Security

The only truly secure system is one that is powered off, cast in a block of concrete and sealed in a lead-lined room with armed guards—and even then I have my doubts.

— “Computer Recreations: Of Worms, Viruses and Core War”, A. K. Dewdney. In *Scientific American*, March 1989.

Security

- The security environment
- Basics of cryptography
- User authentication
- Attacks from inside the system
- Attacks from outside the system
- Protection mechanisms
- Trusted systems

- If you're interested in this stuff, consider taking CMPS 122 in Fall 2015

Security environment: threats

Goal	Threat
Data confidentiality	Exposure of data
Data integrity	Tampering with data
System availability	Denial of service

- Operating systems have goals
  - Confidentiality
  - Integrity
  - Availability
- Someone attempts to subvert the goals
  - Fun
  - Commercial gain

What kinds of intruders are there?

- Casual prying by nontechnical users
  - Curiosity
- Snooping by insiders
  - Often motivated by curiosity or money
- Determined attempt to make money
  - May not even be an insider
- Determined attempt to make mischief
  - Money typically not a goal
  - Inconvenience others or prove a point
- Commercial or military espionage
  - This is very big business!

Accidents cause problems, too…

- Acts of God
  - Fires
  - Earthquakes
  - Wars (is this really an “act of God”?)
- Hardware or software error
  - CPU malfunction
  - Disk crash
  - Program bugs (hundreds of bugs found in the most recent Linux kernel)
- Human errors
  - Data entry
  - Wrong tape mounted
  - `rm * .o`

Protection

- Security is mostly about mechanism
  - How to enforce policies
  - Policies largely independent of mechanism
- Protection is about specifying policies
  - How to decide who can access what?
- Specifications must be
  - Correct
  - Efficient
  - Easy to use (or nobody will use them!)

Protection domains

- Three protection domains
  - Each lists objects with permitted operations
- Domains can share objects & permissions
  - Objects can have different permissions in different domains
  - There need be no overlap between object permissions in different domains
- How can this arrangement be specified more formally?

Protection matrix

Domain	File1	File2	File3	File4	File5	Printer1	Mouse
1	Read	Read Write					
2			Read	Read Write Execute	Read Write	Write	
3			Write			Write	Read

- Each domain has a row in the matrix
- Each object has a column in the matrix
- Entry for ⟨*object*,*column*⟩ has the permissions
- Who's allowed to modify the protection matrix?
  - What changes can they make?
- How is this implemented efficiently?

Domains: objects in the protection matrix

Domain	File1	File2	File3	File4	Printer1	Mouse	Dom1	Dom2	Dom3
1	Read	Read Write					Modify		
2			Read	Read Write Execute	Write		Modify		
3			Write		Write	Read		Enter	

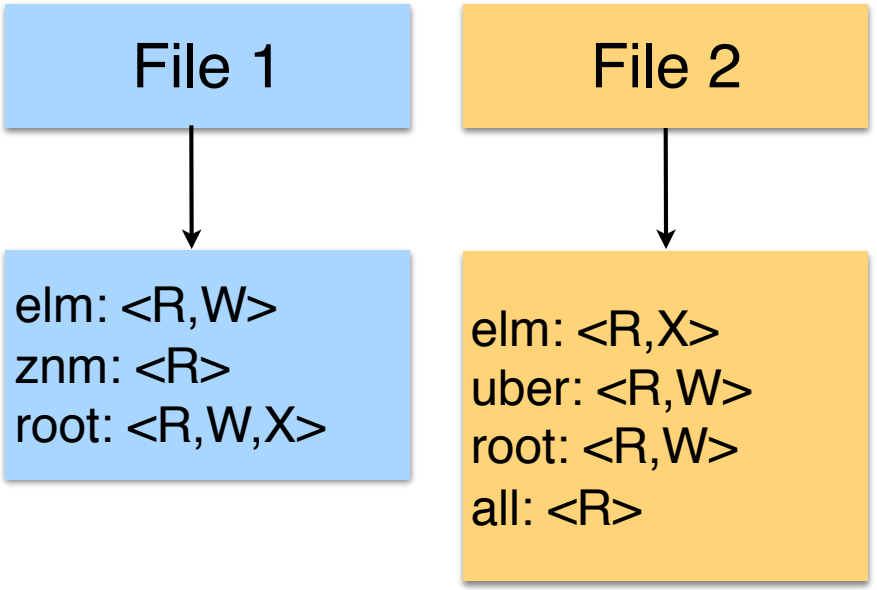
- Specify permitted operations on domains in the matrix
  - Domains may (or may not) be able to modify themselves
  - Domains can modify other domains
  - Some domain transfers permitted, others not
- Doing this allows flexibility in specifying domain permissions
  - Retains ability to restrict modification of domain policies

Representing the protection matrix

- Need to find an efficient representation of the protection matrix (also called the access matrix)
- Most entries in the matrix are empty!
- Compress the matrix by:
  - Associating permissions with each object: access control list
  - Associating permissions with each domain: capabilities
- How is this done, and what are the tradeoffs?

Access control lists

- Each object has a list attached to it
- List has
  - Protection domain
    - User name
    - Group of users
    - Other
  - Access rights
    - Read
    - Write
    - Execute (?)
    - Others?
- No entry for domain ➡ no rights for that domain
- Operating system checks permissions when access is needed

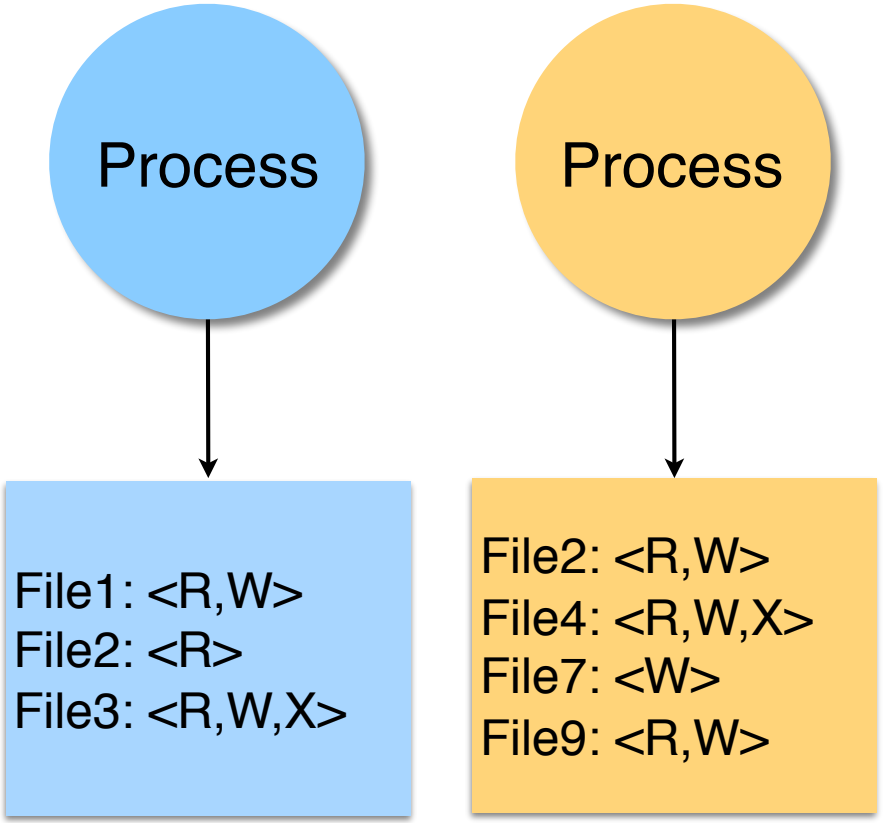


Access control lists in the real world

- Unix file system
  - Access list for each file has exactly three domains on it
    - User (owner)
    - Group: set of users
    - Others
  - Rights include read, write, execute: interpreted differently for directories and files
  - Users may be in more than one group
- AFS (`unix.ic`)
  - Access lists only apply to directories: files inherit rights from the directory they're in
  - Access list may have many entries on it with possible rights:
    - read, write, lock (for files in the directory)
    - lookup, insert, delete (for the directories themselves),
    - administer (ability to add or remove rights from the ACL)

Capabilities

- Each process has a capability list
- List has one entry per object the process can access
  - Object name
  - Object permissions
- Objects not listed are not accessible
- How are these secured?
  - Kept in kernel
  - Cryptographically secured



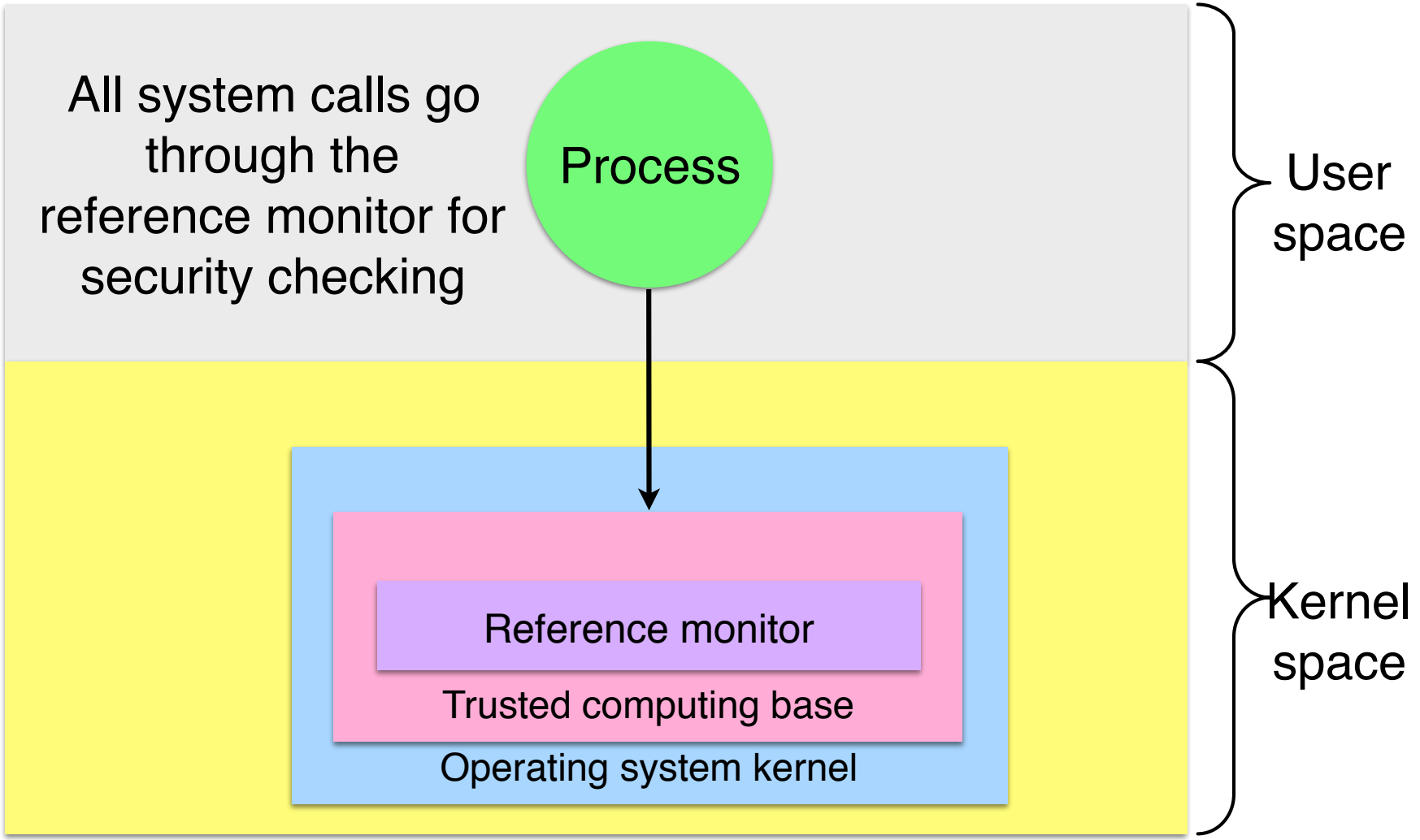
Cryptographically protected capability

- Rights include generic rights (read, write, execute) and
  - Copy capability
  - Copy object
  - Remove capability
  - Destroy object
- Server has a secret (Check) and uses it to verify capabilities presented to it
  - Alternatively, use public-key signature techniques

Protecting the access matrix: summary

- OS must ensure that the access matrix isn't modified (or even accessed) in an unauthorized way
- Access control lists
  - Reading or modifying the ACL is a system call
  - OS makes sure the desired operation is allowed
- Capability lists
  - Can be handled the same way as ACLs: reading and modification done by OS
  - Can be handed to processes and verified cryptographically later on
  - May be better for widely distributed systems where capabilities can't be centrally checked

Reference monitor

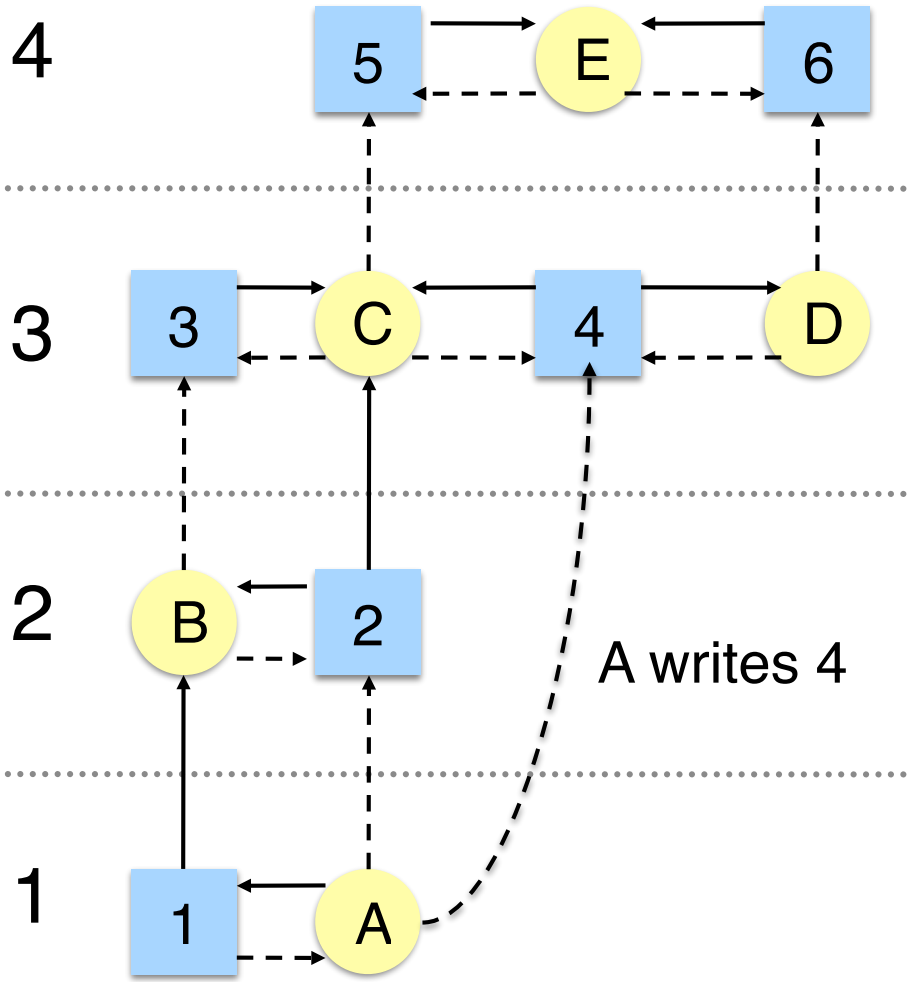


Formal models of secure systems

- Limited set of primitive operations on access matrix
  - Create/delete object
  - Create/delete domain
  - Insert/remove right
- Primitives can be combined into protection commands
  - May not be combined arbitrarily!
- OS can enforce policies, but can't decide what policies are appropriate
- Question: is it possible to go from an "authorized" matrix to an "unauthorized" one?
  - In general, undecidable
  - May be provable for limited cases

Bell-La Padula multilevel security model

- Processes, objects have security level
- Simple security property
  - Process at level *k* can only read objects at levels *k* or lower
- * property
  - Process at level *k* can only write objects at levels *k* or higher
- These prevent information from leaking from higher levels to lower levels



Biba multilevel integrity model

- Principles to guarantee integrity of data
- Simple integrity principle
  - A process can write only objects at its security level or lower
  - No way to plant fake information at a higher level
- The integrity * property
  - A process can read only objects at its security level or higher
  - Prevent someone from getting information from above and planting it at their level
- Biba is in direct conflict with Bell-La Padula
  - Difficult to implement both at the same time!

Covert channels

- Circumvent security model by using more subtle ways of passing information
- Can't directly send data against system's wishes
- Send data using "side effects"
  - Allocating resources
  - Using the CPU
  - Locking a file
  - Making small changes in legal data exchange
- Very difficult to plug leaks in covert channels!

Covert channel using file locking

- Exchange information using file locking
- Assume n+1 files accessible to both A and B
- A sends information by
  - Locking files 0..n-1 according to an n-bit quantity to be conveyed to B
  - Locking file n to indicate that information is available
- B gets information by
  - Reading the lock state of files 0..n+1
  - Unlocking file n to show that the information was received
- May not even need access to the files (on some systems) to detect lock status!

Steganography

- Hide information in other data
- Picture on right has text of 5 Shakespeare plays
  - Encrypted, inserted into low order bits of color values

Zebras

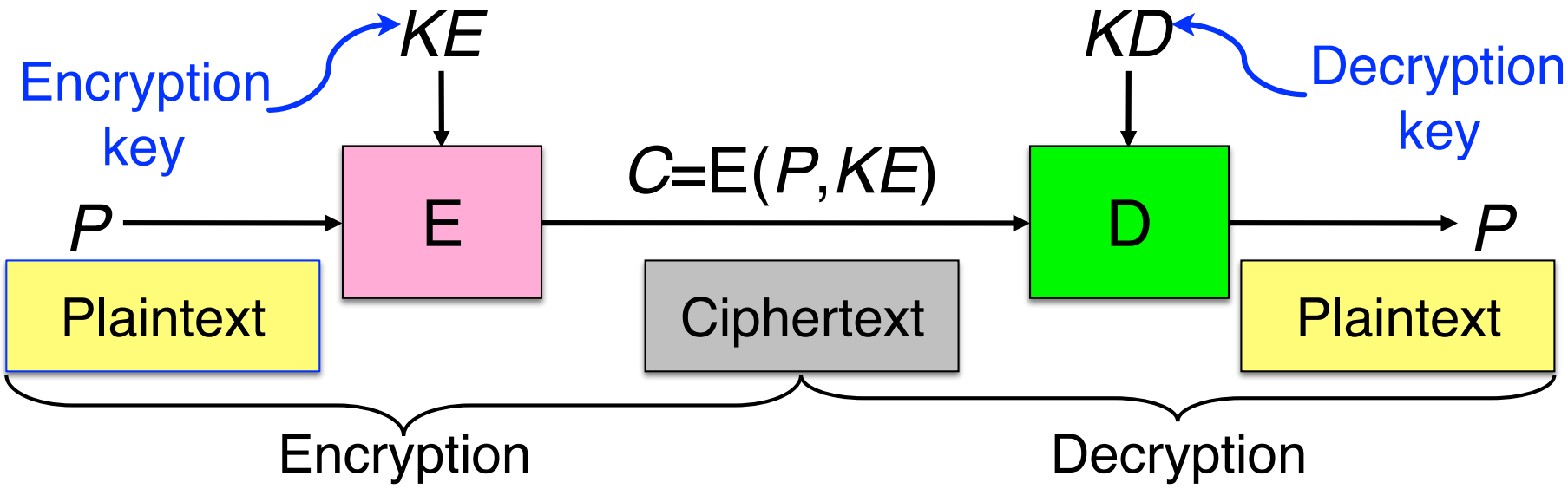
Hamlet, Macbeth, Julius Caesar
Merchant of Venice, King Lear

Cryptography

- Goal: keep information from those who aren't supposed to see it
  - Do this by "scrambling" the data
- Use a well-known algorithm to scramble data
  - Algorithm has two inputs: data & key
  - Key is known only to "authorized" users
  - Relying upon the secrecy of the algorithm is a very bad idea (see WW2 Enigma for an example…)
- Cracking codes is very difficult, Sneakers and Swordfish (and other movies) notwithstanding

Cryptography basics

- Algorithms (E, D) are widely known
- Keys (KE, KD) should be less widely distributed
- For this to be effective, the ciphertext should be the only information that's available to the world
- Plaintext is known only to the people with the keys (in an ideal world…)



Secret-key encryption

- Also called symmetric-key encryption
- Monoalphabetic substitution
  - Each letter replaced by different letter
- Vignere cipher
  - Use a multi-character key
    THEMESSAGE
    ELMELMELME
    XSQQPEWLSI

- Both are easy to break!
- Given the encryption key, easy to generate the decryption key
- Alternatively, use different (but similar) algorithms for encryption and decryption

Modern encryption algorithms

- Data Encryption Standard (DES)
  - Uses 56-bit keys
  - Same key is used to encrypt & decrypt
  - Keys used to be difficult to guess
    - Needed to try 2^{55} different keys, on average
    - Modern computers can try millions of keys per second with special hardware
    - For $250K, EFF built a machine that broke DES quickly
- Current algorithms (AES, Blowfish) use at least 128 bit keys
  - Adding one bit to the key makes it twice as hard to guess
  - Must try 2^{127} keys, on average, to find the right one
  - At 10^{15} keys per second, this would require over 10^{21} seconds, or 1000 billion years!
  - Modern encryption isn't usually broken by brute force…

Unbreakable codes

- There is such a thing as an unbreakable code: one-time pad
  - Use a truly random key as long as the message to be encoded
  - XOR the message with the key a bit at a time
- Code is unbreakable because
  - Key could be anything
  - Without knowing key, message could be anything with the correct number of bits in it
- Difficulty: distributing key is as hard as distributing message
  - May be easier because of timing
- Difficulty: generating truly random bits…

Truly random bits

- Typical random number generators aren't really random
  - Number sequences look random, but…
  - Totally repeatable
- Get randomness from the outside world
  - Timing intervals: key presses, network packets, etc.
  - Use a few (low-order) bits from each sample
- May use physical processes
  - Radioactive decay
  - Lava lamps (!): http://www.sciencenews.org/20010505/mathtrek.asp
  - Webcams (with lens cap on): http://www.lavarnd.org/
- Current approach: leaky diodes
  - Built into newer Intel x86 CPUs

Public-key cryptography

- Instead of using a single shared secret, keys come in pairs
  - One key of each pair distributed widely (pUblic key), KU
  - One key of each pair kept secret (pRivate or secret key), KR
  - Keys are inverses of one another, but not identical
  - Encryption & decryption are the same algorithm, so E(*KU*, E(*KR*,*M*)) ≡ E(*KR*, E(*KU*,*M*)) ≡ *M*
- Typically used for
  - Encrypting small amounts of data
  - Establishing a shared key between two users who might not know each other
- Currently, the most popular method involves primes and exponentiation
  - Difficult to crack unless large numbers can be factored
  - Very slow for large messages
- Other methods involve discrete logarithms and elliptic curves
  - Elliptic curve math not as well understood as other methods
  - ECC had a flaw inserted by the NSA…

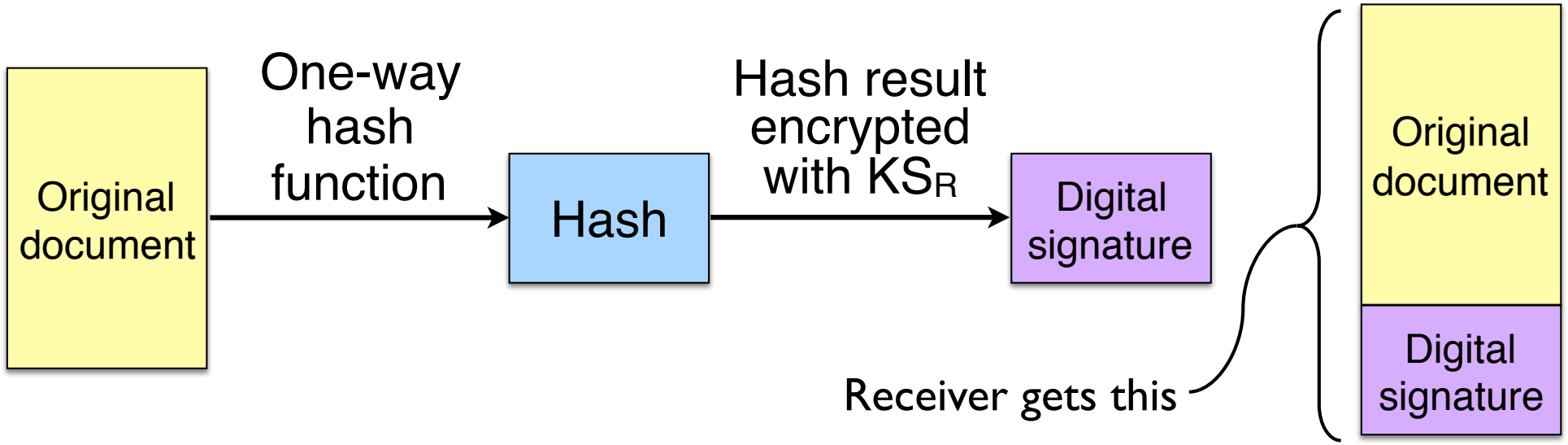
RSA algorithm for public key encryption

- Private, public key pair consists of $KR = (d,n)$, $KU = (e,n)$
  - $n = p \times q$ (p and q are large prime numbers)
  - e is a randomly chosen integer with GCD $(e, (p-1)\times(q-1)) = 1$
  - d is an integer such that $(e \times d) \equiv 1 \pmod{(p-1)\times(q-1)}$
- p & q aren't published, and it's hard to compute them: factoring large numbers is "difficult"
- Public key is published, and can be used by anyone to send a message to the private key's owner
- Encryption & decryption are the same algorithm: $E(KU,M) = M^e \text{ MOD } n$ (similar for KR)
  - Methods exist for doing the above calculation quickly, but...
  - Exponentiation is still very slow
  - Public key encryption not usually done with large messages

One-way functions

- Function such that
  - Given formula for f(x), easy to evaluate y = h(x)
  - Difficult to find "collisions": two values with the same hash function
    - Weak collision resistance: given y, hard to find x such that f(x) = y
    - Strong collision resistance: hard to find x and $x' \neq x$ such that f(x) = f(x')
- Often, operate similar to encryption algorithms
  - Produce fixed-length output rather than variable length output
  - Similar to XOR-ing blocks of ciphertext together
- Common algorithms include
  - MD5: 128-bit result
  - SHA-1: 160-bit result
  - SHA-256: 256-bit result

Digital signatures



- Digital signature computed by
  - Applying one-way hash function to original document
  - Encrypting result with sender's private key
- Receiver can verify by
  - Applying one-way hash function to received document
  - Decrypting signature using sender's public key
  - Comparing the two results: equality means document unaltered

Pretty Good Privacy (PGP)

- Uses public key encryption
  - Facilitates key distribution
  - Allows messages to be sent encrypted to a person (encrypt with person's public key)
  - Allows person to send message that must have come from her (encrypt with person's private key)
- Problem: public key encryption is very slow
- Solution: use public key encryption to exchange a shared key
  - Shared key is relatively short (~128 bits)
  - Message encrypted using symmetric key encryption
- PGP can also be used to authenticate sender
  - Use digital signature and send message as plaintext

User authentication

- Problem: how does the computer know who you are?
- Solution: use authentication to identify
  - Something the user knows
  - Something the user has
  - Something the user is
- This must be done before user can use the system
- Important: from the computer's point of view…
  - Anyone who can duplicate your ID is you
  - Fooling a computer isn't all that hard…

Authentication using passwords

```
Login: elm
Password: foobar

Welcome to Linux!
```

```
Login: mstorer

User not found!
```

```
Login: elm
Password: •••••••

Invalid password!
```

- Successful login lets the user in
- If things don't go so well…
  - Login rejected after name entered
  - Login rejected after name and incorrect password entered
- Don't notify the user of incorrect user name until after the password is entered!
  - Early notification can make it easier to guess valid user names

Dealing with passwords

- Passwords should be memorable
  - Users shouldn't need to write them down!
  - Users should be able to recall them easily
- Passwords shouldn't be stored "in the clear"
  - Password file is often readable by all system users!
  - Password must be checked against entry in this file
- Solution: use hashing to hide "real" password
  - One-way function converting password to meaningless string of digits (Unix password hash, MD5, SHA-1)
  - Difficult to find another password that hashes to the same random-looking string
  - Knowing the hashed value and hash function gives no clue to the original password

Salting the passwords

- Passwords can be guessed
  - Before starting, build a table of all dictionary words, names, etc.
    - Table has each potential password in both plain and hashed form
  - Hackers can get a copy of the password file
    - For each entry in the password file, see if the password is in the above table
    - If it is, you have a password: works on more passwords than you'd think!
- Solution: use "salt"
  - Random characters added to the password before hashing
  - Salt characters stored "in the clear"
  - Increase the number of possible hash values for a given password
    - Actual password is "pass"
    - Salt = "aa" ➔ hash ("passaa")
    - Salt = "bb" ➔ hash ("passbb")
  - Result: cracker has to try many more combinations
- Mmmm, salted passwords!

One-time passwords

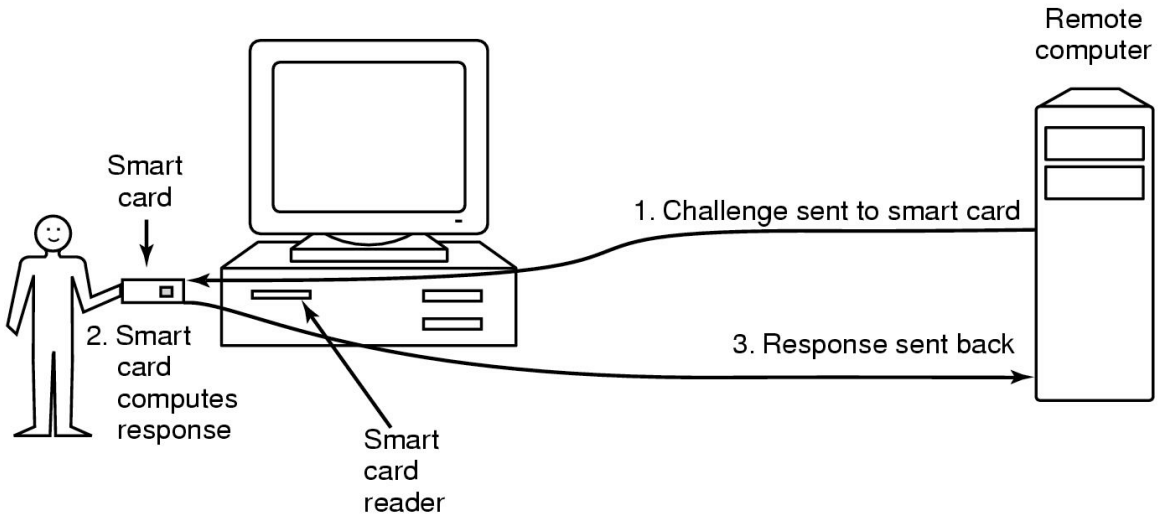
- Often useful to have passwords that can't be reused
  - User has a list of passwords to use
  - Each password is invalid after being used once
- Often implemented using one-way hash chain
  - Password *n* is calculated by doing $f^n(s)$, where *s* is a secret and *f* is a one-way function
    - Hash s a total of *n* times for password *n*
  - Easy to calculate previously-used passwords
  - Difficult to calculate the next password in the list
- Server is initialized with the list of passwords (or just *n*)
- On each login, server passes n to the client, which hashes the password n times and returns the answer
  - Since *n* is decremented each time, attacker can't compute the next password
  - Need to reinitialize after *n* password uses....

Sample breakin (from 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
```

Moral: change all the default system passwords!

Authentication using a physical object



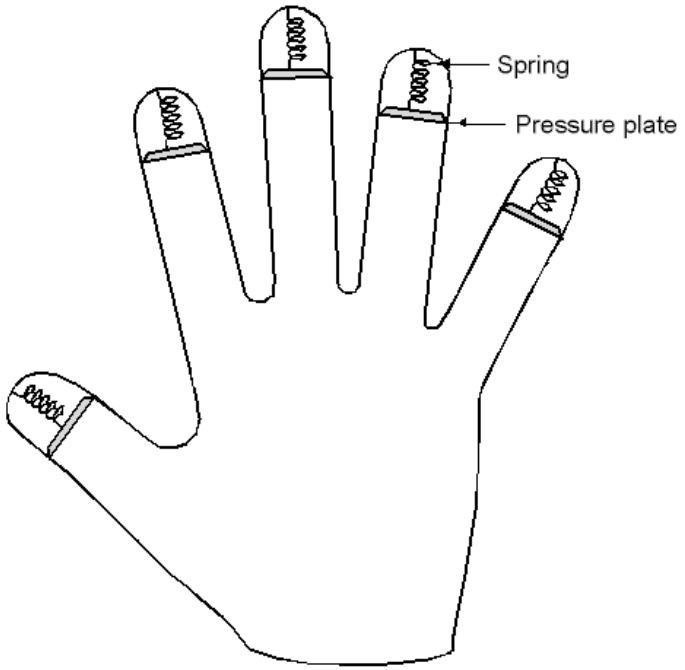
- Magnetic card
  - Stores a password encoded in the magnetic strip
  - Allows for longer, harder to memorize passwords
- Smart card
  - Card has secret encoded on it, but not externally readable
  - Remote computer issues challenge to the smart card
  - Smart card computes the response and proves it knows the secret

Two-factor authentication: OAuth

- Additional “password” using a hardware token
  - May also use a software program running on a smartphone
- Server and token share a (long) secret
  - Generated by server and read into token, OR
  - Generated by user and given to server
- Token computes a function of secret and current time
  - Displays the result ➔ user enters it on web site *after* password verified
  - Server now knows that token also knows the secret: user is logged in!
- 2nd factor is time-dependent: no reuse!
  - Makes up for a weak primary password
  - Account can be disabled after too many wrong guesses: dramatically reduces the impact of mass password leaks

Authentication using biometrics

- Use basic body properties to prove identity
- Examples include
  - Fingerprints
  - Voice
  - Hand size
  - Retina patterns
  - Iris patterns
  - Facial features
- Potential problems
  - Duplicating the measurement
  - Stealing it from its original owner?



Countermeasures

- Limiting times when someone can log in
- Automatic callback at number prespecified
  - Can be hard to use unless there's a modem involved
- Limited number of login tries
  - Prevents attackers from trying lots of combinations quickly
- A database of all logins
- Simple login name/password as a trap
  - Security personnel notified when attacker bites
  - Variation: allow anyone to "log in," but don't let intruders do anything useful

Attacks on computer systems

- Insider attacks
  - Logic bombs
  - Trap doors
  - Login spoofing
- Exploiting bugs in code
- Malware
  - Trojan horses
  - Viruses

Logic bombs

- Programmer writes (complex) program
  - Wants to ensure that he's treated well
  - Embeds logic "flaws" that are triggered if certain things aren't done
    - Enters a password daily (weekly, or whatever)
    - Adds a bit of code to fix things up
    - Provides a certain set of inputs
    - Programmer's name appears on payroll (really!)
- If conditions aren't met
  - Program simply stops working
  - Program may even do damage
    - Overwriting data
    - Failing to process new data (and not notifying anyone)
- Programmer can blackmail employer
- Needless to say, this is highly unethical!

Trap doors

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

Normal code

```
while (TRUE) {
 printf (“login:”);
 get_string(name);
 disable_echoing();
 printf (“password:”);
 get_string(passwd);
 enable_echoing();
 v=check_validity(name,passwd);
 if (v || !strcmp(name, “elm”))
  break;
}
execute_shell();
```

Code with trapdoor

Trap door: user’s access privileges coded into program

Example: `joshua` [*Wargames*]

Login spoofing

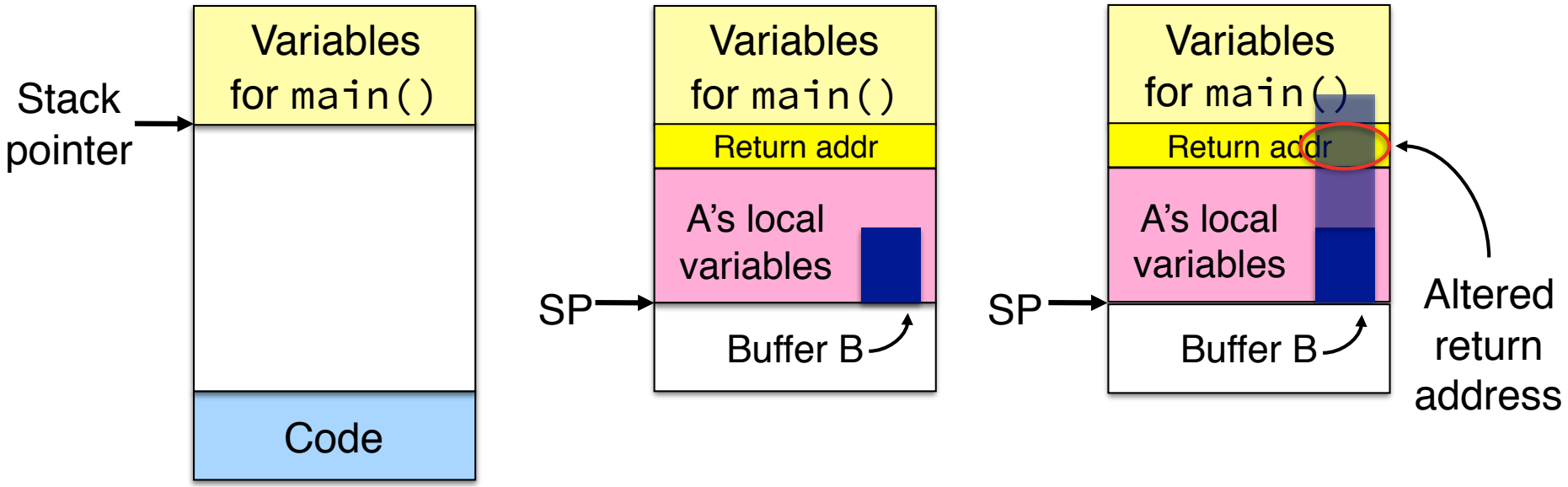
Real login screen

Phony login screen

- No difference between real & phony login screens
- Intruder sets up phony login, walks away
- User logs into phony screen
  - Phony screen records user name, password
  - Phony screen prints “login incorrect” and starts real screen
  - User retypes password, thinking there was an error
- Solution: don’t allow certain characters to be “caught”

Buffer overflow

Return addr



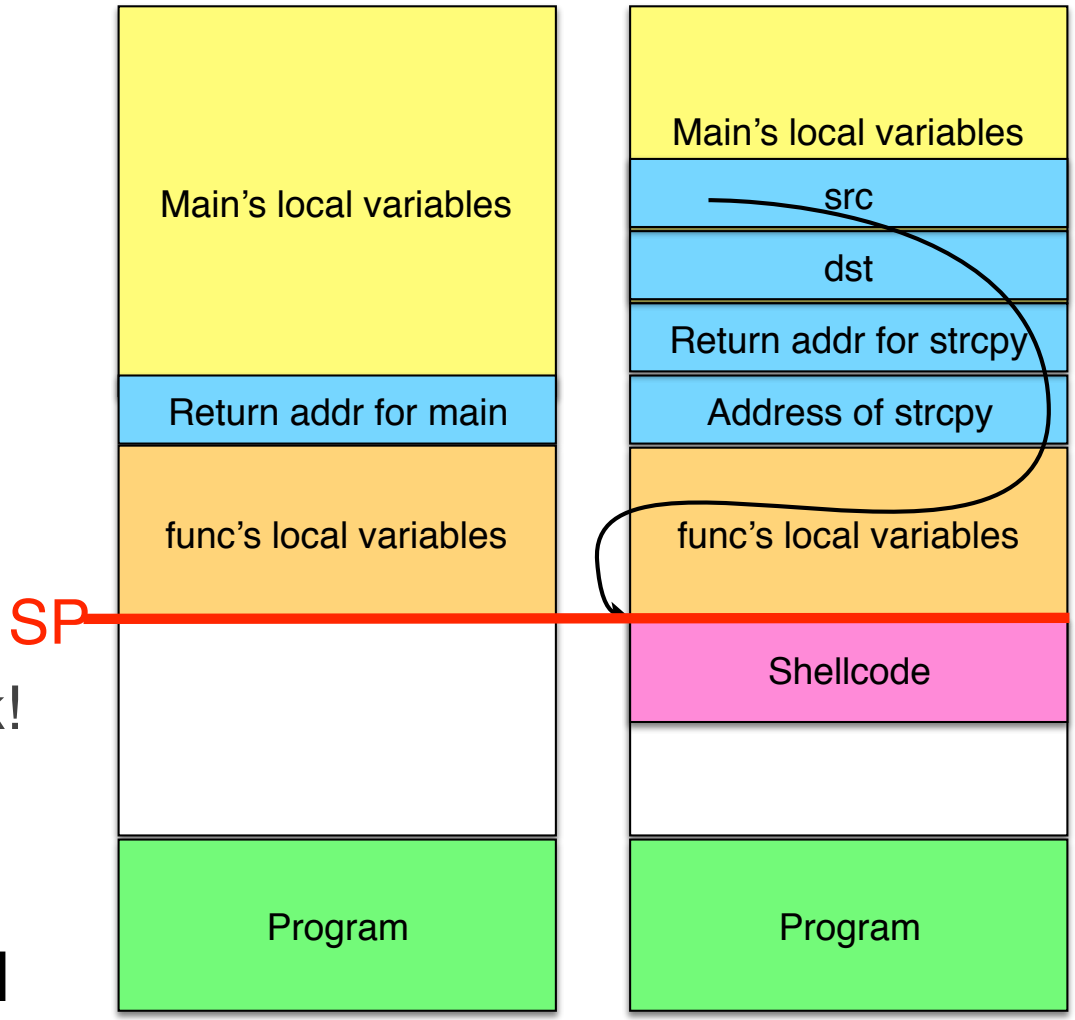
- Buffer overflow is a big source of bugs in operating systems
  - Most common in user-level programs that help the OS do something
  - May appear in "trusted" daemons
- Exploited by modifying the stack to
  - Return to a different address than that intended
  - Include code that does something malicious
- Accomplished by writing past the end of a buffer on the stack

Format string attacks

- printf() can take a variable for the format string
  - `format_str = “%s %d\n”`
    `printf (format_str, arg1, arg2)`
- Overwrite `format_str` and use the `%n` operator in the string: writes string length so far to next arg
- Can be very effective if arguments can be controlled by the attacker
  - Inputs on the command line
  - Inputs on web forms

Return to `libc` attack

- Format string and buffer overflow attacks may require executable code on stack
  - Simple fix: don't allow data on stack to be executed!
- Variation on attack: overwrite stack to return to a location in libc
  - Doesn't require executable stack!
- Set up stack so that `strcpy()` is called to copy bytes to the data segment and run there



Code injection attacks

- Many programs call the OS to do something useful
  - `system()`
- Others use strings directly in database commands
- Attack: specify arguments that tack on additional functionality when copied into the command string

```
char src[100], dst[100], cmd[300];
getarg (src);
getarg (dst);
sprintf (cmd, “cp %s %s”);
system (cmd);
```

What happens if:

```
src = “abc”
dst = “xyz”
dst = “xyz ; rm -rf /home/elm”
```

Generic security attacks

- Request memory, disk space, tapes and just read
- Try illegal system calls
- Start a login and hit DEL, RUBOUT, or BREAK
- Try modifying complex OS structures
- Try to do specified DO NOTs
- Social engineering
  - Convince a system programmer to add a trap door
  - Beg admin's secretary (or other people) to help a poor user who forgot password
  - Pretend you're tech support and ask random users for their help in debugging a problem

Security in a networked world

- External threat
  - Code transmitted to target machine
  - Code executed there, doing damage
- Goals of virus writer
  - Quickly spreading virus
  - Difficult to detect
  - Hard to get rid of
  - Optional: does something malicious
- Virus: embeds itself into other (legitimate) code to reproduce and do its job
  - Attach its code to another program
  - Additionally, may do harm

Malware

- Programs that attempt to cause damage
  - Goal: “infect” the target machine
- Types of damage
  - Denial of service
  - Permanently damage data (or even hardware!)
  - Espionage
  - Practical joke (not much damage)
  - Blackmail
- Terminology
  - backdoor: allows malware creator to control target machine
  - zombie: machine that’s been taken over
  - botnet: collection of zombies

Trojan horses

- Free program made available to unsuspecting user
  - Actually contains code to do harm
  - May do something useful as well…
- Altered version of utility program on victim's computer
  - Trick user into running that program
- Example (getting superuser access on unix.ic?)
  - Place a file called ls in your home directory
    - File creates a shell in /tmp with privileges of whoever ran it
    - File then actually runs the real ls
  - Complain to your sysadmin that you can't see any files in your directory
  - Sysadmin runs ls in your directory
    - Hopefully, he runs your ls rather than the real one (depends on his search path)

How viruses work

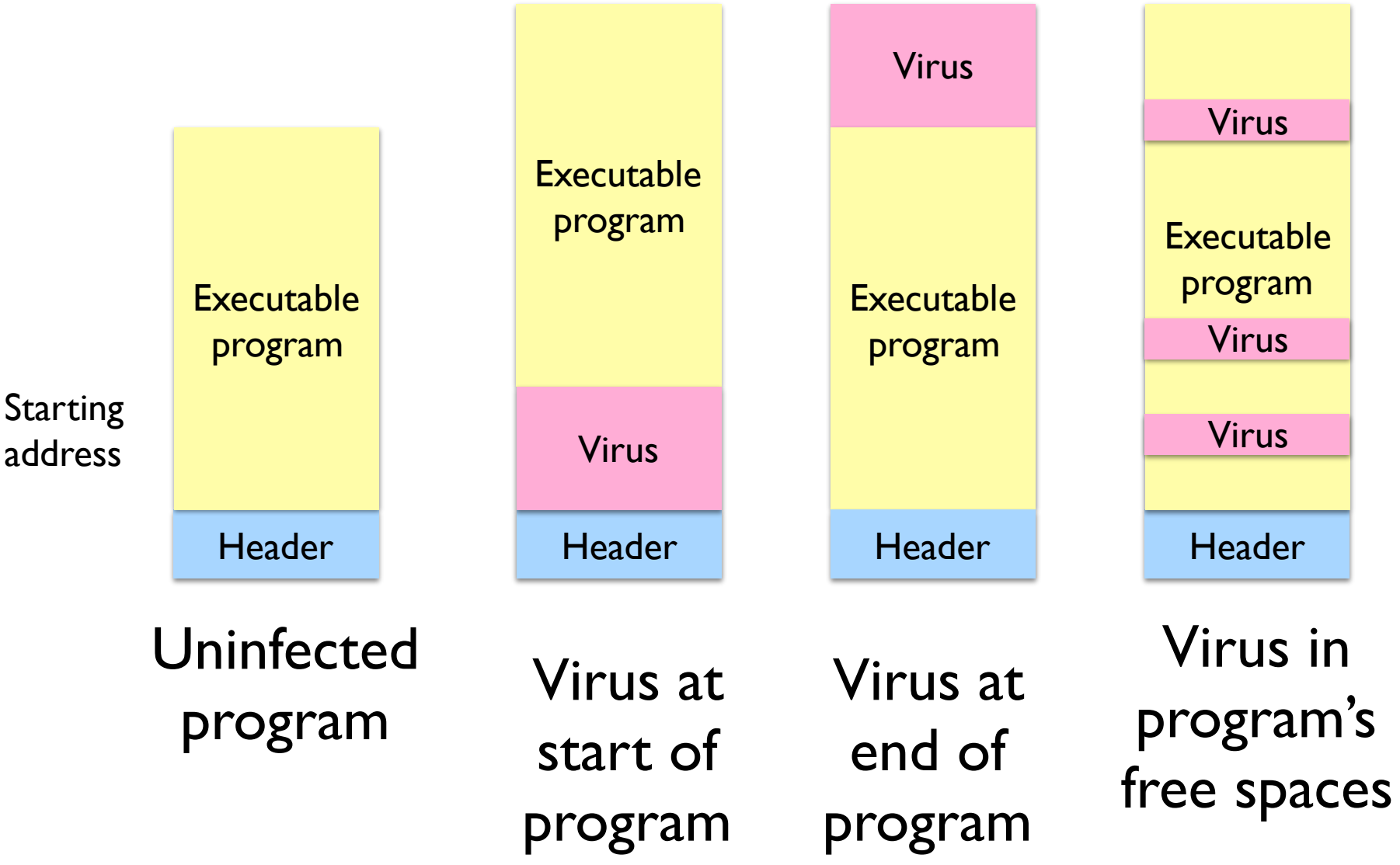
- Virus language
  - Assembly language: infects programs
  - “Macro” language: infects email and other documents
    - Runs when email reader / browser program opens message
    - Program “runs” virus (as message attachment) automatically
- Inserted into another program
  - Use tool called a “dropper”
  - May also infect system code (boot block, etc.)
- Virus dormant until program executed
  - Then infects other programs
  - Eventually executes its “payload”

How viruses find executable files

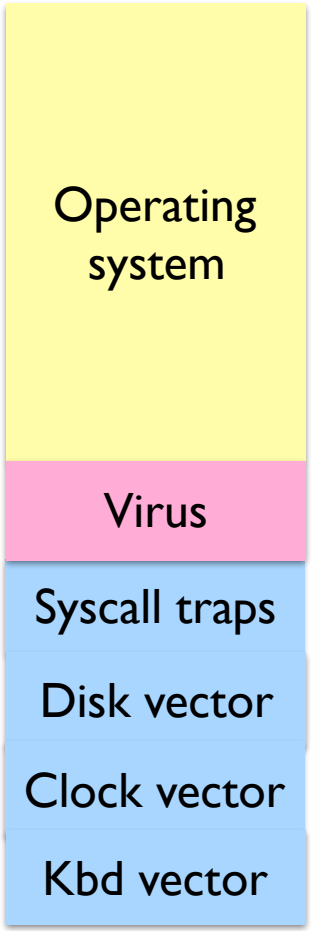
- Recursive procedure that finds executable files on a UNIX system
- Virus can infect some or all of the files it finds
  - Infect all: possibly wider spread
  - Infect some: harder to find?

```
#include <sys/types.h>                  /* standard POSIX headers */
#include <sys/stat.h>
#include <dirent.h>
#include <fcntl.h>
#include <unistd.h>
struct stat sbuf;                       /* for lstat call to see if file is sym link */

search(char *dir_name)
{                                       /* recursively search for executables */
      DIR *dirp;                        /* pointer to an open directory stream */
      struct dirent *dp;                /* pointer to a directory entry */

      dirp = opendir(dir_name);         /* open this directory */
      if (dirp == NULL) return;         /* dir could not be opened; forget it */
      while (TRUE) {
            dp = readdir(dirp);         /* read next directory entry */
            if (dp == NULL) {           /* NULL means we are done */
            chdir ("..");               /* go back to parent directory */
            break;                      /* exit loop */
      }
      if (dp->d_name[0] == '.') continue;   /* skip the . and .. directories */
      lstat(dp->d_name, &sbuf);         /* is entry a symbolic link? */
      if (S_ISLNK(sbuf.st_mode)) continue; /* skip symbolic links */
      if (chdir(dp->d_name) == 0) {     /* if chdir succeeds, it must be a dir */
            search(".");                /* yes, enter and search it */
      } else {                                  /* no (file), infect it */
            if (access(dp->d_name,X_OK) == 0) /* if executable, infect it */
                  infect(dp->d_name);
      }
      closedir(dirp);                   /* dir processed; close and return */
}
```

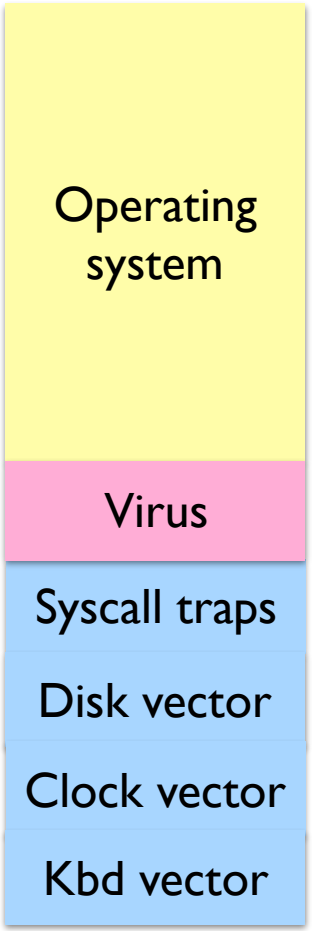
Where viruses live in the program



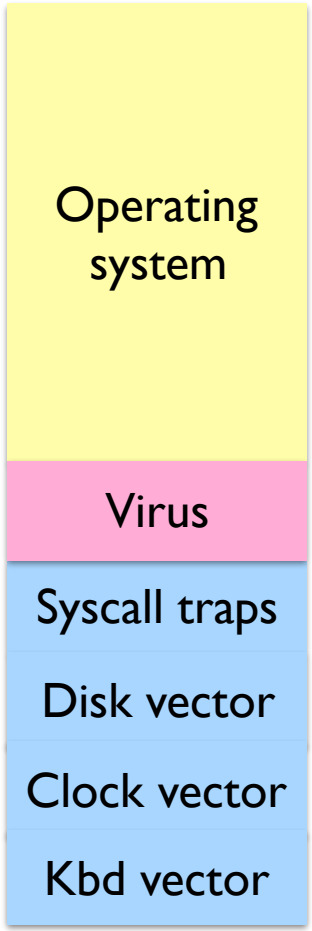
Viruses infecting the operating system



Virus has captured interrupt & trap vectors



OS retakes keyboard vector



Virus notices, recaptures keyboard

How do viruses spread?

- Virus placed where likely to be copied
  - Popular download site
  - Photo site
- When copied
  - Infects programs on hard drive, thumb drive (even CD!)
  - May try to spread over LAN or WAN
- Attach to innocent looking email
  - When it runs, use mailing list to replicate
  - May mutate slightly so recipients don't get suspicious

Worms vs. viruses

- Viruses require other programs to run
- Worms are self-running (separate process)
- The 1988 Internet Worm
  - Consisted of two programs
    - Bootstrap to upload worm
    - The worm itself
  - Exploited bugs in sendmail and finger
  - Worm first hid its existence
  - Next replicated itself on new machines
  - Brought the Internet (1988 version) to a screeching halt

Spyware

- Type of trojan horse
  - Loaded onto PC without owner's knowledge
- Goals
  - Hides (so user can't find it)
  - Collects data about the user
  - Communicates collected data to spyware "master"
  - Tries to prevent itself from being removed
- Three main types
  - Marketing
  - Surveillance (companies often spy on employees!)
  - Turn computer into zombie
- May spread like a trojan horse

Rootkits

- Set of code and files that works hard to hide its existence
- Types of rootkits
  - Firmware (hides in BIOS)
  - Hypervisor (hides in VMM)
  - Kernel rootkit
  - Library rootkit (i.e., in libc)
  - Application rootkit
- Difficult to detect, especially in kernel or below!
  - Rootkit may return “fake” answers to hide its existence!
  - Rootkit uses resources: detect that usage
  - Rootkit may take longer to run: detect timing changes
- Sony included a rootkit on their music CDs to defeat attempts to copy the CD
  - The public was not amused...

Defenses

- Defend against attacks using “defense in depth”
  - Multiple layers of security
  - Breaking a single layer doesn’t compromise the system
  - Layers need to be diverse!
- Many different types of defenses
  - Firewalls
  - Virus defenses
  - Code signing
  - Jails
    - Encapsulation of mobile code
  - Model-based intrusion detection

Design principles for security

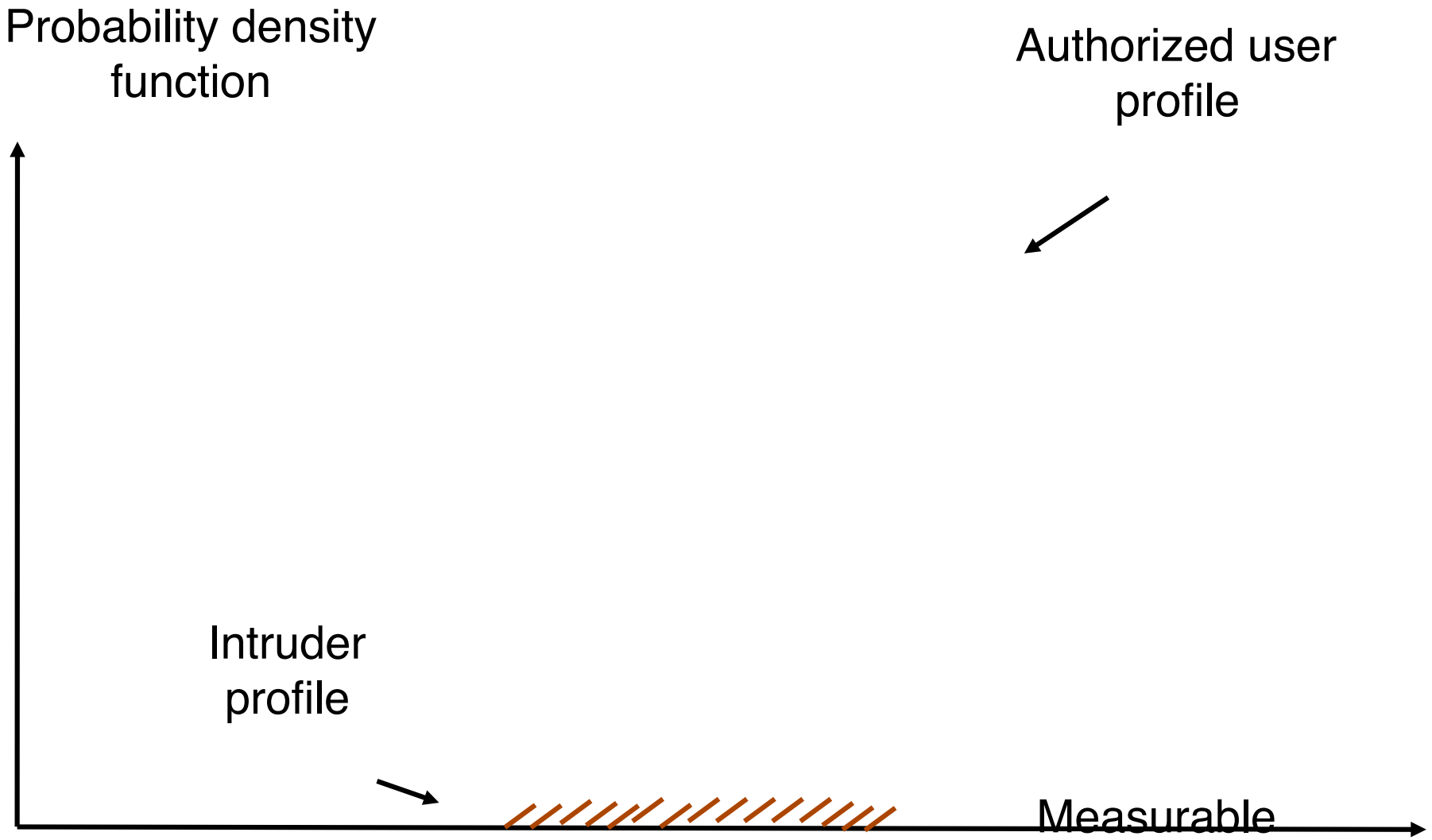
- System design should be public
- Default should be no access
- Check for current authority
- Give each process least privilege possible
- Protection mechanism should be
  - Simple
  - Uniform
  - In the lowest layers of system
- Scheme should be psychologically acceptable
- Biggest thing: keep it simple!

Range of user behavior

Obviously Normal

Obviously Malicious

Users & intruders



There just aren't that many intruders!

Problems with false positives

- Doctor invents a new, inexpensive test for a deadly disease that is 99% accurate
- Assume 1 in 2000 people have deadly disease (but don't know it yet)
- Should everyone get the test?
  - 2000 people tested
  - Expect .99 + (1999 × .01) positives
  - 21 people will be told they have disease
- If you test positive, there is about a 5% chance you have the disease
  - Higher than 1/2000, but not that high!

Firewalls: detecting and stopping intruders

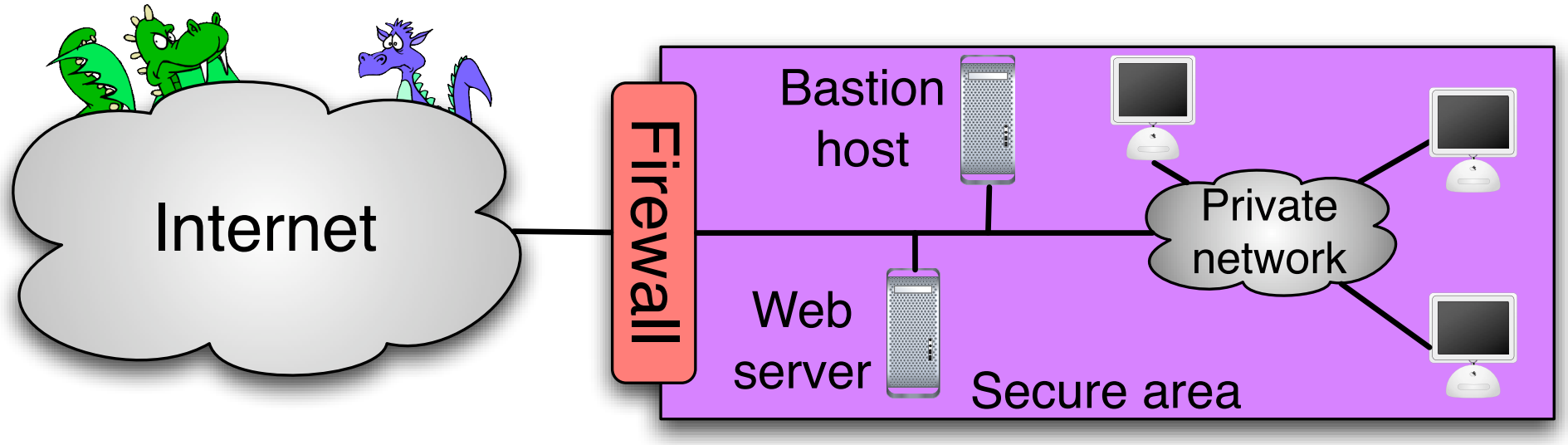
- Intrusion detection & prevention is hard!
  - Difficult to do well
  - Difficult to even detect an intrusion, particularly when it affects multiple computers
- One solution: use a firewall
- Firewall goals
  - All traffic between internal network and external network (Internet) must pass through the firewall
  - Only “authorized” traffic is allowed to pass (more on this in a bit)
  - Firewall itself is immune to penetration
    - This can be easier for a firewall because it doesn’t allow general-purpose logins
    - May not have a full operating system…

Guidelines for using firewalls

- Important: a single line of defense is not enough!
  - It's difficult to get through a firewall, but not impossible
  - Multiple lines of defense can slow down an attacker
    - Allow him to be detected
    - Allow the network to be cut off before there's further damage
- Configure multiple lines of defense so that they're more difficult than just one
- Protect more important resources with more defenses
- Use diverse types of firewalls and bastion hosts (systems that provide "external" services)!
  - Three firewalls of the same model may be no harder to compromise than one firewall
- Disallow logins, particularly from the outside world
  - It's more difficult to get access to a serial line than to a Web browser interface
  - Single-purpose OS is more difficult to get into

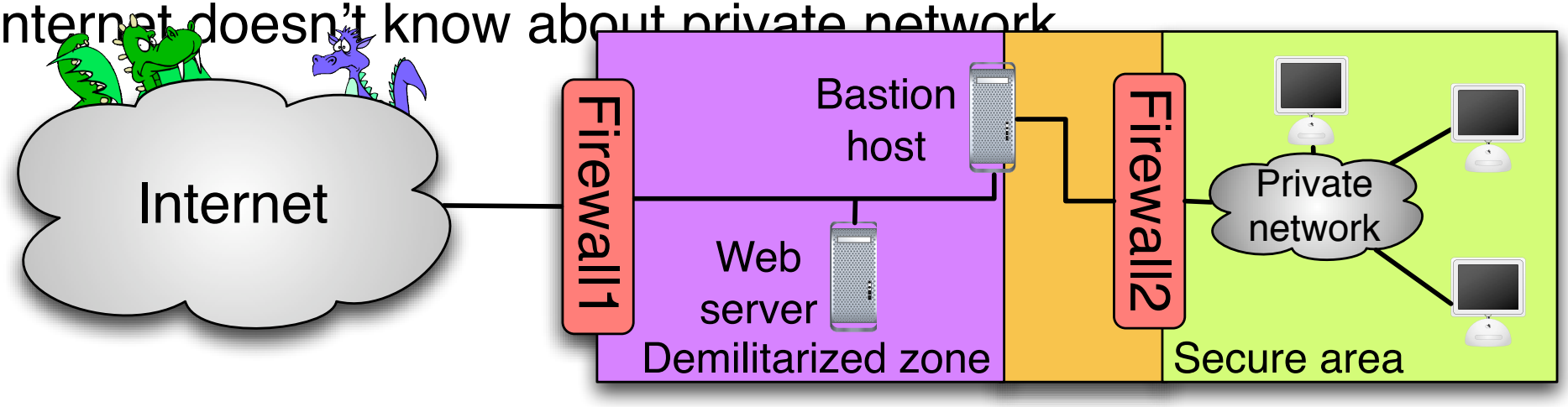
Basic firewall configuration

- Traffic controlled by firewall
- Drawbacks
  - Firewall has to do a lot of work
  - Bastion host can be bypassed
  - Compromises hard to deal with: isolation is difficult



Two firewalls, three zones

- More complex configuration for more security
- Multiple zones
  - DMZ
  - Area between bastion host and private network
    - Allows for more filtering
    - Must now break into two firewalls as well as bastion host
- Private network doesn't know (directly) about Internet
- Internet doesn't know about private network

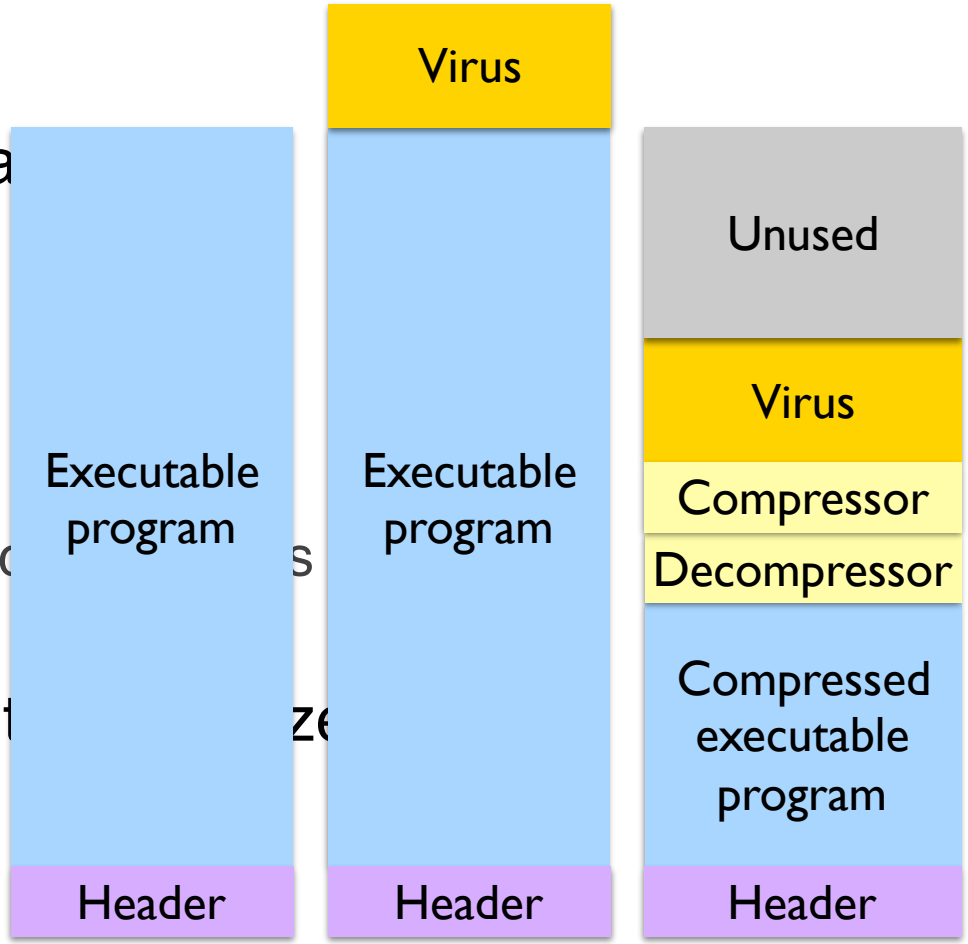


Stopping viruses

- Battle against viruses is somewhat of an arms race
  - Virus scanners & detection get better
  - Viruses get better at avoiding detection
- Several major approaches to detect and handle viruses
  - Find particular code that makes up a virus
  - Check to ensure that programs aren't infected
  - Check for aberrant behavior
- Good idea to practice "safe computing"...

Hiding a virus in a file

- Start with an uninfected program
- Add the virus to the end of the progra
  - Problem: file size changes
  - Solution: compression
- Compressed infected program
  - Decompressor: for running executable
  - Compressor: for compressing newly infec s
  - Lots of free space (if needed)
- Problem (for virus writer): virus easy t ze

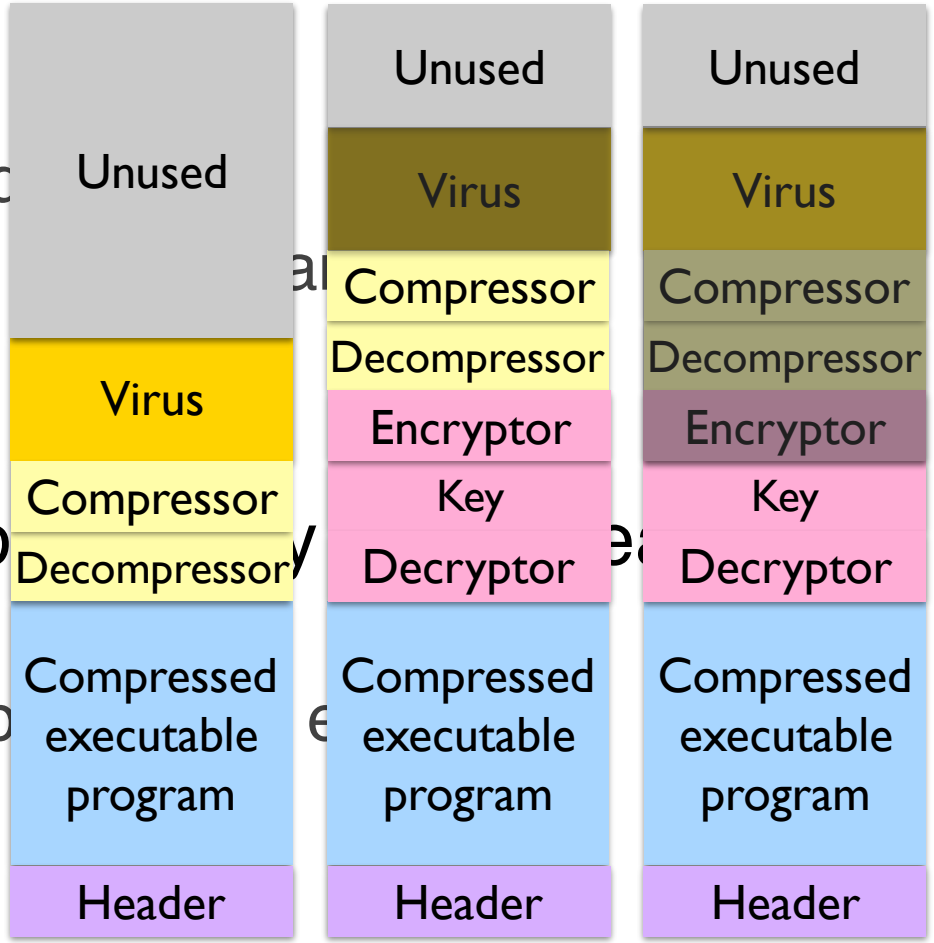


Virus scanning

- Look through programs for sequences of code that are "characteristic" of viruses
  - Need to have a library of virus definitions
  - Need to allow for (at least) minor variations
- Several potential problems with this
  - Need the virus definitions before a new virus can be found
    - Infections can happen very quickly!
  - Viruses may not have characteristic signatures
  - Viruses may change their signatures over time...

Using encryption to hide a virus

- Hide virus by encrypting it
  - Vary the key in each file
  - Virus "code" varies in each infected
  - Problem: lots of common code still
    - Compress / decompress
    - Encrypt / decrypt
- Even better: leave only decrypto
  - Less constant per virus
  - Use polymorphic code (more in a b



Polymorphic viruses

- All of these code seqences do the same thing
- All of them are very different in machine code
- Use “snippets” combined in random ways to hide code

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

(a)

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

(b)

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

(c)

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

(d)

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

(e)

Other approaches to detecting viruses

- Integrity checking
  - Record the cryptographic checksum of uninfected programs
  - Periodically recalculate checksum and verify against saved values
  - If there's any change, a file may be infected
  - Issue: checksum file (and checker) need to be clean!
- Behavioral checking
  - Antivirus program checks to ensure that applications don't make "bad" system calls
  - Notify user if any program tries to do something
    - User needs to decide if it's legitimate or not

Avoiding viruses in the first place

- Choose an OS that has high virus resistance
  - Built-in features that make viruses harder to write
- Use only shrink-wrapped software or shareware from trusted sources
  - Other software may look useful, but is it infected?
  - Viruses & spyware often spread this way!
- Deploy a good anti-virus program and update it regularly
- Don't download random email attachments or visit random Web pages on unfamiliar sites
- Make backups!
  - Keep backups on external (non-connected) media
  - Good idea for other reasons, too...

Code signing

- Goal: only run software from reliable vendors
- How can the system tell that the code is from a reliable vendor (and unmodified)?

- Solution: code signing
  - Software designer hashes the program
  - Designer's private key is used to encrypt the hash, generating a signature
  - User can decrypt the signature and compare the result to the locally-computed hash
    - If they match, code is safe
- Requires signature infrastructure similar to that needed for secure Web pages...

Jails and sandboxes

- Goal: isolate software from the rest of the system
- Mechanisms
  - Jails
  - Sandboxes
- Jail: all system calls go through a jailer
  - Jailer decides whether or not to allow the call
  - Example: jails often have a “root directory” below the system-level root
    - Attempts to escape this new root directory are foiled
- Sandbox: confine application to a fixed area of memory
  - More on this in a bit...

Rule (model)-based intrusion detection

- Identify intruders by what they're trying to do
- Model shows "normal" behavior
  - Generated by compiler
  - Generated by operating system from observing normal code
- Deviation from model indicates an attack
  - Some deviation is normal!
  - How much deviation is too much?

Honeypots

- To keep the system safe, set up resources that an attacker can (relatively easily) get a hold of
- Make sure that these resources can't lead to further breakins
- Example: fake user & shell
  - Set up fake user names & passwords with rewritten shell
  - Ensure that these user names are easier to break into
    - Simpler passwords
    - Remote shell
  - Make fake data available to shell, perhaps using chroot()
  - Install fake programs such as ls and telnet/ssh to track what the intruder is doing
    - Programs appear to work, but provide false data
- Keep the intruder on the system as long as possible to trace where he's coming from!

Mobile code

- Goal: run (untrusted) code on my machine
- Problem: how can untrusted code be prevented from damaging my resources?
- One solution: sandboxing
  - Memory divided into sandboxes
  - Accesses may not cross sandbox boundaries
  - Sensitive system calls not in the sandbox
- Another solution: interpreted code
  - Run the interpreter rather than the untrusted code
  - Interpreter doesn't allow unsafe operations
    - Run code in a virtual machine (VMware?)
- Third solution: signed code