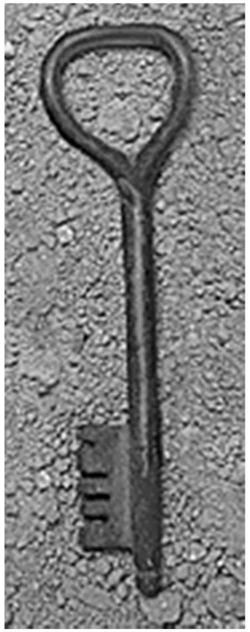
Pseudocode

```
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:
```



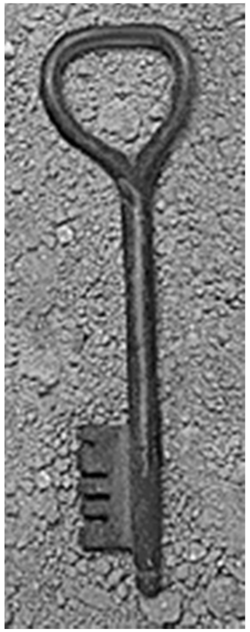
History

- Programmers for Apple II wrote some in 1980
  - Not called viruses; very experimental
- Fred Cohen
  - Graduate student who described them in 1983
  - Teacher (Adleman) named it “computer virus”
  - Tested idea on UNIX systems and UNIVAC 1108 system in 1984



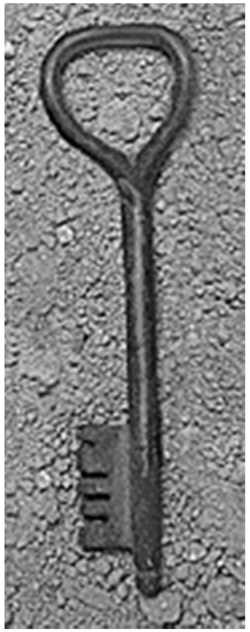
Cohen's Experiments

- 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 (MAC): goal was to spread
  - Implemented simple security property of Bell-LaPadula
  - As writing not inhibited (no *-property enforcement), viruses spread easily



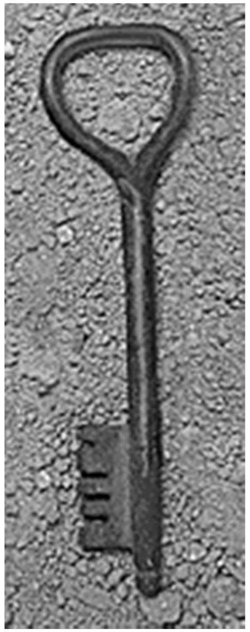
First Reports

- 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



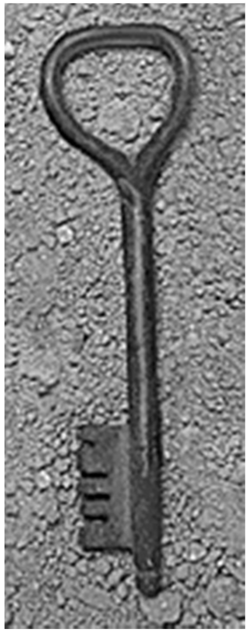
More Reports

- Duff's experiments (1987)
  - Wrote a Bourne shell script virus
  - Small virus placed on UNIX system, spread to 46 systems in 8 days
- 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



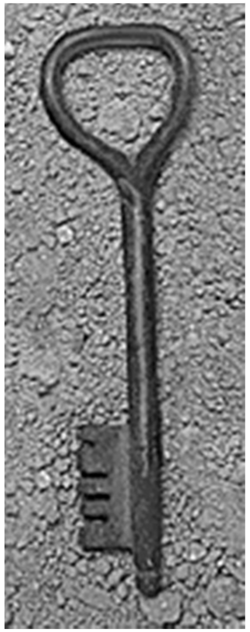
Types of Viruses

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

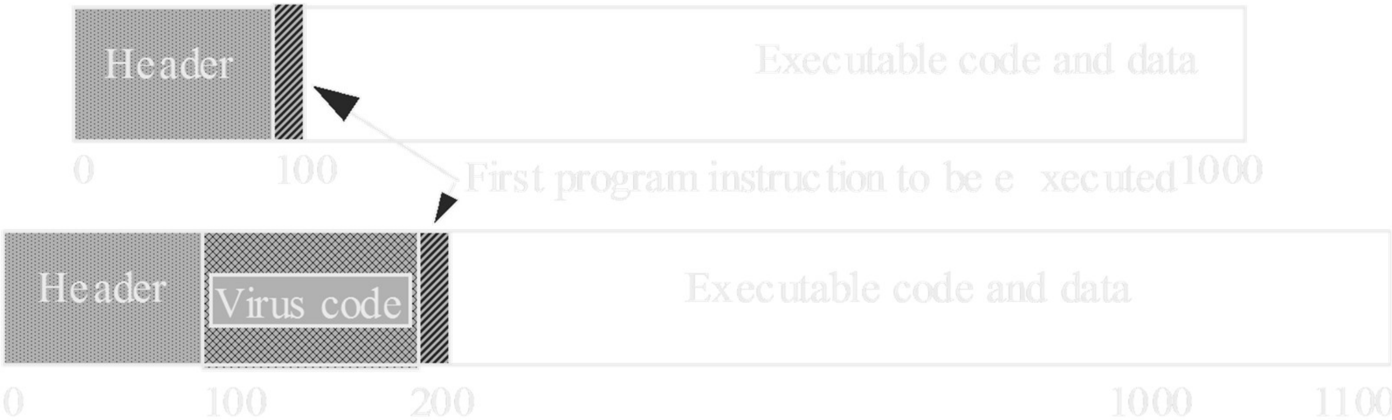


Boot Sector Infectors

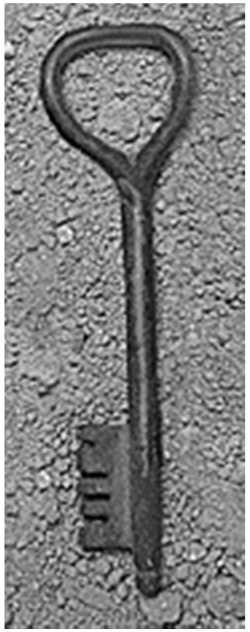
- A virus that inserts itself into the boot sector of a disk
  - Section of disk containing code
  - Executed when system first "sees" the disk
    - Including at boot time …
- Example: Brain virus
  - Moves disk interrupt vector from 13H to 6DH
  - Sets new interrupt vector to invoke Brain virus
  -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



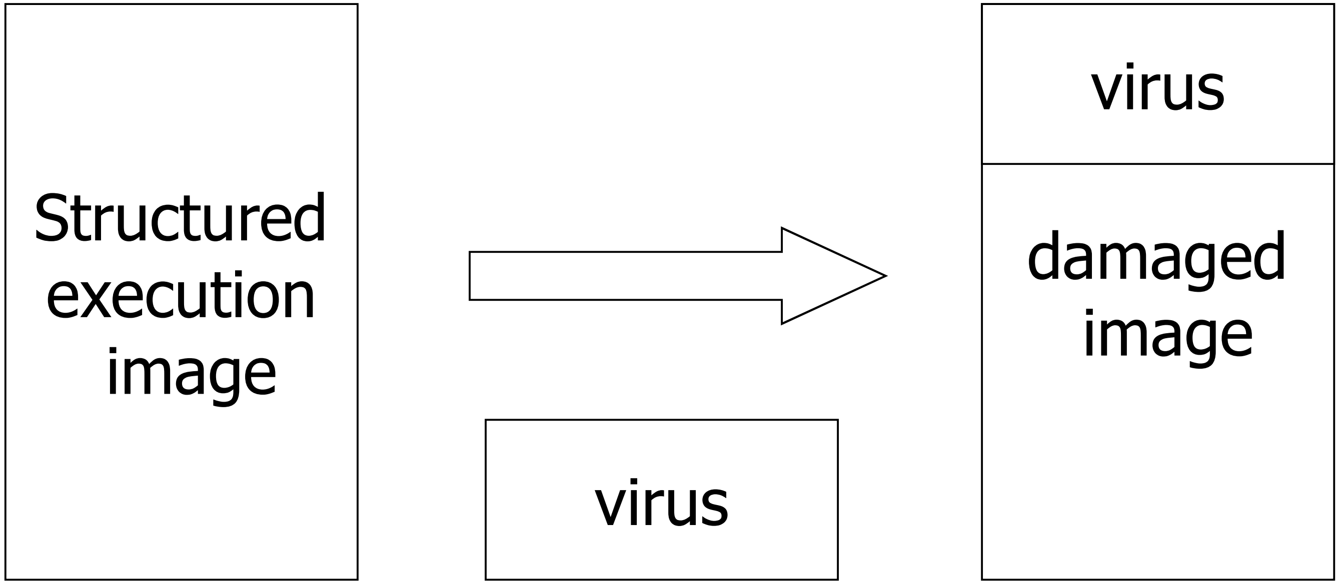
Executable Infectors



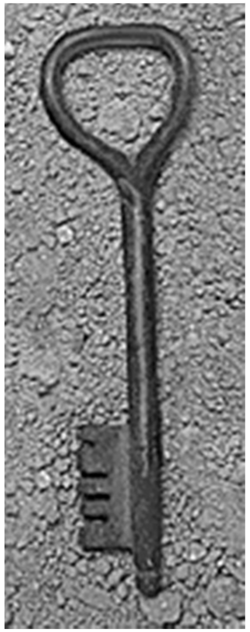
- A virus that infects executable programs
  - Can infect either .EXE or .COM on PCs
  - May prepend itself (as shown) or put itself anywhere, fixing up binary so it is executed at some point



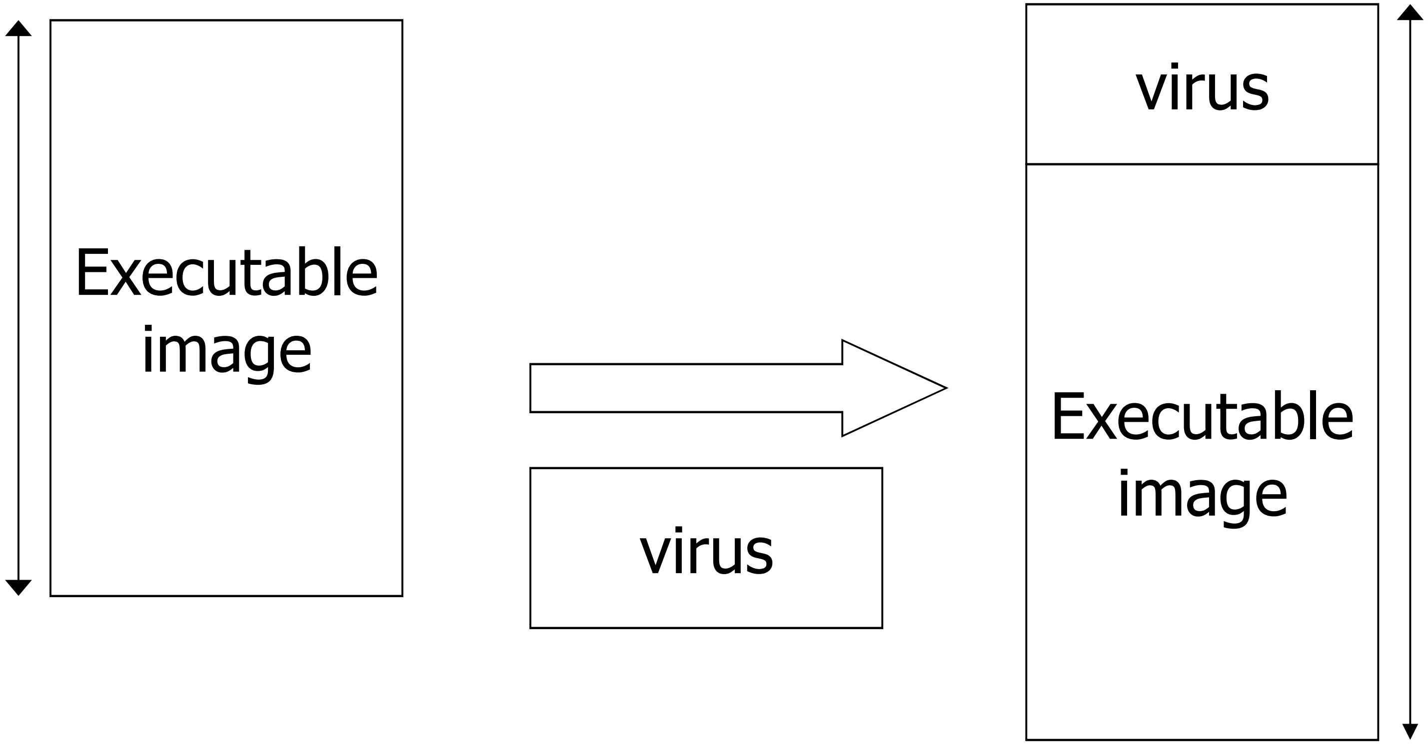
Means of attaching: overwriting (virus *replaces* part of program)



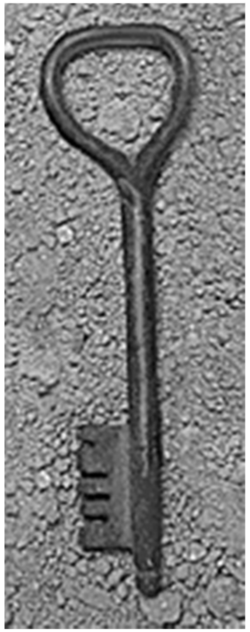
- Virus overwrites an executable file
- Easiest mechanism
- Since original program is damaged easily detected



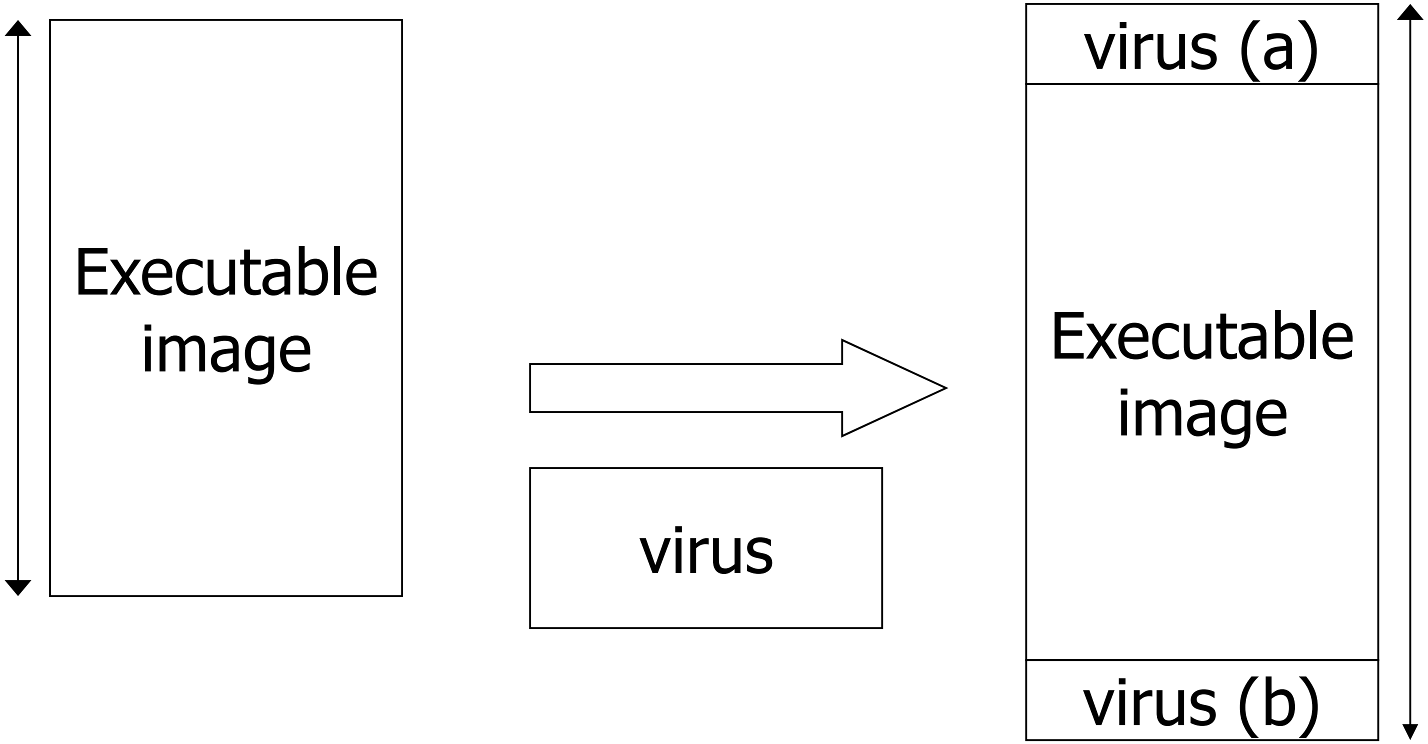
Means of attaching: at the beginning (virus is *appended* to program)



- Improved stealth because original program is intact
- If original program is large, copying it may be slow
- File size grows if multiple infections occur

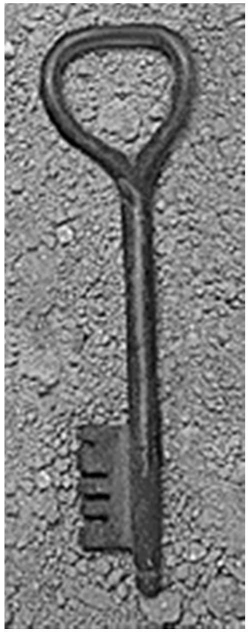


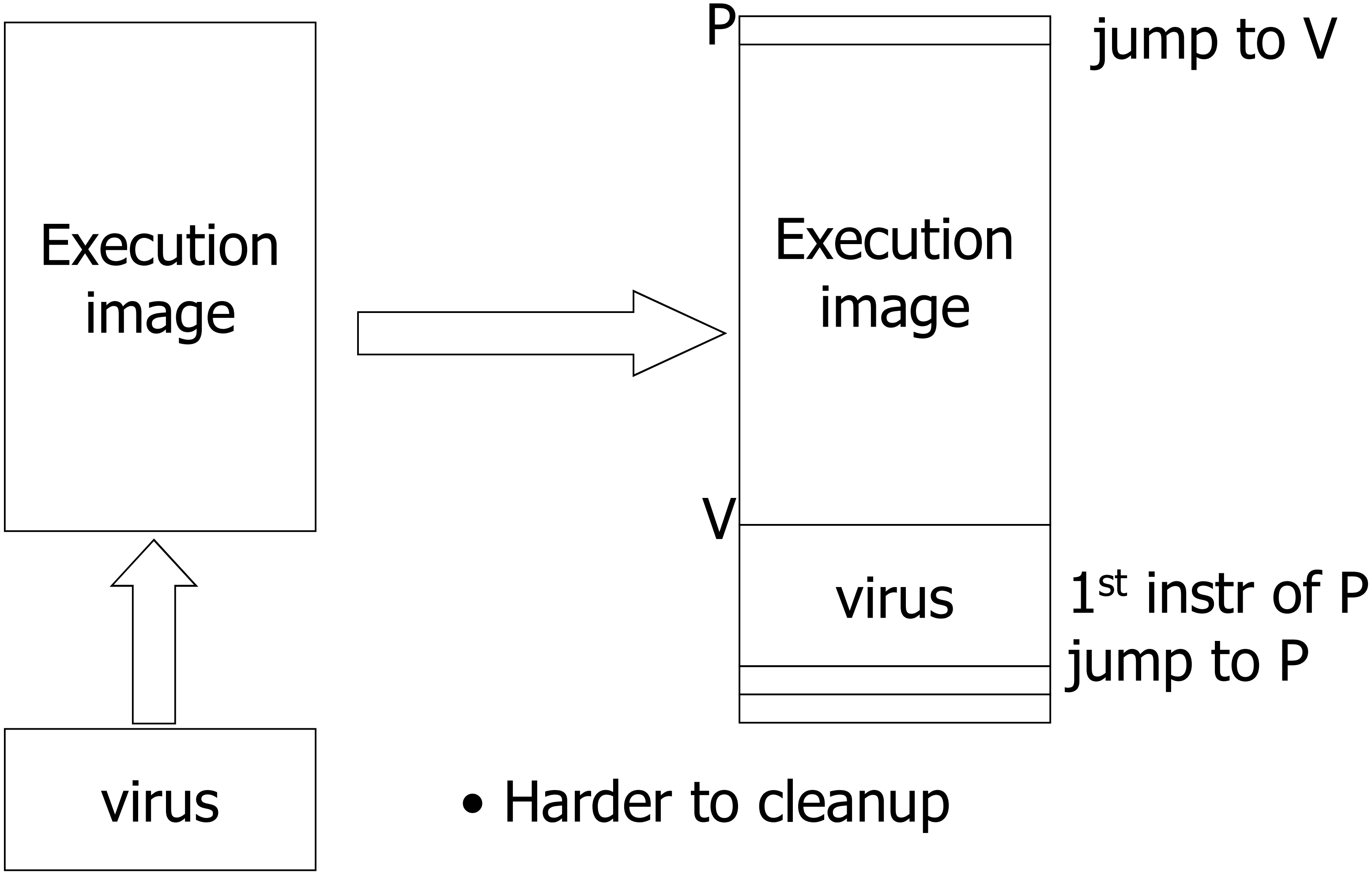
Means of attaching: beginning and end (virus *surrounds* program)



- Properties of appended virus +
- Ability to clean up and avoid detection
- Example: attach to program that constructs file lists with sizes; modify after program has ended

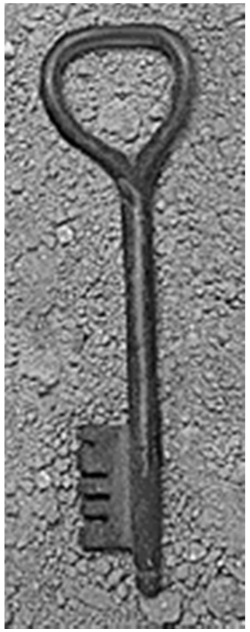
Means of attaching: intersperse (virus is *integrated* into program)

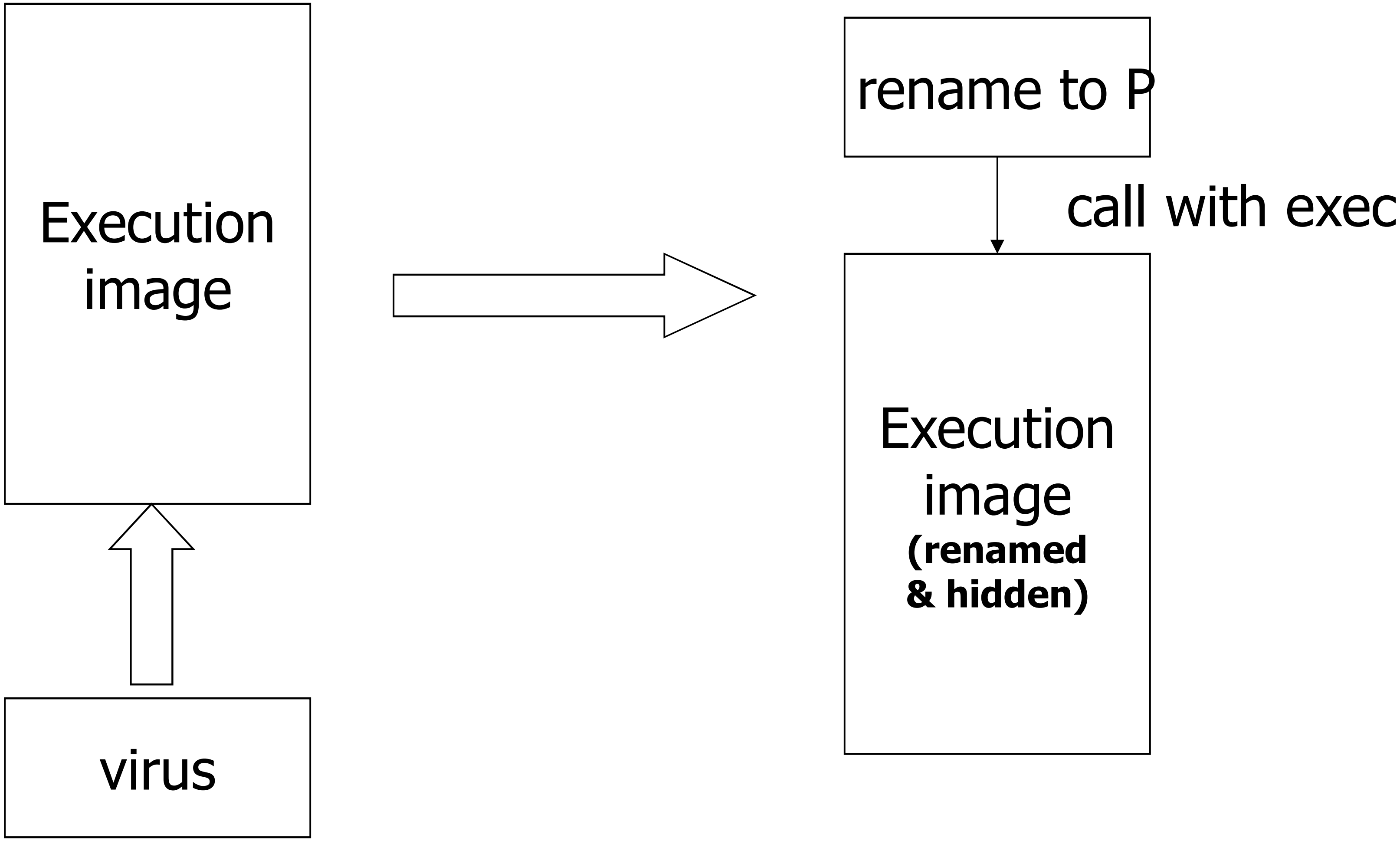


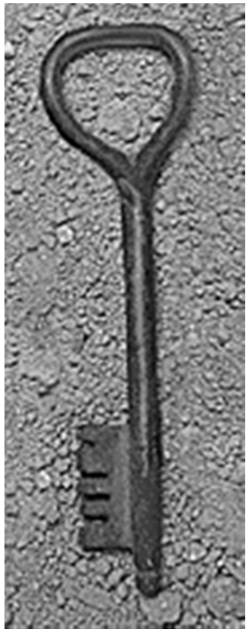


• Harder to cleanup

Means of attaching: companions

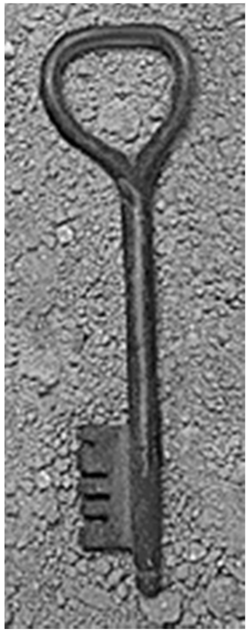






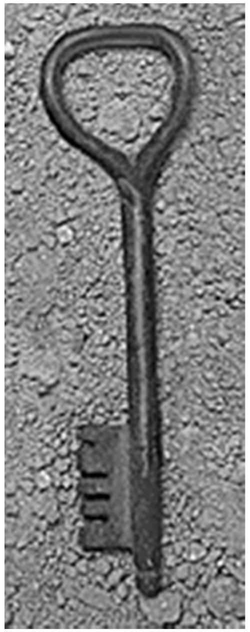
Executable Infectors (*con't*)

- 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
  - BUG!: doesn't set signature when .EXE executes
    - So .EXE files continually reinfected, size goes up quickly



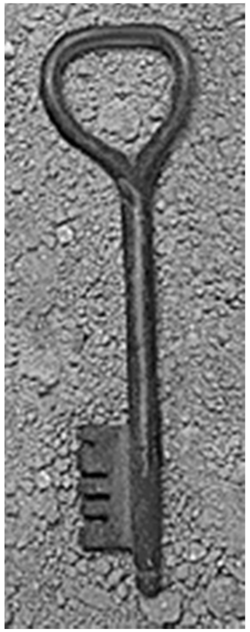
Multipartite Viruses

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



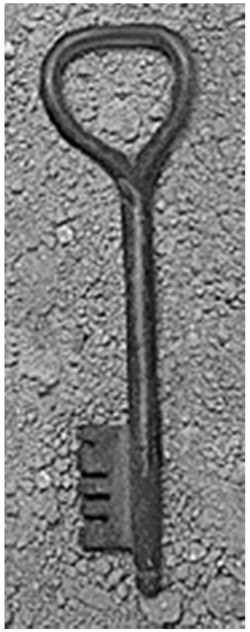
TSR Viruses

- 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



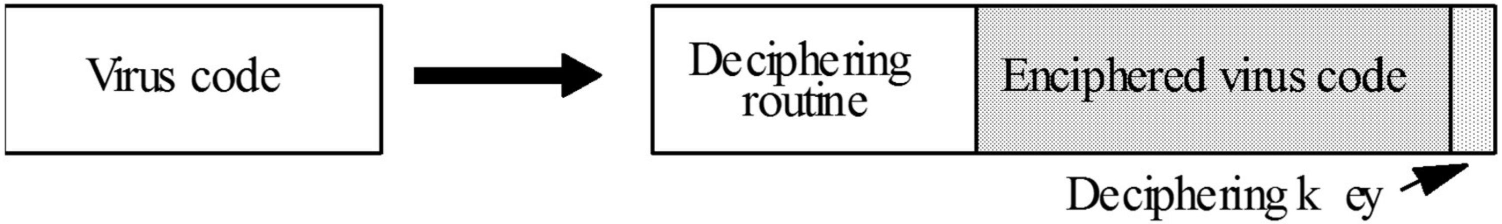
Stealth Viruses

- 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

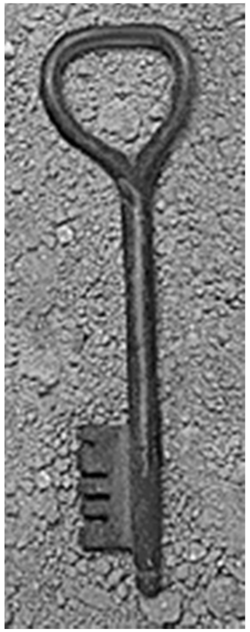


Encrypted Viruses

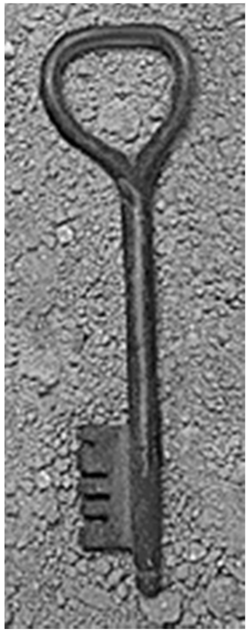
- A virus that is enciphered except for a small deciphering routine
  - Detecting virus by signature now much harder as most of virus is enciphered



Example



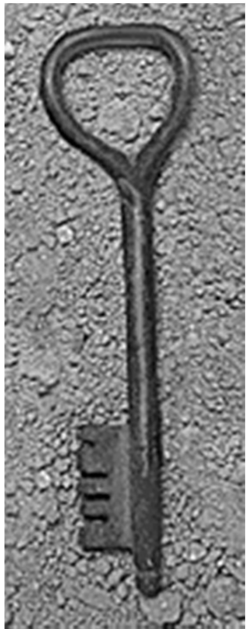
```
(* Decryption code of the 1260 virus *)
(* initialize the registers with the keys *)
rA = k1; rB = k2;
(* initialize rC with the virus; starts at sov, ends at eov *)
rC = sov;
(* the encipherment loop *)
while (rC != eov) do begin
    (* encipher the byte of the message *)
    (*rC) = (*rC) xor rA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

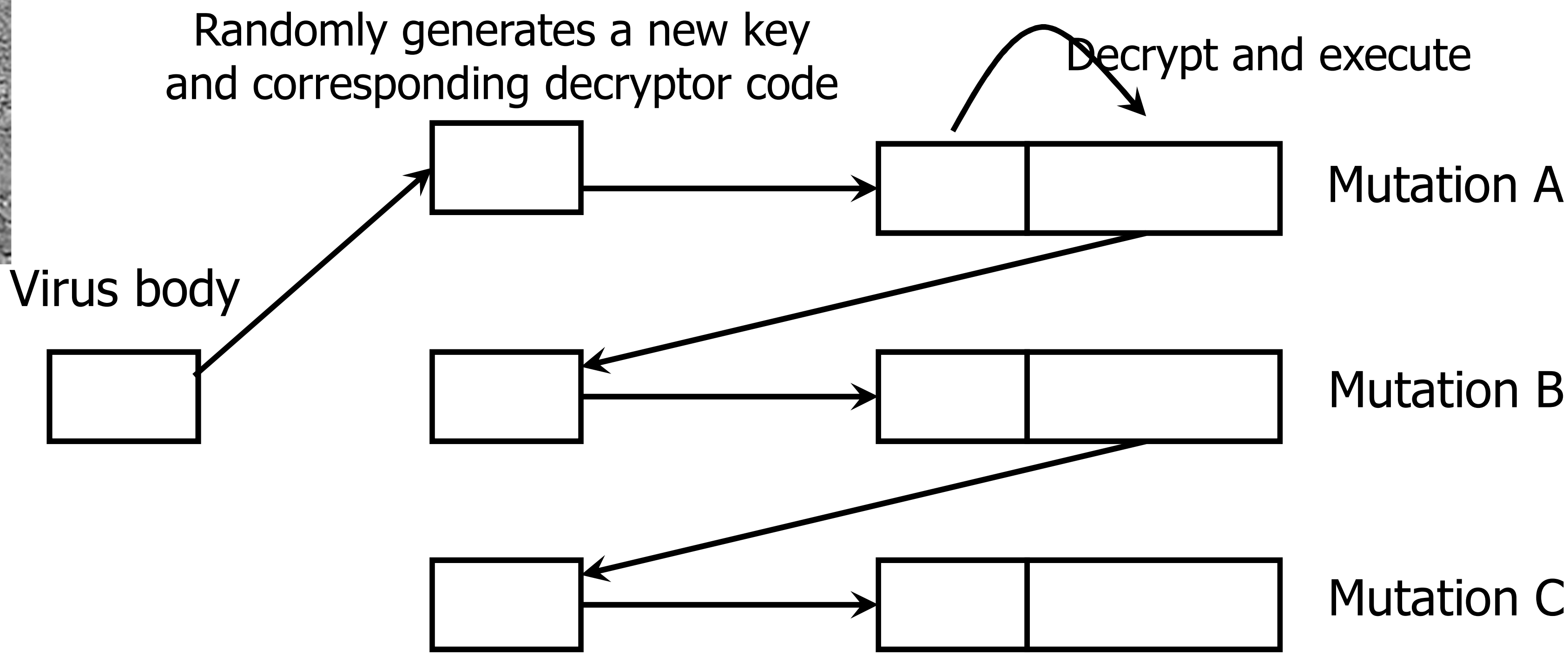


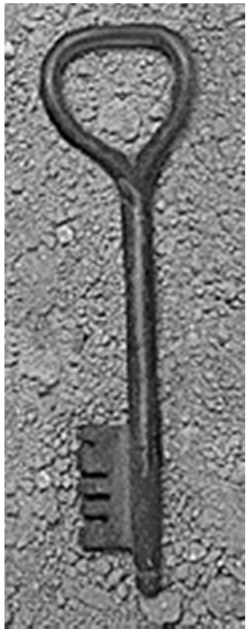
Anti-virus tools' answer to encryption

- Select the signature from the unencrypted portion of the code, i.e. the decryption engine
- Problems:
  - Anti-virus tools usually want to determine which virus is present, not just determine that some virus is present (in order to "disinfect").
    - Can emulate the decryption then further analyze the decrypted code.
  - virus writers have responded by obscuring the encryption engine through mutations
- It's a game of cat and mouse

Virus Emulation

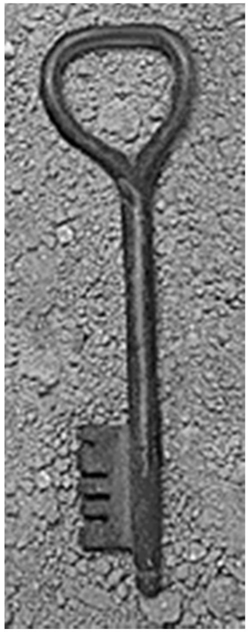






Polymorphic Viruses

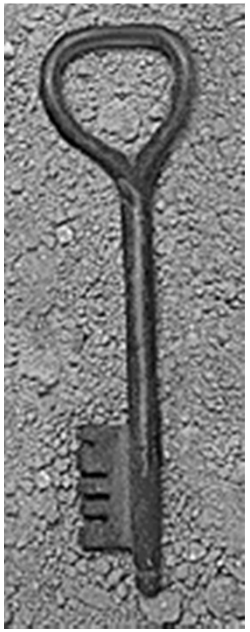
- Polymorphic = “many forms”. A virus that changes its form each time it replicates
- Prevent signature detection by changing the “signature” or instructions used for deciphering
- At instruction level: substitute instructions
- At algorithm level: different algorithms to achieve the same purpose
  - Given two code segments, evaluating their semantic equivalency is an undecidable problem!



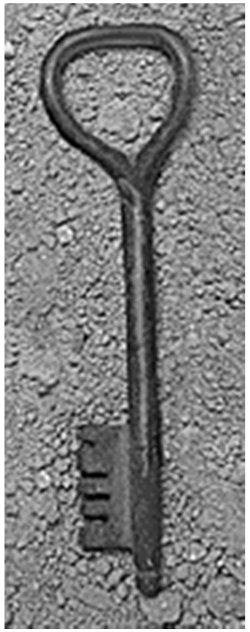
Example

- 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

Example

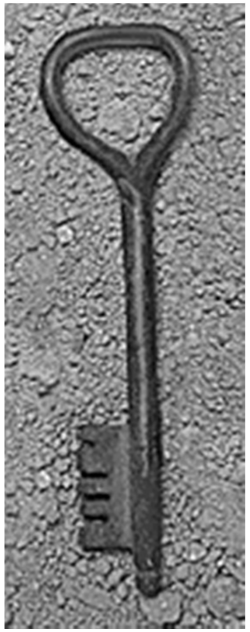


```
(* Polymorphic code of the 1260 virus *)
(* initialize the registers with the keys *)
rA = k1; rB = k2;
rD = rD +1; (* random code*)
(* initialize rC with the virus;    starts at sov, ends at eov *)
rC = sov;
rC = rC +1; (* random code*)
(* the encipherment loop *)
while (rC != eov) do begin
    rC = rC - 1; (* random code*)
    (* encipher the byte of the message *)
    (*rC) = (*rC) xor rA xor rB;
    (* advance all the counters *)
    rC = rC + 2;
    rD = rD + 1; (* random code*)
    rA = rA + 1;
end
While ( rC != sov) do begin (* random code*)
    rD = rD - 1; (* random code*)
    rC = rC - 1; (* random code*)
end (* random code*)
```



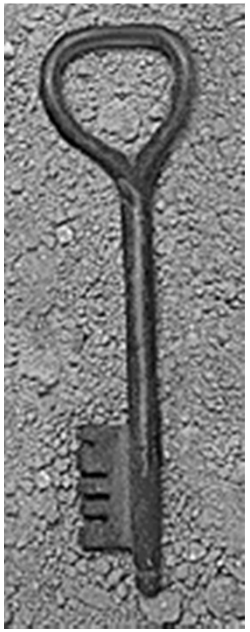
Macro Viruses

- 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



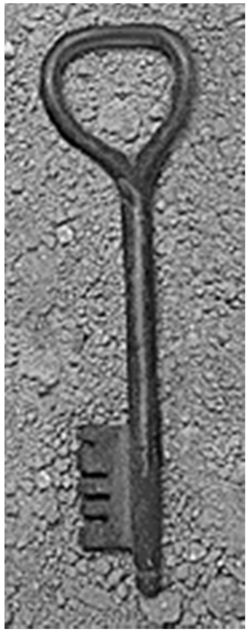
Example

- 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



Overview

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



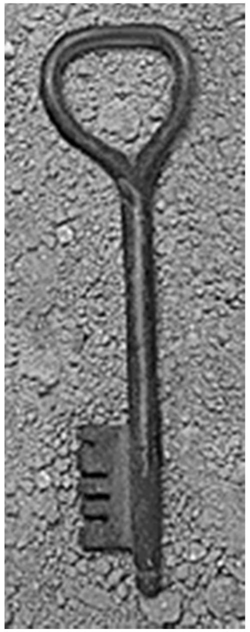
Viruses vs. Worms

VIRUS

- Propagates by infecting other programs
- Usually inserted into host code (not a standalone program)

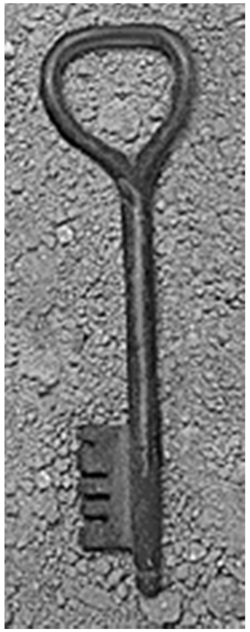
WORM

- Propagates automatically by copying itself to target systems
- Is a standalone program



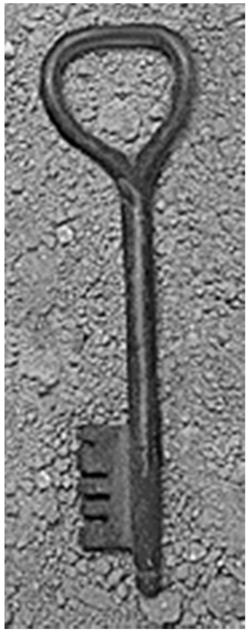
Computer Worms Origins: distributed computations

- Schoch & Hupp (1982): 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



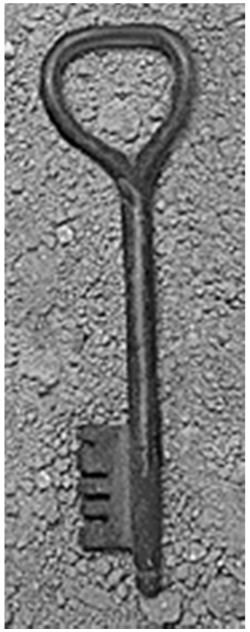
Example: Christmas Worm

- 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
  - Can cross different system platform!



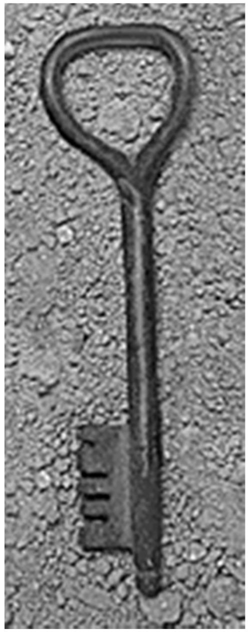
Case study: 1988 Internet Worm

- Worm was released in 1988 by Robert Morris
  - Graduate student at Cornell, son of NSA chief scientist
  - Convicted under Computer Fraud and Abuse Act, sentenced to 3 years of probation and 400 hours of community service
  - Now a computer science professor at MIT
- Worm was intended to propagate slowly and harmlessly measure the size of the Internet
- Due to a coding error, it created new copies as fast as it could and overloaded infected machines
- Disabled 3000--4000 machines, or 5% of the machines on the Internet then, \$10-100M damage



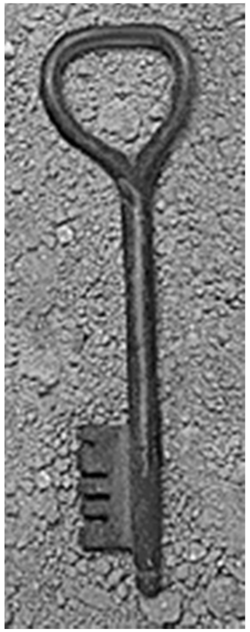
Components of Worm

- Morris Worm Attack Components
  - Sendmail Attack
  - Finger Attack
  - Trusted Remote Host Attack
  - Dictionary Password Attack



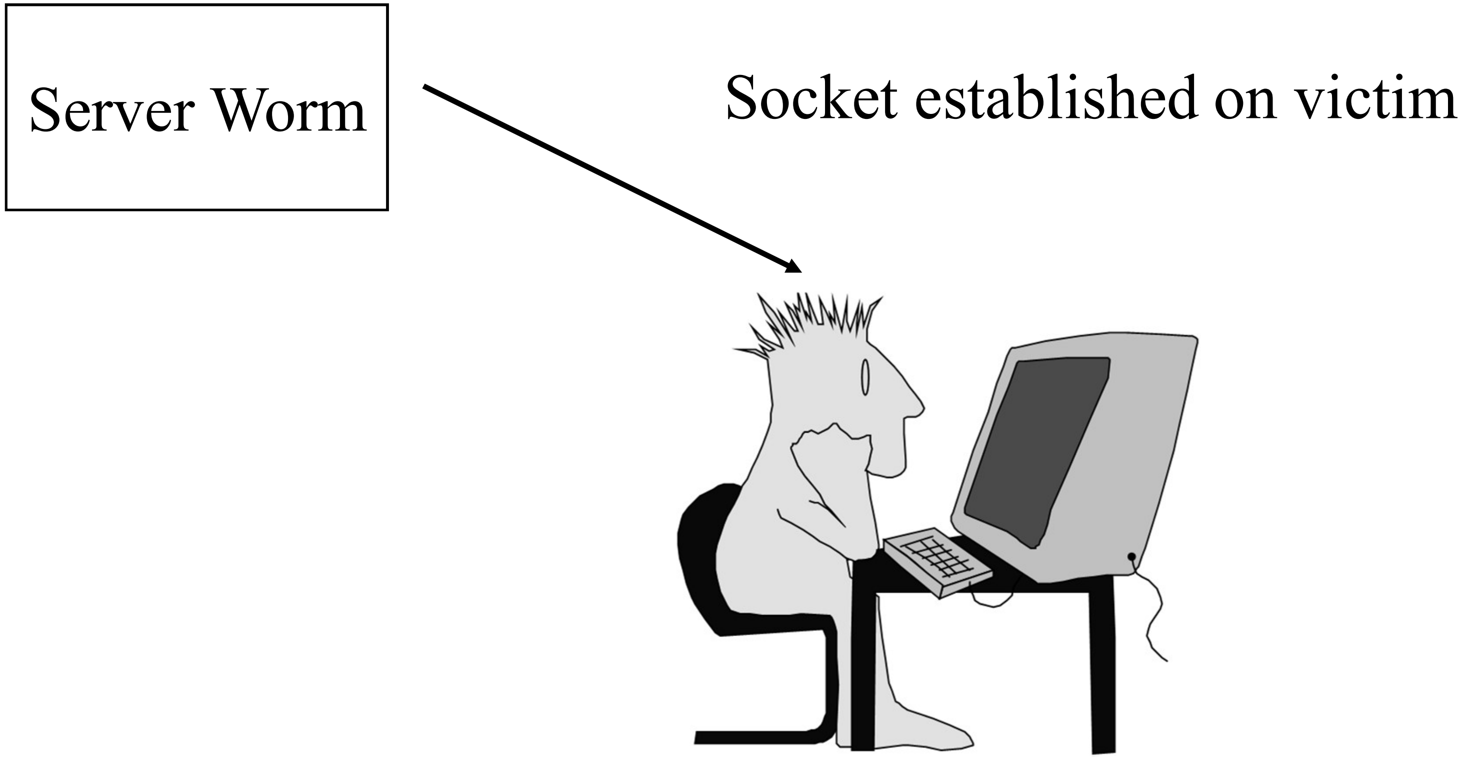
Overview of the Morris Worm

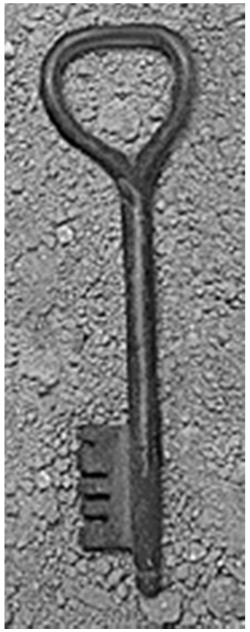
- Worm selects host for infection.
- Place hook (grappling hook) on host.
- Causes hook to compile and run.
- Executing hook, the hook will copies remainder of code over.



Step 1: About to Infect

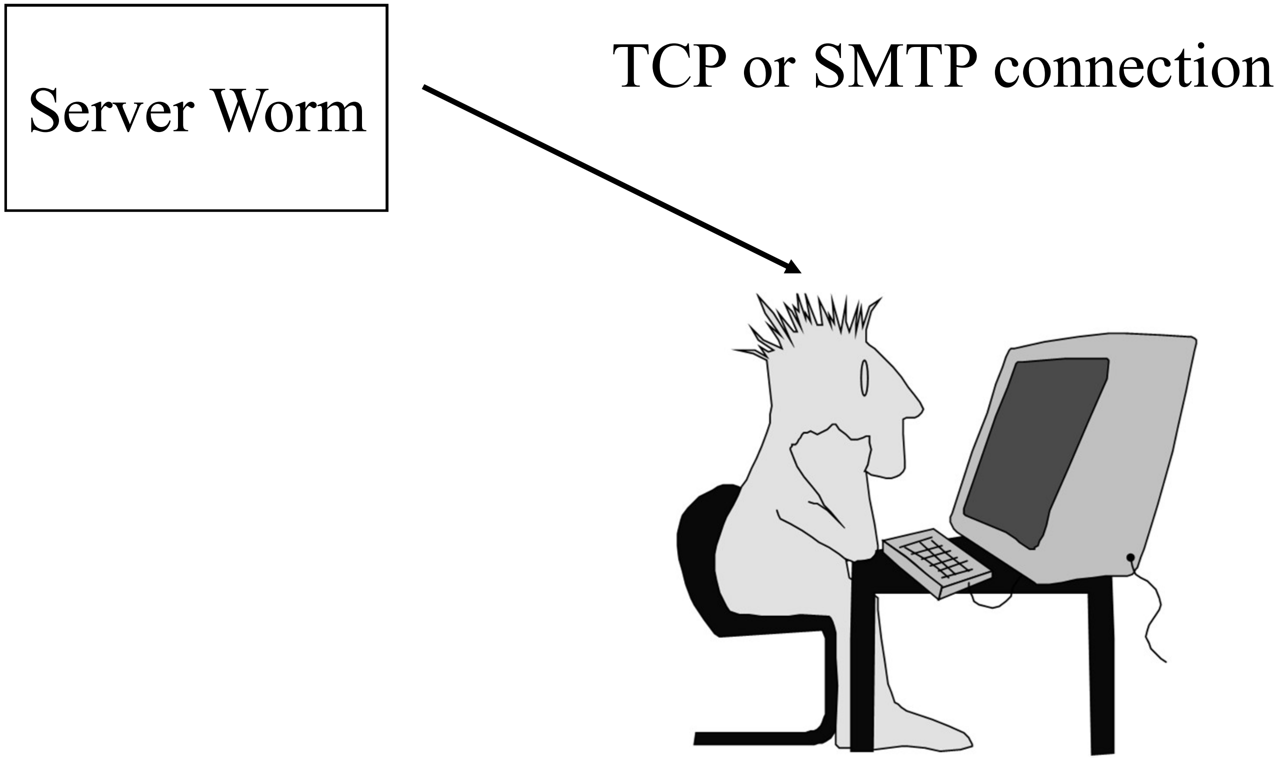
♦ Status: infecting machine has found a victim

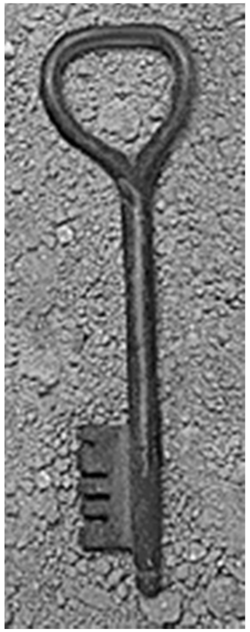




Step 2: Placing Grappling hook

- Status: Send a small hook code across





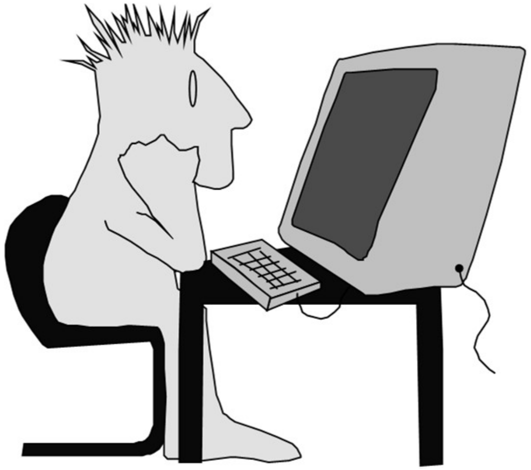
Step 3: Pull in code from server

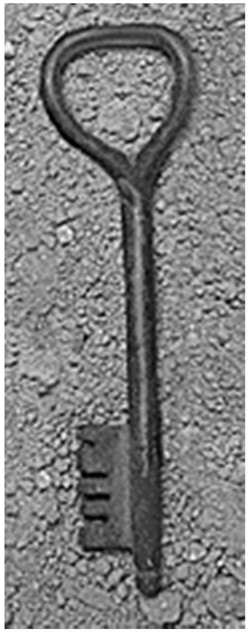
- Status: Send challenge string back, transfer Sun, VAX binaries and vector Server Worm

Server Worm

Check challenge string; transmit files

Send challenge;
Copy files back;
Execl shell and maintain socket





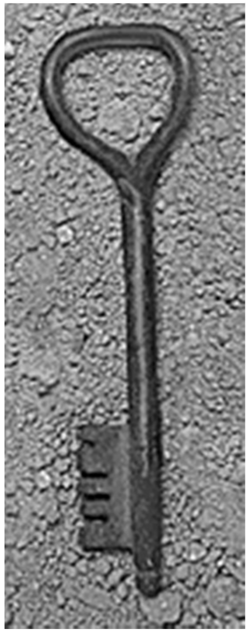
Step 4: Get further compiler commands from server worm

♦ Status: Server sends code to compile

Server Worm

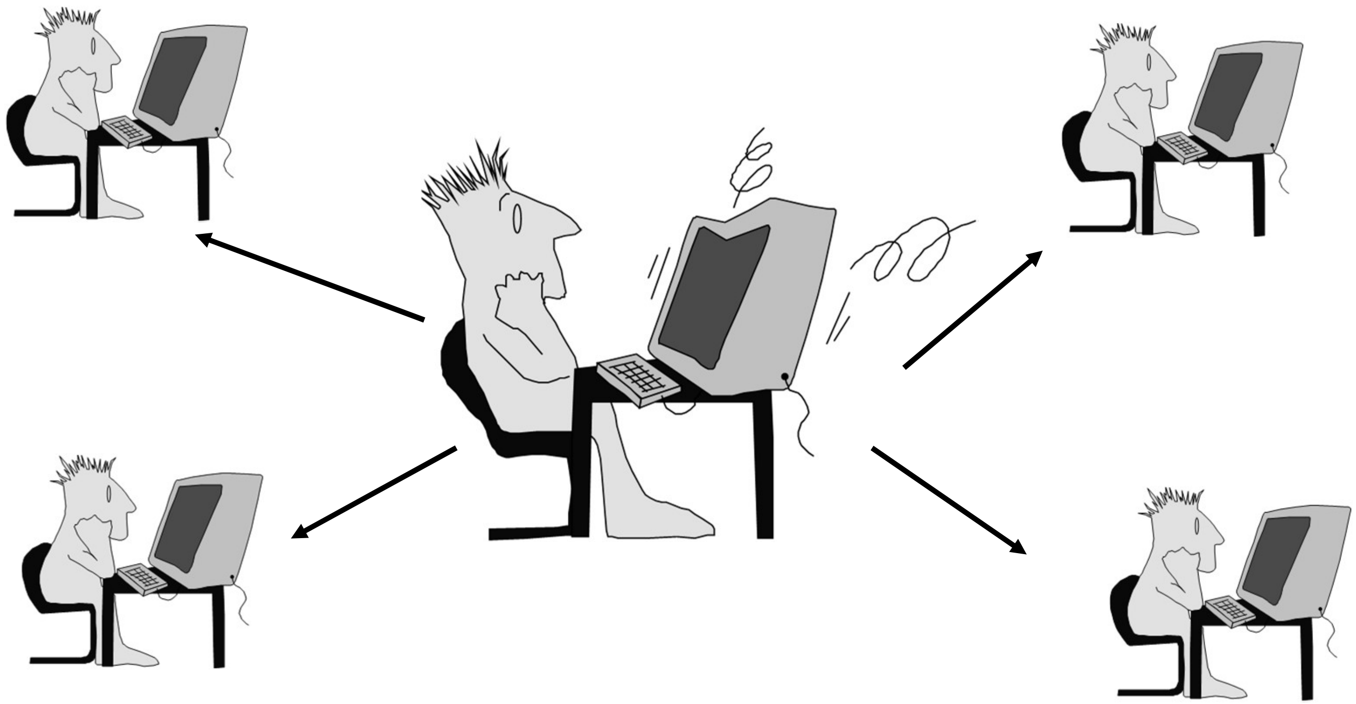
Send shell commands
to attempt compile
of binaries
(one after the other)

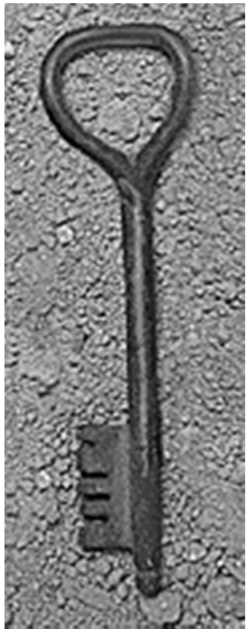
Execute compile commands
as sent by Server Worm; only
the appropriate binary will
link.



Step 5: Hide and gather information

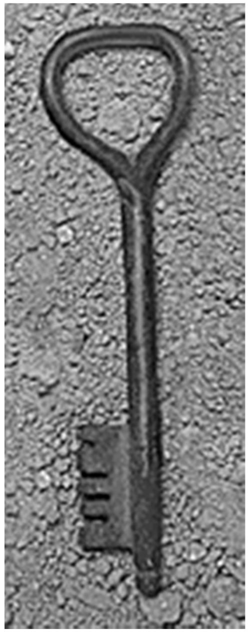
- Status: New worm generates victim lists





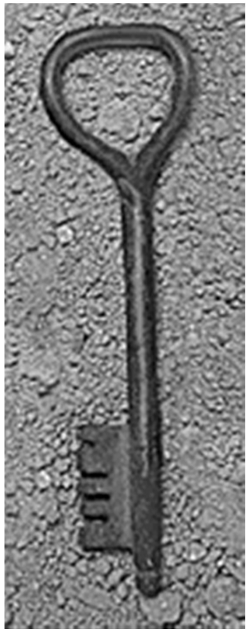
Step 6: Attempt infection

- Read through hosts.equiv, /.rhosts , .forward (not user .rhosts!)
- Attempt to break each user password ...
  - with simple guesses
  - with internal dictionary
  - with UNIX online dictionary
- For any successful password compromise
  - look for remote machines where the user has an account (.forward .rhosts)
  - For each, attempt a remote shell (rexec)
- Loop “forever” trying to infect new hosts



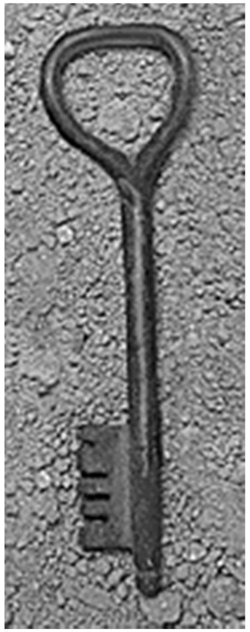
Major Tricks

- ♦ Sendmail attack
- ♦ Finger attack
- ♦ Trusted remote host attack
- ♦ Dictionary-based password attack



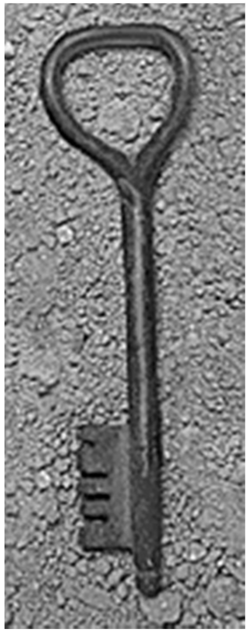
Sendmail Attack

- DEBUG command in Sendmail (early ver.)
  - Possible to execute a command on a remote machine by sending an SMTP message
  - Intended for in-house debugging
- Simply put, the worm did the following:
  - Put commands in the body of a mail message
  - While running, deleted mail header
  - Body was run through an interpreter, and it:
    - Stored small 99-line program in a file (grappling hook)
    - Compiled program
    - Started it executing



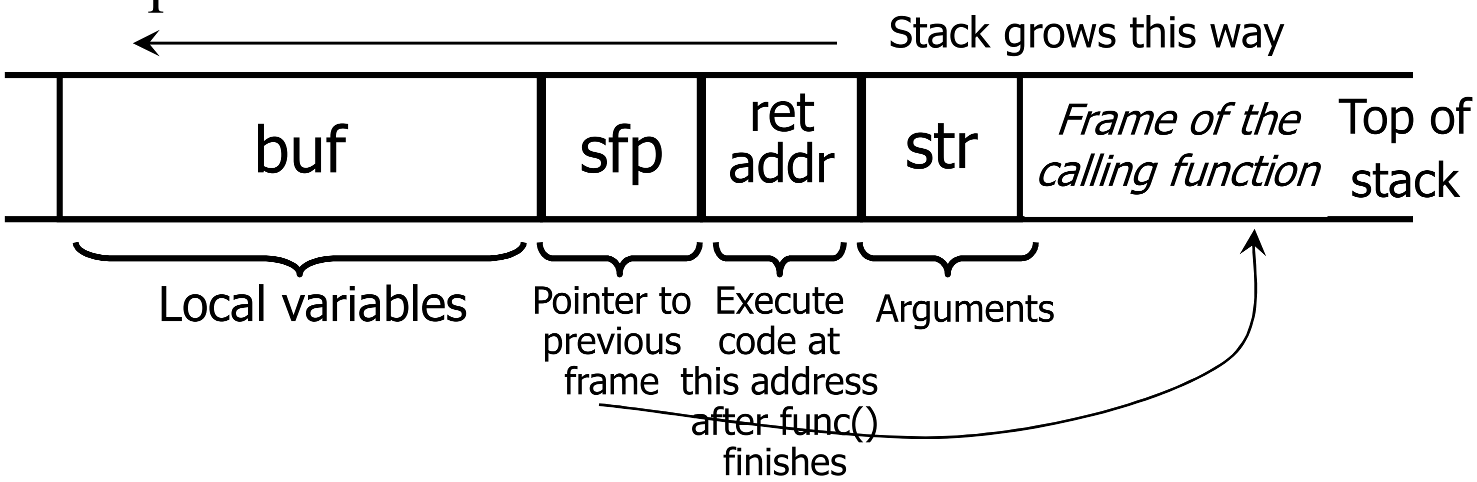
Fingerd Attack

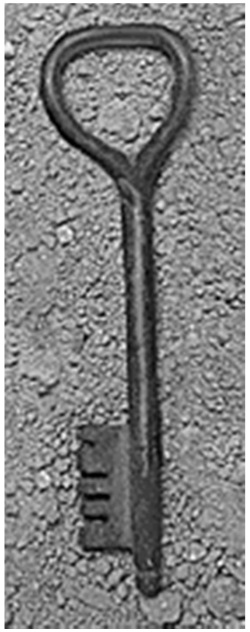
- Buffer Overflow attack against a vulnerable version of fingerd on VAX systems
  - By sending special string to finger daemon, worm caused it to execute code creating a new worm copy
  - Unable to determine remote OS version, worm also attacked fingerd on Suns running BSD, causing them to crash (instead of spawning a new copy)



Buffer Overflow Attack

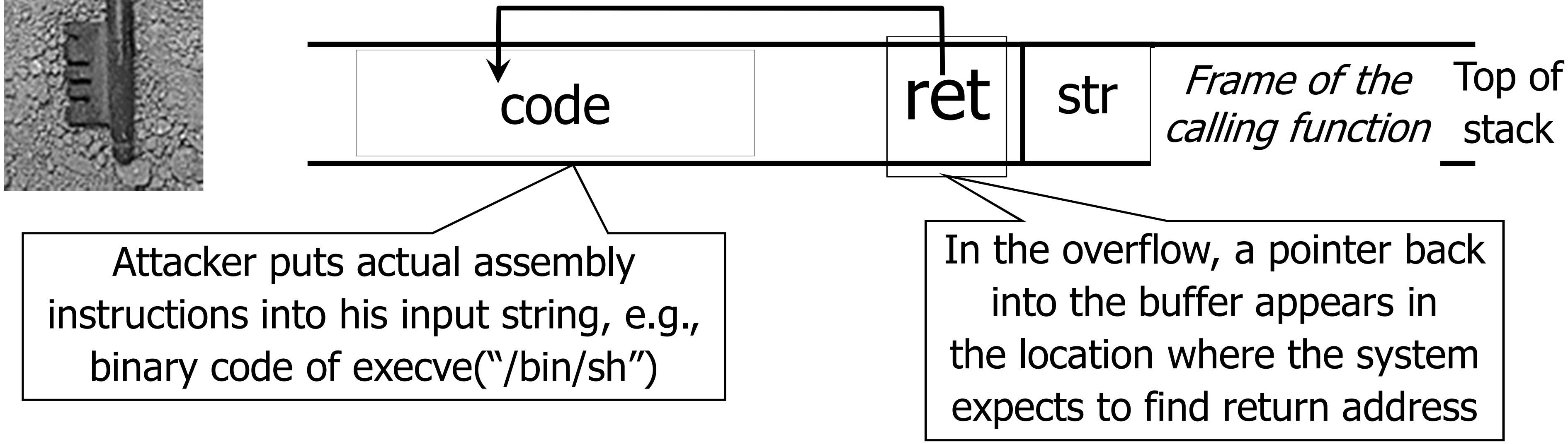
- A kind of buffer overflow attack
  - Returned information was stored in a large buffer. Bounds weren't checked on this buffer.
  - Worm sent "too many" bytes, with the extra bytes actually being program code. This code over-wrote the original code
  - PC of the routine, after return from obtaining data, now pointed to the new code



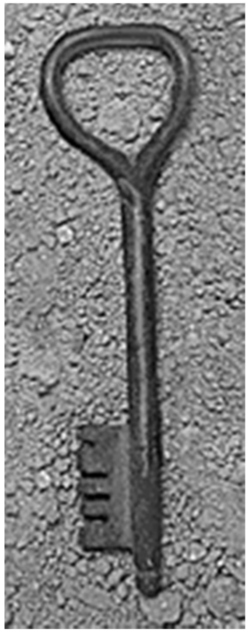


Buffer Overflow Attack

- Suppose buffer contains attacker-created string

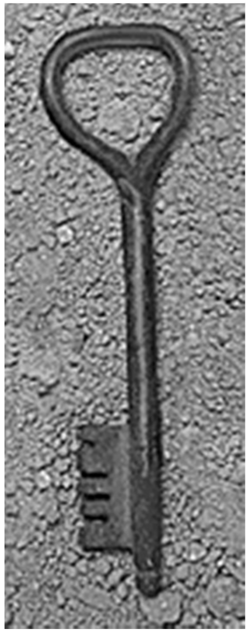


- When function exits, code in the buffer will be executed, giving attacker a shell
  - Root shell if the victim program is setuid root



Trusted Remote Host Attack

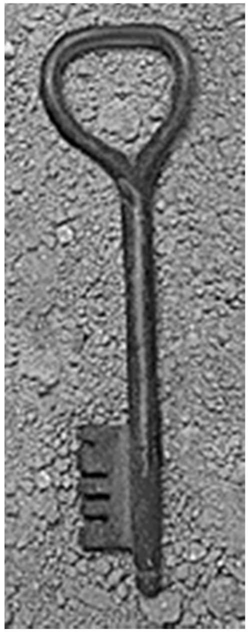
- Many Unixes have a way to indicate that some hosts can be trusted 'just as much' as the current host. Use rsh to remote execute a command.
- The names of these hosts are stored in world-readable places, and can be network-specific or user-specific.
- Worm targeted:
  - hosts in this list of network-specific trusted hosts
  - hosts in user-specific list whenever a password was compromised



Dictionary-based password attack

- ♦ The worm used a very simple form:
  - – Scan password file to get user names
  - – Try common passwords using a quick implementation of crypt(3).
    - Account name
    - Account name reversed
    - First and last name
    - Short standard online dictionary

A desire to help system administrators quickly identify such easily guessable passwords was behind Moffet's development of Crack.



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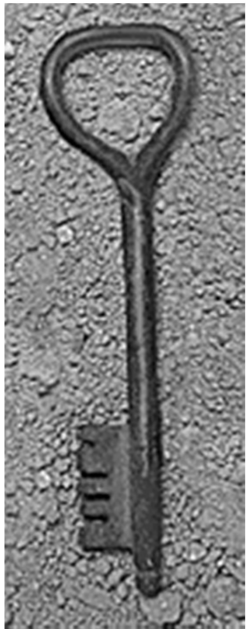
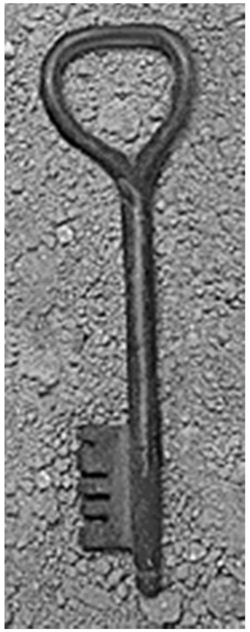


Others: Rabbits, Bacteria

- A program that absorbs all of some class of resources
- Example: for UNIX system, shell commands [Dennis 1979]:

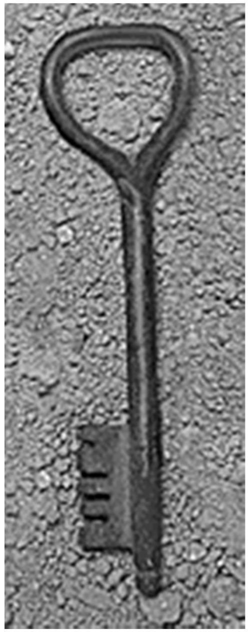
```
while true
do
     mkdir x;  chdir x
done
```

- Exhausts either disk space or file allocation table (inode) space, may crash the system. But very easy to trace back!
- Countermeasures: Quote for each user



Others: Logic Bombs

- A program that performs an action that violates the site security policy when some external event occurs (Ex. Special Holiday, Special Name,…)
- 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
  - =rand(100,2) in Microsoft Word
  - 联通 in Microsoft Notebook



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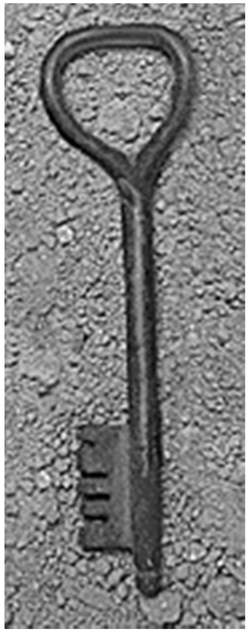
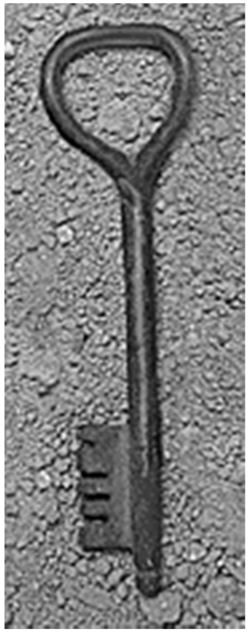


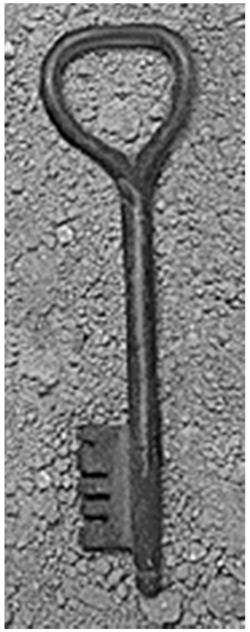
How Hard Is It to Write a Virus?

- 2268 matches for “virus creation tool” in CA′s Spyware Information Center
  - Including dozens of poly- and metamorphic engines
- OverWritting Virus Construction Toolkit
  - "The perfect choice for beginners‟
- Biological Warfare Virus Creation Kit
  - Note: all viruses will be detected by Norton Anti-Virus
- VBS Worm Generator (for Visual Basic worms)
  - Used to create the Anna Kournikova worm
- Many others



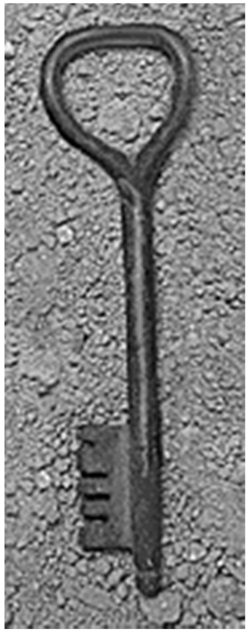
Theory of Virus Detection

- There is No algorithm to detect all possible virus/malicious code.
- Proved by Cohen in “Computers and Security” in 1989.



No perfect solutions : Now what?

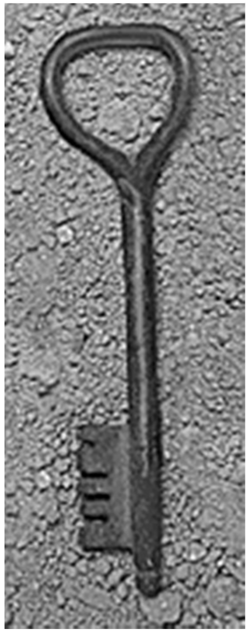
- Signature-based antivirus
  - Look for known patterns in malicious code
  - Always a battle with the attacker
  - *Great business model!*

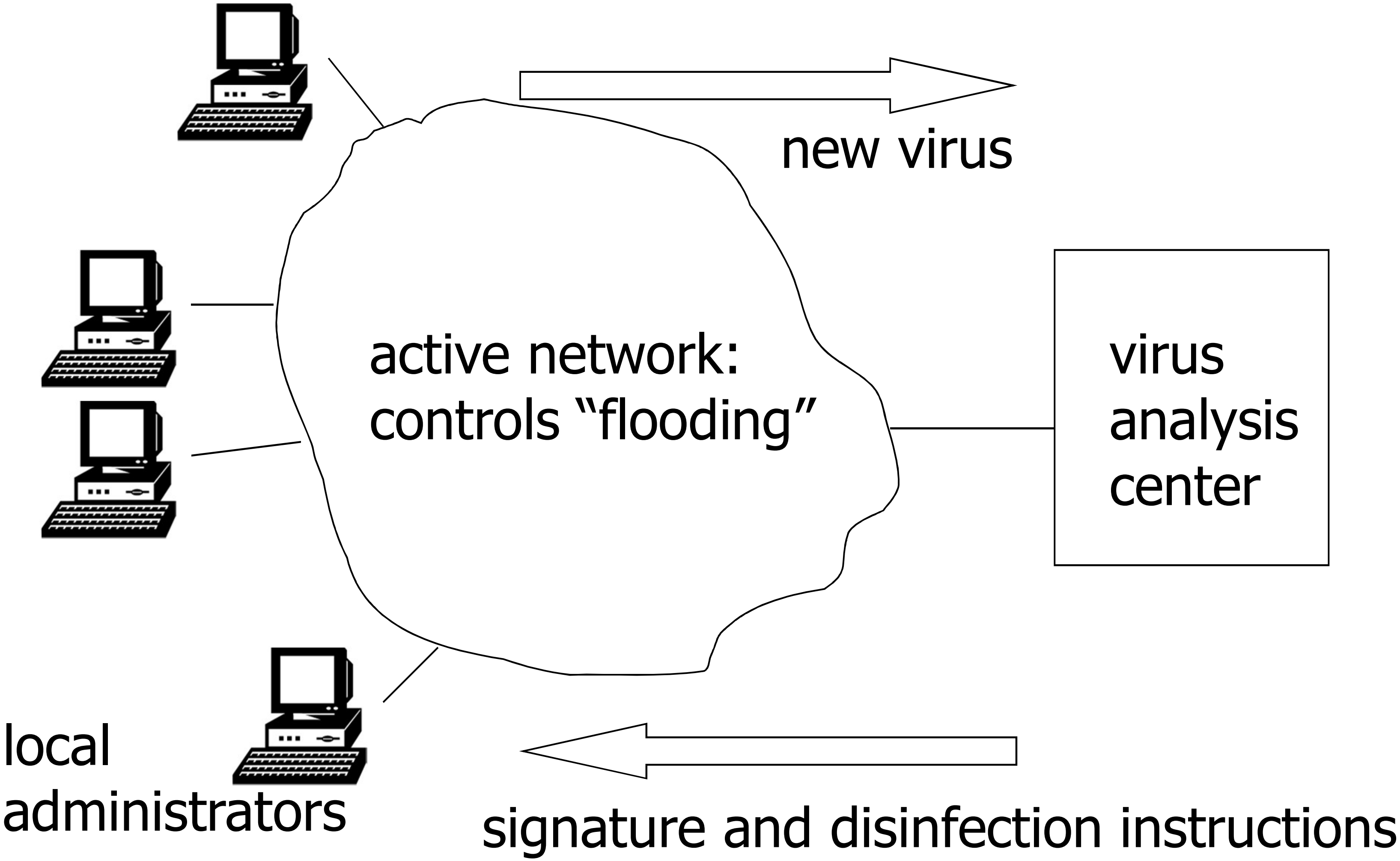


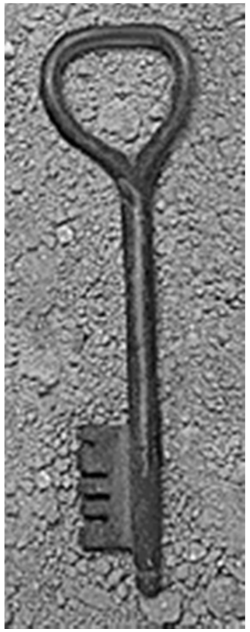
Virus Analysis

- Analysis of virus by human expert
  - slow: by the time signature has been extracted, posted to AV tool database, downloaded to users, virus may have spread widely.
    - pre-1995: 6 months to a year for virus to spread world-wide
    - mid-90's: a few months
    - now: days or hours
  - labor-intensive: too many new viruses
    - currently, 8-10 new viruses per day
  - can't handle epidemics:
    - queue of viruses to be analyzed overflows
    - heavy demand on server that posts signatures & fixes
- Automated analysis, e.g. "Immune System"
    - developed at IBM Research
    - licensed to Symantec

Immune System Architecture

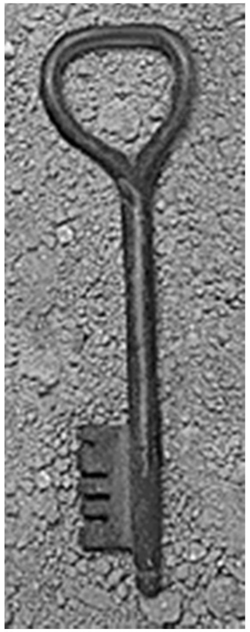






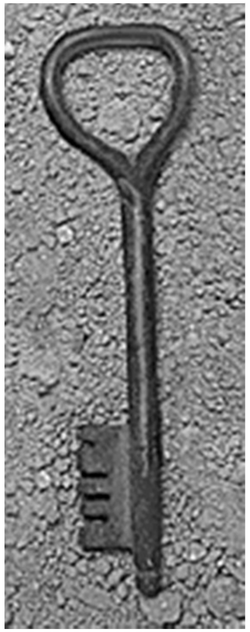
Signature Extraction at VAC

- Virus allowed (encouraged) to replicate in controlled environment in immune center
- This yields collection of infected files
- In addition, a collection of "clean" files is available
- Machine learning techniques used to find strings that appear in most infected files and in few clean files, e.g.:
  - search files for candidate strings
    - add points if found in infected file
    - subtract points if found in clean file



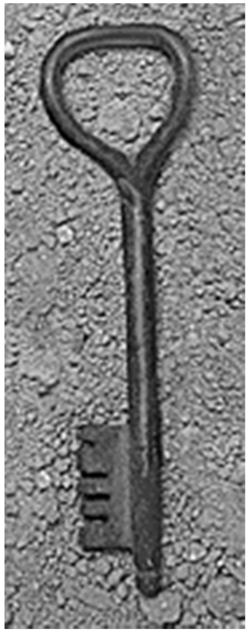
Defenses

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



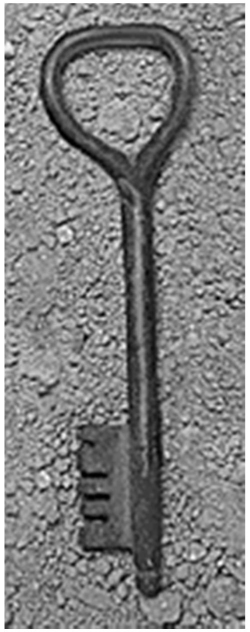
Clear Distinction between Data and Executable

- Virus must write to program
  - Write only allowed to data
- Must execute to spread/act
  - Data not allowed to execute
- Auditable action required to change data to executable



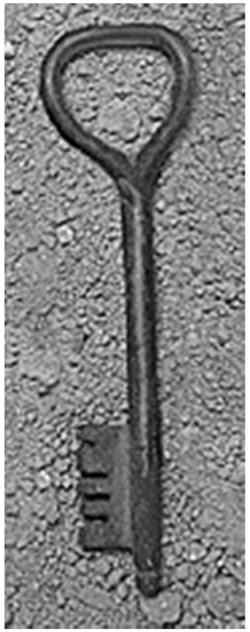
Example: LOCK

- ♦ 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



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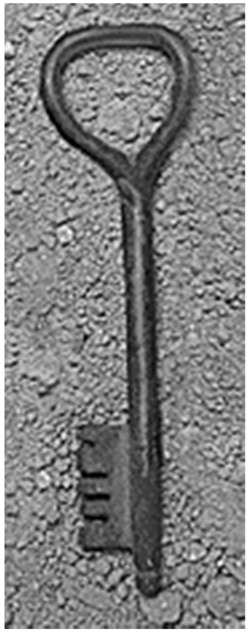
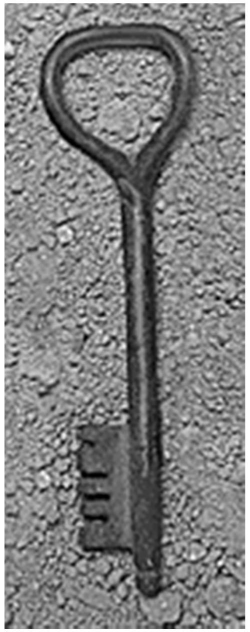


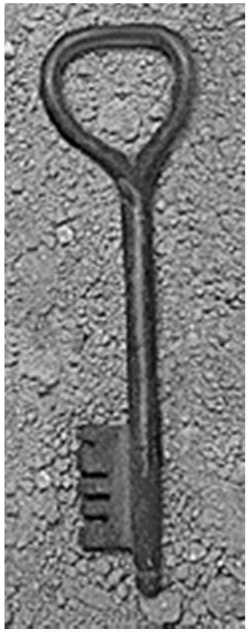
Limiting Accessibility

- Information Flow
  - Malicious code usurps authority of user
  - Limit information flow between users
    - If *A* talks to *B*, *B* can no longer talk to *C*
  - Limits spread of virus
  - Problem: Tracking information flow



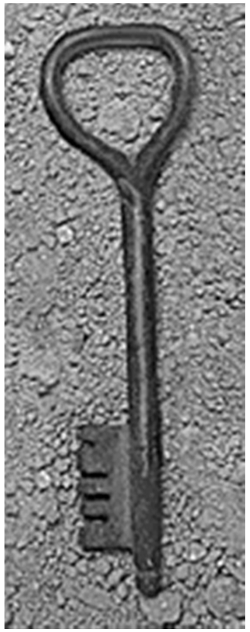
Application of principle of least privilege

- 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



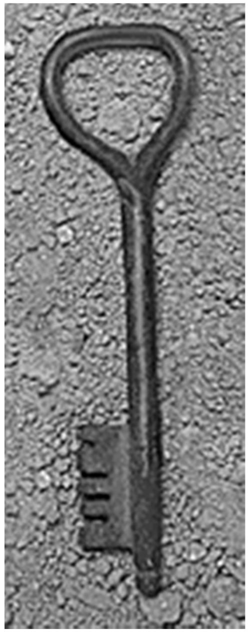
Karger's Scheme

- 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



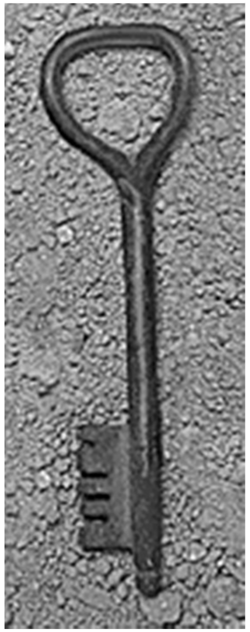
Lai and Gray

- 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 – VAL 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

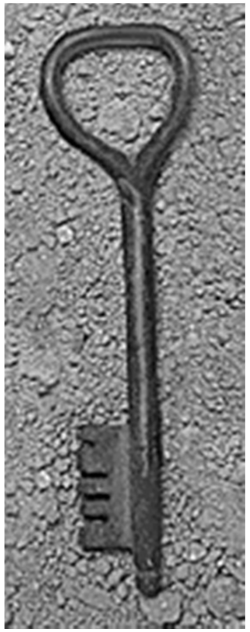
```
as x.s /tmp/ctm2345
```

  and creates temp file /tmp/as1111

  – VAL is

```
x.s /tmp/ctm2345 /tmp/as1111
```

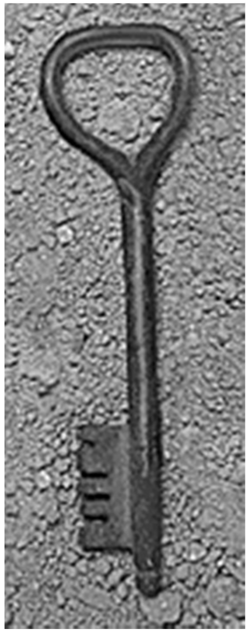
- Now Trojan horse tries to copy x.s to another file
  – On creation, file inaccessible to all except creating user so attacker cannot read it (rule 3)
  – If file created already and assembler tries to write to it, user is asked (rule 4), thereby revealing Trojan horse



Trusted Programs

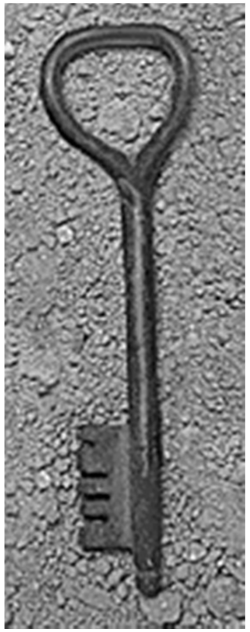
- No VALs applied here
  - UNIX command interpreters
    - csh, sh
  - Program that spawn them
    - getty, login
  - Programs that access file system recursively
    - ar, chgrp, chown, diff, du, dump, find, ls, restore, tar
  - Programs that often access files not in argument list
    - binmail, cpp,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

They are ideal targets for virus!



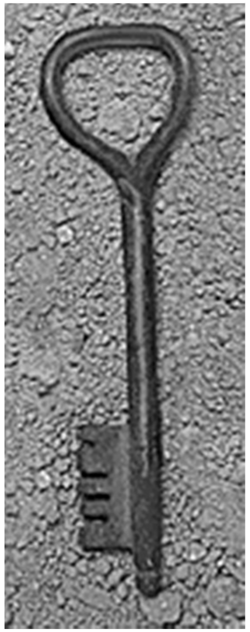
Guardians, Watchdogs (1)

- 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



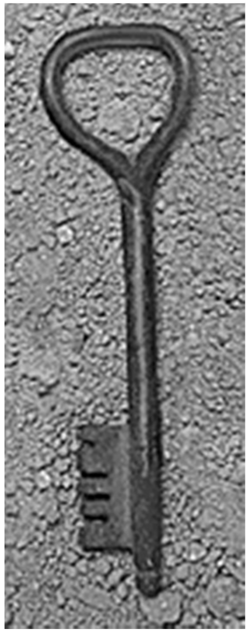
Guardians, Watchdogs (2) Trust

- 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



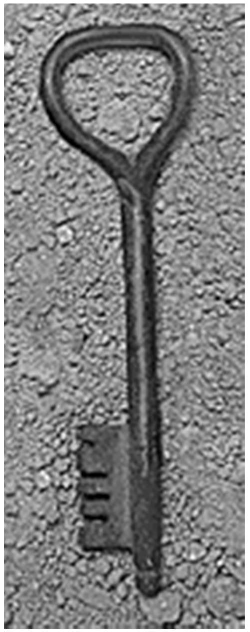
Sandbox / Virtual Machine

- ♦ Run in protected area
- ♦ Libraries / system calls replaced with limited privilege set



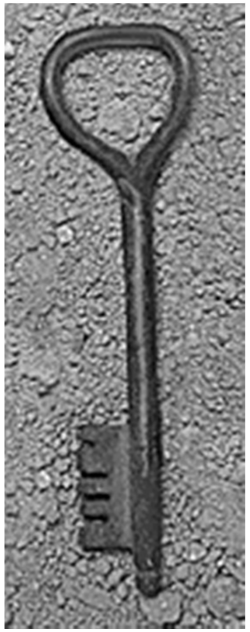
Defenses

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



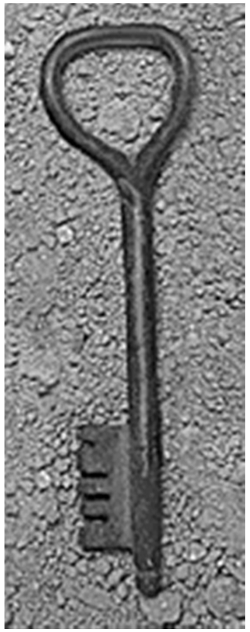
Inhibit Sharing

- ♦ 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



Use Multilevel Security Mechanisms

- Use Multi-Level Security Mechanisms
  - Place programs at lowest level
  - Don’t allow users to operate at that level
  - *Prevents writes by malicious code*
- Example: DG/UX system
  - All executables in “virus protection region” below user and administrative regions



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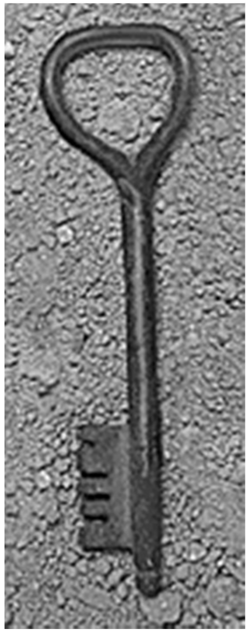
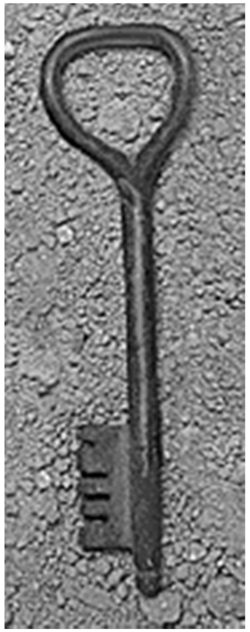


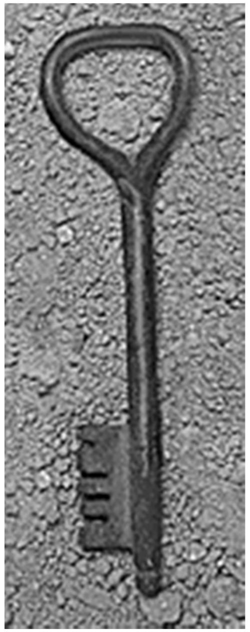
Detect Alteration of Files (1)

- 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 (size, owner id, protection mode, inode no.), cryptographic checksums chosen from among MD4, MD5, HAVAL, SHS, CRC-16, CRC-32, etc.)



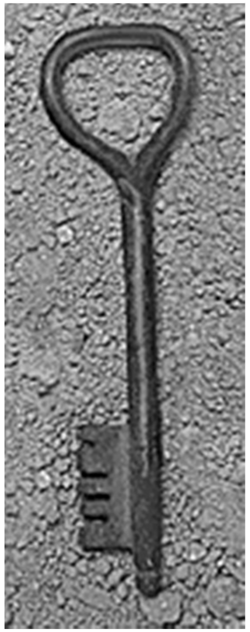
Detect Alteration of Files (2)

- Assumptions: Files do not contain malicious logic when original signature block generated
- Pozzo & Grey: implement Biba's model on distributed LOCUS O.S. 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 the special command "run-untrusted" to run program
- Cons: performance, cryptographic key mangement



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



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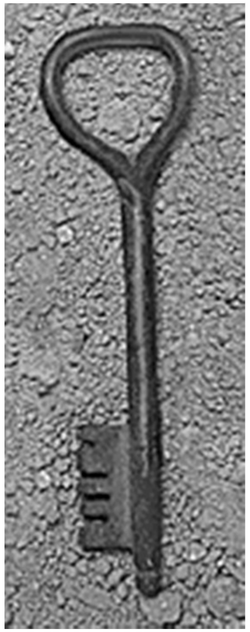
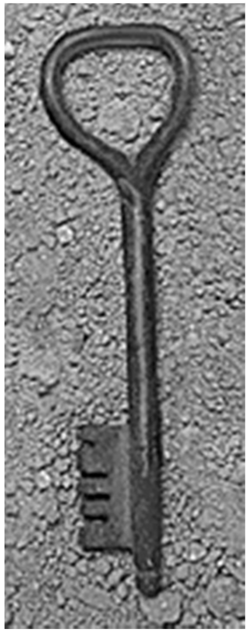


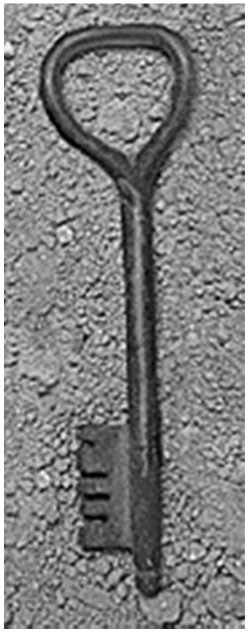
Detect Actions Beyond Spec

- 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



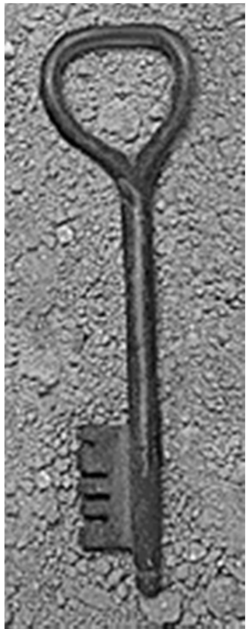
N-Version Programming

- 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
- Conflicts:
  - In order to control the propogation of the virus, all the algorithms must vote for each file accesses.
  - They have to be almost the same!



Proof-Carrying Code

- Code consumer (user) specifies safety requirement
- Code producer (author) generates proof code meets this requirement
- Binary (code + proof) delivered to consumer
- Consumer validates proof
  - Changing the code will make the validation process failed, so that the consumer will reject the code
- Example statistics on Berkeley Packet Filter [Necula & Lee 1996]: proofs 300–900 bytes, validated in 0.3 –1.3 ms
  - Startup cost higher, runtime cost considerably shorter



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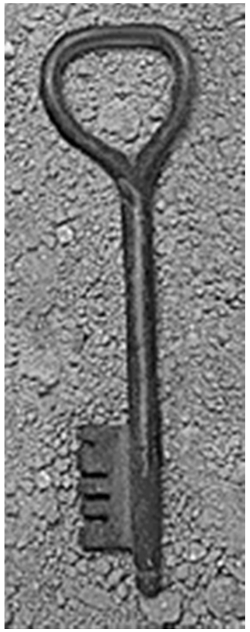
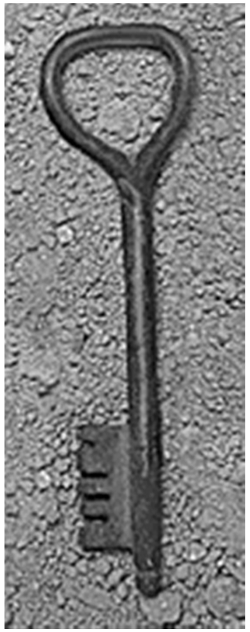


Detecting Statistical Changes

- Based on: each programmer has his own coding style. This style can be collected by statistical data
- 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!
  - Source code level: format, comments, etc
  - Binary code level: data structure, algorithm, etc
- Application Statistical
  - High/low number of files read/written
  - Unusual amount of data transferred
  - Abnormal usage of CPU time
  - Denning: use intrusion detection system to detect these
  - *Only works after the damage is done!*



Summary – the 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