COMP4108 Final Exam Practice

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Contents

1 Preamble

1.1 Textbook

- here is a link to "Tools and Jewels"

1.2 General

1. Please follow the provided format
2. We should prioritize the mock exam over notes

Part I

Mock Exam

1 Basic Concepts and Principles

1. Provide definitions for the following:

   a) Confidentiality

   b) Data integrity

   c) Authentication

   d) Authorization

   e) Availability

f) Accountability

2. Briefly explain how repudiation violates accountability.

3. Describe the difference between a *trusted* and *trustworthy* actor.

4. Compare and contrast *privacy*, *protection*, and *anonymity*.

5. Come up with a simple example of a security policy for a house and describe a way it might be violated.

6. Label each number in Figure 1.1 using the following terms:

a) target asset

b) vulnerability

c) attacker

d) attack vector

e) threat agent

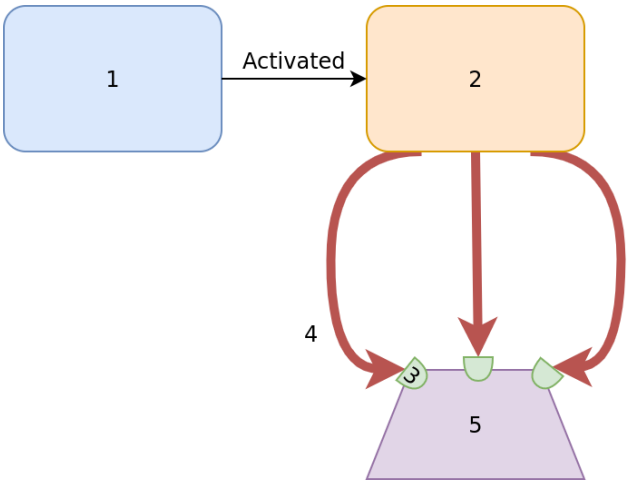


Figure 1.1

7. Draw a state machine diagram of a system's transition from a secure state to either a secure state or an insecure state.

8. Compare and contrast quantitative and qualitative risk assessment. Consider the advantages and disadvantages of each, as well as how each might work in theory/practice.

Qualitative	Quantitative

9. Consider $R = T \times V \times C$.

   a) What is this equation for?

   b) Describe each variable in this equation. How does each variable relate to the equation's purpose?

   c) Which two variables may be combined into P? What does the simplified equation look like? What does P represent?

10. Describe two risk assessment challenges.

11. Which of the following is not an adversary attribute?

    a) objectives

    b) outsider/insider

    c) methods

    d) funding level

    e) capabilities

    f) attack vector

12. What is a categorical schema? How is it different from a capability-level schema?

13. Compare and contrast a formal security evaluation with penetration testing.

Formal Security Evaluation	**Penetration Testing**

14. What is white-box pen testing? Black-box?

15. Consider STRIDE. What does each letter stand for?
    a) S:
    b) T:
    c) R:
    d) I:
    e) D:
    f) E:

16. Draw a tree model for compromising the password to a bank account. Include at least three leaf nodes.

17. Is it possible to completely test a comprehensive (and practical) set of security mechanisms for a system? Why or why not?

18. Explain the observability (or lack thereof) of security in the context of *negative goals*.

19. Assurance in security is best described as which of the following?

a) Simple, effective

b) Difficult, partial

c) Simple, practical

d) Difficult, complete

e) None of the above

2 Cryptographic Building Blocks

20. Suppose Alice encrypts a message to Bob using $E_k(m) = c$. How does Bob decrypt the message?

21. What is an exhaustive key search? What does the attacker try to do? Is this the worst case for attacking a cryptosystem?

22. Label each of the following attacks as either an action by an *active* or a *passive* adversary. Once you have labeled the attack, describe it.

a) Known plaintext attack

b) Ciphertext only attack

c) Chosen plaintext attack

d) Chosen ciphertext attack

23. What is the main advantage of a one-time pad? Describe three disadvantages. Why are one-time pads not used?

24. What is the current standard for block ciphers?

25. Describe a situation in which we would need to use a stream cipher. Why can't you use another type of cipher?

26. What is a mode of operation used for?

27. What is one major flaw with the ECB mode of operation?

28. Draw a picture of the CBC mode of operation.

29. Draw a picture of the CTR mode of operation.

30. If Alice wants to send a message to Bob using public-key encryption, _____ is used to encrypt and _____ is used to decrypt.

a) Bob's private key, Alice's public key

b) Bob's public key, Alice's private key

c) Bob's public key, Bob's private key

d) Alice's private key, Alice's public key

e) None of the above

31. If Alice wants to send a message to Bob using a public-key signature scheme, _____ is used to sign and _____ is used to verify

a) Bob's private key, Alice's public key

b) Bob's public key, Alice's private key

c) Bob's public key, Bob's private key

d) Alice's private key, Alice's public key

e) None of the above

32. How does hybrid encryption work? What role does symmetric key encryption play? Public-key encryption?

33. What three security properties do digital signature schemes provide? To whom to they provide them?

34. What two security properties do MACs provide? To whom do they provide them?

35. What security property does a cryptographic hash provide? To whom does it provide the property?

36. Describe each of the following properties of cryptographic hash functions.

a) Preimage resistance

b) Second preimage resistance

c) Collision resistance

37. How are hash functions used for password storage and verification? What property or properties of hash functions make this a desirable use case?

38. Is it generally better to MAC then encrypt, or encrypt then MAC?

3 User Authentication

39. Describe each of the following ways to defeat password authentication. For each technique you describe, provide one way to prevent it.

a) Online guessing

b) Offline guessing

c) Defeating password recovery

d) Bypassing authentication interface

e) Password capture

40. Describe 3 advantages of passwords. Describe 3 disadvantages.

41. What is a password hash salt? A pepper?

42. What is iterated hashing? What is it used for? How does it compare with other techniques to solve the same problem?

43. Explain the following:

a) Dictionary attack

b) Mangling rules

44. Describe the trade-off that occurs when using system-assigned passwords. How do these passwords help to mitigate dictionary attacks

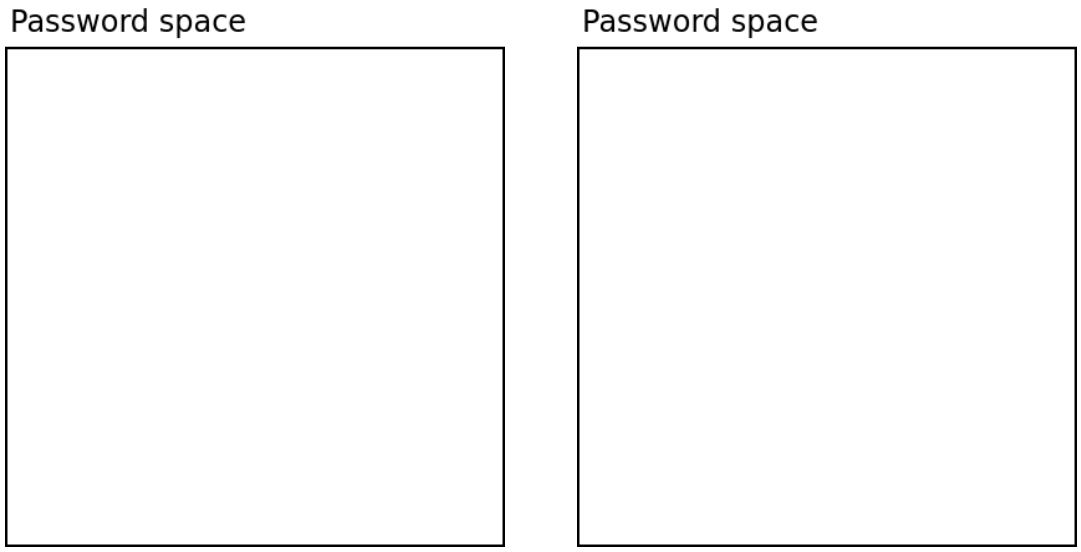
45. Suppose you had a password scheme that has an alphabet of size b and allows passwords as long as n characters. How long would it take to brute force passwords in this scheme in:

a) The worst case?

b) The average case?

46. Consider $q = GT/R$. What does this equation describe? What is each variable for?

47. Draw password distributions in Figure 3.1 according to the captions.



(a) Password distribution we want.

(b) Password distribution we see in practice.

Figure 3.1

48. Discuss rate limiting and password change policies with respect to online guessing attacks. How does $q = GT/R$ factor into making decisions regarding these policies?

49. Discuss the drawbacks of complex site login password composition policies. Suggest at least three better alternatives.

50. What is a passkey? Why are complex passwords preferred for passkeys? How can passphrases help with usability issues associated with these complex passwords?

51. How can password blacklisting be used to reduce the effectiveness of dictionary attacks?

52. Why are secret questions generally a terrible method for password recovery? Why do you think they are so widely used despite their drawbacks?

53. What is a one-time password? How can a Lamport Hash Chain be used to extend a single key word to t one-time passwords?

54. Explain how Lamport Hash Chains are vulnerable to a man-in-the-middle attack using small $n = t - i$.

55. Describe the following categories of authentication and provide an example for each:

a) What you have

b) What you are

c) What you know

d) Where you are

56. What is multi-factor authentication?

57. Describe some advantages and disadvantages of hardware token authentication.

58. Give an example of each of the following modalities with respect to biometric authentication:

a) Physical

b) Behavioral

c) Mixed

59. Biometrics are secrets.

a) True

b) False

60. Biometric authentication to a remote site via a phone sends your biometric signature for authentication.

a) True

b) False

61. Is it better to have a higher false acceptance rate or false rejection rate? Make an argument using the definitions of each.

62. Draw a bimodal distribution with a higher false acceptance rate than false rejection rate. Clearly define where your t is located with a straight line.

63. What is EER? How is it used in practice?

64. What is the difference between identification and authentication?

65. Describe at least three criteria used for the evaluation of biometric authentication.

66. Explain failure to enroll and failure to capture in the context of biometric authentication.

4 Authentication Protocols and Key Establishment

5 Operating Systems Security and Access Control

6 Software Security – Privilege and Escalation

7 Malicious Software

8 Public Key Certificate Management and Use Cases

67. What is a distinguished name? What does it do?

68. What is a public key certificate? What does it do? What trusted third party does it rely on?

69. Which of the following is generally preferred?

    a) An entity sends a public key in their certification request

    b) An entity sends a certification request and the CA generates their key pair

    c) These are equivalent

70. What does a PKI do? Give one example of a PKI and how it is used in practice.

71. What is X509 used for? What does it specify?

72. What is a certificate chain? Why are they necessary?

73. What part of a certificate chain requires implicit trust? What part(s) is expected to sign its own certificate?

74. What happens if part of a certificate chain is broken?

75. What is an out-of-band channel? What do we use them for when checking certificate integrity?

76. Why is allowing users to manually trust certificates not always the best idea? Why do browsers do it anyway?

77. Consider Trust-On-First-Use under the following circumstances. What is the result in each case?

a) An attacker has replaced a self-signed certificate with their own

b) The self-signed certificate is legitimate

78. Suppose you tried to browse a site with an X509v3 certificate that had 4 extension fields, one marked critical, the other three non-critical. What would happen in the following scenarios (assuming the rest of the certificate is fine)?

a) You have an older browser that cannot handle the critical extensions

b) You have an older browser that cannot handle one of the non-critical extensions

c) You have an older browser that cannot handle any of the non-critical extensions

79. Draw a picture of a cross certificate between two hierarchies. Describe one use case for cross certificates.

80. Consider the difference between *trust* and *trustworthiness*. What does a certificate trust model provide with respect to these terms?

81. Label (a), (b), and (c) in Figure 8.1 with the correct label from the following choices:

a) Ring mesh

b) Bridge CA model

c) Separate domains

82. Circle the trust anchor(s) for the right-most leaves in each diagram in Figure 8.1.

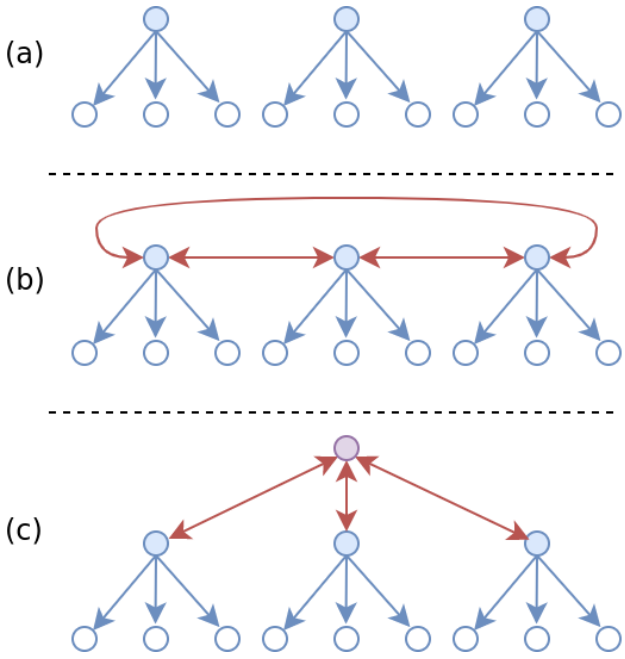


Figure 8.1

83. What are the leaf nodes in the browser trust model for CAs?

84. For each label in Figure 8.2, decide which of the following terms suits it best.

    a) Browser trust model

    b) Strict CA hierarchy model

    c) Enterprise PKI model

85. Circle the trust anchor(s) for the right-most leaves in each diagram in Figure 8.2.

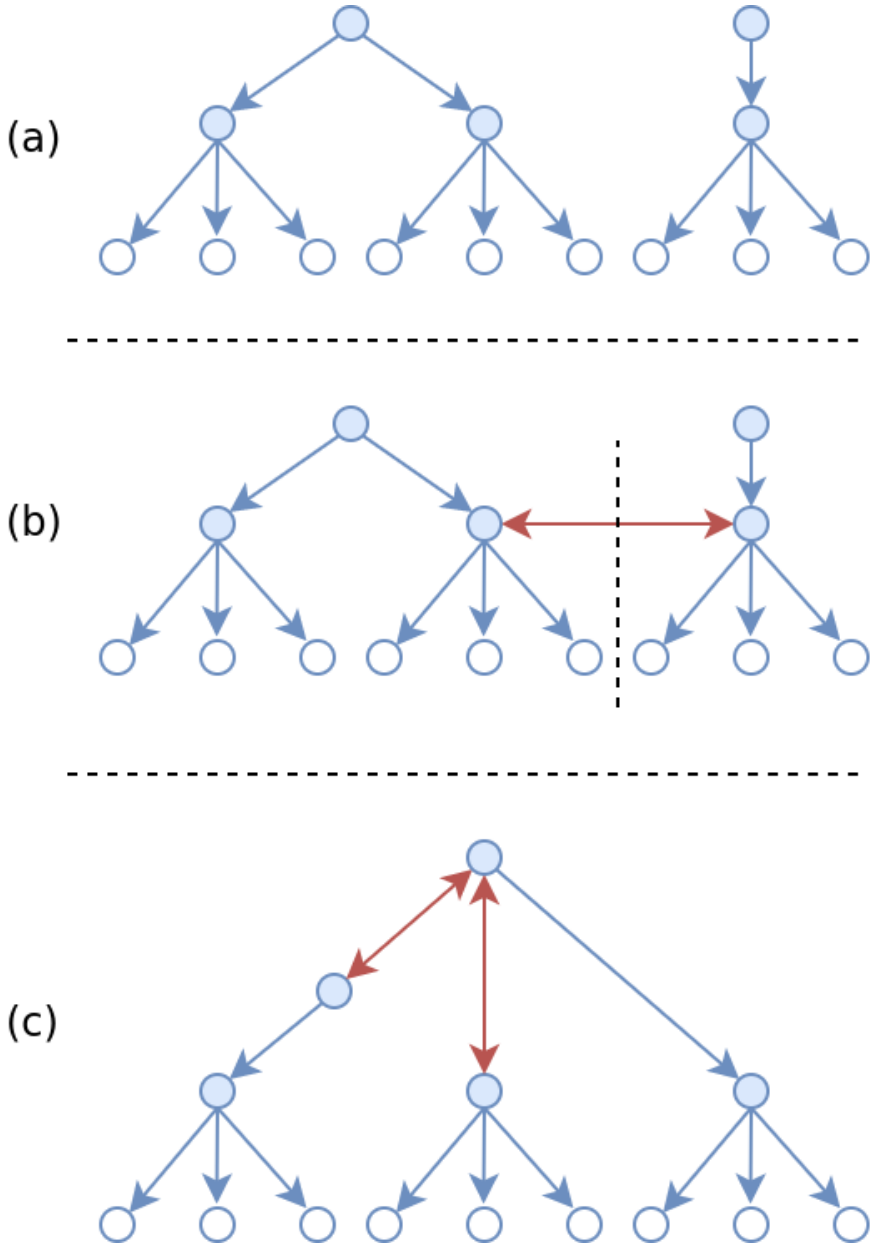


Figure 8.2

86. What is Web of Trust? Give an example of where we might use it.

87. Order the following validation types from least to most thorough:

a) DV

b) OV

c) EV

d) IV

88. What is a certificate substitution attack? What does this mean for the browser trust model?

89. How easy is it for a user to alter the browser trust model? Answer in terms of both accepting and revoking trust. Is this a good thing or a bad thing?

90. What do PEM, PGP, and S/MIME all have in common?

91. Where is the security header added in secure email?

92. Briefly explain how secure email uses public-key and/or symmetric-key cryptography.

93. What is a public key server? What is a certificate directory? What problem do these hope to solve?

9 Web and Browser Security

Click here for questions.

10 Firewalls and Tunnels

11 Intrusion Detection and Network-Based Attacks

Part II

Notes

12 Basic Concepts and Principles

12.1 Security Goals

12.2 Policies and Attacks

12.3 Risk Assessment and Management

Risk Equations.

Expected Loss.

Cost-Benefit Analysis.

Risk Assessment Challenges.

- model-reality gaps
- rapidly evolving technology -> changing vulnerabilities, adversarial capabilities
- incomplete picture of what adversaries are and what they can do
- difficulty of quantifying the value of intangible assets

12.4 Adversary Modeling

Attributes.

Schemas.

Pen Testing.

- blackbox
- whitebox

12.5 Thread Modeling

Diagrams.

Trees.

Checklists / STRIDE.

- S: spoofing

- T: tampering
- R: repudiation
- I: information disclosure
- D: denial of service
- E: escalation of privilege

13 Cryptographic Building Blocks

13.1 Symmetric-Key Crypto

One-Time Pad.

- needs key as long as plaintext
- perfect secrecy
- ciphertext is malleable
- not used in practice

Stream Ciphers.

- encrypt one bit at a time
- either synchronous or asynchronous
- rely on cryptographically secure PRNGs

Block Ciphers.

- all block ciphers have a key size and block length
  - require modes of operation to encrypt plaintext longer than block length
- AES is the best one at the moment
  - DES, 2DES, 3DES used to be where it was at, but each one was broken

Block Cipher Modes.

- ECB
  - encrypt one block at a time, and just plunk them together
  - this is fast and can be parallelized but....
  - this sucks, don't use it
  - it has no semantic security
- CBC
  - block chaining
  - start with an IV and XOR with first plaintext block
  - encrypt that to get first ciphertext
  - then use previous ciphertext as IV for next block and so on
- CTR
  - start with a nonce, increment the nonce eat time
  - at each step, run that nonce through the block cipher
  - then XOR the output with plaintext block to get ciphrtext

    - CTR mode technically works like a stream cipher (no padding needed!)

13.2 Public-Key Crypto

- generate public, private key pair
    - encrypt with their public key, they decrypt with their private key

Key Distribution and Hybrid Encryption.

- public key crypto often used for key distribution of a symmetric key
    - this allows us to establish an ephemeral session key for symmetric encryption

13.3 Digital Signatures

- generate public, private key pair
- you sign with your private key, they verify with your public key
- your public key must not be changed by an adversary
    - need integrity and authenticity
- generally we run the algorithm on a hash of the message instead of the message itself
- this provides
    - data integrity for anyone
    - data origin authentication for anyone (assuming nobody has replaced your public key)
    - non-repudiation (assuming nobody has stolen your private key)
        - MACs don't provide this one like digital signatures do

13.4 Cryptographic Hashes

- easy to compute
- provide compression (output is always same length)

Properties of Crypto Hashes.

- preimage resistance
    - hard to find m given $H(m)$
- second preimage resistance
    - given $m, H(m)$, hard to find $m' \neq m$ such that $H(m) = H(m')$
- collision resistance
    - hard to find any pair $m' \neq m$ such that $H(m) = H(m')$
    - implies the other two

What They're Good for on Their Own.

- on its own, a crypto hash can provide data integrity
- we can use them as primitive to help build MACs and digital signature schemes

13.5 MACs

- message authentication code
- generally a keyed hash function (HMAC)
- CBC-MAC is also a thing
  - use last block of CBC ciphertext
  - unless we use EMAC, this is vulnerable if we allow variable length messages
- HMAC with a good hash function is generally the standard here

14 User Authentication

- main types
  - what you have (hardware tokens, key cards, etc.)
  - what you know (passwords, etc.)
  - what you are/do (biometric, behavioral, etc.)
  - where you are (location-based, etc.)

14.1 Storing Hashes vs Cleartext

- storing hashes is necessary
- cleartext exposes passwords in the event of a breach
- hashes provide verifiable text without exposing the underlying password
  - (still weak to dictionary attacks)

14.2 Targeted vs Trawling Scope Attacks

- targeted
  - focus one user
- trawling
  - focus all users equally

14.3 Approaches to Defeat Passwords

Offline Guessing.

- attacker steals hash file and uses it as verifiable text to guess passwords
- generally a trawling scope attack
- defend with salts, peppers, iterated hashing, MAC on passwords

Online Guessing.

- attacker attempts to guess passwords on a password-protected server
- better if they know user IDs first
- defend with rate limiting according to guess rate
- also mandatory password changes in conjunction with rate limiting

Password Capture.

- attacker captures a password or a hashed password
- they can then replay this back
- key loggers, unencrypted traffic, etc.

Defeat Password Recovery Mechanisms.

- attacker abuses password recovery mechanism to make a new password for your account instead of stealing the old one
- email theft
- SIM swap attack
- OTP pre-capture

Password Interface Bypass.

- simply get around the password interface altogether
- exploit a flaw in password interface design

14.4 Password Composition Policies and Strength

Ineffectiveness of Policies.

- LUDS (3/4)
  - require at least 3 out of the 4:
  - lowercase
  - uppercase
  - digits
  - symbols
- this is generally not that great
  - it only really stops simple guessing attacks
- mangling rules on a dictionary attack completely defeat this

Usability / Security Trade-off.

- in general, the more usable a password is, the less secure it is
- the really secure passwords are almost unrecognizable, random
  - but people generally don't want to use these
- ideal password space is uniformly random, but in practice it is very skewed

Probability of Guessing a Password.

- $q = GT/R$ where
  - R is the password space b^n
  - G is guessing rate
  - T is time
- we can use this to tune our rate limiting and password change policies for online attacks

Enforcing Password Blacklists.

- password blacklists can help stop the very weakest passwords
- we simply detect when a user enters an extremely common password and block it
- in practice, these lists only need to be around 10^6 words long

14.5 Password Guessing Defenses

Rate Limiting.

- slow down guessing by blocking after a certain number of attempts
- we can tune this according to the expected rate of password guessing
- this can be used in conjunction with things like mandatory password changes

Iterated Hashing.

- take the $H^n(w)$ of the password w
- slows down guessing attacks by a factor of n
- also slows down password verification, but this is generally acceptable
  - remember an attacker has to do this for all passwords, we just have to do it for one at a time

Salting and Peppering.

- good against offline attacks
- makes it harder to use hash as verifiable text
- salting
- peppering
  - secret salt
  - random value within a certain range
  - server has to try each salt to get it right
  - but now the attacker doesn't know the verifiable text

MAC on Password.

- for example, use a keyed hash
- good against offline attacks
  - this makes stolen password hash files effectively useless, unless attacker can get the key

System-Assigned Passwords.

- this eliminates password bias (stops dictionary attacks)
- the downside is that usability goes way down
  - users will have a hard time remembering system assigned passwords

14.6 Password Recovery

Recovery Links.

- recovery links send to email
- just make sure your email doesn't get compromised

One-Time Passwords.

- one-time password used to reset current password
- sometimes sent as a code to a cellphone or sent by email (see above)
  - watch our for SIM swap attacks or stolen email

Question-Based Recovery.

- secret questions/answers
- this is generally terrible
  - space of possible answers is way to small
  - answers often based on easily verifiable information about a person's real life
- making nonsense answers to counter this reduces usability
- potential for more than one right answer, user has a hard time remembering which

14.7 OTP Generators and Hardware Tokens

Mobile OTPs.

- often used for 2FA
- one-time password is generated by some means and send to a mobile phone

SIM Swap Attack.

- attacker uses social engineering to get a new SIM for your number and put it in their phone
- now they can receive your OTPs if they are sent via SMS

Lamport Hash Chains for OTPs.

- technique for generating OTPs using weak secret
- $H^{t-i}(w)$ where t is a fixed parameter and i is the number of protocol runs
  - thanks to preimage resistance, a passive attacker has no way of figuring out $H^{99}(w)$ given $H^{100}(w)$
- after it wraps around, we choose a new weak secret w
- weak to something called the small-n attack
  - active attacker
- also, if attacker knows t and knows that run i is approaching, then the attacker knows the number of hashes, which gives them verifiable text to guess w

Hardware Tokens.

- hardware that securely stores secrets and uses them to generate digital tokens in response to challenges
- could be a USB stick or chip card, for example

Multiple Factors.

- often one time passwords are used as multi-factor authentication
- this means that you use them to augment other ways of authenticating
  - 2FA with a smartphone is a great example of this
- also, two-stage authentication
  - user to device, then device to web
  - for example, a fingerprint to sign into your banking app

14.8 Biometric Authentication

Modalities: Physical, Behavioral, Mixed.

- physical
  - e.g., a fingerprint, facial recognition
- behavioral
  - e.g., how fast your typing speed is
- mixed
  - e.g., voice recognition

Enrollment and Verification.

- scheme specifies as confidence threshold, t
- user registers biometric several times, and the system determines if they average within this threshold

FAR, FRR, EER.

- false acceptance rate
  - rate at which invalid signatures are accepted
- false rejection rate
  - rate at which valid signatures are rejected
- equal error rate
  - not really useful in practice
  - only really used for simple point comparisons of protocols
- difficult to balance FRR and FAR

FTE, FTC.

- failure to enroll
  - users are unsuccessful in registering the template
- failure to capture
  - system is unable to get adequate sample in order to proceed

Fallback Mechanisms.

- important to have fallback mechanisms in case of false rejections or failure to capture
- for example, a smartphone can use a password as a backup
- in this case, biometric authentication becomes more about convenience than security
  - since we are only as strong as the backup anyway...

15 Authentication Protocols and Key Establishment

15.1 Unilateral vs Mutual Authentication

- unilateral
  - one party authenticates to another
- mutual
  - both parties authenticate to each other

15.2 Key Establishment

- both parties reach an agreement of a secret key to use for a session
- two subcases
  - key transport
  - key agreement
- in key transport, one party decides the secret key and relays it to the other
- in key agreement, both parties contribute to deciding on the secret key

DH Key Agreement.

- take a large prime p and a generator g in that group
  - can also be done with elliptic curves instead
- Alice sends $g^a \bmod p$ and Bob sends $g^b \bmod p$
- they construct the same shared secret $g^{ab} \bmod p$
- Eve can't reconstruct the secret using g^a and g^b because of:
  - discrete log problem
  - computational diffie hellman problem
  - decisional diffie hellman problem

Problems With DH.

- weak to man in the middle attack
  - person in the middle performs DH with Alice and DH with Bob
  - Eve relays messages from Alice to Bob and vice versa, but can inspect them in the mean time
  - Alice and Bob think they are talking to each other
- how to fix this?
  - authenticated diffie hellman (for example with RSA, etc.)

Problems With Key Transport.

- when we use key transport instead of key agreement, we rely wholly on long term keys
- when these long-term keys are compromised, all future sessions are compromised
- key agreement is better because we can incorporate more depth into determining session keys

Ephemeral Keys.

- key data only persists during a sessions, disappears after
- important so that we don't provide verifiable means of reconstructing the key
- also, a compromised key now only compromises the session

Authentication-Only Protocols.

- we only authenticate, and don't bother with session keys
- these protocols see use in limited contexts
- an example is authentication when using a bank card -> we don't need to establish a session key here

Unauthenticated Key Establishment.

- things like textbook DH Key Agreement
  - no authentication takes place, parties still establish a shared secret
  - secret is the ephemeral session key
- these protocols are weak to man in the middle attacks

Authenticated Key Establishment.

- a way of pursuing key establishment and authentication in one protocol
  - using separate protocols and trivially gluing them together ends badly
- we can use symmetric key systems, public key systems, or some combination
  - there are many pitfalls and challenges here though, particularly when connecting for the first time

Initial Keying Material.

- usually shared via out of band means
  - either an alternate secure channel prior
  - pre-shared secret
  - or using independent cryptographic mechanisms

Strong Secrets vs Weak Secrets.

- perfectly random secrets are strong / crypto-strength
- deterministic secrets (e.g., from hashing as password) are weak secrets

15.3 Attacks on Authentication Protocols

Replay Attack.

- capture and replay a hashed secret without knowing the secret
- use it to impersonate someone if authenticating with a weak secret

Dictionary Attack on Weak Secret.

- use a dictionary to make educated guesses about a weak secret
- hash lookup tables on this dictionary
- verifiable text allows offline guessing attacks to recover a weak secret w

Reflection Attack.

- **unsure about this one**

Relay Attack.

- capture signal in one place, relay it in real time to another place
- defend this with tight bounds for time variant parameters

Time-Variant Parameters.

- attempts to defeat the relay attacks, replay attacks, reflection attacks
- introduce parameters that are time-sensitive
  - timestamps
  - random numbers
  - sequence numbers
- these parameters should expire before attacks have a chance to occur

15.4 Authenticated DH

Small Subgroup Attacks.

- an attacker who substitutes small values for g^a and g^b forces key space to be extremely small
- we can counter this by limiting the range of potential g^a and g^b (both high and low since we are working in modular arithmetic)
  - these checks are easy, but essential

Middle Person Attacks.

- Alice wants to talk to Bob
- Eve pretends to be Alice to Bob, Bob to Alice
  - Alice performs DH with Eve, Bob performs DH with Eve
  - they think they performed DH with each other
- now Eve has a session key for Alice and a session key for Bob and relays messages

- she can inspect/modify/change messages

Proof of Knowledge vs Relay Attack.

- just proving knowledge is not enough to authenticate DH vs a middle person
- middle person could simply ask Bob for his secret and send that along to Alice

STS Protocol.

- this turns DH into authenticated DH
- use digital signatures to authenticate DH
  - e.g. RSA, ElGamal, DSS

15.5 Key Authentication Goals

Forward Secrecy.

- exposing long term secret should not jeopardize future session keys

Known-Key Security.

- exposing long term secret should not reveal past session keys

Liveness.

- entity authentication ensures that a participating entity is active at the current moment
- provides a liveness property not present in store-and-forward like email
- key-use confirmation
  - one party has evidence that another has the correct session key
  - the other party sends an explicit demonstration of knowledge using that key

Implicit vs Explicit Authentication.

- implicit
  - Alice sends authentication to Bob and assumes Bob has received it
  - narrow possession down to Bob, but don't confirm it
- explicit
  - Alice sends authentication to Bob and requires an explicit response to confirm that it was received
  - narrow possession down to Bob and confirm it

15.6 Password Authenticated Key Exchange

- passwords are weak secrets
  - these protocols have to be designed carefully to avoid leaking information
- protocol information may provide verifiable text to an attacker
  - this is bad

    - protocols must be carefully designed to avoid this

EKE.

- encrypted key exchange

DH-EKE.

- DH where g^a and g^b are encrypted with a weak secret
- vulnerable to partition attacks unless we choose very large p

SPEKE.

- do DH as normal, except keep g a secret by creating it using $H(w)^2$
- they will only have the same value if they use the same weak secret

16 Operating Systems Security and Access Control

16.1 Memory Protection

- physical memory -> pages
- virtual memory -> joins pages from all over the place to appear as if they are continuous

Descriptor Register.

- OS maintains per-process descriptor segment that holds a table of indices (segment descriptors)
- descriptor base register points to this segment
- each index has starting address, current size, and access permissions

Memory Access Permissions.

- `r` readable by non-supervisor
- `w` writable by non-supervisor
- `x` executable by non-supervisor
- `m` supervisor mode when executing
- `f` fault bit: trap to supervisor on access (overrides other bits)

16.2 Reference Monitor, Access Matrix, Security Kernel

- rows = subjects
    - each row is a capability list for a subject
- columns = objects
    - each column is an access control list for an object
- reference monitor controls access attempts to resources
    - in practice, this will be several monitors for several access types

- these ideas taken together form a security kernel
- reference monitor is only a model, implementation varies in practice

16.3 Audit Logs

- OS maintains audit logs that describe user attempts to access resources, run programs, etc.
- basically leaves an audit trail of how the user interacts with the system
- these logs can be useful for host-based IDS data collection

16.4 File / Directory Permission Bits

- binary
  - `d rwx rwx rwx`
  - read write execute for user, group, other
  - first bit specifies special file types (directory, symlink, char device, block device, named pipe)
- octal
  - 777 -> `rwx` for all
  - 7777 -> `rwx` for all and also sets setuid, setgid, and sticky bit
  - the left most octal digit specifies: 1 -> sticky bit, 2 -> setgid, 4 -> setuid

`setuid`, `setgid`.

- special bits that specify we run with the euid and egid of the owner respectively
- often used with root-owned binaries
- denoted with an `s` in the character permission model on top of the execute bit for user and group
  - if we don't have execute permissions, we still can't run it though

Real, Effected, Saved `uid` and `gid`.

- `ruid`, `rgid`
  - the actual uid and gid of the user
- `euid`, `egid`
  - effective uid and gid of the user, changed when running a setuid or setgid executable
- `suid`, `sgid`
  - saved uid and gid, used to restore privilege back to normal when dropping privileges

Sticky Bit (`t-bit`).

- prevents the deletion and renaming of files within a directory
  - unless they are owned by you
  - or you are the owner of the directory

`umask`.

- permissions to take away from default permissions on file creation
- for example, if we created a file with
  - rw -> `666` and had a umask `022` (very common)
  - we would end up with `644`
  - this corresponds to rw for owner and r for group and other
- for octal, this is easy, we just subtract them
- for binary, just and it with the notted umask

ACLs.

- augments user group other model
- specify permissions for specific users and groups in addition to `ugo`
- mask specifies limits for these specific users and groups
  - for example, if I set `user:william:rwx` but mask was `mask::r-x`, `william` would not be able to write

16.5 Symbolic Links, Hard Links, Deleting Files

- symbolic link
  - points to pathname of another file
  - deleting original breaks link
- hard link
  - associates new path name with same inode
  - deleting original preserves link
- deleting a file
  - removes a pathname-inode association
  - file is only "deleted" once last link is removed
  - but even then, data still exists, can be recovered
  - only way to truly delete is to overwrite with `0`s then unlink

16.6 Role-Based Access Control / Mandatory Access Control

17 Software Security – Privilege and Escalation

17.1 Race Conditions

- TOCTOU
  - time of check to time of use
  - setuid has owner's privileges, but we need to make sure real user can access the file
  - `access` system call traditionally used
  - but an attacker can attempt to change the file between checking access and opening it for writing
  - this allows us to access another file that we shouldn't
- how to stop this?
  - atomic privilege checks would be nice

        - not portable
    - drop privileges and then fork before opening the file, make descriptor available to parent before exiting
        - also not portable
    - use system calls that deal directly with file descriptors
        - also not portable
    - no perfect solution, application dependent
- other notes
    - niceness can tip the balance in the attacker's favor
    - make checking process much higher niceness (slower) -> larger window to win the race

17.2 Integer-Based Vulnerabilities and C Issues

- problems:
    - signedness
    - overflow
    - underflow

17.2.1 Problems with C

- favor efficiency/direct access over security
    - it lets us make mistakes like the ones above without warning
- undefined behavior -> machine-dependent results
    - signed integers have undefined behavior, unsigned integers use modular wrapping
- pointer arithmetic
- accessing memory using overflow/underflow values
- using overflow/underflow values for branching conditions
- pointer arithmetic changes based on size of type
- types can have different sizes based on architecture

Why We Can't Just Fix This.

- some developers rely on the behavior we described above (intentional overflows)
    - introducing runtime errors breaks backwards compatibility
- warning about possible errors is not necessarily possible
- safe integer libraries are a good option, but how do we enforce adoption?

17.3 Stack-Based Buffer Overflows

- too many bytes written to stack may overflow into adjacent memory
- natural vs intentional
    - natural yields unexpected outcomes
    - intentional results in security issues

17.3.1 Memory Layout

- text and global data segments are lowest, initialized at start
- heap is low, grows up
- stack is high, grows down

17.3.2 How it Works

- on function call, new args are pushed onto stack
- current instruction pointer is pushed as return address
- now we push local vars onto stack and execute the function
- overflowing a local var overwrites higher memory
  - if we overwrite return address, we can point it elsewhere, including into our overwritten memory

17.4 Heap-Based Buffer Overflows

- dynamic allocation is less predictable, varies between systems
- attacker has to experiment to find a vulnerable variable
  - there needs to be a useful higher memory address that is exploitable
- this is also only useful if memory corruption does not crash the program

17.4.1 Heap Spraying

- inject code many, many times into various locations in the heap
- then use an independent exploit to trigger code execution
- you only need to get it right once

17.5 Three Main Steps for Buffer Overflows

1. Code injection
   - inject code into an area of memory
2. Corruption of control flow
   - change control flow to go to that code
3. Seizure of control
   - run that code

17.6 Buffer Overflow Exploit Defenses

- make head and stack non-executable
- stack canaries
  - key words that detect code injection
  - if the key word is overwritten, raise an error
- run-time bounds checking
- ASLR, random heap allocators
  - randomize memory layout

    - disrupts attacks that rely on known memory locations
- type-safe languages
- safe C libraries
- static analysis tools
    - analyze code and flag potential problems

17.7 Privilege Escalation

- move from fixed functionality to a command shell
- escape a sandbox
- gain root privileges
- move from root privileges to kernel privileges (e.g., install a rootkit kernel module)

18 Malicious Software

18.1 Viruses vs Worms

- both propagate, carry a payload
    - mechanisms differ
- virus
    - requires user interaction to propagate, run
    - payload triggers on a condition
    - infect host files / software
        - even documents -> macro viruses
- worm
    - propagate automatically, over networks
    - don't need to be run by a user
    - exploit running software

Virus Infection Strategies.

1. Write beginning of file
2. Write end of file
3. Overwrite entire file
4. Overwrite a specific portion of file

- appending or prepending does not damage functionality, but is noticeable due to file size change
- overwriting harms functionality of program
    - make sure it's not critical to running the system

Virus Detection.

- impossible to write a program to detect all possible viruses
- instead, we play a cat and mouse game with attackers
    - increasing complexity

- detection: data signature-based detection, integrity checking, behavioral signatures

Virus Anti-Detection.

- encrypt and store internal decryptor key
- polymorphic virus that changes decryptor portions across infections
- place decryption key in an external file
- metamorphic virus -> mutates both body and mutation engine

Auto Rooters.

- scan for vulnerable targets, exploit opportunistically
- only need one vulnerability to spawn a root shell and/or install a rootkit

Fast Worm Spreading.

- generate hit lits by scanning for vulnerable hosts
- permute compromised addresses to find new targets strategically
- internet-scale hit lists
  - scan servers

18.2 Trojan Horses

- disguises malicious functionality as useful functionality
- sometimes combines malicious functionality with useful functionality
- often social engineering
  - disguised updates for legitimate programs
- may remain undetected for some time

18.3 Backdoors

- bypass normal entrypoints (and access control)
- remote-access Trojan (spawn a remote root shell)
- malicious remote desktop/shell tools
- rootkits

18.4 Key Loggers

- can be implemented with rootkits hooking system calls
- log user actions / keystrokes to steal information
- more severe -> surveillance software

18.5 Rootkits

- installed after an attack to allow attacker to keep coming back
- goals

    - conceals its presence
    - controls or manipulates applications/OS
    - facilitates long-term additional malicious activity
- rootkits often provide backdoors
- can be implemented in userspace or kernelspace
    - kernelspace is more dangerous (supervisor mode, control whole OS, easier to conceal itself)

Rootkit Methods.

- hooking system calls (patch dispatch table)
- inline hooking
    - detour and trampoline functions
- kernel object modification (to hide activity)
    - either directly change the kernel object
    - or modify the return values of key system calls via postprocessing
- installation strategies
    - exploit buffer overflows in kernel
    - alter shared library or application in userspace
    - install loadable kernel module (after gaining root privilege via some other means)

18.6 Drive-By Downloads

- exploit browser vulnerability + code injection to legitimate site (or by phishing with a malicious site)
- results in downloading a malicious executable silently
- defenses?
    - downloader graphs
    - comparing download patterns

18.7 Droppers

- malicious software whose job it is to download and install other malicious software
- can arrive by means of a worm, virus, trojan, or drive-by-download

18.8 Ransomware

- malware designed to extort users into paying
- often controlled via a botnet
- anonymous payment methods like bitcoin are exacerbating their effectiveness
- examples
    - encryption file lockers (use encryption to lock users out of their files and require payment to unlock the key)
    - other methods of file locking (access control, threaten to erase data, syskeying in Windows)

18.9 Botnets

- a coordinated network of enslaved machines
  - exploited initially via shell code or other means
- attack establishes control over many remote systems
  - the controlling machine is called the botnet header
- uses these systems to commit cyber crimes
  - provide an economy of scale to attackers
  - DDOS attacks, spread ransomware, malicious crypto mining, etc.

18.10 Zero-Day Exploits

- target a vulnerability in a program that was not known previously
- only useful before the vulnerability is patched
- users not patching their software can make this especially problematic

18.11 Logic Bomb

- malicious payload executed when a condition is met
- this is used in viruses and worms for example

19 Public Key Certificate Management and Use Cases

19.1 PKIs

- public key infrastructure
- basic function is to provide a means of verifying a public key belongs to an entity
- CAs, sPKI, WoT

19.2 Certificates

- fields
  - subject (DN)
  - issuer (DN)
  - version information
  - validity period
  - extension fields
    - critical and non-critical (if you can't handle critical, reject)
- X509 tells you what fields
- DN
  - distinguished name (uniquely IDs an actor)
  - Country
  - Organization
  - Organizational Unit
  - Common name

- subject alternate name(s)
  - other names that a subject can go by
- certificate can be
  - issued
  - revoked
  - expired
  - valid
  - invalid

19.3 Certificate Authorities

- issue certificates
- root CA requires implicit trust
  - intermediate CAs to distribute the task of issuing/verifying
- each CA has its own certificate
  - root CA (trust anchor) signs its own

Certificate Chains.

- intermediate CAs
- root of the chain is the root CA
  - root CA is generally trusted via information obtained from an out of band channel
  - e.g., browsers have a list of root CAs they trust implicitly
    - cross certificate pairs can handle the test

Cross Certificate Pair.

- two CAs sign each other's certificates
- if you trust one, you can trust the other one
- builds connected trust on the internet

19.4 Certificate Trust Models

Single-CA.

- each tree has one CA
- Separate Domains
  - one CA for each set of leaf nodes
  - everything is kept completely separate otherwise
  - no cross certificate pairs
- Ring Mesh
  - like separate domains except all top-level CAs are linked with cross certificate pairs
- Bridge CA Model

  - cross certificate pairs with a central hub

Strict Hierarchy.

- root CA with intermediate CAs forming a connected tree
- cross certification is possible within the tree but not between separate trees

Ring-Mesh of Tree Roots.

- like strict hierarchy except now tree roots are free to cross-certify

Browser Trust Model.

- list of trust anchors for each end point
- no cross certificates in browser trust model
- each tree is a hierarchy
- leaf nodes correspond to servers

Enterprise PKI.

- intermediate CAs at lower levels cross certify between departments
- allows fine-grained control of trust

Web of Trust.

- each entity signs their own keys and then entities sign each other's keys
- you pick a subset to trust, and then trust keys trusted by those you already trust
- used in PGP, secure email for example

19.5 Grades of Certificate

- IV
  - user decides to trust a self-signed certificate
- DV
  - validates a domain only
- OV
  - validates domain and organization
- EV
  - extensive validation process

20 Web and Browser Security

N.B., I am omitting all the webdev review stuff at the beginning of this chapter. If somebody would like to make a PR to add it, that would surely be appreciated.

20.1 TLS and HTTPS

TLS Layers.

- two layers

1. handshake layer
   - (unencrypted) key exchange
   - (encrypted) server parameters
   - (encrypted) integrity and authentication
2. record layer
   - protects all data using negotiated parameters

TLS Key Exchange.

- three options

1. DHE (ephemeral diffie-hellman)
   - either finite fields (integers mod p)
   - or elliptic curves
2. PSK (pre-shared key)
   - either pre-shared via out-of-band channel or from a previous TLS session
3. PSK combined with DHE

TLS Server Authentication.

- two (or technically four) options

1. either PSK session key
2. or digital signature (based on certificate)
   - digital signature RSA
   - or ECDSA
   - or EdDSA

- client and server send MAC codes to signal they are done

TLS Encryption and Integrity.

- usually encryption is done in two ways

1. either via ChaCha20 (stream cipher)
2. or AES (block cipher) using an acceptable mode

- hash algorithms provide data integrity

20.2 DOM Objects

- `location` -> sent by server in HTTP header
- `domain` -> origin server can increase cookie's scope
- `document.domain` -> hostname that document was loaded from

- `window.location.href` -> URL of requested document; modify to redirect

20.3 HTTP Cookies

- HTTP is stateless
- cookies allow persistent state
  - by default, persist over a session (in browser memory)
- multiple cookies can be set by an origin server using headers
  - these cookies are returned from the origin server on later visits
- cookie attributes
  1. max-age/expires -> max age in seconds or expiration data of the cookie
  2. domain -> set scope of cookie to a higher level domain but not TLD
  3. path -> which origin server pages a cookie is returned to
  4. secure -> if specified, use HTTPS (over TLS) instead of HTTP
  5. httponly -> only HTTP can access, no javascript / DOM API access

20.4 Same-Origin Policy

- isolates documents
- document from one origin should not be able to interfere with or manipulate a document from another origin
- prevent javascript from being used by a malicious page to redirect to a sensitive page and access or modify data
  - recall from the assignment

SOP Rules.

1. assign an origin to a document based on URL
2. scripts and images are assigned an origin based on who loaded them (not who they are retrieved from)
3. scripts may only access content whose origin is the same as their own

Problems.

- goals are hard to capture precisely
- difficult to enforce

How to Identify an Origin.

- based on a 3-tuple of information
  1. scheme
  2. host
  3. port
- content from distinct origins needs to be in new frames or windows
  - `<iframe src="url">`
  - `window.open("url")`

Relaxing SOP.

- developers can change `document.domain` to classify domains sharing the same suffix as belonging to the same origin
- this is bad from a security perspective

How Things Are Different For Cookies.

- cookies use different attributes for origin identification
  - they no longer use port
  - they use `secure` and `httponly` in place of `scheme`

20.5 Authentication Cookies

- server stores session ID in a cookie
- user logs in once, and cookie authenticates them next time they visit the site for the duration of the session
- server may specify a session expiration time
- persistent cookies may extend authentication beyond the lifespan of the browser window

Cookie Theft.

- javascript, proxies, client-side malware, physical/manual filesystem access
  - steal cookie, use to authenticate as the victim
- session hijacking (not the same thing as TCP session hijacking)
- defense against javascript is to set `httponly` in the cookie
  - this does not work against the other attacks

Cookie Protection.

- the server should encrypt and either MAC or sign the cookie to provide data integrity and data origin authentication
- server will then decrypt and verify the cookie when it comes back

20.6 CSRF

- cross site request forgery

20.7 XSS

- cross site scripting
- insert HTML script tags that cause malicious javascript to be executed

XSS-Stored.

- when the page is rendered based on content stored on the server
- e.g. a comments section

- loaded persistently whenever a user accesses the site

XSS-Reflected.

- exploit parameterized script to insert XSS
- e.g. a file not found error message that pops up based on requested path
  - change requested path to a script tag

Possible Impacts.

- cookie theft
- redirection to malicious site
- altering the contents of the site
- seizure of browser control

20.8 SQL Injection

- common tricks
  - terminate quotes early by adding a quote of your own
  - terminate a statement by adding a `;` (works well after integers)
  - insert a comment with `--` to eliminate query checks
  - insert `OR` that always resolves to true followed by `--`

20.9 Sanitization

- used to defeat XSS, SQL injection
  - this is a lot harder than just sanitizing `<script>`, `;`, `"`, etc.
  - there are a lot of factors to consider
  - for example, evasive encoding is a problem that may not seem obvious at first

For SQL Specifically.

- adjust input to remove bad characters
- blacklisting known-bad input
- only allowing known-good input (whitelisting)

21 Firewalls and Tunnels

- inbound (ingress) packets
  - protect network from internet
- outbound (egress) packets
  - protect from compromised machines or malicious insiders (accessing the outside world)

As a Chokepoint.

- requires secure perimeter
- this isn't really a thing anymore thanks to mobile data, etc
- but firewalls remain useful
  - protect legacy apps
  - enforce IP security policies lacking wireless access to physical hosts

Limitations.

- assume true perimeters exist
- insider the network is trusted, little protection from users cooperating with outsiders
- trusted users make bad connections
- tunneling can bypass them
- can't inspect encrypted content

21.1 Packet Filter Firewalls

- actions
  - `ALLOW` -> allow packet
  - `DROP` -> silently drop (type-1 deny)
  - `REJECT` -> drop and notify (type-2 deny)
- rules are based on 5 TCP/IP Header fields
  - src address
  - dest address
  - src port
  - dest port
  - protocol (TCP/UDP/ICMP)

Stateless vs Stateful.

- stateless
  - packets processed independently of others
- stateful
  - remembers previous packets when processing
  - state is kept in a state table
- dynamic
  - rules change on the fly

21.2 Proxy Firewalls and Firewall Architectures

- two properties desired
  - transparency
  - performance

Circuit-Level.

- checks TCP 3-way handshake, not packets themselves

    - syn
    - syn-ack
    - ack
- most common implementation
    - client-side library and proxy server daemon `sockd`
    - client-daemon network protocol called `SOCKS`

Application-Level.

- firewall establishes a connection on your behalf and inspects incoming data packet
- can block packets entirely or even alter packet payloads
- requires detailed knowledge of specific application-level protocols

Internal Firewalls.

- gateways between internal subnets
- bastion hosts
    - defensive host exposed to a hostile network
- dual-homed host
    - two network interfaces
    - one address per interface
    - can be suitable for a circuit-level proxy

Enterprise Firewall Architectures.

- screening router (router with packet filtering) + a bastion host
- another strategy uses a perimeter network (network DMZ), a subnet between internal and external network
- another possibility: bastion host in the DMZ between two screening routers (one internal, one external)

21.3 SSH

- secure shell
    - does not provide a shell itself
    - provides an encrypted tunnel to *get to a shell* (or another application)
- before SSH, we sent cleartext over the network -> this is *bad*

Three Protocols -> Three Layers.

- transport layer protocol
    - encrypts and provides integrity
    - includes negotiation of crypto parameters and keys
- user authentication protocol
    - handles SSH authentication, runs over transport layer protocol
- connection protocol

    - single SSH connection for multiple purposes
    - each instance gets a logical channel
    - channels support
        - interactive sessions
        - connection forwarding

Client Authentication.

- during transport layer negotiation, server decides which authentication methods it will accept
    - password
    - kerberos ticket
    - client public key
- for public key login
    - server receives client public key and signature
        - verifies the signature relative to session data (incl. ID)
        - checks that public key is in list of allowed public keys

Server Authentication.

- in non-enterprise, usually it's TOFU
    - if the key we choose to trust is okay, we're all good
    - otherwise, we have connected to a middle person
    - generally this gamble is acceptable if we have no backing PKI
- to make TOFU better, we can cross-check the host's fingerprint hash against one obtained in an out of band channel
- PKI support is the best, two options
    - client database of SSH keys
    - CA-certified SSH keys

SSH Tunnel.

- `-L localport:host:hostport remotehost`
    - listen on local machine at port `localport`
    - forward it to `host:hostport` from `remotehost`
- `-R` same thing but backwards (remote to local instead of local to remote)

21.4 VPNs and Encrypted Tunnels

Tunneling.

- data stream on one protocol travels inside another
- encapsulation
- not necessarily a higher level protocol, encapsulating a lower level
- two technologies often used
    - ssh -> lightweight

  - IPsec -> heavier

VPN.

- physical private network
  - accessed only by trusted users
  - physical isolation, access control, firewalls/gateways
- VPN is a private network created via encrypted tunnels and special protocols

Site-to-Site VPNs.

- bridge private networks across a public channel

Remote Access VPNs.

- authorized clients remote access to a private network
- experience is transparent to physically located

22 Intrusion Detection and Network-Based Attacks

22.1 Response Types: Detection vs Prevention

- Intrusion Detection System
  - detect intrusions and issue an alarm
  - for example, to a sysadmin
- Intrusion Prevention System
  - take active steps to prevent the attack
  - this is not always possible, depends on design, locality, and other limitations
  - e.g., external sensors in a NIDS may not be able to respond in time since they have to copy traffic

22.2 Architecture: Host-Based vs Network-Based

Host Based.

- collect event data on a local machine
- can be used cooperatively across multiple machines on a network
- checking network events on a local machine is still host-based, not network-based

Network Based.

- collect events on a network
- for example, on a specialized gateway device

22.3 Event Outcomes

False Positives.

- when an IDS mistakenly flags a valid event as invalid

False Negatives.

- when an IDS mistakenly flags an invalid event as valid

True Positives.

- when an IDS correctly identifies an invalid event

True Negatives.

- when an IDS correctly identifies a valid event

Base Rates and FPR/FNR Trade-Off.

- base rates
  - if the base rate of incidents is low, very low FPR might produce a lot of false positive in practice
  - people tend to ignore this when thinking about FPR and FNR -> it's a logical fallacy
  - base rate fallacy -> ignore base rate when calculating conditional probabilities
- trade-off between FPR and FNR
  - hard to get both low FPR and FNR
  - IDS systems generally have to make compromised based on use case and desired level of cautiousness

22.4 Methodologies: Anomalies vs Signatures vs Specifications

Blacklisting vs Whitelisting.

- blacklisting
  - specifying disallowed behavior and flagging matches
- whitelisting
  - specifying allowed behavior and flagging mismatches

Anomaly Detection.

- learned profiles used to generate white lists
- alarm when an event deviates from normal

Signatures.

- expert-defined blacklist

- alarm when behavior matches blacklist

Specifications.

- expert-defined whitelist
- alarm when behavior does not match whitelist

22.5 Sniffers, Reconnaissance Scanners, Vulnerability Scanners

- these all have both white-hat and black-hat uses

Sniffers.

- tools need to process packets at line speed (to avoid slowdowns or self-inflicted DoS)
- monitor network traffic (even passively)
  - look at things like headers
  - for unencrypted traffic, we can even look at contents
- attackers can use these tools too
  - this is a motivation for encrypted traffic

Hubs vs Switches.

- hubs broadcast to all neighbors
- switches selectively forward

Reconnaissance Scanners.

- common precursor to an attack
- also useful for sysadmins to map their own network and get an idea of what is going on
  - network introspection/visibility
- send probe connection requests to look for open ports and running services
- port can be
  - open (daemon waiting)
  - closed (no service offered)
  - blocked (denied by access control)
- OS fingerprinting
  - port scanners can identify an OS with high confidence

Vulnerability Scanners.

- scan a system for known vulnerabilities
- produces a comprehensive report
- does so using benign payloads (unlike penetration testing)
- limitations/cautions?
  - responsible release of exploit modules -> attackers already have, so legitimate parties might as well
  - credentialed scans can produce far more detailed results (but be careful)