Passwords

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Review: Authentication of humans

Categories: [IBM, TR G520-2169, 1970]

• **Something you know**
  
  password, passphrase, PIN, answers to security questions

• **Something you have**
  
  physical key, ticket, {ATM, prox, credit} card, token

• **Something you are**
  
  fingerprint, retinal scan, hand silhouette, a pulse
Password lifecycle

1. **Create:** user chooses password
2. **Store:** system stores password with user identifier
3. **Use:** user supplies password to authenticate
4. **Change/recover/reset:** user wants or needs to change password
4. PASSWORD CHANGE
Password change

Motivated by...

• **User** forgets password (maybe just *recover* password)

• **System** forces password expiration
  – Naively seems wise
  – Research suggests otherwise:
    • When users do change passwords, they change them predictably
    • Foreknowledge of expiration causes users to choose weaker passwords
Digression: Password research

Where to get password corpus for research?

• Pay users to participate in experiments
  – Validity? low-stakes passwords might be different than high-stakes

• Use cracked password databases posted by attackers

• Participate with IT departments to run approved code against plaintext passwords
Password change

Motivated by...

- **Administrator** forces password change
  - Perhaps intrusion or weak password detected

- **Attacker** learns password:
  - **Social engineering**: deceitful techniques to manipulate a person into disclosing information
  - **Online guessing**: attacker uses authentication interface to guess passwords
  - **Offline guessing**: attacker acquires password database for system and attempts to *crack* it
Change mechanisms

• Tend to be *more vulnerable* than the rest of the authentication system
  – Not designed or tested as well
  – Have to solve the authentication problem without the benefit of a password

• Common mechanisms...
Security questions

• Something you know: attributes of identity established at enrollment

• **Pro:** you are unlikely to forget answers

• **Assumes:** attacker is unlikely to be able to answer questions

• **Con:** might not resist targeted attacks

• **Con:** linking is a problem; same answers re-used in many systems
Emailed password

• Might be your old password or a new temporary password
  – **one-time password**: valid for single use only, maybe limited duration
• Something you know: emailed password
• **Assumes**: attacker is unlikely to have compromised your email account
• **Assumes**: email service correctly authenticates you
• Something you ?: however you authenticated to email
3. PASSWORD USAGE
When authentication fails

- **Guiding principle:** the system might be under attack, so don't make the attacker's job any easier
- Don't leak valid usernames:
  - Prompt for username and password in parallel
  - Don't reveal which was bad
- Rate limit, and eventually disable
- Record failed attempts and review
  - Perhaps in automated way (A4)
  - Perhaps manually by user at next successful login
Mutual authentication

• Before entering their password, the user ought to be authenticating the system itself: mutual authentication

• Some mechanisms:
  – **Secure attention key:** key (or key sequence) that OS itself detects and handles
    • e.g., Ctrl+Alt+Del in Windows
    • Defends against login spoofing
    • Provides a trusted path
  
  – **Visual secrets:** user and system share a secret image
    • User enters username; system retrieves and displays image
    • User authenticates image before entering password
    • Makes phishing attacks harder but not impossible: if users can't or won't discern who is on the other side, man-in-the-middle attack will succeed anyway
2. PASSWORD STORAGE
Storage by humans

• To keep identities **independent**, humans should have separate password for every identity
• But humans have little memory capacity
• So we...
  – **reuse** passwords across systems
  – **record** passwords either physically or digitally
  – both introduce vulnerabilities
Storage by machines

- Passwords typically stored in a file or database indexed by username
- **Strawman idea:** store passwords in plaintext
  - requires perfect authorization mechanisms
  - requires trusted system administrators
  - ...
- In the real world, password files get stolen
Storage by machines

- **Want:** a function $f$ such that...
  1. easy to compute and store $f(p)$ for a password $p$
  2. hard given disclosed $f(p)$ for attacker to recover $p$
  3. easy to check at time of authentication given a password $q$ and stored password $f(p)$ whether $q=p$

- **Cryptographic hash functions suffice!**
  - one-way property gives (1) and (2)
  - collision resistance gives (3)

- So would encryption, but then the key has to live somewhere
Hashed passwords

- Each user has:
  - username uid
  - password p
- System stores: uid, H(p)
- Assume: human Hu authenticating to a local machine L over trusted secure channel (e.g., keyboard)

To authenticate Hu to L:
1. Hu→L: uid, p
2. L: let h = stored hashed password for uid;
   if h = H(p)
   then uid is authenticated
Hashed passwords

To authenticate Hu to remote server S using local machine L:

1. Hu→L: uid, p
2. L and S: establish secure channel
3. L→S: uid, p
4. S: let h = stored hashed password for uid;
   if h = H(p)
   then uid is authenticated
**Dictionary attacks**

**Assume:** attacker does learn password file (offline guessing attack)

- Hard to invert: i.e., given $H(p)$ to compute $p$
- But what if attacker didn't care about inverting hash on arbitrary inputs?
  - i.e., only have to succeed on a small set of $p$'s: $p_1$, $p_2$, ..., $p_n$
- Then attacker could build a dictionary...
Dictionary attacks

**Dictionary:**
- p1, H(p1)
- p2, H(p2)
- ...
- pn, H(pn)

- **Dictionary attack:** lookup H(p) in dictionary to find p
- And *it works* because most passwords chosen by humans are from a (relatively) small set
Typical passwords

[Schneier quoting AccessData in 2007]:

- 7-9 character root plus a 1-3 character appendage
  - Root typically pronounceable, though not necessarily a real word
  - Appendage is a suffix (90%) or prefix (10%)
- Dictionary of 1000 roots plus 100 suffixes (= 100k passwords) cracks about 24% of all passwords
- More sophisticated dictionaries crack about 60% of passwords within 2-4 weeks
- Given biographical data (zip code, names, etc.) and other passwords of a user...
  - success rate goes up a little
  - time goes down to days or hours
- For comparison: a scan of every printable character string on your hard drive breaks >50% of passwords

...defense against offline guessing?
Defense 1: slow down

- **Vulnerability:** hashes are easy to compute
- **Countermeasure:** hash functions that are slow to compute
  - Slow hash wouldn't bother user: delay in logging hardly noticeable
  - But would bother attacker constructing dictionary: delay multiplied by number of entries
  - Ideally, enough to make constructing a large dictionary prohibitively expensive
- **Examples:** crypt, bcrypt, scrypt, PBKDF2, Argon2, ...
Slowdown by iterated hashing

- Given a fast hash function...
- Slow it down by iterating it many times:

\[
\begin{align*}
z_1 &= H(p) \\
z_2 &= H(p, z_1) \\
&\vdots \\
z_{1000} &= H(p, z_{999}) \\
\text{output } z_1 \text{ XOR } z_2 \text{ XOR } \ldots \text{ XOR } z_{1000}
\end{align*}
\]

- Number of iterations is a parameter to control slowdown
  - originally thousands
  - current thinking is 10s of thousands
- Aka key stretching
Defense 2: add salt

- **Vulnerability:** one dictionary suffices to attack every user
- **Vulnerability:** passwords chosen from small space
- **Countermeasure:** include a unique system-chosen nonce as part of each user's password
  - make every user's stored hashed password different, even if they chose the same password
  - make passwords effectively be from larger space
Salted hashed passwords

• Each user has:
  – username uid
  – unique salt s
  – password p
• System stores: uid, s, H(s, p)

To authenticate Hu to L:
1. Hu->L: uid, p
2. L: let h = stored hashed password for uid;
   let s = stored salt for uid;
   if h = H(s, p)
   then uid is authenticated
Salt

- Salt is as public as username, not as secret as password
- Salt needs to be unique even across systems; easiest way to achieve is to choose randomly
- Length of salt should be related to strength of cryptography employed in rest of system
Salt

To combine with iterated hashing, include salt in first hash:

\[
\begin{align*}
z_1 &= H(p, s); \\
z_2 &= H(p, z_1); \\
&\cdots \\
&\cdots \\
z_{1000} &= H(p, z_{999}); \\
\text{output } &= z_1 \text{ XOR } z_2 \text{ XOR } \cdots \text{ XOR } z_{1000}
\end{align*}
\]

this idea used in widely-deployed algorithm for deriving encryption keys from passwords... (next time)
Upcoming events

• [next Wed] A4 due

Treat your password like your toothbrush. Don't let anybody else use it. – Clifford Stoll