# CS162
# Operating Systems and Systems Programming
# Lecture 26

## Protection and Security in Distributed Systems II

December 5, 2007

Prof. John Kubiatowicz
http://inst.eecs.berkeley.edu/~cs162

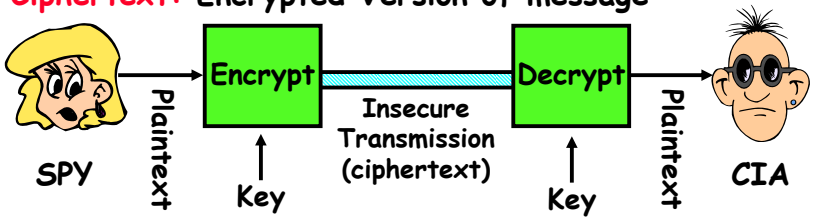
## Review: Authentication: Identifying Users

- How to identify users to the system?
  - Passwords
    - » Shared secret between two parties
    - » Since only user knows password, someone types correct password ⇒ must be user typing it
    - » Very common technique
  - Smart Cards
    - » Electronics embedded in card capable of providing long passwords or satisfying challenge → response queries
    - » May have display to allow reading of password
    - » Or can be plugged in directly; several credit cards now in this category
  - Biometrics
    - » Use of one or more intrinsic physical or behavioral traits to identify someone
    - » Examples: fingerprint reader, palm reader, retinal scan
    - » Becoming quite a bit more common



## Review: Private Key Cryptography

- Private Key (Symmetric) Encryption:
  - Single key used for both encryption and decryption
- Plaintext: Unencrypted Version of message
- Ciphertext: Encrypted Version of message




- Important properties
  - Can't derive plain text from ciphertext (decode) without access to key
  - Can't derive key from plain text and ciphertext
  - As long as password stays secret, get both secrecy and authentication
- Symmetric Key Algorithms: DES, Triple-DES, AES



## Goals for Today

- Public Encryption
- Use of Cryptographic Mechanisms
- Authorization Mechanisms
- Worms and Viruses

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne. Many slides generated from my lecture notes by Kubiatowicz.

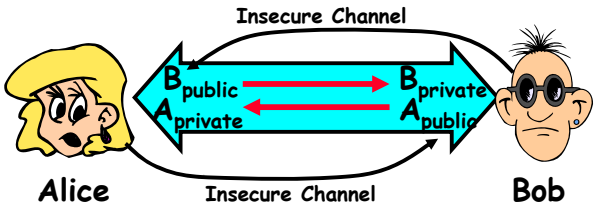
## Public Key Encryption

- Can we perform key distribution without an authentication server?
  - Yes. Use a Public-Key Cryptosystem.
- Public Key Details
  - Don't have one key, have two: $K_{public}$, $K_{private}$
    - » Two keys are mathematically related to one another
    - » Really hard to derive $K_{public}$ from $K_{private}$ and vice versa
  - Forward encryption:
    - » Encrypt: $(\text{cleartext})^{K_{public}} = \text{ciphertext}_1$
    - » Decrypt: $(\text{ciphertext}_1)^{K_{private}} = \text{cleartext}$
  - Reverse encryption:
    - » Encrypt: $(\text{cleartext})^{K_{private}} = \text{ciphertext}_2$
    - » Decrypt: $(\text{ciphertext}_2)^{K_{public}} = \text{cleartext}$
  - Note that $\text{ciphertext}_1 \neq \text{ciphertext}_2$
    - » Can't derive one from the other!
- Public Key Examples:
  - RSA: Rivest, Shamir, and Adleman
    - » $K_{public}$ of form $(k_{public}, N)$, $K_{private}$ of form $(k_{private}, N)$
    - » $N = pq$. Can break code if know p and q
  - ECC: Elliptic Curve Cryptography



## Public Key Encryption Details

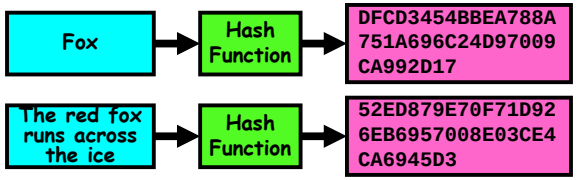
- Idea: $K_{public}$ can be made public, keep $K_{private}$ private




- Gives message privacy (restricted receiver):
  - Public keys (secure destination points) can be acquired by anyone/used by anyone
  - Only person with private key can decrypt message
- What about authentication?
  - Use combination of private and public key
  - Alice→Bob: $[(\text{I'm Alice})^{A_{private}}\ \text{Rest of message}]^{B_{public}}$
  - Provides restricted sender and receiver
- But: how does Alice know that it was Bob who sent her $B_{public}$? And vice versa…



## Secure Hash Function



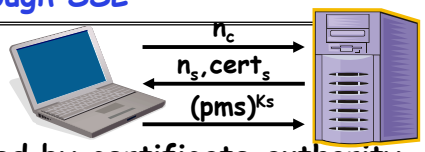

- Hash Function: Short summary of data (message)
  - For instance, $h_1 = H(M_1)$ is the hash of message $M_1$
    - » $h_1$ fixed length, despite size of message $M_1$.
    - » Often, $h_1$ is called the "digest" of $M_1$.
- Hash function H is considered secure if
  - It is infeasible to find $M_2$ with $h_1 = H(M_2)$; ie. can't easily find other message with same digest as given message.
  - It is infeasible to locate two messages, $m_1$ and $m_2$, which "collide", i.e. for which $H(m_1) = H(m_2)$
  - A small change in a message changes many bits of digest/can't tell anything about message given its hash
- Hash function Examples: MD5, SHA-1, SHA-256



## Signatures/Certificate Authorities

- Can use $X_{public}$ for person X to define their identity
  - Presumably they are the only ones who know $X_{private}$.
  - Often, we think of $X_{public}$ as a "principle" (user)
- Suppose we want X to sign message M?
  - Use private key to encrypt the digest, i.e. $H(M)^{X_{private}}$
  - Send both M and its signature:
    - » Signed message = $[M, H(M)^{X_{private}}]$
  - Now, anyone can verify that M was signed by X
    - » Simply decrypt the digest with $X_{public}$
    - » Verify that result matches H(M)
- Now: How do we know that the version of $X_{public}$ that we have is really from X???
  - Answer: Certificate Authority
    - » Examples: Verisign, Entrust, Etc.
  - X goes to organization, presents identifying papers
    - » Organization signs X's key: $[X_{public}, H(X_{public})^{CA_{private}}]$
    - » Called a "Certificate"
  - Before we use $X_{public}$, ask X for certificate verifying key
    - » Check that signature over $X_{public}$ produced by trusted authority
- How do we get keys of certificate authority?
  - Compiled into your browser, for instance!

## Security through SSL




- SSL Web Protocol
  - Port 443: secure http
  - Use public-key encryption for key-distribution
- Server has a certificate signed by certificate authority
  - Contains server info (organization, IP address, etc)
  - Also contains server's public key and expiration date
- Establishment of Shared, 48-byte "master secret"
  - Client sends 28-byte random value $n_c$ to server
  - Server returns its own 28-byte random value $n_s$, plus its certificate cert$_s$
  - Client verifies certificate by checking with public key of certificate authority compiled into browser
    - » Also check expiration date
  - Client picks 46-byte "premaster" secret (pms), encrypts it with public key of server, and sends to server
  - Now, both server and client have $n_c$, $n_s$, and pms
    - » Each can compute 48-byte master secret using one-way and collision-resistant function on three values
    - » Random "nonces" $n_c$ and $n_s$ make sure master secret fresh

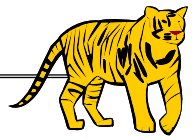


## SSL Pitfalls

- Netscape claimed to provide secure comm. (SSL)
  - So you could send a credit card # over the Internet
- Three problems (reported in NYT):
  - Algorithm for picking session keys was predictable (used time of day) – brute force key in a few hours
  - Made new version of Netscape to fix #1, available to users over Internet (unencrypted!)
    - » Four byte patch to Netscape executable makes it always use a specific session key
    - » Could insert backdoor by mangling packets containing executable as they fly by on the Internet.
    - » Many mirror sites (including Berkeley) to redistribute new version – anyone with root access to any machine on LAN at mirror site could insert the backdoor
  - Buggy helper applications – can exploit *any* bug in either Netscape, or its helper applications



## Cryptographic Summary



- Private Key Encryption (also Symmetric Key)
  - Pros: Very Fast
    - » can encrypt at network speed (even without hardware)
  - Cons: Need to distribute *secret* key to both parties
- Public Key Encryption (also Asymmetric Key)
  - Pros: Can distribute keys in public
    - » Need certificate authority (Public Key Infrastructure)
  - Cons: Very Slow
    - » 100—1000 times slower than private key encryption
- Session Key
  - Randomly generated private key used for single session
  - Often distributed via public key encryption
- Secure Hash
  - Fixed length summary of data that is hard to spoof
- Message Authentication Code (MAC)
  - Technique for using secure hash and session key to verify individual packets (even at the IP level)
  - IPSEC: IP Protocol 50/51, authentic/encrypted IP
- Signature over Document
  - Hash of document encrypted with private key



## Administrivia

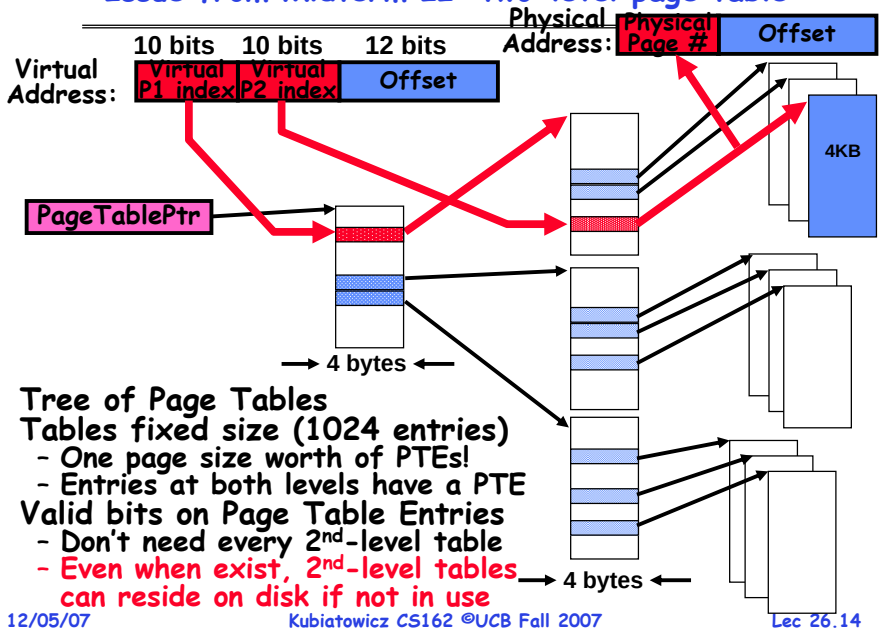
- Final Exam
  - December 17th,5:00-8:00, 10 Evans
  - Covers whole course (except last lecture)
  - Two pages of handwritten notes, both sides
- Last Day of Class – Next Monday
- Final Topics suggestions (so far):
  - Peer-to-peer systems
  - Realtime Systems
  - Speech, handwriting recognition, etc
  - Dragons
  - Quantum Computers

## Aside: Powers of 10 and 2

- Strict powers of 10:
  - yotta: $10^{24}$
  - exa: $10^{18}$
  - peta: $10^{15}$
  - tera: $10^{12}$
  - giga: $10^{9}$
  - mega: $10^{6}$
  - kilo: $10^{3}$
  - milli(m): $10^{-3}$
  - micro (μ): $10^{-6}$
  - nano(n): $10^{-9}$
  - pico: $10^{-12}$
  - femto: $10^{-15}$
  - atto: $10^{-18}$
  - yocto: $10^{-24}$
- Strict powers of 2:
  - yotta: $2^{80} \cong 10^{24}$
  - exa: $2^{60} \cong 10^{18}$
  - peta: $2^{50} \cong 10^{15}$
  - tera: $2^{40} \cong 10^{12}$
  - giga: $2^{30} = 1{,}073{,}741{,}824 \cong 10^{9}$
  - mega: $2^{20} = 1{,}048{,}576 \cong 10^{6}$
  - kilo: $2^{10} = 1024 \cong 10^{3}$
- When use one or the other?
  - Powers of 2
    - » Memory sizes
  - Powers of 10
    - » Time
    - » Bandwidth



## Issue from Midterm II: two-level page table




- Tree of Page Tables
- Tables fixed size (1024 entries)
  - One page size worth of PTEs!
  - Entries at both levels have a PTE
- Valid bits on Page Table Entries
  - Don't need every 2nd-level table
  - Even when exist, 2nd-level tables can reside on disk if not in use



## Recall: Authorization: Who Can Do What?

- How do we decide who is authorized to do actions in the system?
- Access Control Matrix: contains all permissions in the system
  - Resources across top
    - » Files, Devices, etc…
  - Domains in columns
    - » A domain might be a user or a group of permissions
    - » E.g. above: User $D_3$ can read $F_2$ or execute $F_3$
  - In practice, table would be huge and sparse!

| domain \ object | $F_1$ | $F_2$ | $F_3$ | printer |
|---|---|---|---|---|
| $D_1$ | read | | read | |
| $D_2$ | | | | print |
| $D_3$ | | read | execute | |
| $D_4$ | read write | | read write | |

- Two approaches to implementation
  - Access Control Lists: store permissions with each object
    - » Still might be lots of users!
    - » UNIX limits each file to: r,w,x for owner, group, world
    - » More recent systems allow definition of groups of users and permissions for each group
  - Capability List: each process tracks objects has permission to touch
    - » Popular in the past, idea out of favor today
    - » Consider page table: Each process has list of pages it has access to, not each page has list of processes …



## How fine-grained should access control be?

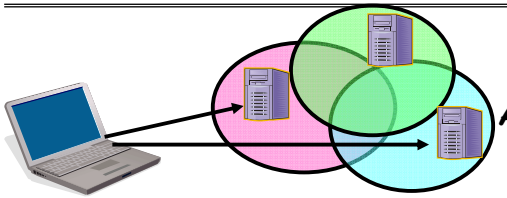
- Example of the problem:
  - Suppose you buy a copy of a new game from "Joe's Game World" and then run it.
  - It's running with your userid
    - » It removes all the files you own, including the project due the next day…
- How can you prevent this?
  - Have to run the program under *some* userid.
    - » Could create a second *games* userid for the user, which has no write privileges.
    - » Like the "nobody" userid in UNIX – can't do much
  - But what if the game needs to write out a file recording scores?
    - » Would need to give write privileges to one particular file (or directory) to your *games* userid.
  - But what about non-game programs you want to use, such as Quicken?
    - » Now you need to create your own private *quicken* userid, if you want to make sure tha the copy of Quicken you bought can't corrupt non-quicken-related files
  - But – how to get this right??? Pretty complex…

## Authorization Continued

- Principle of least privilege: programs, users, and systems should get only enough privileges to perform their tasks
  - Very hard to do in practice
    - » How do you figure out what the minimum set of privileges is needed to run your programs?
  - People often run at higher privilege then necessary
    - » Such as the "administrator" privilege under windows
- One solution: Signed Software
  - Only use software from sources that you trust, thereby dealing with the problem by means of authentication
  - Fine for big, established firms such as Microsoft, since they can make their signing keys well known and people trust them
    - » Actually, not always fine: recently, one of Microsoft's signing keys was compromised, leading to malicious software that looked valid
  - What about new startups?
    - » Who "validates" them?
    - » How easy is it to fool them?



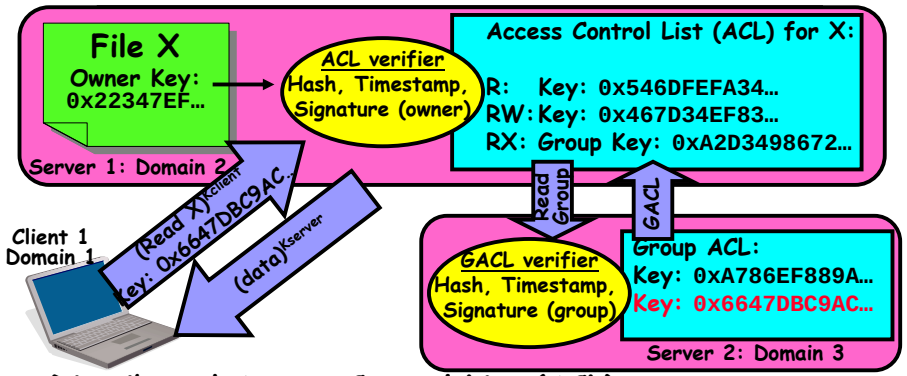
## How to perform Authorization for Distributed Systems?




- Issues: Are all user names in world unique?
  - No! They only have small number of characters
    - » kubi@mit.edu → kubitron@lcs.mit.edu → kubitron@cs.berkeley.edu
    - » However, someone thought their friend was kubi@mit.edu and I got very private email intended for someone else…
  - Need something better, more unique to identify person
- Suppose want to connect with any server at any time?
  - Need an account on every machine! (possibly with different user name for each account)
  - OR: Need to use something more universal as identity
    - » Public Keys! (Called "Principles")
    - » People *are* their public keys



## Distributed Access Control




- Distributed Access Control List (ACL)
  - Contains list of attributes (Read, Write, Execute, etc) with attached identities (Here, we show public keys)
    - » ACLs signed by owner of file, only changeable by owner
    - » Group lists signed by group key
  - ACLs can be on different servers than data
    - » Signatures allow us to validate them
    - » ACLs could even be stored separately from verifiers



## Analysis of Previous Scheme

- Positive Points:
  - Identities checked via signatures and public keys
    - » Client can't generate request for data unless they have private key to go with their public identity
    - » Server won't use ACLs not properly signed by owner of file
  - No problems with multiple domains, since identities designed to be cross-domain (public keys domain neutral)
- Revocation:
  - What if someone steals your private key?
    - » Need to walk through all ACLs with your key and change…!
    - » This is very expensive
  - Better to have unique string identifying you that people place into ACLs
    - » Then, ask Certificate Authority to give you a certificate matching unique string to your current public key
    - » Client Request: (request + unique ID)$^{Cprivate}$; give server certificate if they ask for it.
    - » Key compromise⇒must distribute "certificate revocation", since can't wait for previous certificate to expire.
  - What if you remove someone from ACL of a given file?
    - » If server caches old ACL, then person retains access!
    - » Here, cache inconsistency leads to security violations!

## Analysis Continued

- Who signs the data?
  - Or: How does the client know they are getting valid data?
  - Signed by server?
    - » What if server compromised? Should client trust server?
  - Signed by owner of file?
    - » Better, but now only owner can update file!
    - » Pretty inconvenient!
  - Signed by group of servers that accepted latest update?
    - » If must have signatures from all servers ⇒ Safe, but one bad server can prevent update from happening
    - » Instead: ask for a threshold number of signatures
    - » Byzantine agreement can help here
- How do you know that data is up-to-date?
  - Valid signature only means data is valid older version
  - Freshness attack:
    - » Malicious server returns old data instead of recent data
    - » Problem with both ACLs and data
    - » E.g.: you just got a raise, but enemy breaks into a server and prevents payroll from seeing latest version of update
  - Hard problem
    - » Needs to be fixed by invalidating old copies or having a trusted group of servers (Byzantine Agrement?)



## Involuntary Installation

- What about software loaded without your consent?
  - Macros attached to documents (such as Microsoft Word)
  - Active X controls (programs on web sites with potential access to whole machine)
  - Spyware included with normal products
- Active X controls can have access to the local machine
  - Install software/Launch programs
- Sony Spyware [Sony XCP] (October 2005)
  - About 50 recent CDs from Sony automatically install software when you played them on Windows machines
    - » Called XCP (Extended Copy Protection)
    - » Modify operating system to prevent more than 3 copies and to prevent peer-to-peer sharing
  - Side Effects:
    - » Reporting of private information to Sony
    - » Hiding of generic file names of form $sys_xxx; easy for other virus writers to exploit
    - » Hard to remove (crashes machine if not done carefully)
  - Vendors of virus protection software declare it spyware
    - » Computer Associates, Symantec, even Microsoft



## Enforcement

- Enforcer checks passwords, ACLs, etc
  - Makes sure the only authorized actions take place
  - Bugs in enforcer⇒things for malicious users to exploit
- In UNIX, superuser can do anything
  - Because of coarse-grained access control, lots of stuff has to run as superuser in order to work
  - If there is a bug in any one of these programs, you lose!
- Paradox
  - Bullet-proof enforcer
    - » Only known way is to make enforcer as small as possible
    - » Easier to make correct, but simple-minded protection model
  - Fancy protection
    - » Tries to adhere to principle of least privilege
    - » Really hard to get right
- Same argument for Java or C++: What do you make private vs public?
  - Hard to make sure that code is usable but only necessary modules are public
  - Pick something in middle? Get bugs and weak protection!



## State of the World

- State of the World in Security
  - Authentication: Encryption
    - » But almost no one encrypts or has public key identity
  - Authorization: Access Control
    - » But many systems only provide very coarse-grained access
    - » In UNIX, need to turn off protection to enable sharing
  - Enforcement: Kernel mode
    - » Hard to write a million line program without bugs
    - » Any bug is a potential security loophole!
- Some types of security problems
  - Abuse of privilege
    - » If the superuser is evil, we're all in trouble/can't do anything
    - » What if sysop in charge of instructional resources went crazy and deleted everybody's files (and backups)???
  - Imposter: Pretend to be someone else
    - » Example: in unix, can set up an .rhosts file to allow logins from one machine to another without retyping password
    - » Allows "rsh" command to do an operation on a remote node
    - » Result: send rsh request, pretending to be from trusted user→install .rhosts file granting you access

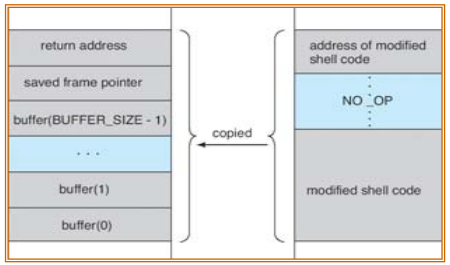
## Other Security Problems

- Virus:
  - A piece of code that attaches itself to a program or file so it can spread from one computer to another, leaving infections as it travels
  - Most attached to executable files, so don't get activated until the file is actually executed
  - Once caught, can hide in boot tracks, other files, OS
- Worm:
  - Similar to a virus, but capable of traveling on its own
  - Takes advantage of file or information transport features
  - Because it can replicate itself, your computer might send out hundreds or thousands of copies of itself
- Trojan Horse:
  - Named after huge wooden horse in Greek mythology given as gift to enemy; contained army inside
  - At first glance appears to be useful software but does damage once installed or run on your computer



## Security Problems: Buffer-overflow Condition

```
#define BUFFER SIZE 256
int process(int argc,
            char *argv[])
{
  char buffer[BUFFER SIZE];
  if (argc < 2)
      return -1;
  else {
      strcpy(buffer,argv[1]);
      return 0;
  }
}
```

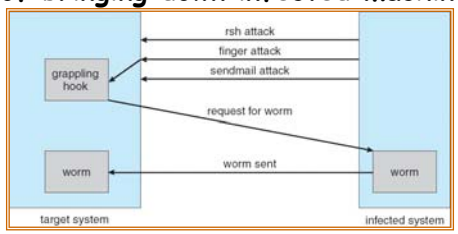



- Technique exploited by many network attacks
  - Anytime input comes from network request and is not checked for size
  - Allows execution of code with same privileges as running program – but happens without any action from user!
- How to prevent?
  - Don't code this way! (ok, wishful thinking)
  - New mode bits in Intel, Amd, and Sun processors
    - » Put in page table; says "don't execute code in this page"



## The Morris Internet Worm

- Internet worm (Self-reproducing)
  - Author Robert Morris, a first-year Cornell grad student
  - Launched close of Workday on November 2, 1988
  - Within a few hours of release, it consumed resources to the point of bringing down infected machines




- Techniques
  - Exploited UNIX networking features (remote access)
  - Bugs in *finger* (buffer overflow) and *sendmail* programs (debug mode allowed remote login)
  - Dictionary lookup-based password cracking
  - Grappling hook program uploaded main worm program



## Some other Attacks

- Trojan Horse Example: Fake Login
  - Construct a program that looks like normal login program
  - Gives "login:" and "password:" prompts
    - » You type information, it sends password to someone, then either logs you in or says "Permission Denied" and exits
  - In Windows, the "ctrl-alt-delete" sequence is supposed to be really hard to change, so you "know" that you are getting official login program
- Salami attack: Slicing things a little at a time
  - Steal or corrupt something a little bit at a time
  - E.g.: What happens to partial pennies from bank interest?
    - » Bank keeps them! Hacker re-programmed system so that partial pennies would go into his account.
    - » Doesn't seem like much, but if you are large bank can be millions of dollars
- Eavesdropping attack
  - Tap into network and see everything typed
  - Catch passwords, etc
  - Lesson: never use unencrypted communication!

## Tenex Password Checking

- Tenex – early 70's, BBN
  - Most popular system at universities before UNIX
  - Thought to be very secure, gave "red team" all the source code and documentation (want code to be publicly available, as in UNIX)
  - In 48 hours, they figured out how to get every password in the system
- Here's the code for the password check:

```
for (i = 0; i < 8; i++)
  if (userPasswd[i] != realPasswd[i])
    go to error
```

- How many combinations of passwords?
  - $256^8$?
  - Wrong!



## Defeating Password Checking

- Tenex used VM, and it interacts badly with the above code
  - Key idea: force page faults at inopportune times to break passwords quickly
- Arrange 1st char in string to be last char in pg, rest on next pg
  - Then arrange for pg with 1st char to be in memory, and rest to be on disk (e.g., ref lots of other pgs, then ref 1st page)

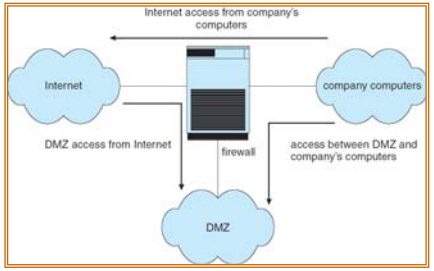
```
          a|aaaaaa
           |
page in memory| page on disk
```

- Time password check to determine if first character is correct!
  - If fast, 1st char is wrong
  - If slow, 1st char is right, pg fault, one of the others wrong
  - So try all first characters, until one is slow
  - Repeat with first two characters in memory, rest on disk
- Only 256 * 8 attempts to crack passwords
  - Fix is easy, don't stop until you look at all the characters



## Defense in Depth: Layered Network Security

- How do I minimize the damage when security fails?
  - For instance: I make a mistake in the specification
  - Or: A bug lets something run that shouldn't?
- Firewall: Examines every packet to/from public internet
  - Can disable all traffic to/from certain ports
  - Can route certain traffic to DMZ (De-Militarized Zone)
    - » Semi-secure area separate from critical systems
  - Can do network address translation
    - » Inside network, computers have private IP addresses
    - » Connection from inside→outside is translated
    - » E.g. [10.0.0.2,port 2390] → [169.229.60.38,port 80]
      [12.4.35.2,port 5592] → [169.229.60.38,port 80]






## Shrink Wrap Software Woes

- Can I trust software installed by the computer manufacturer?
  - Not really, most major computer manufacturers have shipped computers with viruses
  - How?
    - » Forgot to update virus scanner on "gold" master machine
- Software companies, PR firms, and others routinely release software that contains viruses
- Linux hackers say "Start with the source"
  - Does that work?

## Ken Thompson's self-replicating program

- Bury Trojan horse in binaries, so no evidence in source
  - Replicates itself to every UNIX system in the world and even to new UNIX's on new platforms. No visible sign.
  - Gave Ken Thompson ability to log into any UNIX system
- Two steps: Make it possible (easy); Hide it (tricky)
- Step 1: Modify login.c

```
A: if (name == "ken")
       don't check password
       log in as root
```

  - Easy to do but pretty blatant! Anyone looking will see.
- Step 2: Modify C compiler
  - Instead of putting code in login.c, put in compiler:

```
B: if see trigger1
     insert A into input stream
```

  - Whenever compiler sees trigger1 (say /*gobbledygook*/), puts A into input stream of compiler
  - Now, don't need A in login.c, just need trigger1



## Self Replicating Program Continued

- Step 3: Modify compiler source code:

```
C: if see trigger2
     insert B+C into input stream
```

  - Now compile this new C compiler to produce binary
- Step 4: Self-replicating code!
  - Simply remove statement C in compiler source code and place "trigger2" into source instead
    - » As long as existing C compiler is used to recompile the C compiler, the code will stay into the C compiler and will compile back door into login.c
    - » But no one can see this from source code!
- When porting to new machine/architecture, use existing C compiler to generate cross-compiler
  - Code will migrate to new architecture!
- Lesson: never underestimate the cleverness of computer hackers for hiding things!



## Conclusion

- Distributed identity
  - Use cryptography (Public Key, Signed by PKI)
- Use of Public Key Encryption to get Session Key
  - Can send encrypted random values to server, now share secret with server
  - Used in SSL, for instance
- Authorization
  - Abstract table of users (or domains) vs permissions
  - Implemented either as access-control list or capability list
- Issues with distributed storage example
  - Revocation: How to remove permissions from someone?
  - Integrity: How to know whether data is valid
  - Freshness: How to know whether data is recent
- Buffer-Overrun Attack: exploit bug to execute code