OUTLINE

1. Basis of authentication:
   - what you know, what you possess, what you are.
2. Password-related techniques
3. Attacks on passwords and defense mechanisms
4. Authentication tokens and biometrics

AUTHENTICATION PROTOCOL

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Weak/Simple Authentication:

- Password-based.
- Unilateral: one entity (claimant) proves its identity to the verifier.
- Prove knowledge of secret by giving up the secret

Strong Authentication:

- Involves mutual authentication; both parties take both the roles of claimant and verifier:
- Challenge-response protocols: sequence of steps to prove knowledge of shared secrets.
- Prove knowledge of secret WITHOUT giving up the secret (zero knowledge proofs)

PASSWORD-RELATED TECHNIQUES

- **Password storage:**
  - **Plaintext (BAD)** or **"encrypted" (fair)** or **"hashed" (good).**
- **Password policies:**
  - What rules need to be imposed on the selection of passwords by users, number of failed attempts, etc.
- **"Salting" of passwords.**
- **Alternative forms of passwords**
  - Passphrases, one-time passwords, visual passwords.

Salt is random data that is used as an additional input to a one-way function that "hashes" a password. Salts are used to safeguard passwords in storage. The primary function of salts is to defend against dictionary attacks.

ONE WAY FUNCTIONS

Password storage security relies on a cryptographic construct called ***one-way function***

A one-way function f is a function that is relatively easy to compute but hard to reverse.

- Given an input x it is easy to compute $f(x)$, but given an output y it is hard to find x so that $y = f(x)$

Hash functions are an example of one-way function:

- A hash function f takes an input x of *arbitrary length*, and produces an output $f(x)$ of *fixed length*.

PROPERTIES OF HASH FUNCTIONS

Suppose *H* is a hash function. We say *H* satisfies:

- *Pre-image resistant* if given a hash value y, it is computationally infeasible to find x such that $H(x) = y$.
- *Collision resistant* if it is computationally infeasible to find a pair (x, y) such that $x \neq y$ and $H(x) = H(y)$.

Recap: A one-way function f is a function that is very easy to compute but hard to reverse. Hash function is an example of one-way function. Impt Hash Functions: : **SHA256,512,KECCAK (crypto)** ,ARGON2,bcrypt (for password hashing)

PASSWORD STORAGE

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Plaintext

- Passwords stored in plaintext.
- Claimant's password is checked against the database of passwords.
- No protection against insider (system admin) or an attacker who gains access to the system. Hence dispute is possible!

Hashed/ encrypted passwords

- Passwords are encrypted, or hashed, and only the encrypted/hashed passwords are stored.
- Claimant's password is hashed/encrypted, and checked against the database of hashed/encrypted password.
- Some degree of protection against insider/attacker.

PASSWORD STORAGE

In operating systems, password hashes are stored in a password file.

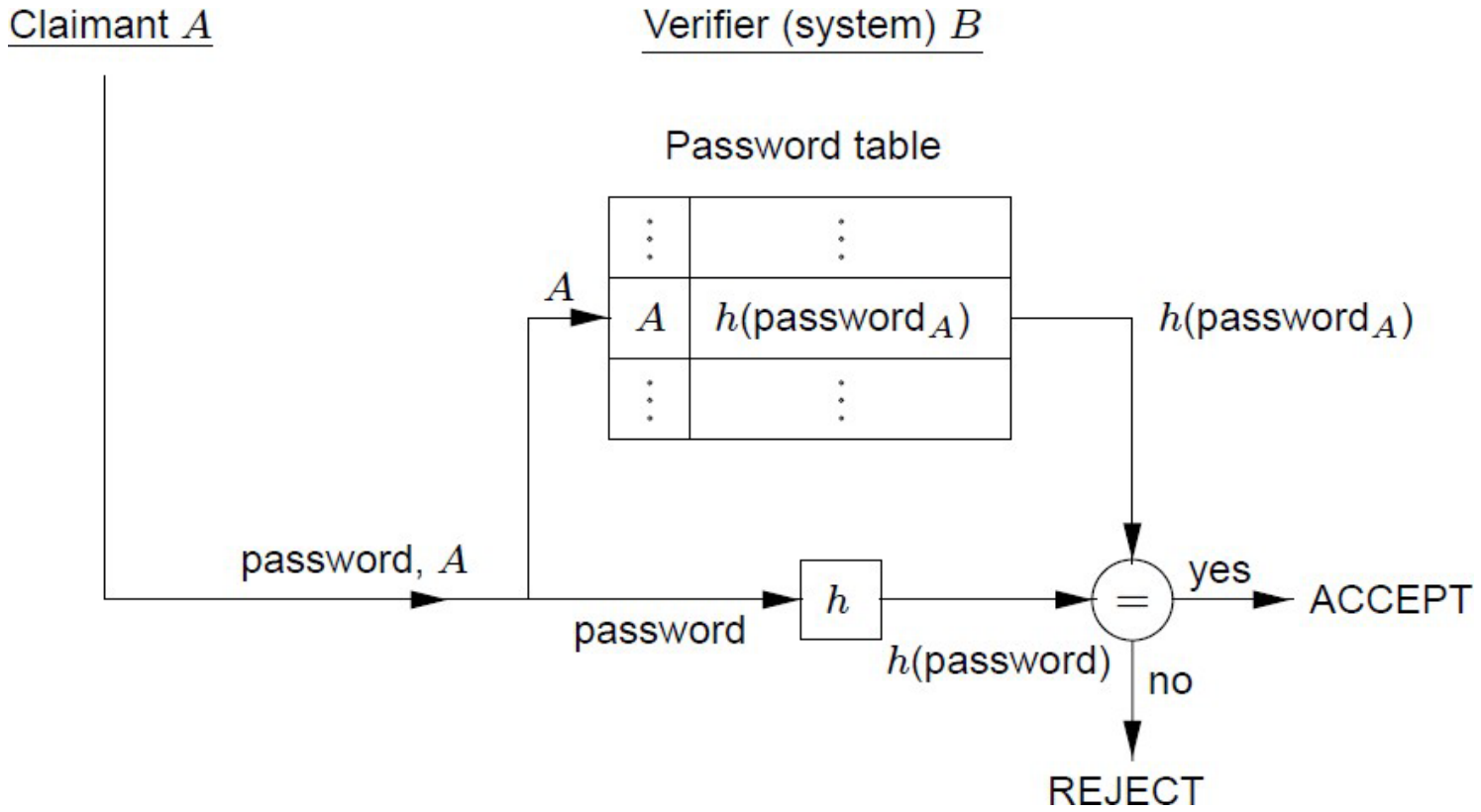
In Windows system, passwords are stored in Security Accounts Manager (SAM) file (**%windir%\system32\config\SAM**).

In Unix, this is **/etc/passwd**, but in modern Unix/Linux systems it is in the *shadow* file in /etc/shadow.

- At the application levels, passwords may be held temporarily in intermediate storage locations like buffers, caches, or a web page (don't save passwords in cache!)
- The management of these storage locations is normally beyond the control of the user; a password may be kept longer than the user has bargained for.

HASHED PASSWORD VERIFICATION

Notice that the verifier **does (should) not** store the passwords, only their hashes



Source: Menezes et al. Handbook of Applied Cryptography.

ATTACK ON PASSWORDS

Offline Guessing Attacks

Exhaustive attacks
Intelligent attacks: Dictionary attacks

“Phishing” and Spoofing

OFFLINE GUESSING ATTACK($)

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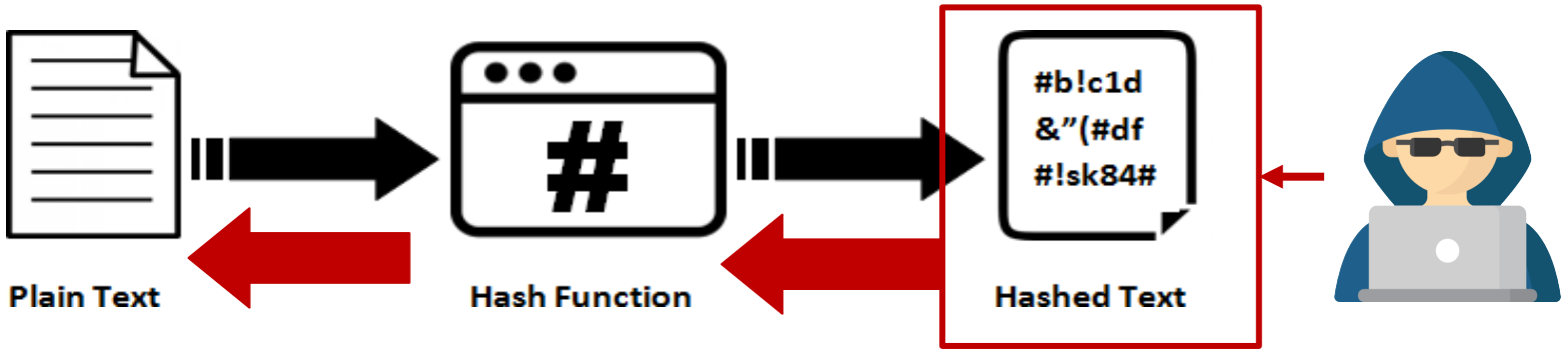
Offline Guessing Attack

An attack where the attacker obtains the hashed passwords, and attempts to guess the passwords.



- This is a plausible threat, due to:
  - many incidents of stolen (hashed) passwords as a consequence of hacks on servers or sniffing traffic
  - usage of the same passwords across different accounts; so compromise of a password for one account affects other accounts.

Recap: In Unix, password hashes are stored in **/etc/passwd**, but in modern Unix/Linux systems it is in the *shadow* file in /etc/shadow.

PASSWORD-RELATED INCIDENTS

SingHealth cyber attack a result of human lapses, IT system weaknesses: COI report

By CYNTHIA CHOO

Reuters file photo

The SingHealth cyber attack happened because of lapses by employees and vulnerabilities with the system.

Published 10 JANUARY, 2019 UPDATED 10 JANUARY, 2019 85 Shares

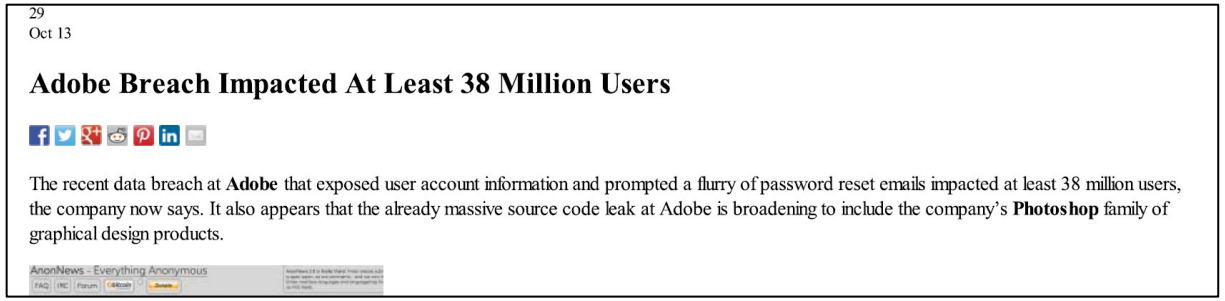
SINGAPORE — The SingHealth cyber attack happened because of lapses by employees and vulnerabilities with the system. Ultimately, the breach into the public healthcare group's database was preventable even though the attacker was skilled.

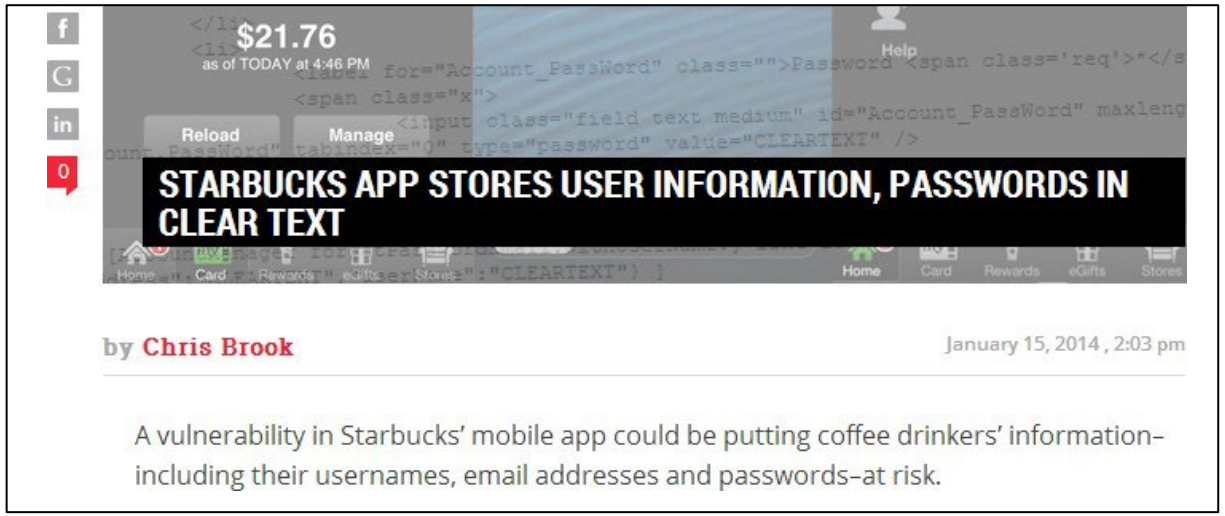
These were the key findings in a report released on Thursday (Jan 10) by

Vulnerabilities and weaknesses in the SingHealth network and SCM system contributed to the attacker's success in obtaining and taking the data

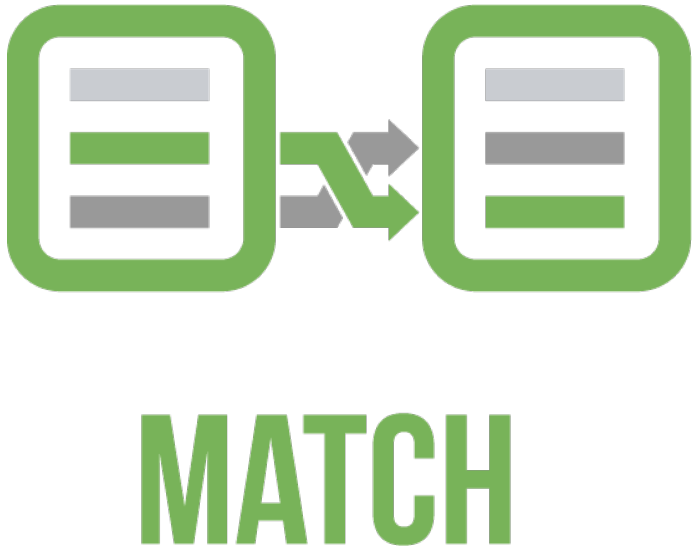
- The SCM database, which is legally owned by SingHealth, functioned on an open network that was linked to the Citrix servers of Singapore General Hospital (SGH), which resulted in a critical vulnerability the attacker exploited.
- It was found that there was a lack of monitoring of the SCM database for unusual queries and access. For one, there was no existing control to detect or block bulk queries being made to the database. For another, the Citrix servers of SGH were not monitored for real-time analysis and alerts of vulnerabilities and issues arising from these servers.
- The Citrix servers were not adequately secured against unauthorised access. Notably, the process requiring 2-factor authentication (2FA) for administrator access was not enforced as the exclusive means of logging in as an administrator. This allowed the attacker to access the server through other routes that did not require 2FA.
- Another weakness which may have been exploited by the attacker included weak administrator account passwords. This was among others discovered during a test but the remediation process undertaken by IHiS was mismanaged and inadequate, and a number of vulnerabilities remained at the time of the cyber attack.

PASSWORD-RELATED INCIDENTS





BRUTE FORCE ATTACK



- Brute force guessing attack against passwords tries to guess password by enumerating all passwords and their hashes in sequence, and check whether they match the target hashes.
- A measure against brute force attack is to increase the space of possible passwords, e.g., longer passwords, allowing more varieties of symbols (alphabets, numerals, signs).

Password policy is an important means to increase difficulties of brute force attack

PASSWORD ENTROPY-measured by 2^k

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$\rightarrow c$ $\downarrow n$	26 (lowercase)	36 (lowercase alphanumeric)	62 (mixed case alphanumeric)	95 (keyboard characters)
5	23.5	25.9	29.8	32.9
6	28.2	31.0	35.7	39.4
7	32.9	36.2	41.7	46.0
8	37.6	41.4	47.6	52.6
9	42.3	46.5	53.6	59.1
10	47.0	51.7	59.5	65.7

Table 10.1: *Bitsize of password space for various character combinations. The number of n-character passwords, given c choices per character, is c^n. The table gives the base-2 logarithm of this number of possible passwords.*

Source: Menezes et al. Handbook of Applied Cryptography.

At present, software password crackers can crack up to 16 million pswd/sec per pc.

Write a program to calculate how long it will take to bruteforce passwords for each entry.

Explanation of Table

- 1st entry corresponds to 5 char lower case passwords.
- How many such passwords around?
- 26^5!
- To find complexity of this password, solve 2^k = 26^5
- Get k = [lg(26^5)]/lg2 = 23.5!

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Now **2^35** complexity can be cracked within **a day** on a 3GHz PC (generous est).

1 FPGA Hardware cracker can crack 56 bits within **5 days** (est).

ASIC crackers can be more than 10 times faster than FPGA.

DICTIONARY ATTACK

- Choosing passwords with high entropy prevents brute-force attack.
- However, hashed passwords, especially for human-generated passwords, are still vulnerable to *dictionary attack*.
- This exploits weakness in human-chosen passwords, which tend to derive from words in natural languages.

Users with same password will have same hash value stored in password file.

- Guess some commonly used passwords
- Compute their hash values
- Look for the same hash values in the password file

PRE-COMPUTED HASH TABLE

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Strategy

A strategy for cracking hashed passwords is to pre-compute a hash table, containing pairs of passwords and their hashes.

- If we have k password candidates and each hash has n bit, then we have a table of size $k \times n$.
- This may not be practical if k is large.

PASSWORD SALTING

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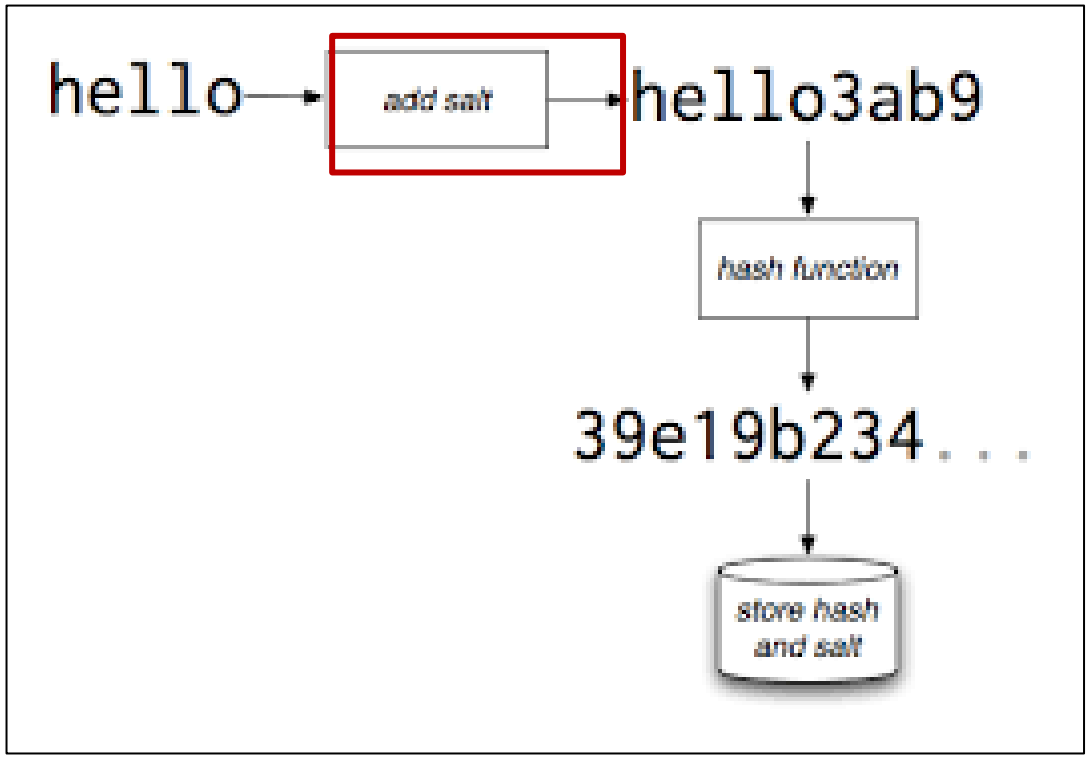
Salting

Illustration



- To reduce the effectiveness of offline attacks using pre-computed hashes, a *salt* is added to a password before applying the hash function.
- A salt is just a random string.
- Each password has its own salt.
- The salt value is stored along with the hash of password+salt.
- For a salt of n-bit, the attacker needs to pre-compute 2^n of hashes for *the same password*.

Password Storage Cheat Sheet

Introduction¶

- It is essential to store passwords in a way that prevents them from being obtained by an attacker even if the application or database is compromised.
- After an attacker has acquired stored password hashes, they are always able to brute force hashes offline.
- As a defender, it is only possible to slow down offline attacks by selecting hash algorithms that are as resource intensive as possible.

Hashing vs Encryption

- Hashing and encryption both provide ways to keep sensitive data safe.
- **Passwords should be hashed, NOT encrypted.**
- **Hashing is a one-way function** (i.e., it is impossible to "decrypt" a hash and obtain the original plaintext value).
- Hashing is appropriate for password validation.
- Even if an attacker obtains the hashed password, they cannot enter it into an application's password field and log in as the victim.
- **Encryption is a two-way function**, meaning that the original plaintext password can be retrieved (if we have the key)

How Attackers Crack (unsalted) Password Hashes

- Although it is not possible to "decrypt" password hashes to obtain the original passwords, it is possible to "crack" the hashes in some circumstances. The basic steps are:
- Select a password you think the victim has chosen (e.g.password1!)
- Calculate the hash
- Compare the hash you calculated to the hash of the victim.
- If they match, you have correctly "cracked" the hash and now know the plaintext value of their password. (stop)

How Attackers Crack Password Hashes

- This process is repeated for a large number of potential candidate passwords.
- Different methods can be used to select candidate passwords, including:
  - Lists of passwords obtained from other compromised sites
  - Brute force (trying every possible candidate)
  - Dictionaries or wordlists of common passwords

How Attackers Crack Password Hashes

- While the number of permutations can be enormous, with high speed hardware (such as GPUs) and cloud services with many servers for rent, the cost to an attacker is relatively small to do successful password cracking especially when best practices for hashing are not followed.
- **Strong passwords stored with modern hashing algorithms and using hashing best practices should be effectively impossible for an attacker to crack.**
- It is your responsibility as an administrator to select a modern hashing algorithm (later)

Password Storage Concepts

- Salting:
- A salt is a unique, randomly generated string that is added to each password as part of the hashing process.
- As the salt is unique for every user, an attacker has to crack hashes one at a time using the respective salt rather than calculating a hash once and comparing it against every stored hash.
- This makes cracking large numbers of hashes significantly harder, as the time required grows in direct proportion to the number of hashes.

Password Storage Concepts

- Salting also protects against an attacker pre-computing hashes using rainbow tables or database-based lookups.
- Finally, salting means that it is impossible to determine whether two users have the same password without cracking the hashes, as the different salts will result in different hashes even if the passwords are the same.
- Modern hashing algorithms such as Argon2id, bcrypt, and PBKDF2 automatically salt the passwords, so no additional steps are required when using them.

Password Hashing Algorithms

- There are a number of modern hashing algorithms that have been specifically designed for securely storing passwords. This means that they should be slow (unlike crypto hashes such as SHA family & KECCAK, which were designed to be fast), and how slow they are can be configured by changing the work factor.

- Argon2 is the winner of the 2015 Password Hashing Competition.
- The bcrypt password hashing function should be the second choice for password storage if Argon2 is not available

PASSWORD SECURITY

Is security highest if users are forced to use long passwords, mixing upper and lower case characters and numerical symbols, generated for them by the system, and changed repeatedly?

1. Users may have difficulty memorizing complex passwords.
2. Users may have difficulty dealing with frequent password changes.
3. Users may find ways of re-using their favourite password.

Passwords will be written on a piece of paper kept close to the computer

Is it always a bad idea to write down your password?

PASSWORD POLICIES - Recap

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1

Set a password

If there is no password for a user account, the attacker does not even have to guess it.

2

Change default passwords

Often passwords for system account have a default value like “manager”.

- Default passwords help field engineers installing the system; if left unchanged, it is easy for an attacker to break in.
- Would it then be better to do without default passwords?

3

Avoid guessable passwords

- Prescribe a minimal password length.
- Password format: mix upper and lower case (case-sensitive), include numerical and other non-alphabetical symbols (alphanumeric).
- Today on-line dictionaries for almost every language exist.

PASSWORD POLICIES

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4

Password ageing

- Set an expiry dates for passwords to force users to change passwords regularly.
- Prevent users from reverting to old passwords, e.g. keep a list of the last “ten” passwords used.

5

Limit login attempts

The system can monitor unsuccessful login attempts and react by locking the user account (completely or for a given time interval) to prevent or discourage further attempts.

6

Inform user

After successful login, display time of last login and the number of failed login attempts since, to warn the user about recently attempted attacks.

ALTERNATIVE FORMS OF PASSWORD

1 Passphrase

User enters sentences or long phrases that are easy to remember, and the system applies a hash function to compute the (fixed-size) actual passwords.

2 Visual drawing patterns

(on touch interface), used in, e.g. Android.

3 Picture passwords

Select objects in pictures and patterns. Used in Windows 8.

4 One-time passwords.

PROTECTING THE PASSWORD FILE

Password File

Operating system maintains a file with user names and passwords

Attacker could try to compromise the confidentiality or integrity of this password file.

- Options for protecting the password file:
  - cryptographic protection,
  - access control enforced by the operating system,
  - combination of cryptographic protection and access control, possibly with further measures to slow down dictionary attacks.

ACCESS CONTROL SETTINGS

1. Only privileged users must have write access to the password file.
   - Otherwise, an attacker could get access to the data of other users simply by changing their password, even if it is protected by cryptographic means.

2. If read access is restricted to privileged users, then passwords in theory could be stored unencrypted.

3. If password file contains data required by unprivileged users, passwords must be “encrypted”; such a file can still be used in dictionary attacks.
   - Thus modern Unix/Linux system hides the actual password file in /etc/shadow that is not accessible to non-privileged users.

FAILURE RATES

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1. Measure similarity between reference features and current features.
2. User is accepted if match is above a predefined threshold.

NEW ISSUE

False Positive

Accept wrong user: security problem.

False Negative

Reject legitimate user: creates embarrassment and an inefficient work environment.

FORGED FINGERS - Recap

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Fingerprints and Biometric Traits	Rubber Fingers	Secure Storage
In general, may be unique but they are no secrets. • In September 2013, hackers show how to lift fingerprints from iPhone 5s. Similar attacks also apply to Samsung S5 phone. http://www.ccc.de/en/updates/2013/ccc-breaks-apple-touchid	Rubber fingers have defeated many commercial fingerprint recognition systems in the past. • Minor issue if authentication takes place in the presence of security personnel. • When authenticating remote users additional precautions have to be taken to counteract this type of fraud.	Secure storage of biometric data is an important requirement from the angle of personal privacy protection.

REFERENCES

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Suggested further reading on authentication (not mandatory):

- Menezes et al. *Handbook of Applied Cryptography*. Chapter 10. http://cacr.uwaterloo.ca/hac/

- R. Anderson. Security Engineering. Chapter 15. https://www.cl.cam.ac.uk/~rja14/book.html
- 2nd edition free & downloadable