16: Exploits and Defenses Up and Down the Stack

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Some slides based on notes from cs515 at UMass

Where in the stack is security?

- Attacks can be targeted at any layer of the protocol stack
  - Application layer: Password and data sniffing, Forged transactions, Security holes, Buffer Overflows?
  - Transport Layer: TCP Session Stealing,
  - Network Layer: IP Spoofing, False Dynamic Routing Updates, ICMP attacks
  - Link Layer: ARP attacks
  - Denial of Service, Intrusion
- Defenses can be implemented at multiple levels of the protocol stack too
  - Application Layer: PGP
  - Transport Layer: SSL
  - Network Layer: Ipsec
  - Link Layer: Static ARP tables, Physical security

Application Layer Network Security

- Many applications are designed with *HUGE* security problems
- On purpose?
  - No! many common applications designed when the goal was just to get it to work (security complicates that)
  - Sometimes the cure is worse than the problem
  - But some applications are bad enough that it makes you wonder

Clear Text Passwords

- We saw many application level protocols where sending your password in the clear is required by the protocol
  - FTP, TELNET, POP, News
- Attack: packet sniffing can capture passwords
- Defenses:
  - Replace these applications with ones that do not send the password in the clear
  - Switched Networks and Physical Security of Backbone networks

Rsh and rcp

- Rsh and rcp are especially bad
- rsh and rcp use the .rhosts file in your directory, which lists hosts and accounts to allows access from without a password.
- Example .rhosts file:

```
mymachine.cs.cornell.edu jnm
*.cs.cornell.edu   jnm
*  *
```

- Now that we know a machine is running rsh, all we need to do is pretend to be another machine in order to gain access?
  - We'll get to IP Spoofing a bit later

Ssh

- Program for logging into a remote machine and executing commands there
- Replaces telnet, rlogin and rsh
- Provides encrypted communications between two hosts over an insecure network
- It does not use authenticate users – still uses the same authentication methods as telnet etc but encrypts the exchange

Connection Establishment

- Clients connect to an SSH server on port 22
- The two sides negotiate an encryption algorithm to be used and exchange keys
  - Each side will have a preferred algorithm and possibly alternate algorithms
  - Send key for preferred algorithm
  - If preferred algorithm is rejected then will send keys for another algorithm if accepted

Data Exchange

- Once connection is accepted (each side authenticated), then a session key is exchanged
- Each packet of data sent over this encrypted connection includes a packet sequence number so that replay attempts are thwarted

Identifying the Server?

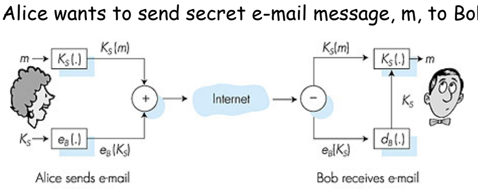
- How does the client know they are talking to the server they think?
- Client maintains a list of the public_keys for all hosts they have ever spoken with (e.g. in ~/.ssh/known_hosts)
- When contact server, server tells client its public key, client must choose to accept or reject the first time
- From then on if doesn't match will warn user

Secure Email?

- Attacks
  - Forged mail?
  - Mail goes in clear text?

Secure e-mail

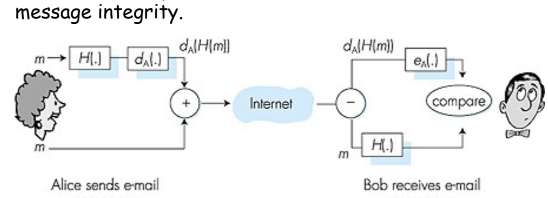
- Alice wants to send secret e-mail message, m, to Bob.



- generates random symmetric private key, K_S.
- encrypts message with K_S
- also encrypts K_S with Bob's public key.
- sends both $K_S(m)$ and $e_B(K_S)$ to Bob.

Secure e-mail (continued)

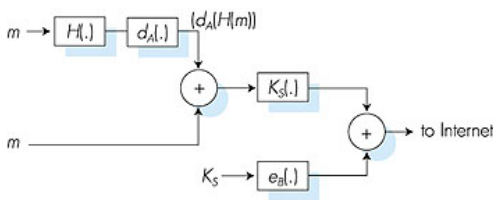
- Alice wants to provide sender authentication message integrity.



- Alice digitally signs message.
- sends both message (in the clear) and digital signature.

Secure e-mail (continued)

- Alice wants to provide secrecy, sender authentication, message integrity.



Note: Alice uses both her private key, Bob's public key.

Pretty good privacy (PGP)

- Internet e-mail encryption scheme, a de-facto standard.
- Uses symmetric key cryptography, public key cryptography, hash function, and digital signature as described.
- Provides secrecy, sender authentication, integrity.
- Inventor, Phil Zimmerman, was target of 3-year federal investigation.

A PGP signed message:

```
---BEGIN PGP SIGNED MESSAGE---
Hash: SHA1

Bob:My husband is out of town
   tonight.Passionately yours,
   Alice

---BEGIN PGP SIGNATURE---
Version: PGP 5.0
Charset: noconv
yhHJRHhGJGhgg/12EpJ+lo8gE4vB3mqJ
   hFEvZP9t6n7G6m5Gw2
---END PGP SIGNATURE---
```


Distributed Trust

- Don't need to trust a certificate authority or key distribution center?!
- Users get others they know to sign their public key indicating that they know this person and this public key really go together
- Users can collect this supporting evidence of their public key
- Users can also collect certificates of others public keys into a "key ring"

PGP key rings

- Allows arbitrary chains of certificates
- PGP software allows users to examine all "evidence" of someones public key
  - Users might require several certificates from people they don't know well to trust a key or just one certificate from people they know well
- If receive a message from x, search key ring for a public key you trust to use in decrypting the message

Transport Layer Network Security

- TCP will accept a segment with an acceptable IP address, port number and sequence number
  - Forging the IP address part isn't hard
  - Port Number and Sequence number you can definitely get if you are using a packet sniffer
  - Port number and sequence number are also pretty predictable
- All this means an attacker has a good chance of inserting data into a TCP stream

What might an attacker insert into an ongoing TCP stream?

- RST or FIN would kill the connection (denial of service)
- Worse if you know how the stream is interpreted on the other side you could add in data
  - Telnet is an example of this because it is just echoing key strokes
  - If hijack a telnet session could insert any command you want (rm * ?!)

Access beyond life of telnet connection

- Attacker can insert commands into the remote account. E.g.
  - `echo "* attacker" > .rhosts`
- Clients connection not dropped so client might not even know!
- However, commands entered by the attacker might appear on a command line history.

Defenses

- Switched networks and physical security of the back bone links
  - Good idea to do yes but to easy for someone to plug into network somewhere
- Run applications that encrypt the data stream
  - Hijacking ssh session vs telnet
  - Can still interupt stream but harder to take it over to do something active
- Secure Socket layer

Secure sockets layer (SSL)

- SSL works at transport layer. Provides security to any TCP-based app using SSL services.
- SSL: used between WWW browsers, servers for ecommerce (https).
- SSL security services:
  - server authentication
  - data encryption
  - client authentication (optional)
- Server authentication:
  - SSL-enabled browser includes public keys for trusted CAs.
  - Browser requests server certificate, issued by trusted CA.
  - Browser uses CA's public key to extract server's public key from certificate.
- Visit your browser's security menu to see its trusted CAs.

HTTPS

Encrypted SSL session:

- Browser generates symmetric session key, encrypts it with server's public key (from CA), sends encrypted key to server.
- Using its private key, server decrypts session key.
- Browser, server agree that future msgs will be encrypted.
- All data sent into TCP socket (by client or server) is encrypted with session key.

- SSL: basis of IETF Transport Layer Security (TLS).
- SSL can be used for non-Web applications, e.g., IMAP.
- Client authentication can be done with client certificates.
- encrypt in the public key given by server and send
- Server can decrypt using private key

Network Layer Security

- Lots of potential problems at the IP layer
  - In Dynamic Routing Protocols, routers exchange messages containing known route information to reach consensus on the best routes through the system – any validation of these messages?
  - No authentication that a packet came from a machine with the IP address listed in the source field (Raw IP Interface)

False Dynamic Routing Updates

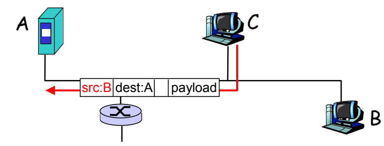
- Attacker injects a RIP update stating she has a path to a particular unused host or network
- All subsequent packets will be routed to her.
- She replies with raw IP packets listing the IP address of the unused host concealing her identity
- Similar attacks for interdomain routing.
- Also allows a man in the middle attack and denial of service attacks
  - Could instead listen/forward or modify incoming packets.
  - Bad routing tables make a routing black hole where legitimate traffic does not reach

ICMP Attack

- Simply, send an ICMP redirect
  - Forces a machine to route through you.
- Send destination unreachable spoofed from the gateway
- Constantly send ICMP source squelches.

IP Spoofing

- can generate "raw" IP packets directly from application, putting any value into IP source address field
- receiver can't tell if source is spoofed
- e.g.: C pretends to be B



Defenses against IP spoofing

- Good for routers not to forward datagrams with IP addresses not in their network
- Doesn't help attacks from local networks
- Really need authentication based on more than IP address
  - Remember authentication using crptography

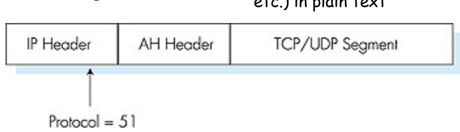
Ipsec: Network Layer Security

- Network-layer secrecy:
  - sending host encrypts the data in IP datagram
  - TCP and UDP segments; ICMP and SNMP messages.
- Network-layer authentication
  - destination host can authenticate source IP address
- Two principle protocols:
  - authentication header (AH) protocol
  - encapsulation security payload (ESP) protocol
- For both AH and ESP, source, destination handshake:
  - create network-layer logical channel called a service agreement (SA)
- Each SA unidirectional.
- Uniquely determined by:
  - security protocol (AH or ESP)
  - source IP address
  - 32-bit connection ID

Authentication Header (AH) Protocol

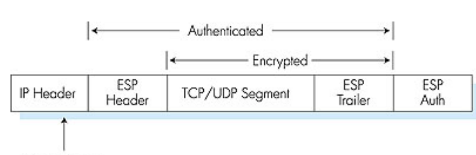
- Provides source host authentication, data integrity, but not secrecy.
- AH header inserted between IP header and IP data field.
- Protocol field = 51.
- Intermediate routers process datagrams as usual.

AH header includes:
- connection identifier
- authentication data: signed message digest, calculated over original IP datagram, providing source authentication, data integrity.
- Next header field: specifies type of data (TCP, UDP, ICMP, etc.) in plain text



ESP Protocol

- Provides secrecy, host authentication, data integrity.
- Data, ESP trailer encrypted.
- Next header field is in ESP header.
- ESP authentication field is similar to AH authentication field.
- Protocol = 50.



ARP Attacks

- When a machines sends an ARP request out, you could answer that you own the address.
  - But in a race condition with the real machine.
- Unfortunately, ARP will just accept replies without requests!
- Just send a spoofed reply message saying your MAC address owns a certain IP address.
  - Repeat frequently so that other machine's caches don't timeout and send query
- Messages are routed through you to sniff or modify or squelch

ARP Spoofing - Countermeasures

- "Publish" MAC address of router/default gateway and trusted hosts to prevent ARP spoof.

  Statically defining the IP to Ethernet address mapping prevents someone from fooling the host into sending network traffic to a host masquerading as the router or another host via an ARP spoof.

Example: `arp -s hostname 00:01:02:03:04:ab pub`

- Other than that, hard to defend from attack on your own LAN

Other common attacks

SYN Flooding DoS

- Pick a machine, any machine.
- Spoof packets to it (so you don't get caught)
- Each packet is a the first hand of the 3-way handshake of TCP: send a SYN packet.
- Send lots of SYN packets.
- Each SYN packet received causes a buffer to be allocated, and the limits of the `listen()` call to be reached.
- Worse yet compromise many machines and then have them all attack the victim

Buffer Overflows

- Program buffer overflows are the most common form of security vulnerability; in fact they dominate.
- 9 of 13 CERT advisories from 1998
- Half of CERT advisories from 1999
- Two have a buffer overflow, you need two things
  - Arrange for root-grabbing code to be available in the program's address space
  - Get the program to jump to that code.

Processes in memory

- Process state in memory consists of several items:
  - the code for running the program
  - the static data for the running program
  - space for dynamic data (the heap) and the heap pointer (hp)
  - the program counter (PC), indicating the next instruction
  - an execution stack with the program's function call chain (the stack)
  - values of CPU registers
  - a set of OS resources in use; e.g., open files
  - process execution state (ready, running, waiting, etc)

Processes in Memory

- We need consider only four regions in memory:
  - static data: pre-allocation memory (int array[9];)
  - text: instructions and read-only data
  - heap: re-sizeable portion containing data malloc()'d and free()'d by the user.
  - Stack: a push and pop data structure. Used to allocate local variables used in functions, pass variables, and return values from function calls.

Calling a function

- The stack consists of a logical stack of ***frames***.
- Frames are the parameters given to a function, local variables, and data used to pop back up to the previous frame (like which instruction to go back to).
- Each frame in the stack looks like this:

	Local vars	Saved frame pointer	return addr	b

Buffer Overrun =Seg fault

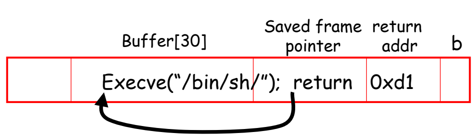
- In memory, if you read data into a buffer, you might write over other variables necessary for program execution.
- Normally this results in a seg fault.

```
input[256];
buffer[16];
strcpy(buffer, input);
```


Careful Buffer Overrun = Attack

- When you read in too many characters into a buffer, you can modify the rest of the stack, altering the flow of the program.
- Normally, writing over array bounds causes a seg fault as you'll actually overwrite into other variables in the program.
- If you are careful about what you overwrite, then you can alter what the program does next without stepping far enough to cause a seg fault.

Smashing the Stack



- If buffer[] gets its input from the command line, and the input is longer than the allocated memory, the program will write into the return address
- If you do it perfectly, you can write into the RA the memory location of your input.
- When your function completes, it will execute next the first command in your input.

Buffer overflow over the net: Morris Worm

- **Fingerd** takes input about whom to finger without checking input size.
- Morris wrote the following code after the buffer overflow to create the morris worm:

```
pushl $68732f '/sh\0'
pushl $6e69622f '/bin'
movl sp,r10
pushl $0
pushl $0
pushl r10
pushl $3
movl sp,ap
chmk $3b
```

upon return to main() execve("/bin/sh",0,0); was executed, opening a shell on the remote. machine.

Defenses

- How do you avoid this exploit?
- Use a language with garbage collection and input will never be able to smash the stack. (i.e., java, lisp, etc)
- Use input functions carefully.
- Don't use strcpy(), strcat(), sprintf(), gets().
- Use instead strncpy(3), strncat(3), snprintf(3), and fgets(3) .
- There are other problematic constructs: fscanf(3), scanf(3), vsprintf(3), realpath(3), getopt(3), getpass(3), streadd(3), strecpy(3), and strtrns(3).

Security Beyond the Stack

- We just thought about exploits and defenses up and down the protocol stack and a couple places in between
- Important to remember that lots of exploits have nothing to do with the network technologies
- If you really want to defend something, defenses must do well beyond the protocol stack

Physical Security

- Are you sure someone can just walk into your building and
  - Steal floppies or CD-ROMs that are lying around?
  - Bring in a laptop and plug into your dhcp-enable ethernet jacks?
  - Reboot your computer into single user mode? (using a bios password?)
  - Reboot your computer with a live CD-ROM and mount the drives?
  - Sit down at an unlocked screen?
- Can anyone sit down *outside* your building and get on your DHCP-enable 802.11 network?

Social Engineering

- Using tricks and lies that take advantage of people's trust to gain access to an otherwise guarded system.
  - Social Engineering by Phone: "Hi this is your visa credit card company. We have a charge for $3500 that we would like to verify. But, to be sure it's you, please tell me your social security number, pin, mother's maiden name, etc"
  - Dumpster Diving: collecting company info by searching through trash.
  - Online: "hi this is Alice from my other email account on yahoo. I believe someone broke into my account, can you please change the password to "Sucker"?
  - Persuasion: Showing up in a FedEx or police uniform, etc.
  - Bribery/Threats

Security: Putting It In Perspective

- How do we manage the security of a valued resource?
  1. Risk assessment: the value of a resource should determine how much effort (or money) is spent protecting it.
     - E.g., If you have nothing in your house of value do you need to lock your doors other than to protect the house itself?
     - If you have an $16,000,000 artwork, you might consider a security guard. (can you trust the guard?)
  2. Policy: define who *should* have access to each resource and to what degree.

Security: Putting it In Perspective

3. Prevention: taking measures that prevent unauthorized access or damage.
   - E.g., passwords, physical security, firewalls or one-time passwords
4. Detection: measures that allow detection of unauthorized access (when an asset has been damaged, altered, or copied).
   - E.g., intrusion detection, trip wire, network forensic
5. Recovery: restoring systems that were compromised; patch holes.
6. Response/Punishment: measures that deter unathorized access not through prevention but through threat of consequences in detected

Outtakes

Secure as the real world

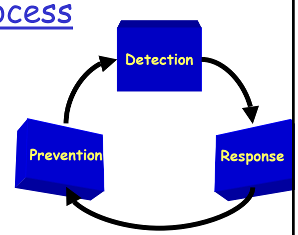
- The more you think about security the more you realize how many holes there are
- A good rule of thumb is to work to make things as secure as the real world

TODO

- Diffie Hellman
  - Suseptible to man in the middle
- Kerberos
  - Central authorities have long term associations with all communicating parties

The Security Process

- Security is an on-going process between these three steps.
- Moreover, most security research can be categorized within these three topics.



- Prevention: firewalls and filtering, secure shell, anonymous protocols
- Detection: intrusion detection, IP traceback
- Response: dynamic firewall rule sets, employee education (post-its are bad)

More 3-faceted views of Security

- Security of an organization consists of
  - Computer and Network Security
    - Everything that we will learn about in this class
    - Firewalls, IDS, virus protection, ssh, passwords, etc.
  - Process security
    - Protected by good policy!
    - No one should be able to get an account by phone: a form should be filled out, an email/phone call sent to a manager, and then the password picked up in person. Don't send notifications after accounts are set up!
    - http://www.nstissc.gov/html/library.html
  - Physical security
    - Protected by alarm systems, cameras, and mean dogs.
    - Are you sure someone can't just steal the hard drive?