Computer Security

08. Authentication

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Authentication

- Identification: who are you?
- Authentication: prove it
- Authorization: you can do it

Some protocols (or services) combine all three

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Cryptographic Authentication

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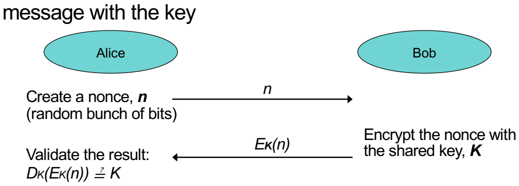
Basic concept: prove you have the key

Ask the other side to prove they can encrypt or decrypt a message with the key



This assumes a **pre-shared key** and symmetric cryptography.
After that, Alice can encrypt & send a **session key**.
Minimize the use of the pre-shared key.

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Mutual authentication

- Alice had Bob prove he has the key
- Bob may want to validate Alice as well
- Bob will do the same thing
  - Have Alice prove she has the key
    - Pre-shared key: Alice encrypts the nonce with the key
    - Public key: Alice encrypts the nonce with her private key

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Combined authentication & key exchange

Basic idea with symmetric cryptography:

Use a trusted third party (Trent) that has all the keys

- Alice wants to talk to Bob: she asks Trent
  - Trent generates a session key encrypted for Alice
  - Trent encrypts the same key for Bob (ticket)
- Authentication is implicit:
  - If Alice can decrypt the session key, she proved she knows her key
  - If Alice can decrypt the session key, he proved he knows his key
- Weaknesses that we need address fix:
  - Replay attacks – add nonces – Needham-Schroeder protocol
  - Replay attacks re-using a cracked old session key
    - Add timestamps: Denning-Sacco protocol, Kerberos
    - Add session IDs at each step: Otway-Rees protocol

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Key exchange algorithms

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Security Protocol Notation

$Z \| W$
- Z concatenated with W

$X \rightarrow Y : \{ Z \| W \} k_{A,B}$
- X sends a message to Y
- The message is the concatenation of Z & W and is encrypted by key $k_{A,B}$, which is shared by users A & B

$X \rightarrow Y : \{ Z \} k_A \; \| \; \{ W \} k_{A,Y}$
- X sends a message to Y
- The message is a concatenation of Z encrypted using A's key and W encrypted by a key shared by A and Y

r_1, r_2
- nonces – strings of random bits

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Bootstrap problem

- How to Alice & Bob communicate securely?
- Alice cannot send a key to Bob in the clear
  - We assume an unsecure network
- We looked at two mechanisms:
  - Diffie-Hellman key exchange
  - Public key cryptography
- Let's examine the problem some more

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Simple Protocol

Use a trusted third party – Trent – who has all the keys

Trent transmits a session key to Alice and Bob

Alice → Trent: { Request session key to Bob } k_A

Alice ← Trent: { ks } k_A || { ks } k_B

Alice → Bob: { ks } k_B

Alice ↔ Bob: { m } ks

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Problems

- How does Bob know he is talking to Alice?
  - Trusted third party, Trent, has all the keys
  - Trent knows the request came from Alice since only he and Alice can have the key
  - Trent can authorize Alice's request
  - Bob gets a message (session key) encrypted with his key, which only Trent could have created
    - But Bob doesn't know who requested the session
    - Trent would have to add sender information to the message
- Vulnerable to replay attacks
  - Eve records the message from Alice to Bob and later replays it
  - Bob might think he's talking to Alice, reusing the same session key
- Protocols should provide authentication & defend against replay

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Needham-Schroeder

Add *nonces* – random strings – avoid replay attacks

① Alice → Trent: { Alice || Bob || r_1 }

② Alice ← Trent: { Alice || Bob || r_1 || ks || { Alice || ks } k_B } k_A

③ Alice → Bob: { Alice || ks } k_B

④ Alice ← Bob: { r_2 } ks

⑤ Alice → Bob: { $r_2 - 1$ } ks

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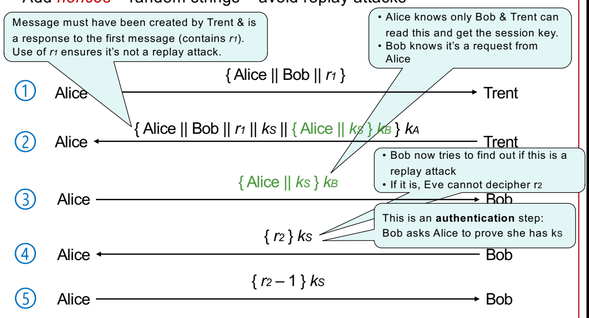
Needham-Shroeder

Add *nonces* – random strings – avoid replay attacks



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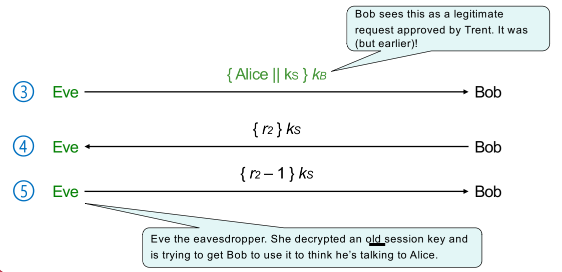
Needham-Schroeder Protocol Vulnerability

Needham-Schroeder is still vulnerable to a certain replay attack … if an old session key is known!

- We assume all keys are secret
- But suppose Eve can obtain the session key from an old message (she worked hard, got lucky, and cracked an earlier message)



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Denning-Sacco Solution

- Problem: replay in the third step of the protocol
  - Eve replays the message: { Alice || k_S } k_B
- Solution: use a time stamp *T* to detect replay attacks
  - The trusted third party (Trent) places a timestamp in a message that is encrypted for Bob
  - The attacker has an old session key but not Alice's, Bob's or Trent's keys
  - Cannot spoof a valid message that is encrypted for Bob.

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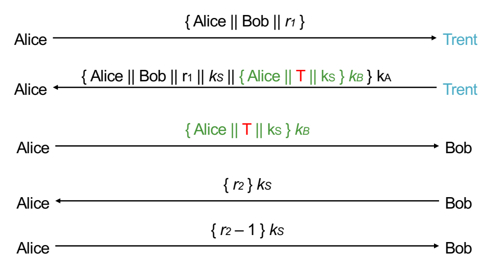
Needham-Shroeder w/Denning-Sacco mods

Add nonces – random strings – AND a timestamp



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Problem with timestamps

- Use of timestamps relies on synchronized clocks
  - Messages may be falsely accepted or falsely rejected because of bad time
- Time synchronization becomes an attack vector
  - Create fake NTP responses
  - Generate fake GPS signals

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Otway-Rees Protocol: Session IDs

- Another way to correct the *third message replay* problem
- Instead of using timestamps
  - Use a random integer, *n*, that is associated with all messages in the key exchange
- The protocol is altered slightly
  - Alice first sends a message to Bob
    - The message contains the session ID & nonce encrypted with Alice's secret key
  - Bob forwards the message to Trent
    - And creates a message containing a nonce & the same session ID encrypted with Bob's secret key
  - Trent creates a session key & encrypts it for both Alice and for Bob

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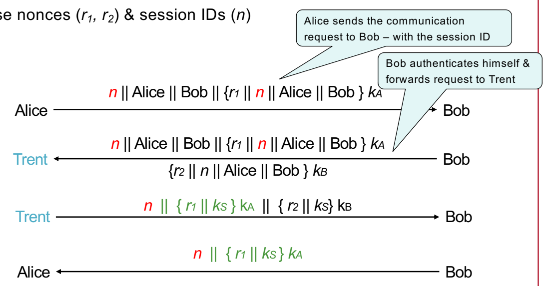
Otway-Rees Protocol

Use nonces (r_1, r_2) & session IDs (n)



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Kerberos

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Kerberos

- Authentication service developed by MIT
  - project Athena 1983-1988
- Uses a trusted third party & symmetric cryptography
- Based on Needham Schroeder with the Denning Sacco modification
- Passwords not sent in clear text
  - assumes only the network can be compromised

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Kerberos

Users and services authenticate themselves to each other

To access a service:
- user presents a ticket issued by the Kerberos authentication server
- service examines the ticket to verify the identity of the user

Kerberos is a trusted third party
- Knows all (users and services) passwords
- Responsible for
  - Authentication: validating an identity
  - Authorization: deciding whether someone can access a service
  - Key exchange: giving both parties an encryption key (securely)

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Kerberos

- User *Alice* wants to communicate with a service *Bob*
- Both Alice and Bob have keys
- Step 1:
  - Alice authenticates with Kerberos server
    - Gets *session key* and *ticket* (*sealed envelope*)
- Step 2:
  - Alice gives Bob the ticket, which contains the session key
  - Convinces Bob that she got the session key from Kerberos

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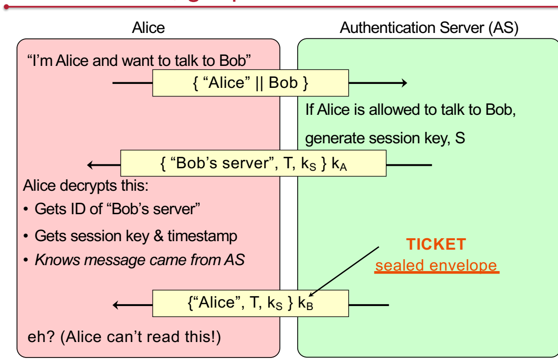
Authenticate, get permission



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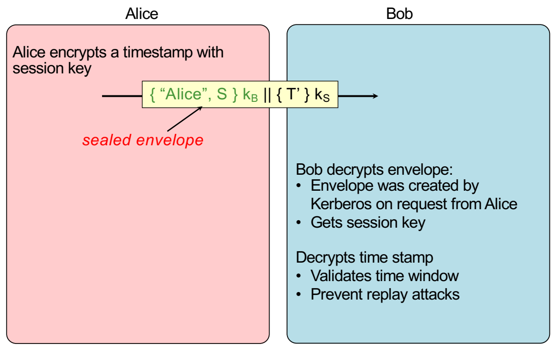
Send key



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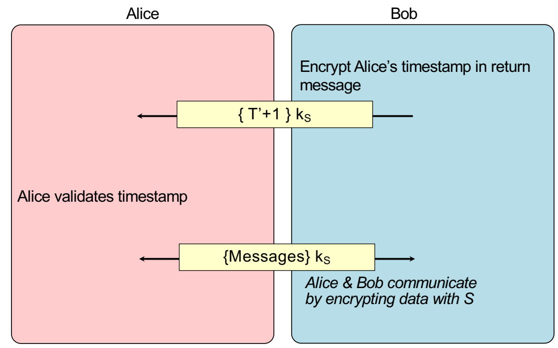
Authenticate recipient of message



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Kerberos key usage

- Every time a user wants to access a service
  - User's password (key) must be used to decode the message from Kerberos
- We can avoid this by caching the password in a file
  - Not a good idea
- Another way: create a temporary password
  - We can cache this temporary password
  - Similar to a session key for Kerberos – to get access to other services
  - Split Kerberos server into
    Authentication Server + Ticket Granting Server

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Ticket Granting Server (TGS)

- TGS works like a temporary ID
- User first requests access to the TGS
  - Contact Kerberos Authentication Server
    - Knows all users & their secret keys
    - User enters a password to do this
    - Gets back a ticket & session key to the TGS – these can be cached
- To access any service
  - Send a request to the TGS – encrypted with the TGS session key along with the ticket for the TGS
  - The ticket tells the TGS what your session key is
  - It responds with a session key & ticket for that service

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Using Kerberos

`$ kinit`

`Password:` *enter password*

ask AS for permission (session key) to access TGS

Alice gets:

{"TGS", S } k_A	← *Session key*
{"Alice", S } k_{TGS}	← *TGS Ticket*
{ T } k_S	← *Encrypted timestamp*

Compute key (A) from password to decrypt session key S and get TGS ID.

You now have a ticket to access the Ticket Granting Service

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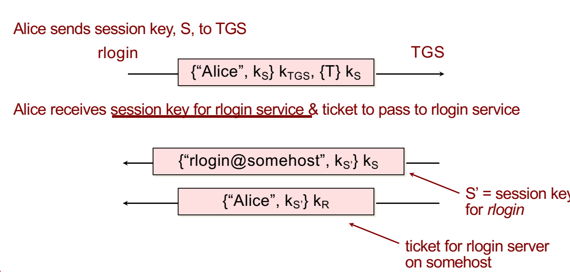
Using Kerberos

`$ rlogin` ***`somehost`***

rlogin uses the TGS Ticket to request a ticket for the *rlogin* service on *somehost*



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Public Key Exchange

We did this

- Alice's & Bob's public keys known to all: e_A, e_B
- Alice & Bob's private keys are known only to the owner: d_a, d_b
- Simple protocol to send symmetric session key: k_S

Alice —— $\{ k_S \} e_B$ ——→ Bob

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Problem

- Vulnerable to forgery or replay
- Public keys are known to anyone
  - Bob has no assurance that Alice sent the message
- Fix: have Alice sign the session key

Alice —— $\{ \{ k_S \} d_a \} e_B$ ——→ Bob

Key k_S encrypted with Alice's private key
Entire message encrypted with Alice's public key

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Problem #2

- How do we know we have the right public keys?
- Send a certificate so Bob can verify it

Alice —— $\{ \{ k_S \} d_a \} e_B$, X ——→ Bob

Add Alice's certificate, which contains Alice's verifiable public key

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Combined authentication & key exchange

- Basic idea with symmetric cryptography:
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      - Add session IDs at each step (Otway-Rees Protocol)

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Cryptographic toolbox

- Symmetric encryption
- Public key encryption
- Hash functions
- Random number generators

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User Authentication

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Authentication

Three factors:

- **Ownership**: something you have
  - *Key, card*
  - Can be stolen
- **Knowledge**: something you know
  - *Passwords, PINs*
  - Can be guessed, shared, stolen
- **Inherence**: something you are
  - *Biometrics*
  - Usually needs hardware, can be copied (sometimes)
  - Once copied, you're stuck

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Multi-Factor Authentication

Factors may be combined

- ATM machine: 2-factor authentication (2FA)
  - ATM card — something you have
  - PIN — something you know
- Password + code delivered via SMS: 2-factor authentication
  - Password — something you know
  - Code — validates that you possess your phone

Two passwords ≠ Two-factor authentication

The factors must be different

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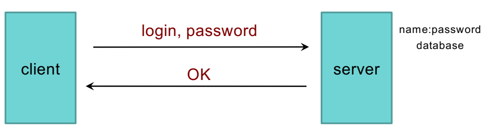
Authentication: PAP

Password Authentication Protocol



- Unencrypted, reusable passwords
- Insecure on an open network
- Also, the password file must be protected from open access
  - But administrators can still see everyone's passwords
    What if you use the same password on Facebook as on Amazon?

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Passwords are bad

- Human readable & easy to guess
  - People usually pick really bad passwords
- Easy to forget
- Usually short
- Static ... reused over & over
  - Security is as strong as the weakest link
  - If a user name (or email) & password is stolen from one server, it might be usable on others
- Replayable
  - If someone can grab it or see it, they can play it back

Recent large-scale leaks of password from servers have shown that people DO NOT pick good passwords

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Common Passwords

Adobe security breach (November 2013)

- 152 million Adobe customer records … with encrypted passwords
- Adobe encrypted passwords with a symmetric key algorithm
- … and used the same key to encrypt every password!

Top 26 Adobe Passwords

	Frequency	Password		Frequency	Password
1	1,911,938	123456	14	61,453	1234
2	446,162	123456789	15	56,744	adobe1
3	345,834	password	16	54,651	macromedia
4	211,659	adobe123	17	48,850	azerty
5	201,580	12345678	18	47,142	iloveyou
6	130,832	qwerty	19	44,281	aaaaaa
7	124,253	1234567	20	43,670	654321
8	113,884	111111	21	43,497	12345
9	83,411	photoshop	22	37,407	666666
10	82,694	123123	23	35,325	sunshine
11	76,910	1234567890	24	34,963	123321
12	76,186	000000	25	33,452	letmein
13	70,791	abc123	26	32,549	monkey

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It's not getting better

Leaks have not convinced people to use good passwords

Rank	2012	2013	2014	2015	2016	2017	2018
1	password	123456	123456	123456	123456	123456	123456
2	123456	password	password	password	password	password	password
3	12345678	12345678	12345	12345678	12345	12345678	123456789
4	abc123	qwerty	12345678	qwerty	12345678	qwerty	12345678
5	qwerty	abc123	qwerty	12345	football	12345	12345
6	monkey	123456789	123456789	123456789	qwerty	123456789	111111
7	letmein	111111	1234	football	1234567890	letmein	1234567
8	dragon	1234567	baseball	1234	1234567	1234567	sunshine

Past seven years of top passwords from SplashData's list

https://en.wikipedia.org/wiki/List_of_the_most_common_passwords

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Policies to the rescue?

- Password rules
  "Everyone knows that an exclamation point is a 1, or an I, or the last character of a password. $ is an S or a 5. If we use these well-known tricks, we aren't fooling any adversary. We are simply fooling the database that stores passwords into thinking the user did something good"
  — Paul Grassi, NIST
- Periodic password change requirements
  - People tend to change passwords rapidly to exhaust the history list and get back to their favorite password
  - Forbidding changes for several days enables a denial of service attack
  - People pick worse passwords, incorporating numbers, months, or years


Here are the guidelines for creating a new password:
Your new password must contain at least 2 of the 3 following criteria:
- At least 1 letter (uppercase or lowercase)
- At least 1 number
- At least 1 of these special characters: ! # $ % + / = @ ~

Also:
- It must be different than your previous 5 passwords.
- It can't match your username.
- It can't include more than 2 identical characters (for example: 111 or aaa).
- It can't include more than 2 consecutive characters (for example: 123 or abc).
- It can't use the name of the financial institution (for example: JPMC, Morgan or Chase).
- It can't be a commonly used password (for example: password1).

Cancel Next

https://fortune.com/2017/05/11/password-rules/
https://pages.nist.gov/800-63-3/sp800-63b.html#sec5

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NIST recommendations

- Remove periodic password change requirements
- Drop complexity requirements (numbers, letters, symbols)
- Choose long passwords
- Avoid
  - Passwords obtained from databases of previous breaches
  - Dictionary words
  - Repetitive or sequential characters (e.g. 'aaaaa', '1234abcd')
  - Context-specific words, such as the name of the service, the username, and derivatives thereof

https://pages.nist.gov/800-63-3/sp800-63b.html

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PAP: Reusable passwords

Problem #1: Open access to the password file

What if the password file isn't sufficiently protected and an intruder gets hold of it? All passwords are now compromised!

Even if a trusted admin sees your password, this might also be your password on other systems.

How about encrypting the passwords?

- Where would you store the key?
- Adobe did that
  - 2013 Adobe security breach leaked 152 million Adobe customer records
  - Adobe used encrypted passwords
    - But the **passwords were all encrypted with the same key**
    - If the attackers steal the key, they get the passwords

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PAP: Reusable passwords

Solution:

Store a hash of the password in a file
- Given a file, you don't get the passwords
- Have to resort to a dictionary or brute-force attack
- Example, passwords hashed with SHA-512 hashes (SHA-2)

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What is a dictionary attack?

- **Suppose you got access to a list of hashed passwords**
- **Brute-force, exhaustive search: try every combination**
  - Letters (A-Z, a-z), numbers (0-9), symbols (!@#$%...)
  - Assume 30 symbols + 52 letters + 10 digits = 92 characters
  - Test all passwords up to length 8
  - Combinations = $92^8 + 92^7 + 92^6 + 92^5 + 92^4 + 92^3 + 92^2 + 92^1 = 5.189 \times 10^{15}$
  - If we test 1 billion passwords per second: ≈ 60 days
- **But some passwords are more likely than others**
  - 1,991,938 Adobe customers used a password = "123456"
  - 345,834 users used a password = "password"
- **Dictionary attack**
  - Test lists of common passwords, dictionary words, names
  - Add common substitutions, prefixes, and suffixes

Easiest to do if the attacker steals a hashed password file – so we read-protect the hashed passwords to make it harder to get them

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How to speed up a dictionary attack

Create a table of precomputed hashes

Now we just search a table for the hash to find the password

SHA-256 Hash	password
8d969eef6ecad3c29a3a629280e686cf0c3f5d5a86aff3ca12020c923adc6c92	123456
5e884898da28047151d0e56f8dc6292773603d0d6aabbdd62a11ef721d1542d8	password
ef797c8118f02dfb649607dd5d3f8c7623048c9c063d532cc95c5ed7a898a64f	12345678
1c8bfe8f801d79745c4631d09fff36c82aa37fc4cce4fc946683d7b336b63032	letmein
…	…

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Salt: defeating dictionary attacks

Salt = random string (typically up to 16 characters)

- Concatenated with the password
- Stored with the password file (it's not secret)

"am$7b22QL" + "password"

- Even if you know the salt, you cannot use precomputed hashes to search for a password
  (because the salt is prefixed to the password string)

  Example: SHA-256 hash of "password", salt = "am$7b22QL"= *hash*("am$7b22QLpassword")=
  7a87d1d5118873b1c16d30176936e1920f33b91d8be1517d5cc295dfd0268906

  You will ***not*** *have a precomputed hash("am$7b22QLpassword")*

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Longer passwords

- English text has an entropy of about 1.2-1.5 bits per character
- Random text has an entropy ≈ $\log_2(1/95)$ ≈ 6.6 bits/character

Assume 95 printable characters

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Defenses

- Use longer passwords
  - But can you trust users to pick ones with enough entropy?
- Rate-limit guesses
  - Add timeouts after an incorrect password
    - Linux waits about 3 secs – and terminates the *login* program after 5 tries
- Lock out the account after *N* bad guesses
  - But this makes you vulnerable to denial-of-service attacks
- Use a slow algorithm to make guessing slow

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People forget passwords

- Especially seldom-used ones
- How do we handle that?
- Email them?
  - Common solution
  - Requires that the server be able to get the password (can't store a hash)
  - What if someone reads your email?
- Reset them?
  - How do you authenticate the requester?
  - Usually send reset link to email address created at registration
  - But – what if someone reads your mail? …or you no longer have that address?
- Provide hints?
- Write them down?
  - OK if the threat model is electronic only

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Reusable passwords in multiple places

- People often use the same password in different places
- If one site is compromised, the password can be used elsewhere
  - People often try to use the same email address and/or user name
- This is the root of phishing attacks
- Password managers
  - Software that stores passwords in an encrypted file
  - Do you trust the protection? The synchronization capabilities?
  - Can malware get to the database?
  - In general, these are good
    - Way better than storing passwords in a file
    - Encourages having unique passwords per site
    - Password managers may have the ability to recognize web sites & defend against phishing

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PAP: Reusable passwords

Problem #2: Network sniffing or shoulder surfing

Passwords can be stolen by observing a user's session in person or over a network:

- Snoop on telnet, ftp, rlogin, rsh sessions
- Trojan horse
- Social engineering
- Key logger, camera, physical proximity
- Brute-force or dictionary attacks

Solutions:

(1) Use an encrypted communication channel

(2) Use one-time passwords

(3) Use multi-factor authentication, so a password alone is not sufficient

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One-time passwords

Use a different password each time

- If an intruder captures the transaction, it won't work next time

Three forms

1. Sequence-based: password = *f*(previous password)
2. Time-based: password = *f*(time, secret)
3. Challenge-based: *f*(challenge, secret)

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S/key authentication

- One-time password scheme
- Produces a limited number of authentication sessions
- Relies on one-way functions

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S/key authentication

Authenticate Alice for 100 logins

- pick random number, R
- using a one-way function, *f*(x):

$x_1 = f(R)$
$x_2 = f(x_1) = f(f(R))$
$x_3 = f(x_2) = f(f(f(R)))$
… …
$x_{100} = f(x_{99}) = f(\ldots f(f(R)))\ldots)$

Give this list to Alice

- then compute:
  $x_{101} = f(x_{100}) = f(\ldots f(f(R)))\ldots)$

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S/key authentication

Authenticate Alice for 100 logins

Store $\mathbf{x_{101}}$ in a password file or database record associated with Alice

alice: x_{101}

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S/key authentication

Alice presents the *last* number on her list:

Alice to host: { "alice", x_{100} }

Host computes f(x_{100}) and compares it with the value in the database

```
if (x100 provided by alice) = passwd("alice")
    replace x101 in db with x100 provided by alice
    return success
else
    fail
```

next time: Alice presents x_{99}

If someone sees x_{100} there is no way to generate x_{99}.

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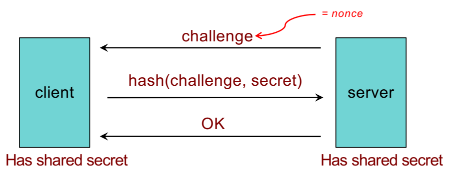
Authentication: CHAP

Challenge-Handshake Authentication Protocol



The challenge is a *nonce* (random bits).

We create a hash of the nonce and the secret.

An intruder does not have the secret and cannot do this!

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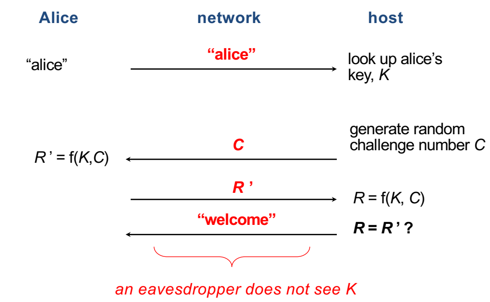
CHAP authentication



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SMS/Email Authentication

- Second factor = your possession of a phone (or computer)
- After login, sever sends you a code via SMS (or email)
- Entering it is proof that you could receive the message
- Dangers
  - SIM swapping attacks (social engineering on the phone company)
    - Viable for high-value targets
  - Social engineering to get email credentials

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Time-Based Authentication

Time-based One-time Password (TOTP) algorithm

- Both sides share a secret key
  - Sometimes sent via a QR code so the user can scan it into the TOTP app
- User runs TOTP function to generate a one-time password

  one_time_password = *hash*(secret_key, time)

- User logs in with:
  - *Name*, *password*, and *one_time_password*
- Service generates the same password

  one_time_password = *hash*(secret_key, time)

- Typically 30-second granularity for time

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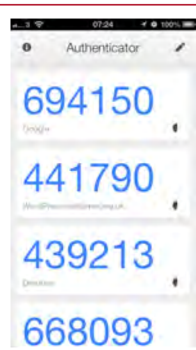
Time-based One-time Passwords

Used by

- Microsoft Two-step Verification
- Google Authenticator
- Facebook Code Generator
- Amazon Web Services
- Bitbucket
- Dropbox
- Evernote
- Zoho
- Wordpress
- 1Password
- Many others…



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RSA SecurID card

Username: paul

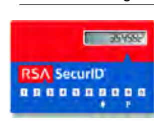
Password: 1234032848

PIN + passcode from card

Something you know

Something you have

Passcode changes every 60 seconds



1. Enter PIN
2. Press ◊
3. Card computes password
4. Read password & enter

Password: 354982

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SecurID card

Same principle as Time-based One-Time Passwords

- Proprietary device from RSA
  - SASL mechanism: RFC 2808
- Two-factor authentication based on:
  - **Shared secret key** (seed) ⇐ Something you have
    - stored on authentication card
  - **Shared personal ID** – PIN ⇐ Something you know
    - known by user

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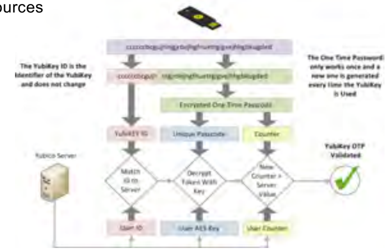
Yubikey: Yubico One Time Password

HOTP = Hash-based One-Time Password

OTP = *f*(hardware_id, passcode, counter)

Passcode generated on the device from session counters, previous values, other sources



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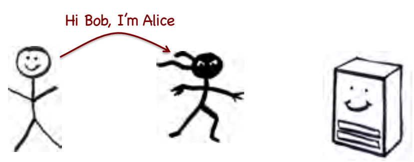
Man-in-the-Middle Attacks

Password systems are vulnerable to man-in-the-middle attacks
– Attacker acts as the server



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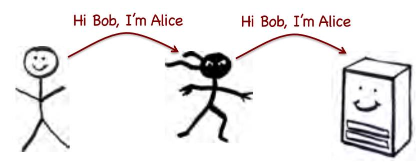

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Man-in-the-Middle Attacks

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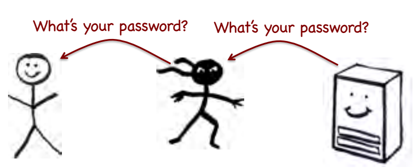

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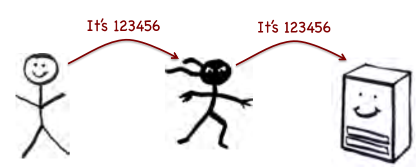

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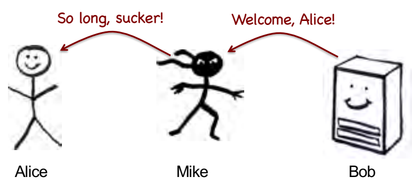

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Man-in-the-Middle Attacks

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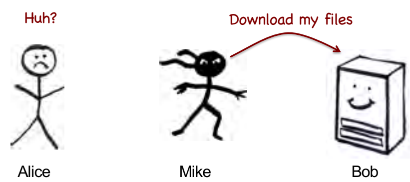

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Guarding against man-in-the-middle attacks

- Use a covert communication channel
  - The intruder won't have the key
  - Can't see the contents of any messages
  - But you can't send the key over that channel!
- Use signed messages for all communication
  - Signed message = { message, encrypted hash of message }
  - Both parties can reject unauthenticated messages
  - The intruder cannot modify the messages
    - Signatures will fail (they will need to know how to encrypt the hash)
- But watch out for replay attacks!
  - May need to use session numbers or timestamps

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The End

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