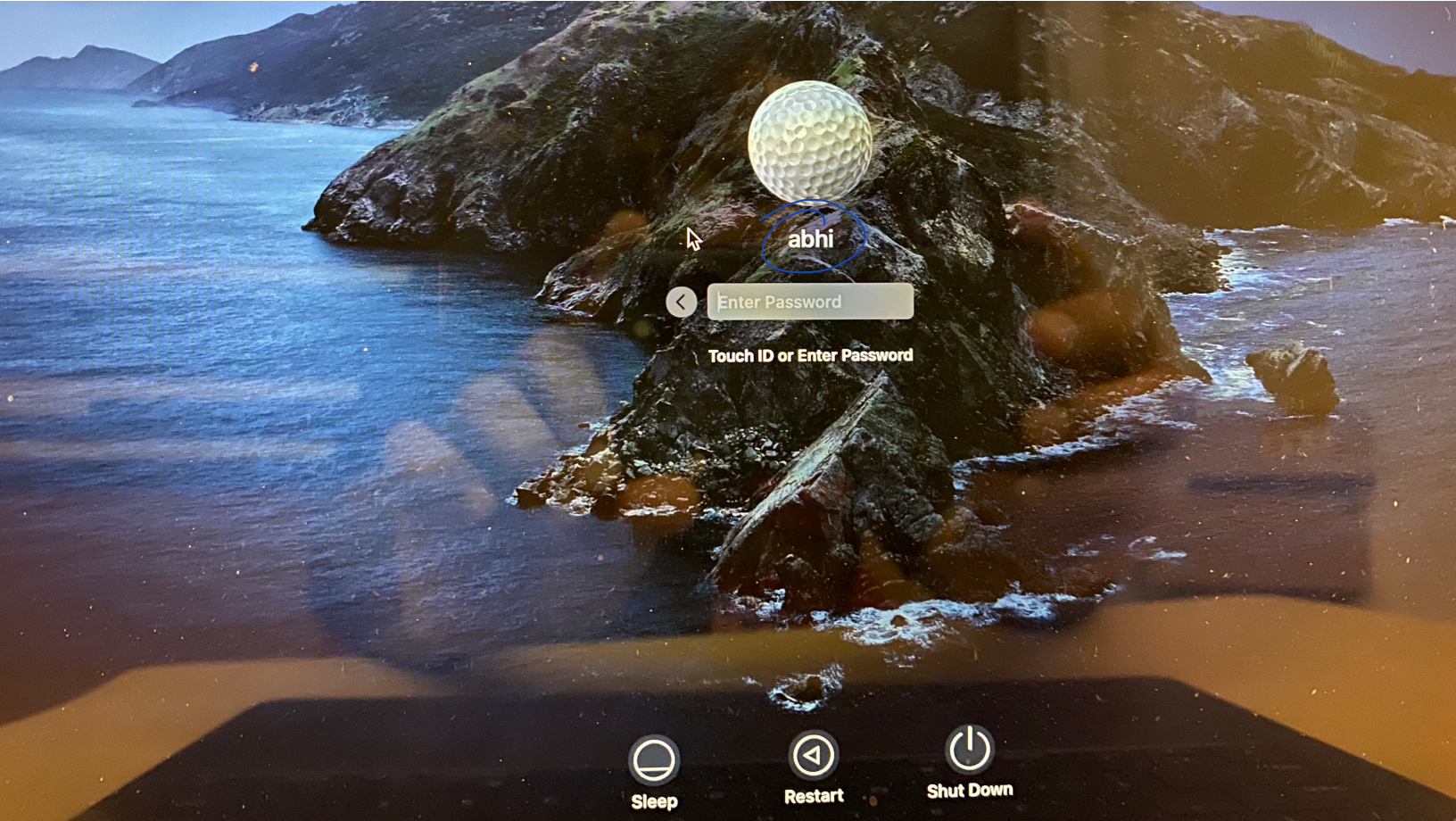
# 2550 Intro to cybersecurity

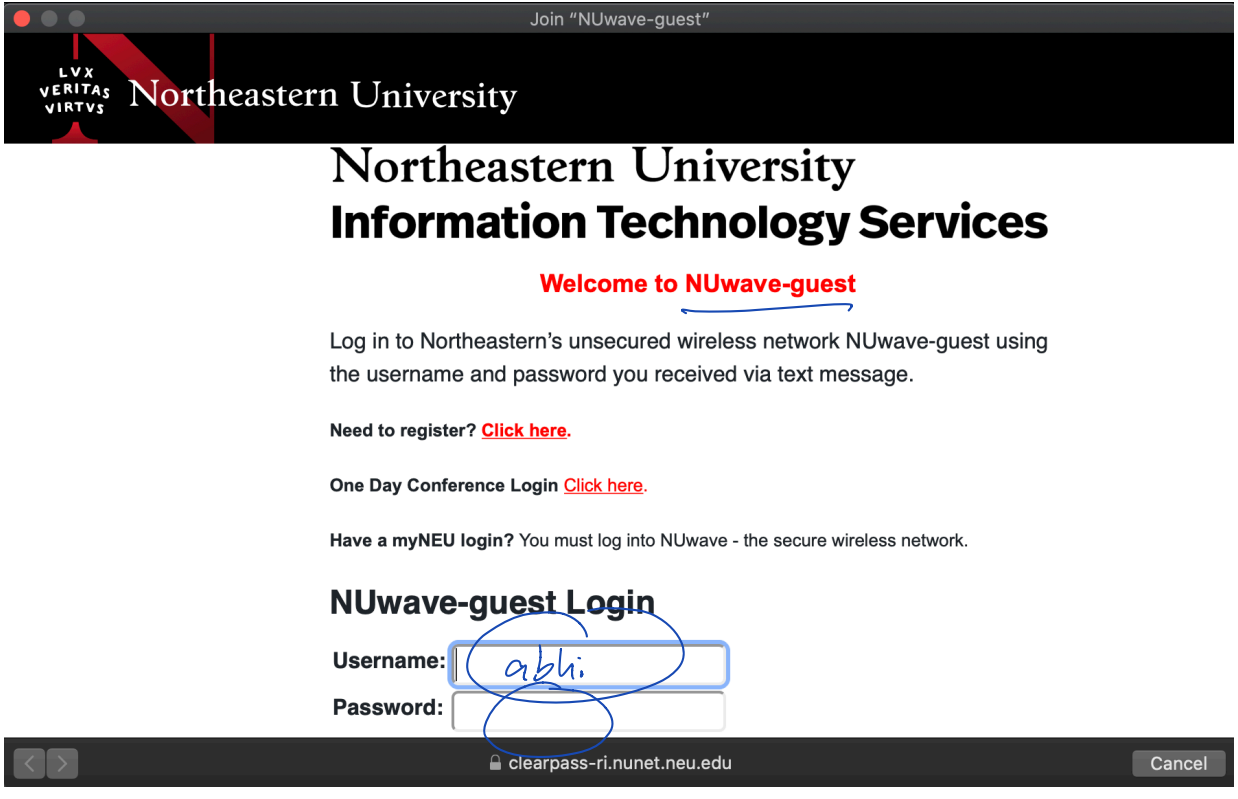
## L2

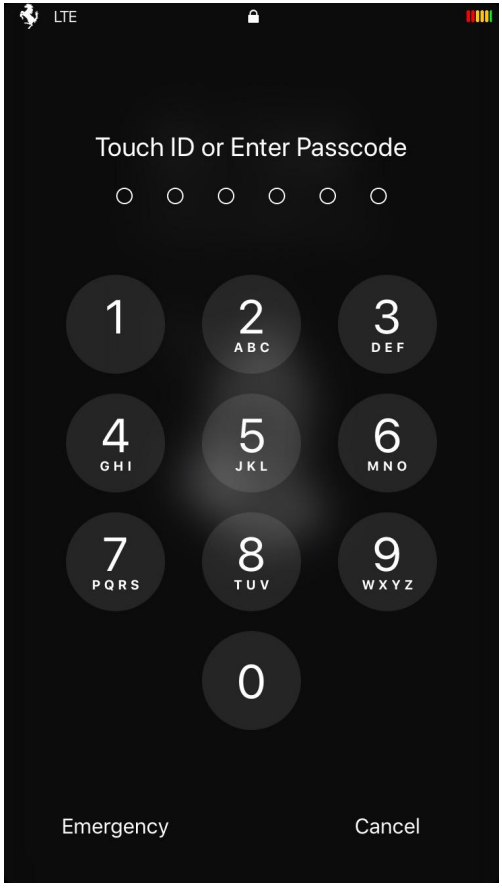
abhi shelat/Ran Cohen

# What does it mean to attack a system?

# What are our expectations?

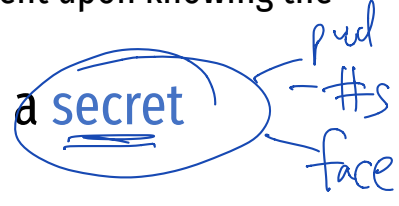

abhi
Enter Password
Touch ID or Enter Password
Sleep
Restart
Shut Down


Join "NUwave-guest"
LVX VERITAS VIRTVS
Northeastern University
Northeastern University
Information Technology Services
Welcome to NUwave-guest
Log in to Northeastern's unsecured wireless network NUwave-guest using the username and password you received via text message.
Need to register? Click here.
One Day Conference Login Click here.
Have a myNEU login? You must log into NUwave - the secure wireless network.
NUwave-guest Login
Username:
abhi
Password:
clearpass-ri.nunet.neu.edu
Cancel


LTE
Touch ID or Enter Passcode
1
2 ABC
3 DEF
4 GHI
5 JKL
6 MNO
7 PQRS
8 TUV
9 WXYZ
0
Emergency
Cancel

# Authentication

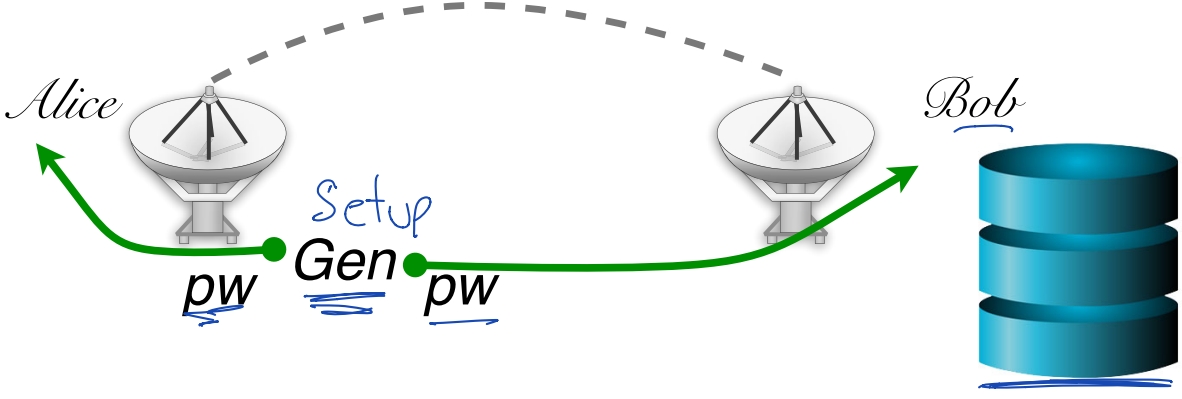
- Authentication is the process of verifying an actor's identity
- Critical for security of systems
  - Permissions, capabilities, and access control are all contingent upon knowing the identity of the actor
- Typically parameterized as a username and a secret
  - The secret attempts to limit unauthorized access
- Desirable properties of secrets include being *unforgeable*, *unguessable*, and *revocable*



# Passwords

Main problem:

# Passwords



Google

# Create your Google Account

First name

Last name

Username @gmail.com

You can use letters, numbers & periods

Use my current email address instead

Password

Confirm

Use 8 or more characters with a mix of letters, numbers & symbols

Sign in instead

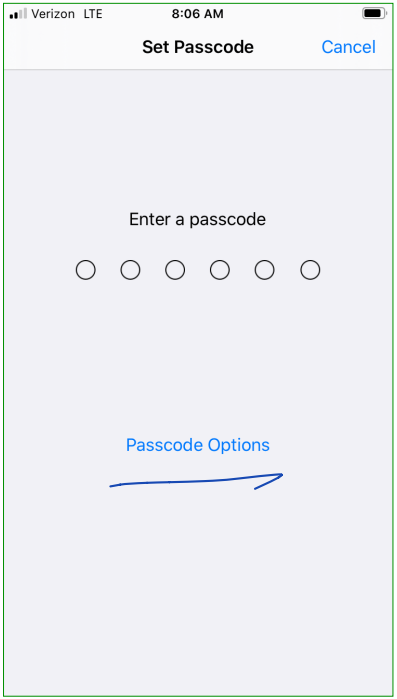
Next

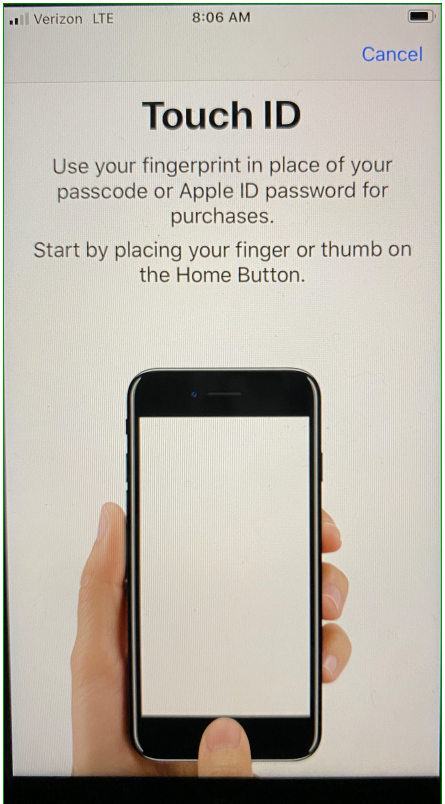
One account. All of Google working for you.

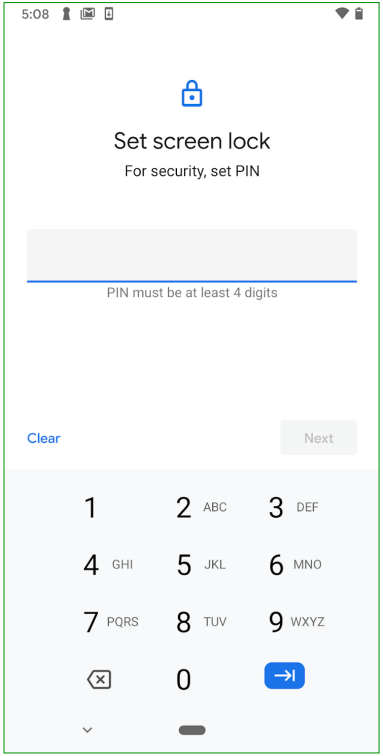
English (United States)

Help Privacy Terms

# PIN setup

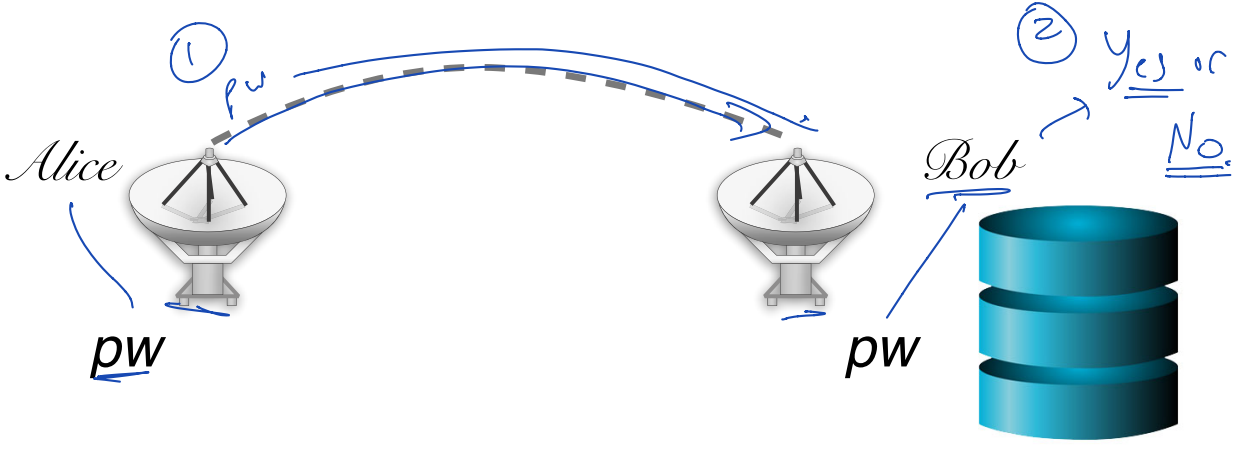

Verizon LTE
8:06 AM
Set Passcode
Cancel
Enter a passcode
Passcode Options


Verizon LTE
8:06 AM
Cancel
Touch ID
Use your fingerprint in place of your passcode or Apple ID password for purchases.
Start by placing your finger or thumb on the Home Button.

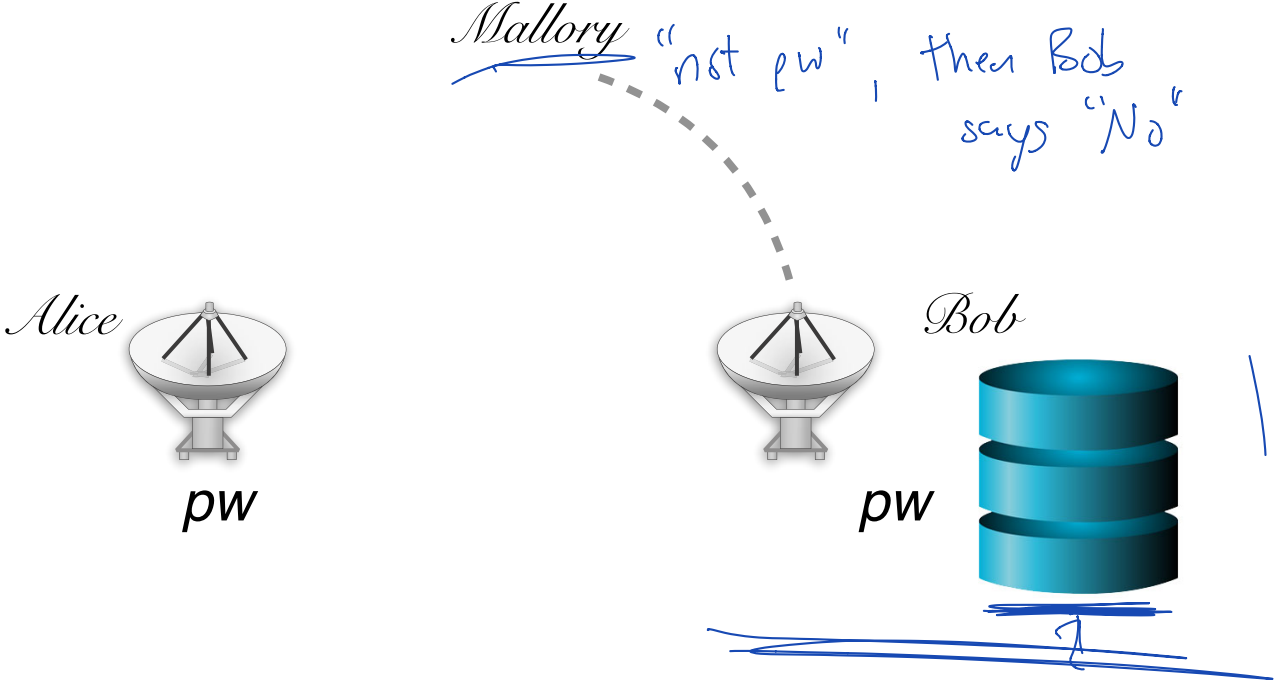

5:08
Set screen lock
For security, set PIN
PIN must be at least 4 digits
Clear
Next
1
2 ABC
3 DEF
4 GHI
5 JKL
6 MNO
7 PQRS
8 TUV
9 WXYZ
0

# Passwords: Alice always succeeds

- If Alice or somebody else sends "pw" then Bob says Yes.



# Passwords: Others do not succeed



# Natural authenticators

- password : "something you know"
- hardware tokens : "something you have"

- property that is hard to forge and presumably unique: (biometrics)

Operating Systems
R. Stockton Gaines Editor

# Password Security: A Case History

Robert Morris and Ken Thompson
Bell Laboratories

**This paper describes the history of the design of the password security scheme on a remotely accessed time-sharing system. The present design was the result of countering observed attempts to penetrate the system. The result is a compromise between extreme security and ease of use.**

**Key Words and Phrases: operating systems, passwords, computer security**
**CR Categories: 2.41, 4.35**

Communications of the ACM
November 1979
Volume 22
Number 11

"The UNIX system was first implemented with a password file that contained the actual passwords of all the users, and for that reason the password file had to be heavily protected against being either read or written. Although historically, this had been the technique used for remote-access systems, it was completely unsatisfactory for several reasons."

# Checking Passwords

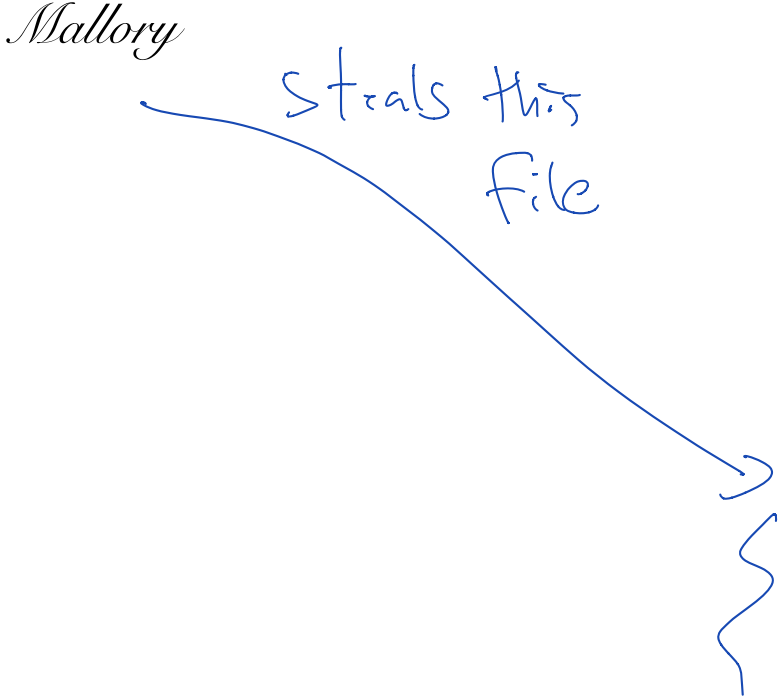
(easiest way to implement, but 1970s technology)

- System must validate passwords provided by users
- Thus, passwords must be *stored* somewhere
- Basic storage: plain text

(wrong) (bad)

| password.txt | |
|---|---|
| Alice | p4ssw0rd |
| Eve | i heart doggies |
| Charlie | 93Gd9#jv*0x3N |
| bob | security |

# Attacks against the Password Model





{username: pwd}

| password.txt | |
|---|---|
| Alice | p4ssw0rd |
| Eve | i heart doggies |
| Charlie | 93Gd9#jv*0x3N |
| bob | security |

# Problem: Password File Theft

- Attackers often compromise systems
- They may be able to steal the password file
  - Linux: /etc/shadow
  - Windows: c:\windows\system32\config\sam
- If the passwords are plain text, what happens?

# Problem: Password File Theft

- Attackers often compromise systems
- They may be able to steal the password file
  - Linux: /etc/shadow
  - Windows: c:\windows\system32\config\sam
- If the passwords are plain text, what happens?
  - The attacker can now log-in as any user, including root/administrator
- **Passwords should never be stored in plain text**

1970s tech fail.

# RockYou Hack: From Bad To Worse

**Nik Cubrilovic**

@nikcub / 2:42 am EST • December 15, 2009

Comment

Earlier today news spread that social application site RockYou had suffered a data breached that resulted in the exposure of over 32 Million user accounts. To compound the severity of the security breach, it was found that **RockYou** are storing all user account data in plain text in their database, exposing all that information to attackers. RockYou have yet to inform users of the breach, and their blog is eerily silent – but the details of the security breach are going from bad to worse.

Data UserAccount [32603388]

==========

1|jennaplanerunner@hotmail.com|mek*****|myspace|0|bebo.com

2|phdlance@gmail.com|mek*****|myspace|1|

3|jennaplanerunner@gmail.com|mek*****|myspace|0|

5|teamsmackage@gmail.com|pro*****|myspace|1|

6|ayul@email.com|kha*****|myspace|1|tagged.com

7|guera_n_negro@yahoo.com|emi*****|myspace|0|

8|beyootifulgirl@aol.com|hol*****|myspace|1|

9|keh2oo8@yahoo.com|cai*****|myspace|1|

10|mawabiru@yahoo.com|pur*****|myspace|1|

11|jodygold@gmail.com|att*****|myspace|1|

12|aryan_dedboy@yahoo.com|iri*****|myspace|0|

13|moe_joe_25@yahoo.com|725*****|myspace|1|

14|xxxnothingbutme@aol.com|1th*****|myspace|0|

15|meandcj069@yahoo.com|too*****|myspace|0|

16|stacey_chim@hotmail.com|cxn*****|myspace|1|

17|barne1en@cmich.edu|ilo*****|myspace|1|

18|reo154@hotmail.com|ecu*****|myspace|1|

19|natapappaslie@yahoo.com|tor*****|myspace|0|

20|ypiogirl@aol.com|tob*****|myspace|1|

21|brittanyleigh864@hotmail.com|bet*****|myspace|1|myspace.com

22|topenga68@aol.com|che*****|myspace|0|

23|marie603412@yahoo.com|cat*****|myspace|0|

24|mellowchick41@aol.com|chu*****|myspace|0|

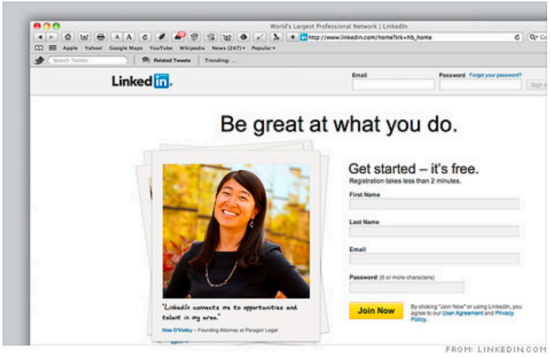
# Pwd breaches

CNN Money

THE CYBERCRIME ECONOMY

## More than 6 million LinkedIn passwords stolen

By David Goldman @CNNMoneyTech June 7, 2012: 9:34 AM ET




Researchers say a stash of what appear to be LinkedIn passwords were protected by a weak security scheme.

NEW YORK (CNNMoney) -- Russian hackers released a giant list of passwords this week, and on Wednesday security researchers identified their likely source: business social networking site LinkedIn.

Operating Systems
R. Stockton Gaines Editor

# Password Security: A Case History

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Communications of the ACM
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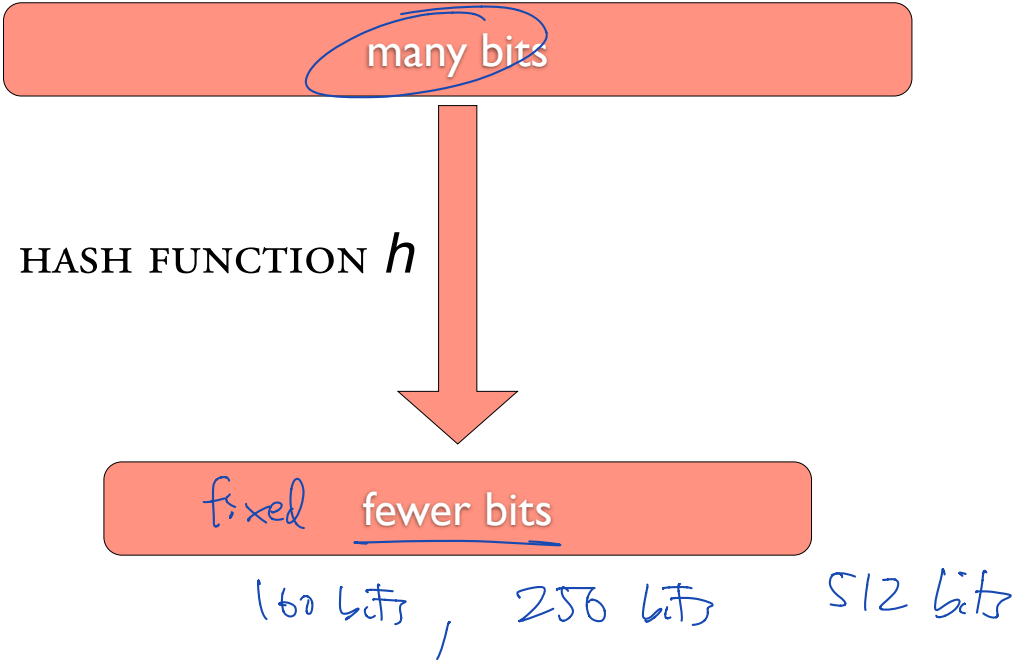
"The obvious solution is to arrange that the passwords not appear in the system at all, and it is not difficult to decide that this can be done by encrypting each user's password, putting only the encrypted form in the pass- word file, and throwing away his original password (the one that he typed in). When the user later tries to log in to the system, the password that he types is encrypted and compared with the encrypted version in the password file. If the two match, his login attempt is accepted."

"encryption" → "hash"

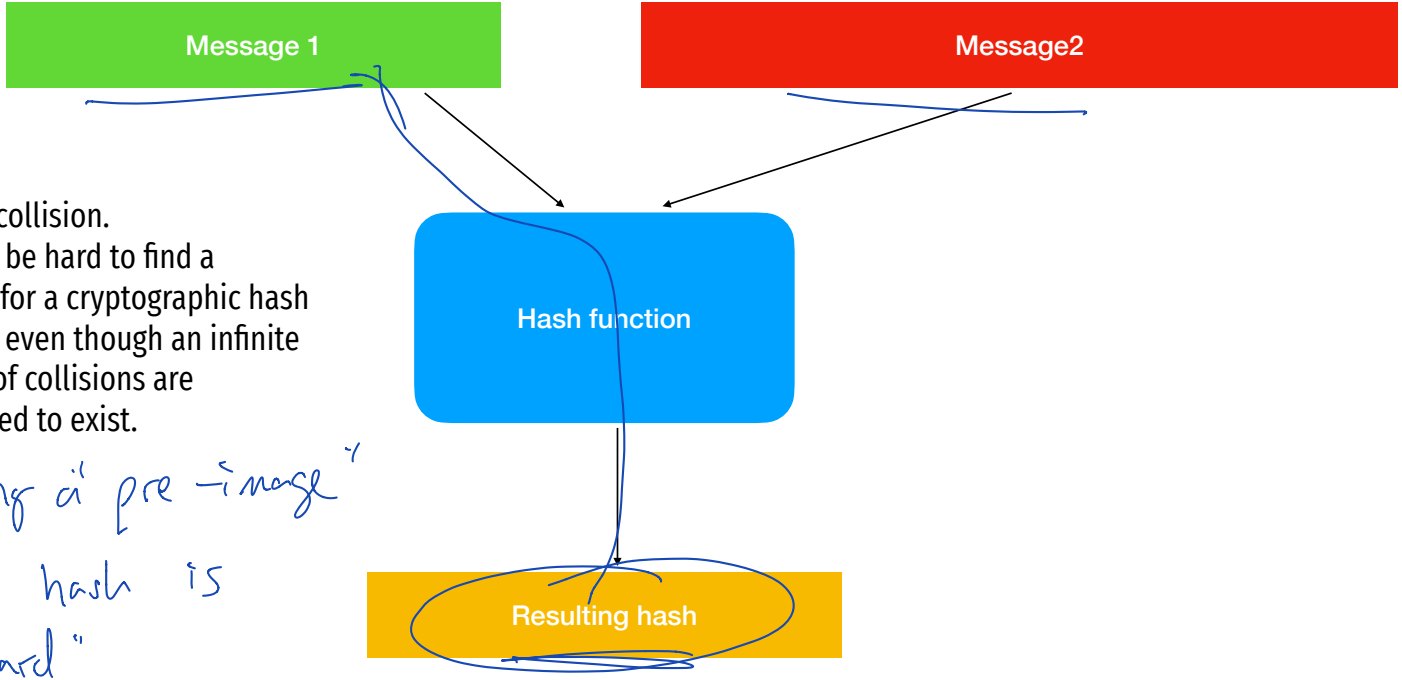
# Hashed Passwords

- Key idea: store “hashed” versions of passwords
  - Use one-way cryptographic hash functions
  - Examples: MD5, SHA1, SHA256, SHA512, bcrypt, PBKDF2, scrypt

# Goal of a hash function



# Goal of a hash function: Collision resistance




This is a collision.
It should be hard to find a collision for a cryptographic hash function, even though an infinite number of collisions are guaranteed to exist.

"finding a pre-image of a hash is hard"

# MD5 is a broken hash function

```
abhi18: abhi$ md5 -s security
MD5 ("security") = e91e6348157868de9dd8b25c81aebfb9

abhi18: abhi$ md5 -s Security
MD5 ("Security") = 2fae32629d4ef4fc6341f1751b405e45


abhi18: abhi$ md5 -s Security1
MD5 ("Security1") = 8d01bda744a7a6392d3393e0ece561e8
```

SHA1 hash (SHA1 is also considered broken)

```
abhi18: abhi$ echo -n "security" | shasum
8eec7bc461808e0b8a28783d0bec1a3a22eb0821  -
```

160

```
abhi18: abhi$ echo -n "security" | shasum -a 256
5d2d3ceb7abe552344276d47d36a8175b7aeb250a9bf0bf00e850cd23ecf2e43  -
```

SHA256

256 bits

# Hashed Passwords

- Key idea: store “hashed” versions of passwords
  - Use one-way cryptographic hash functions
  - Examples: MD5, SHA1, SHA256, SHA512, bcrypt, PBKDF2, scrypt
- Cryptographic hash function transform input data into scrambled output data
  - Deterministic: hash(A) = hash(A)
  - High entropy:
    - MD5(‘security’) = e91e6348157868de9dd8b25c81aebfb9
    - MD5(‘security1’) = 8632c375e9eba096df51844a5a43ae93
    - MD5(‘Security’) = 2fae32629d4ef4fc6341f1751b405e45
  - Collision resistant
    - Locating A’ such that hash(A) = hash(A’) takes a long time (hopefully)
    - Example: $2^{21}$ tries for md5

Note:MD5 is broken

# Hashed Password Example

User: Charlie

hash(pwd)

| hashed_password.txt | |
|---|---|
| charlie | 2a9d119df47ff993b662a8ef36f9ea20 |
| greta | 23eb06699da16a3ee5003e5f4636e79f |
| alice | 98bd0ebb3c3ec3fbe21269a8d840127c |
| bob | e91e6348157868de9dd8b25c81aebfb9 |

Note:MD5 is broken

# Hashed Password Example

User: Charlie

MD5(‘p4ssw0rd’) =
2a9d119df47ff993b662a8ef36f9ea20

**hashed_passwo txt**

| | |
|---|---|
| charlie | 2a9d119df47ff993b662a8ef36f9ea20 |
| greta | 23eb06699da16a3ee5003e5f4636e79f |
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| alice | 98bd0ebb3c3ec3fbe21269a8d840127c |
| bob | e91e6348157868de9dd8b25c81aebfb9 |

Note:MD5 is broken

# Hashed Password Example

User: Charlie

MD5('p4ssw0rd') =
2a9d119df47ff993b662a8ef36f9ea20

MD5('2a9d119df47ff993b662a8ef36f9ea20')
= b35596ed3f0d5134739292faa04f7ca3

steals that file

| hashed_password.txt | |
|---|---|
| charlie | 2a9d119df47ff993b662a8ef36f9ea20 |
| greta | 23eb06699da16a3ee5003e5f4636e79f |
| alice | 98bd0ebb3c3ec3fbe21269a8d840127c |
| bob | e91e6348157868de9dd8b25c81aebfb9 |

very hard to find pre-image

Note:MD5 is broken

# Hashed Password Example

User: Charlie

MD5(‘p4ssw0rd’) =
2a9d119df47ff993b662a8ef36f9ea20

MD5(‘2a9d119df47ff993b662a8ef36f9ea20’)
= b35596ed3f0d5134739292faa04f7ca3

| hashed_passw[illegible]xt | |
|---|---|
| charlie | 2a9d119df47ff993b662a8ef36f9ea20 |
| greta | 23eb06699da16a3ee5003e5f4636e79f |
| alice | 98bd0ebb3c3ec3fbe21269a8d840127c |
| bob | e91e6348157868de9dd8b25c81aebfb9 |

# Attacking Password Hashes

- Recall: cryptographic hashes are collision resistant
  - Locating A’ such that hash(A) = hash(A’) takes a long time (hopefully)
- Are hashed password secure from cracking?

# Attacking Password Hashes

- Recall: cryptographic hashes are collision resistant
  - Locating A' such that hash(A) = hash(A') takes a long time (hopefully)
- Are hashed password secure from cracking?
  - **No!**
- Problem: users choose poor passwords
  - Most common passwords: 123456, password
  - Username: cbw, Password: cbw
- Weak passwords enable dictionary attacks

1979

The authors have conducted experiments to try to determine typical users' habits in the choice of passwords when no constraint is put on their choice. The results were disappointing, except to the bad guy. In a collection of 3,289 passwords gathered from many users over a long period of time,

15 were a single ASCII character;
72 were strings of two ASCII characters;
464 were strings of three ASCII characters;
477 were strings of four alphamerics;
706 were five letters, all upper-case or all lower-case;
605 were six letters, all lower-case.

An additional 492 passwords appeared in various available dictionaries, name lists, and the like. A total of 2,831 or 86 percent of this sample of passwords fell into one of these classes.

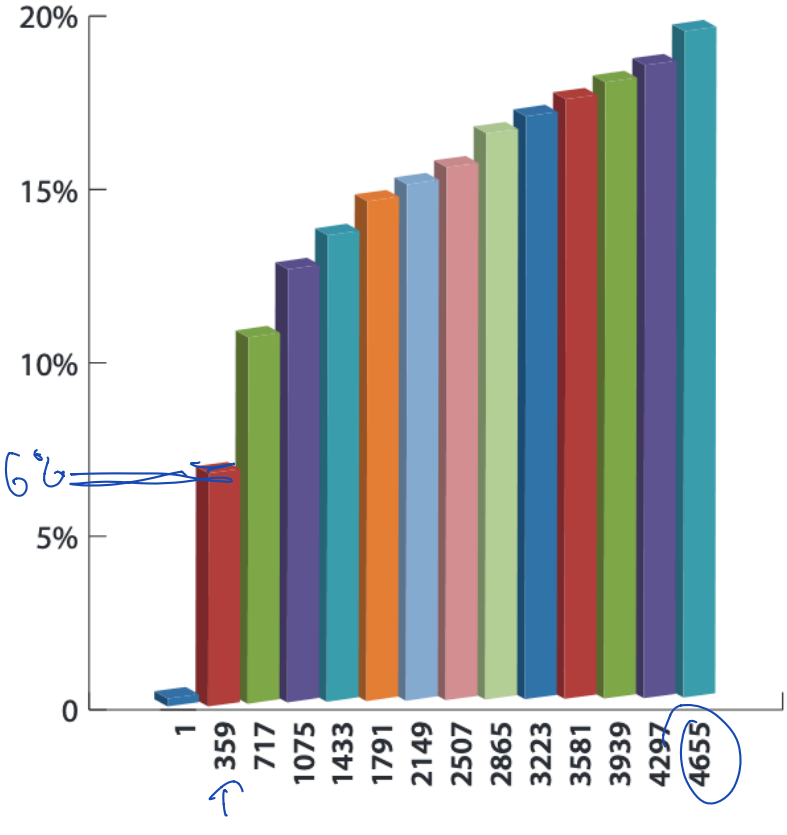
# From Rockyou breach

| Rank | Password | Number of Users with Password (Absolute) |
|---|---|---|
| 1 | 123456 | 290731 |
| 2 | 12345 | 79078 |
| 3 | 123456789 | 76790 |
| 4 | Password | 61958 |
| 5 | iloveyou | 51622 |
| 6 | princess | 35231 |
| 7 | rockyou | 22588 |
| 8 | 1234567 | 21726 |
| 9 | 12345678 | 20553 |
| 10 | abc123 | 17542 |

| Rank | Password | Number of Users with Password (Absolute) |
|---|---|---|
| 11 | Nicole | 17168 |
| 12 | Daniel | 16409 |
| 13 | babygirl | 16094 |
| 14 | monkey | 15294 |
| 15 | Jessica | 15162 |
| 16 | Lovely | 14950 |
| 17 | michael | 14898 |
| 18 | Ashley | 14329 |
| 19 | 654321 | 13984 |
| 20 | Qwerty | 13856 |

*Password Popularity—Top 20*

https://www.imperva.com/docs/gated/WP_Consumer_Password_Worst_Practices.pdf




20% of the 33m pwds

# Most Common Passwords

| Rank | 2013 | 2014 |
|---|---|---|
| 1 | 123456 | 123456 |
| 2 | password | password |
| 3 | 12345678 | 12345 |
| 4 | qwerty | 12345678 |
| 5 | abc123 | qwerty |
| 6 | 123456789 | 123456789 |
| 7 | 111111 | 1234 |
| 8 | 1234567 | baseball |
| 9 | iloveyou | dragon |
| 10 | adobe123 | football |

2012: 6.5 million hashes leaked onto Internet 90% cracked in 2 weeks
2016: 177.5 million more hashes leaked 98% cracked in 1 week

# 2012 Linkedin Breach had 117 Million Emails and Passwords Stolen, Not 6.5M

May 18, 2016


Long time users of Linkedin users may very well need to change their passwords once more

## Related Posts

- Web Skimming Attack on Blue Bear Affects School Admin

by Paul Ducklin

One month ago today, we wrote about Adobe's giant data breach.

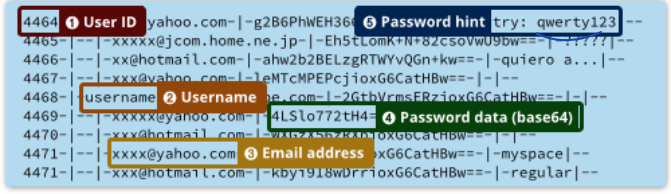

As far as anyone knew, including Adobe, it affected about 3,000,000 customer records, which made it sound pretty bad right from the start.

But worse was to come, as recent updates to the story bumped the number of affected customers to a whopping 38,000,000.

We took Adobe to task for a lack of clarity in its breach notification.

## OUR COMPLAINT

One of our complaints was that Adobe said that it had lost *encrypted* passwords, when we thought the company ought to have said that it had lost




| Adobe password data | | Password hint | |
|---|---|---|---|
| 110edf2294fb8bf4 | -> | numbers 123456 | ❶ 123456 |
| 110edf2294fb8bf4 | -> | ==123456 | |
| 110edf2294fb8bf4 | -> | c'est "123456" | |
| 8fda7e1f0b56593f e2a311ba09ab4707 | -> | numbers | ❷ 12345678 |
| 8fda7e1f0b56593f e2a311ba09ab4707 | -> | 1-8 | |
| 8fda7e1f0b56593f e2a311ba09ab4707 | -> | 8digit | |
| 2fca9b003de39778 e2a311ba09ab4707 | -> | the password is password | ❸ password |
| 2fca9b003de39778 e2a311ba09ab4707 | -> | password | |
| 2fca9b003de39778 e2a311ba09ab4707 | -> | rhymes with assword | |
| e5d8efed9088db0b | -> | q w e r t y | ❹ qwerty |
| e5d8efed9088db0b | -> | ytrewq tagurpidi | |
| e5d8efed9088db0b | -> | 6 long qwert | |
| ecba98cca55eabc2 | -> | sixxone | ❺ 111111 |
| ecba98cca55eabc2 | -> | 1*6 | |
| ecba98cca55eabc2 | -> | sixones | |

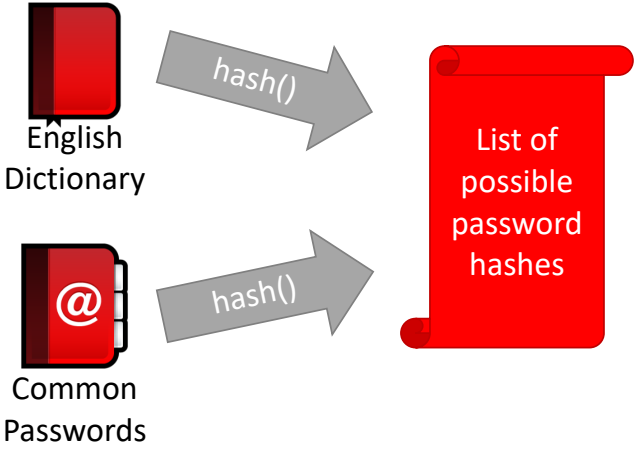
# Dictionary Attacks

English Dictionary


Common Passwords

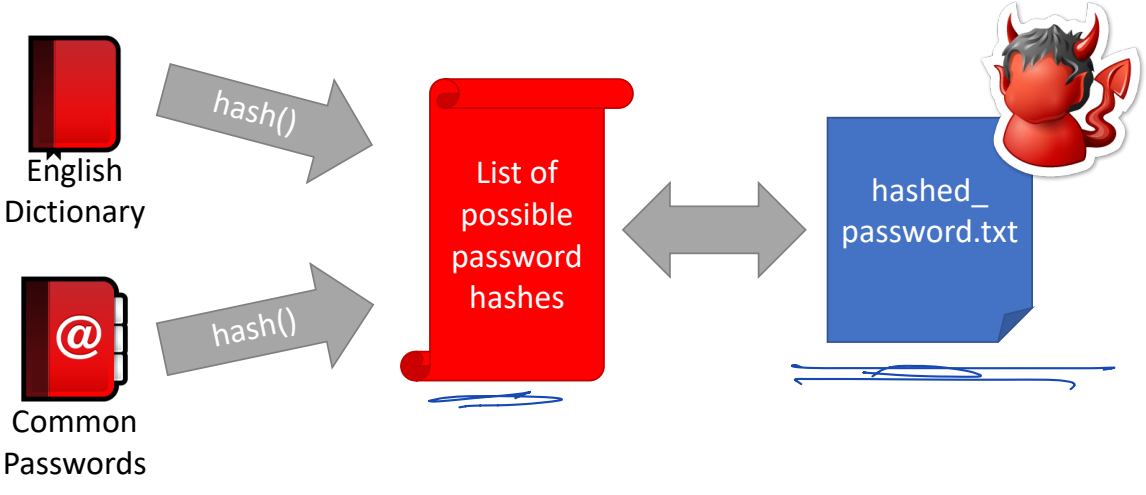
from breaches

# Dictionary Attacks

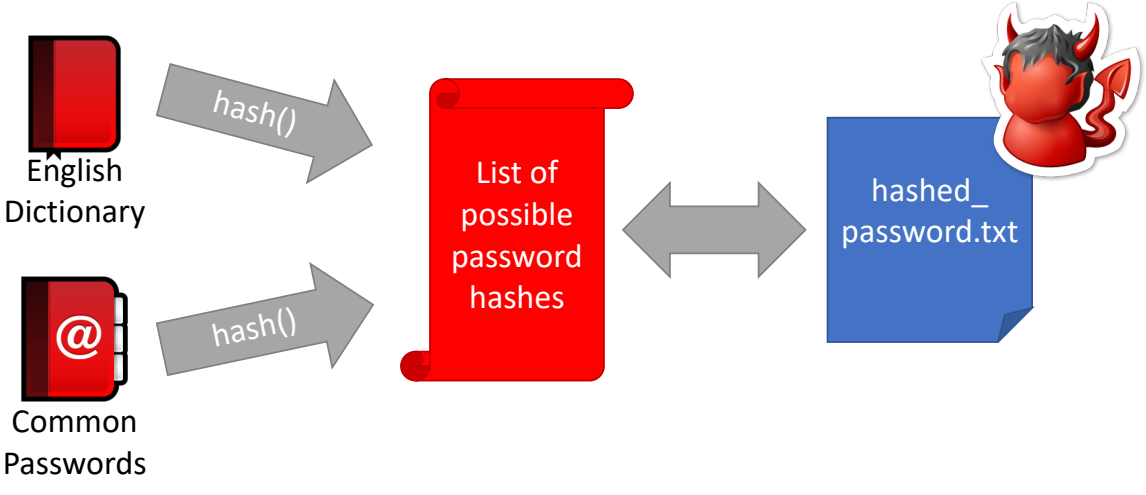


# Dictionary Attacks

offline brute force attack

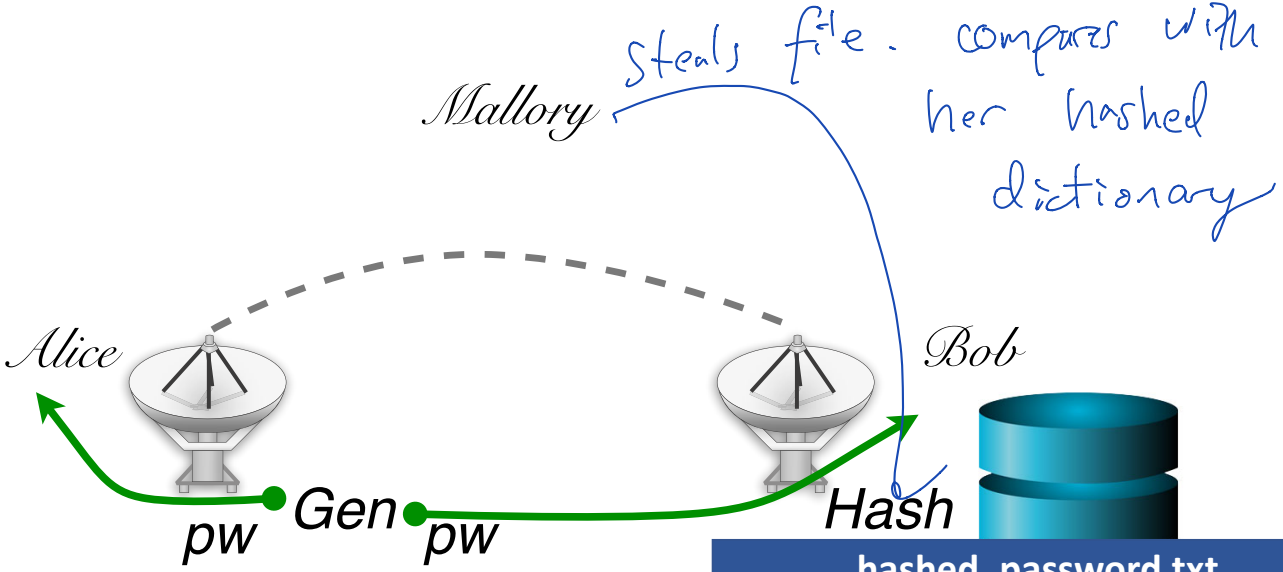


# Dictionary Attacks

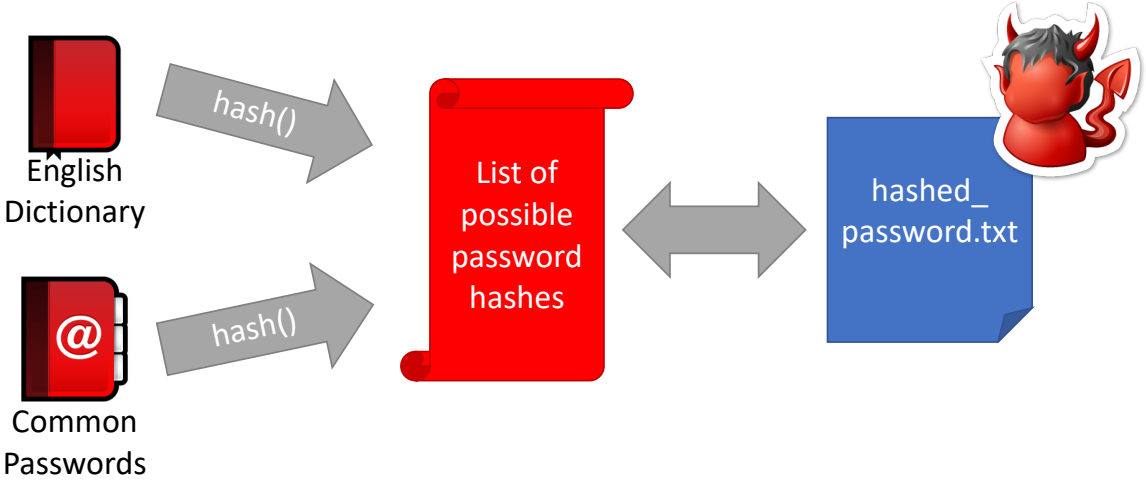



- Common for 60-70% of hashed passwords to be cracked in <24 hours

# Attack 1


Steals file. compares with her hashed dictionary
Mallory
Alice
Bob
pw
Gen
pw
Hash
hashed_password.txt
charlie 2a9d119df47ff993b662a8ef36f9ea20
greta 23eb06699da16a3ee5003e5f4636e79f

# Dictionary Attacks




- Common for 60-70% of hashed passwords to be cracked in <24 hours

# Brute force attack estimates

How big is the alphabet from which pwd are chosen?

| | |
|---|---|
| a - z | 26 |
| A - Z | 26 |
| 0 - 9 | 10 |
| symbols | 32 |
| | 94 |

# Brute force attack estimates

How big is the alphabet from which pwd are chosen?

95 symbols

How long is a password?

8

Size of password domain:

$95^8$

# Brute force attack estimates

Size of password domain: $95^8$ 6,634,204,312,890,625

6600 trillions × 16 bytes.

~ 100,000 terabytes of storage

~ 100 petabytes

100,000 tb × 20¢ ≈ $2M

Built by Edward Betts. Comments welcome: edward@4angle.com

Last updated: 07 February 2020.

20$ / tb.

## 3.5" internal drives

| Price per TB | Price | Size | Drive |
|---|---|---|---|
| $18.75 | $149.99 | 8TB | Seagate BarraCuda ST8000DM004 8TB 5400 RPM 256MB Cache SATA 6.0Gb/s 3.5" Internal Hard Drive Bare Drive |
| $22.25 | $88.99 | 4TB | WD Blue 4TB Desktop Hard Disk Drive - 5400 RPM SATA 6Gb/s 64MB Cache 3.5 Inch - WD40EZRZ |
| $22.50 | $89.99 | 4TB | Seagate BarraCuda ST4000DM004 4TB 5400 RPM 256MB Cache SATA 6.0Gb/s 3.5" Hard Drives Bare Drive - OEM |
| $22.52 | $135.12 | 6TB | Seagate BarraCuda ST6000DM003 6TB 5400 RPM 256MB Cache SATA 6.0Gb/s 3.5" Internal Hard Drive Bare Drive |
| $23.33 | $139.99 | 6TB | WD Blue 6TB Desktop Hard Disk Drive - 5400 RPM SATA 6Gb/s 256MB Cache 3.5 Inch - WD60EZAZ |
| $23.92 | $334.88 | 14TB | Seagate Exos X16 ST14000NM001G 14TB 7200 RPM 256MB Cache SATA 6.0Gb/s 3.5" Hard Drives, 512E/4KN |
| $24.00 | $71.99 | 3TB | WD Blue 3TB Desktop Hard Disk Drive - 5400 RPM SATA 6Gb/s 64MB Cache 3.5 Inch - WD30EZRZ |
| $24.06 | $384.99 | 16TB | Seagate Exos 16TB Enterprise HDD X16 SATA 6Gb/s 512e/4Kn 7200 RPM 256MB Cache 3.5" Internal Hard Drive ST16000NM001G |
| $24.42 | $292.99 | 12TB | Seagate 12TB HDD Exos X14 7200 RPM 512e/4Kn SATA 6Gb/s 256MB Cache 3.5-Inch Enterprise Hard Drive (ST12000NM0008) |
| $24.66 | $73.99 | 3TB | Seagate BarraCuda ST3000DM007 3TB 5400 RPM 256MB Cache SATA 6.0Gb/s 3.5" Hard Drives |
| $25.00 | $49.99 | 2TB | Seagate BarraCuda ST2000DM008 2TB 7200 RPM 256MB Cache SATA 6.0Gb/s 3.5" Hard Drive Bare Drive |
| $25.00 | $99.99 | 4TB | Seagate IronWolf 4TB NAS Hard Drive 5900 RPM 64MB Cache SATA 6.0Gb/s 3.5" Internal Hard Drive ST4000VN008 |
| $25.40 | $253.99 | 10TB | Seagate Exos Enterprise Capacity 3.5" HDD 10TB (Helium) 7200 RPM SATA 6Gb/s 256MB Cache Hyperscale 512e Internal Hard Drive ST10000NM0016 |
| $25.67 | $307.99 | 12TB | Seagate Exos Enterprise Capacity ST12000NM0007 12TB 7200 RPM SATA 6Gb/s 256MB Enterprise Hard Drive (Helium & 3.5 inch) |
| $25.75 | $102.99 | 4TB | WD Purple 4TB Surveillance Hard Disk Drive - 5400 RPM Class SATA 6Gb/s 64MB Cache 3.5 Inch WD40PURZ |
| $26.00 | $103.99 | 4TB | Seagate SkyHawk 4TB Surveillance Hard Drive 64MB Cache SATA 6.0Gb/s 3.5" Internal Hard Drive ST4000VX007 |

more

# Attack 2: brute force attack

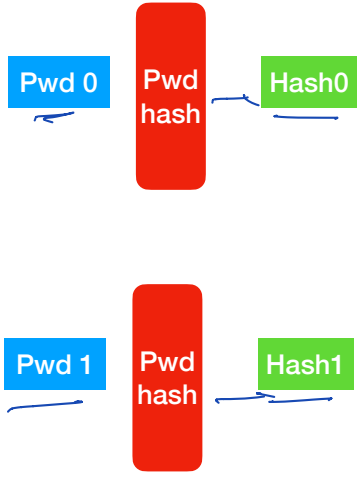
*Mallory*

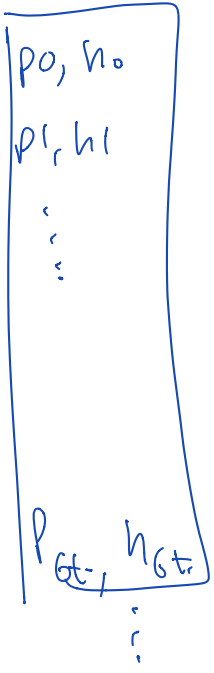
1. Buy storage system $2M.
2. compute all pwds & store their hashes.
3. steal Bob's pwd file
4. look for the intersection in your stored pwd file.

*Bob*

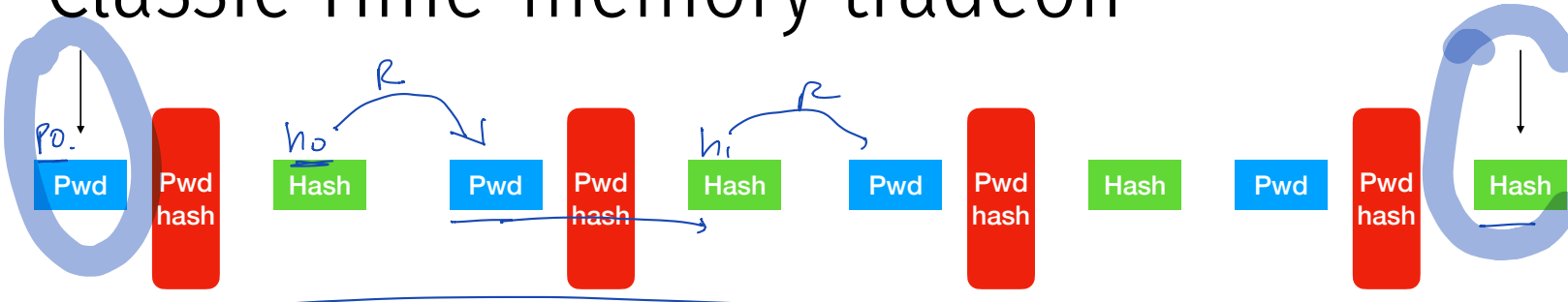
# Classic Time-memory tradeoff

RAINBOW TABLE ATTACK



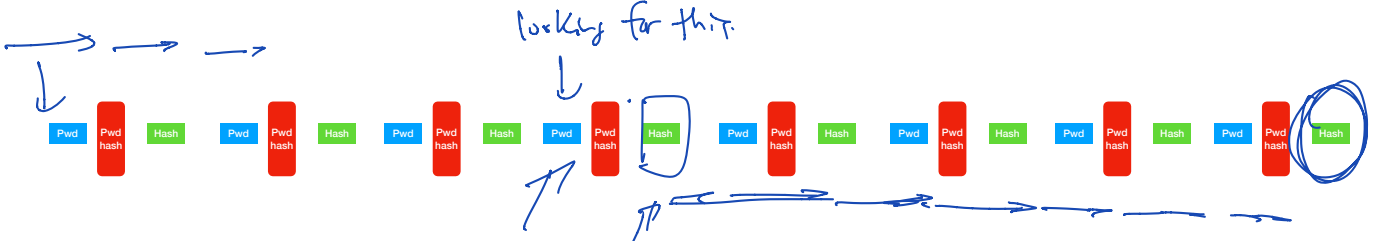



# Classic Time-memory tradeoff




chain, 10,000 long.

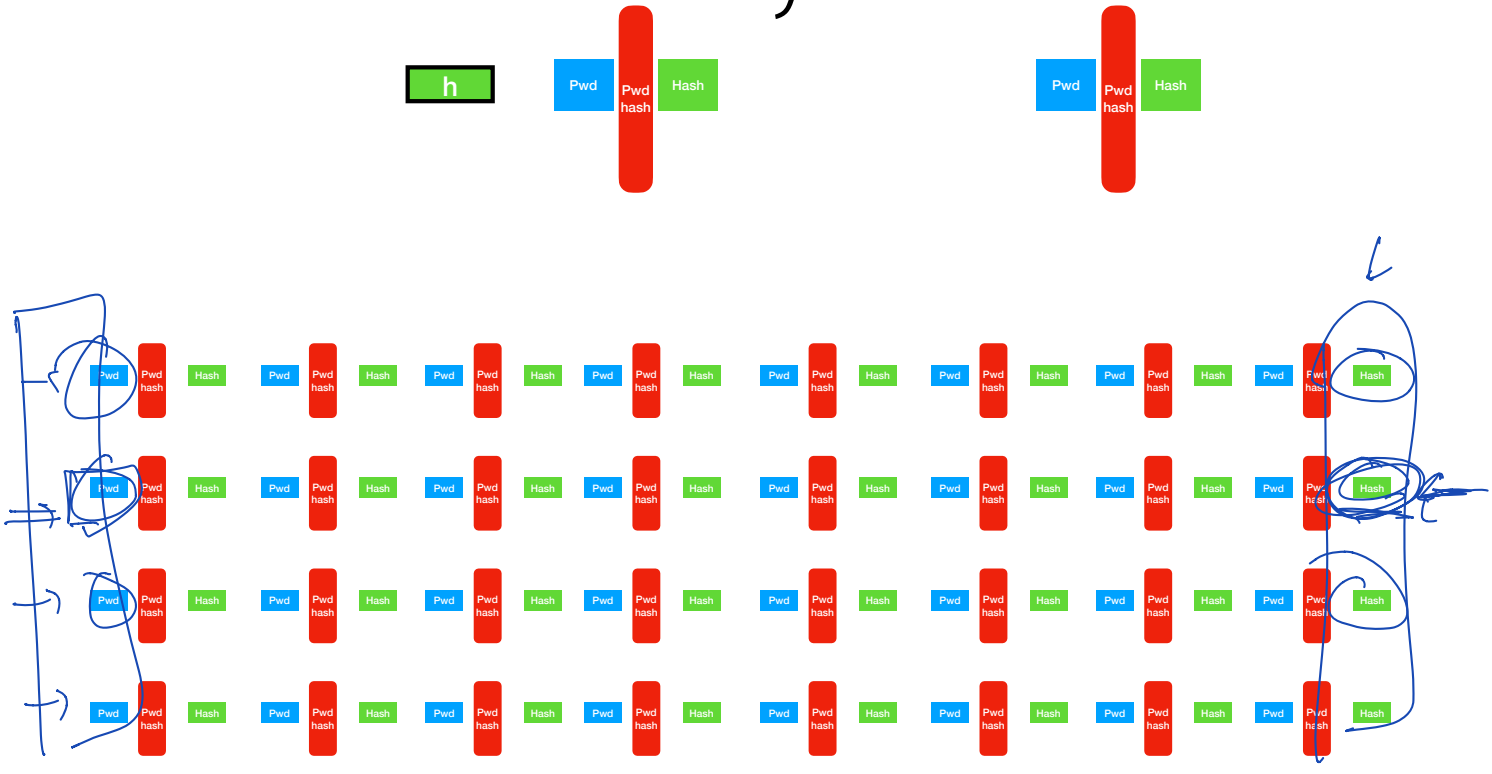
- first & last are the only things you save.




Given a hash [h] that you want to invert, you can:

h

# Classic Time-memory tradeoff



## SHA1 Rainbow Tables

| Table ID | Charset | Plaintext Length | Key Space | Success Rate | Table Size | Files | Performance |
|---|---|---|---|---|---|---|---|
| sha1_ascii-32-95#1-7 | ascii-32-95 | 1 to 7 | 70,576,641,626,495 | 99.9 % | 52 GB<br>64 GB | Perfect<br>Non-perfect | Perfect<br>Non-perfect |
| sha1_ascii-32-95#1-8 | ascii-32-95 | 1 to 8 | 6,704,780,954,517,120 | 96.8 % | 460 GB<br>576 GB | Perfect<br>Non-perfect | Perfect<br>Non-perfect |
| sha1_mixalpha-numeric#1-8 | mixalpha-numeric | 1 to 8 | 221,919,451,578,090 | 99.9 % | 127 GB<br>160 GB | Perfect<br>Non-perfect | Perfect<br>Non-perfect |
| sha1_mixalpha-numeric#1-9 | mixalpha-numeric | 1 to 9 | 13,759,005,997,841,642 | 96.8 % | 690 GB<br>864 GB | Perfect<br>Non-perfect | Perfect<br>Non-perfect |
| sha1_loweralpha-numeric#1-9 | loweralpha-numeric | 1 to 9 | 104,461,669,716,084 | 99.9 % | 65 GB<br>80 GB | Perfect<br>Non-perfect | Perfect<br>Non-perfect |
| sha1_loweralpha-numeric#1-10 | loweralpha-numeric | 1 to 10 | 3,760,620,109,779,060 | 96.8 % | 316 GB<br>396 GB | Perfect<br>Non-perfect | Perfect<br>Non-perfect |

https://project-rainbowcrack.com/table.htm

RainbowCrack Software Features

- High performance hash cracking on PC (> 10,000,000,000,000 plaintext tests per second)
- Optimized implementation of time-memory trade-off algorithm
- GPU acceleration with NVIDIA and AMD GPUs
- GPU acceleration with multiple GPUs
- Supports 64-bit Windows operating system
- Easy to use



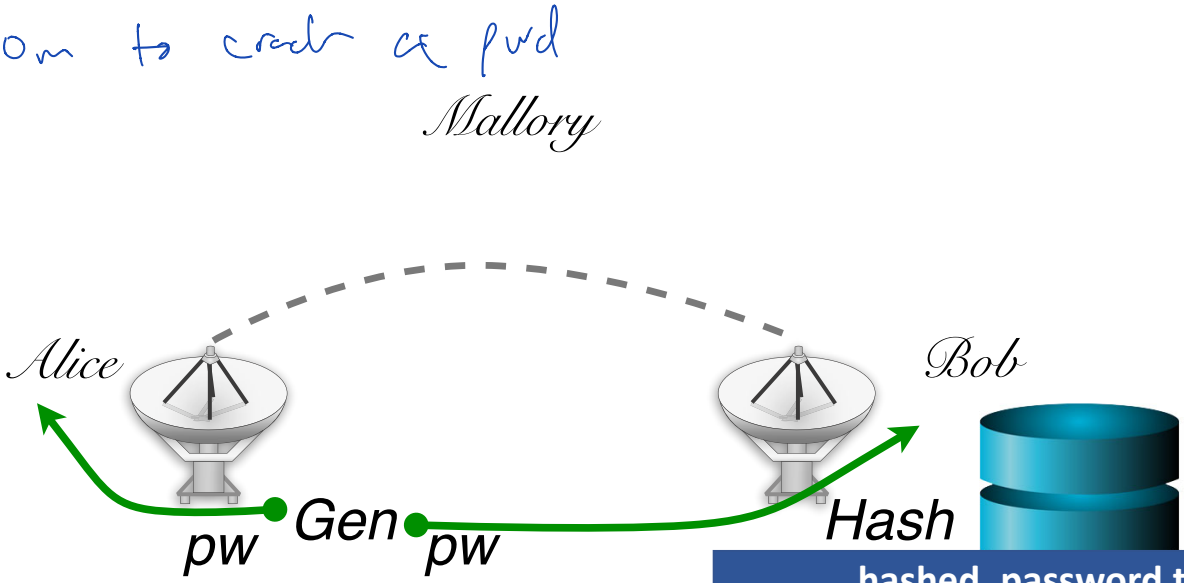
- RainbowCrack 1.7 software
- One Seagate BarraCuda 6TB ST6000DM003 (SATA) hard drive containing rainbow tables and software
- License in USB dongle

# The attack is highly effective

https://www.youtube.com/watch?v=TkMZJ3fTgrM

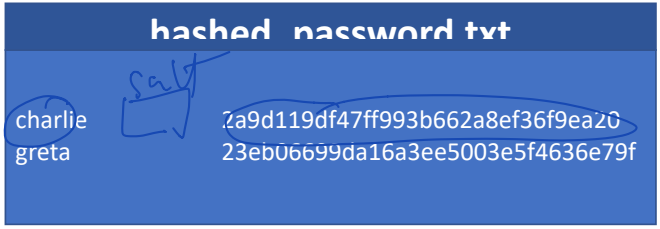
# Attack 2: offline brute force

~10m to crack a pwd



# How to hamper offline brute force attacks?

*Mallory*




"SALT" pubic random string that is added to your pwd to increase the keyspace

# Hardening Password Hashes

- Key problem: cryptographic hashes are deterministic
  - hash(‘p4ssw0rd’) = hash(‘p4ssw0rd’)
  - This enables attackers to build lists of hashes

# Hardening Password Hashes

- Key problem: cryptographic hashes are deterministic
  - hash('p4ssw0rd') = hash('p4ssw0rd')
  - This enables attackers to build lists of hashes
- Solution: make each password hash unique
  - Add a random salt to each password before hashing
  - hash(salt + password) = password hash
  - Each user has a unique, random salt
  - Salts can be stores in plain text

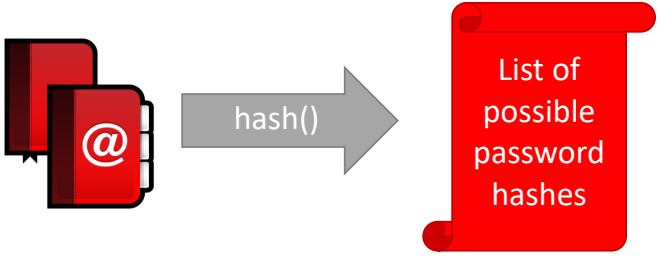
# Example Salted Hashes

| hashed_password.txt | |
|---|---|
| cbw | 2a9d119df47ff993b662a8ef36f9ea20 |
| sandi | 23eb06699da16a3ee5003e5f4636e79f |
| amislove | 98bd0ebb3c3ec3fbe21269a8d840127c |
| bob | e91e6348157868de9dd8b25c81aebfb9 |

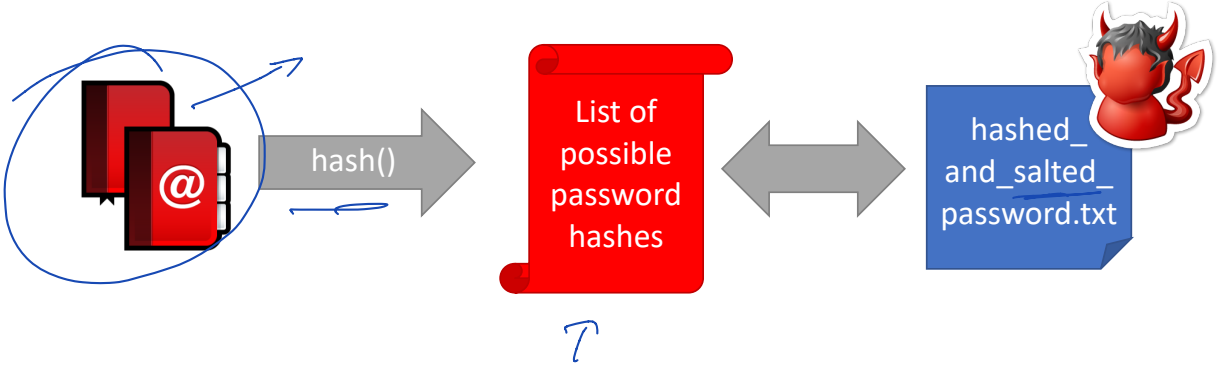
Salt

| hashed_and_salted_password.txt | | |
|---|---|---|
| cbw | a8 | af19c842f0c781ad726de7aba439b033 |
| sandi | 0X | 67710c2c2797441efb8501f063d42fb6 |
| amislove | hz | 9d03e1f28d39ab373c59c7bb338d0095 |
| bob | K@ | 479a6d9e59707af4bb2c618fed89c245 |

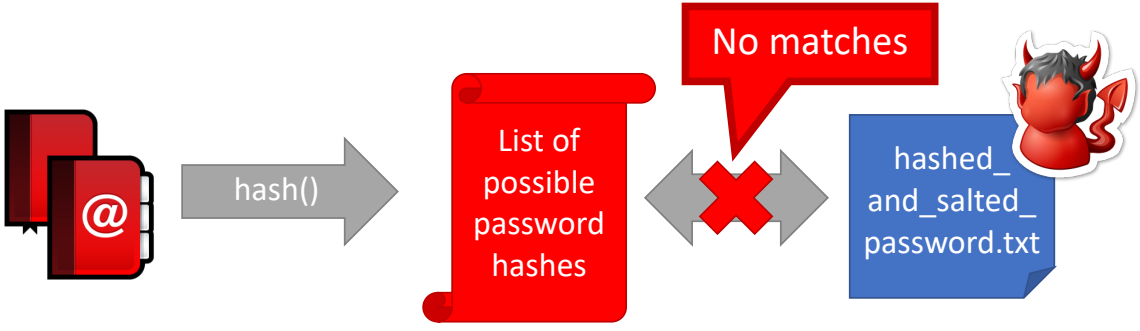
# Attacking Salted Passwords



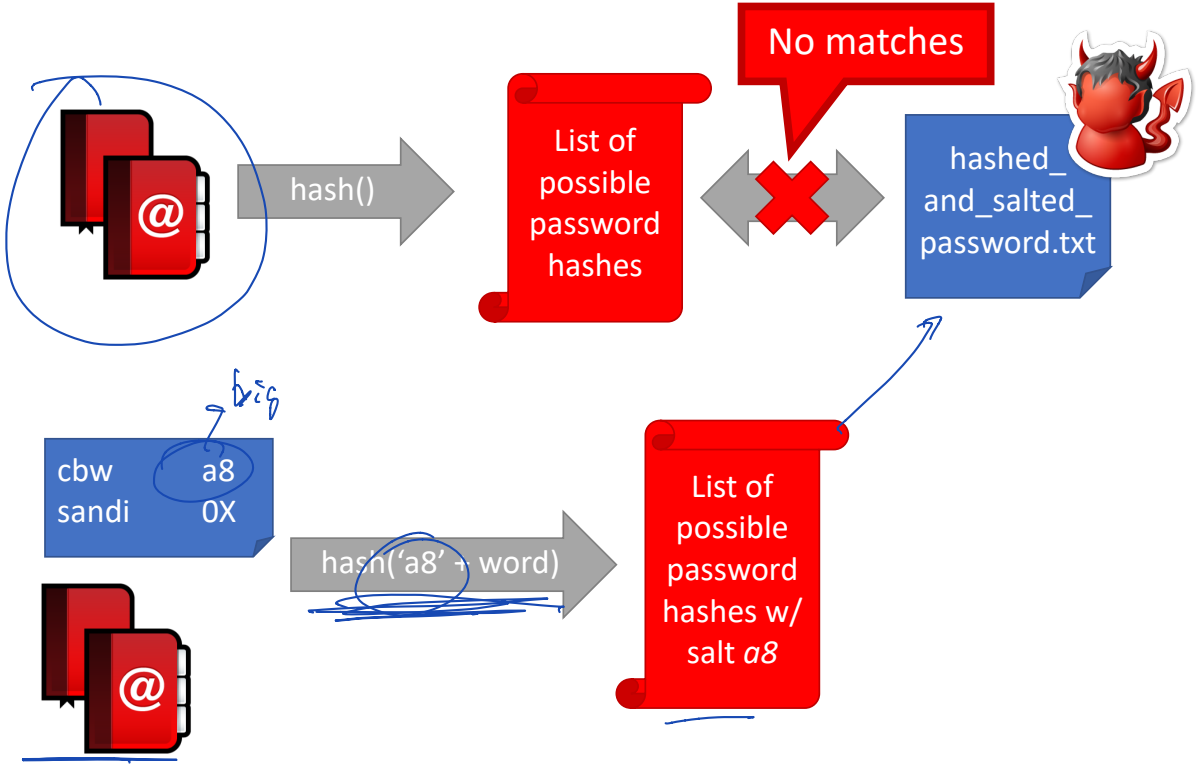
# Attacking Salted Passwords



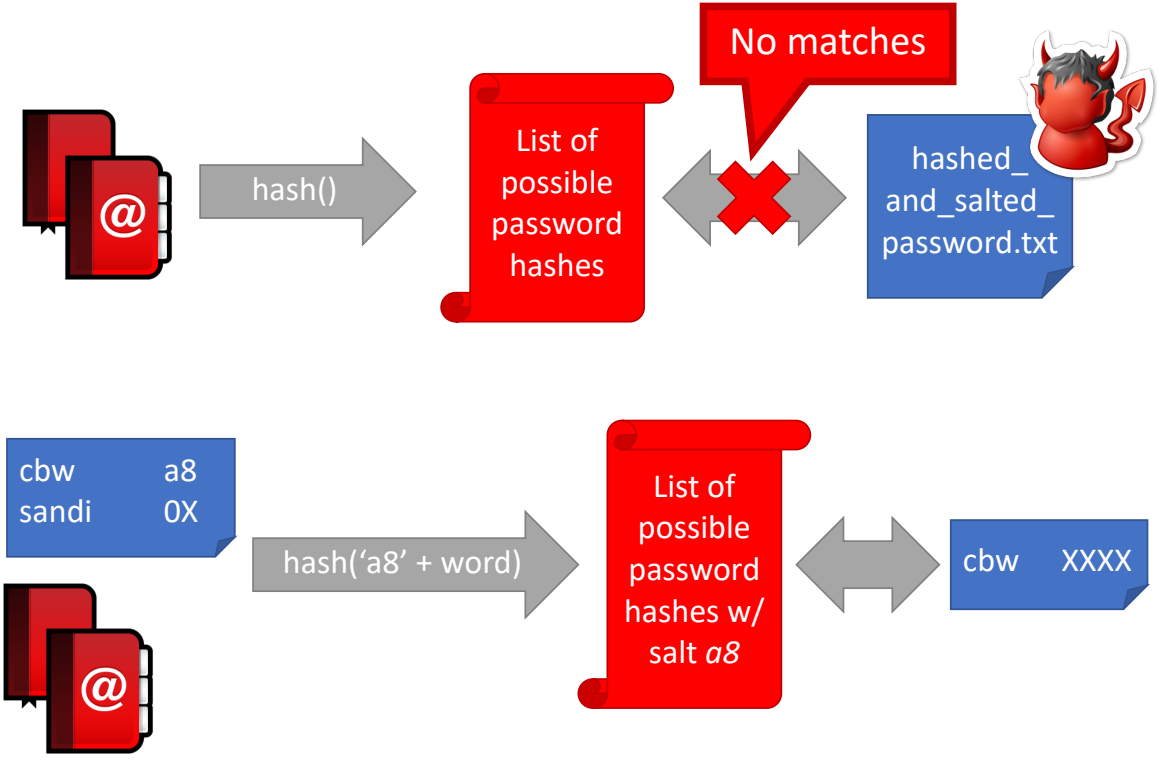
# Attacking Salted Passwords



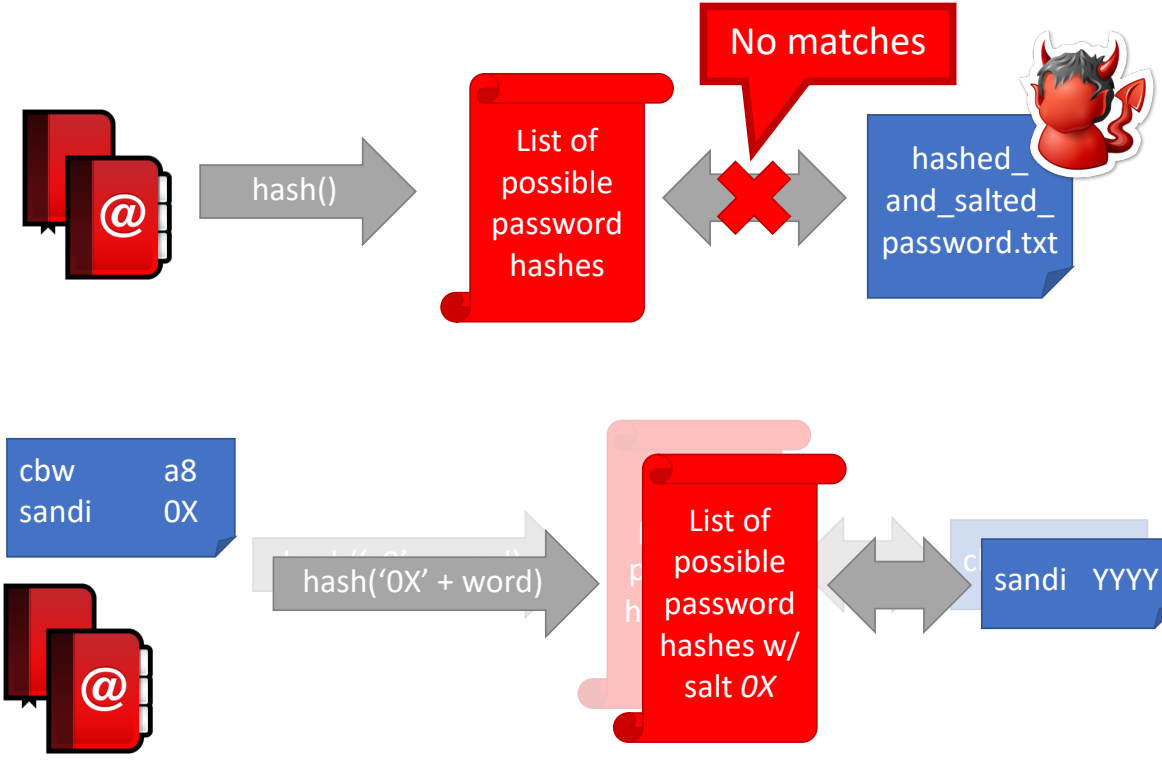
# Attacking Salted Passwords



# Attacking Salted Passwords



# Attacking Salted Passwords



# Breaking Hashed Passwords

- **Stored passwords should always be salted**
  - Forces the attacker to brute-force each password individually

# Breaking Hashed Passwords

- **Stored passwords should always be salted**
  - Forces the attacker to brute-force each password individually
- Problem: it is now possible to compute hashes very quickly
  - GPU computing: hundreds of small CPU cores
  - nVidia GeForce GTX Titan Z: 5,760 cores
  - GPUs can be rented from the cloud very cheaply
    - $0.9 per hour (2018 prices)

# Examples of Hashing Speed

- A modern x86 server can hash all possible 6 character long passwords in 3.5 hours
  - Upper and lowercase letters, numbers, symbols
  - $(26+26+10+32)^6$ = 690 billion combinations

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- A modern GPU can do the same thing in 16 minutes

210 minutes

# Examples of Hashing Speed

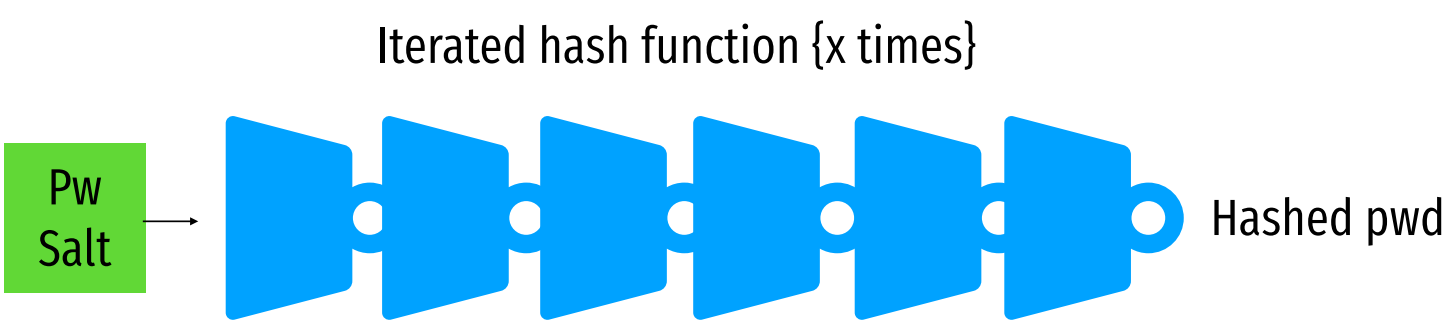
- A modern x86 server can hash all possible 6 character long passwords in 3.5 hours
  - Upper and lowercase letters, numbers, symbols
  - $(26+26+10+32)^6$ = 690 billion combinations
- A modern GPU can do the same thing in 16 minutes
- Most users use (slightly permuted) dictionary words, no symbols
  - Predictability makes cracking much faster
  - Lowercase + numbers → $(26+10)^6$ = 2B combinations

# Hardening Salted Passwords

- Problem: typical hashing algorithms are too fast
  - Enables GPUs to brute-force passwords
- Old solution: hash the password multiple times
  - Known as key stretching
  - Example: *crypt* used 25 rounds of DES
- New solution: use hash functions that are designed to be **slow**
  - Examples: bcrypt, PBKDF2, scrypt
  - These algorithms include a work factor that increases the time complexity of the calculation
  - scrypt also requires a large amount of memory to compute, further complicating brute-force attacks

ARGON

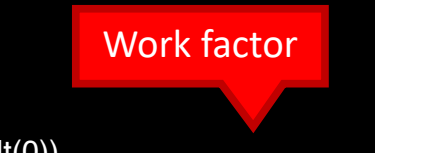
# Slow hash movement


Iterated hash function {x times}
Pw
Salt
Hashed pwd

# bcrypt Example

- Python example; install the *bcrypt* package

```
[cbw@localhost ~] python
>>> import bcrypt
>>> password = "my super secret password"
>>> fast_hashed = bcrypt.hashpw(password, bcrypt.gensalt(0))
>>> slow_hashed = bcrypt.hashpw(password, bcrypt.gensalt(12))
>>> pw_from_user = raw_input("Enter your password:")
>>> if bcrypt.hashpw(pw_from_user, slow_hashed) == slow_hashed:
...         print "It matches! You may enter the system"
...     else:
...         print "No match. You may not proceed"
```



# Best practices so far:

1. hashed & salted pwd storage
2. use a slow hash function.

---

3. how to handle pwd breaches
4. what kinds of failures of operation can we expect??

# Dealing With Breaches

# Dealing With Breaches

- Suppose you build an extremely secure password storage system
  - All passwords are salted and hashed by a high-work factor function
- It is still possible for a dedicated attacker to steal and crack passwords
  - Given enough time and money, anything is possible
  - E.g. The NSA
- Question: is there a principled way to detect password breaches?

# Honeywords

- Key idea: store multiple salted/hashed passwords for each user
  - As usual, users create a single password and use it to login
  - User is unaware that additional honeywords are stored with their account

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- Implement a honeyserver that stores the index of the correct password for each user
  - Honeyserver is logically and physically separate from the password database
  - Silently checks that users are logging in with true passwords, not honeywords

- assuming this server is secured

# Honeywords

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- Implement a honeyserver that stores the index of the correct password for each user
  - Honeyserver is logically and physically separate from the password database
  - Silently checks that users are logging in with true passwords, not honeywords
- What happens after a data breach?
  - Attacker dumps the user/password database…
  - But the attacker doesn't know which passwords are honeywords
  - Attacker cracks all passwords and uses them to login to accounts
  - If the attacker logs-in with a honeyword, the honeyserver raises an alert!

# Honeywords example

Database

| User | Salt 1 | H(PW 1) | Salt 2 | H(PW 2) | Salt 3 | H(PW 3) |
|---|---|---|---|---|---|---|
| Bob | aB | y4DvF7 | fl | bHDJ8l | 52 | Puu2s7 |
| sandi | 0x | plDS4F | K2 | R/p3Y8 | 8W | S8x4Gk |
| Alice | 9j | 0F3g5H | /s | 03d5jW | cV | 1sRbJ5 |

Honeyserver

| User | Index |
|---|---|
| Bob | 2 |
| sandi | 3 |
| Alice | 1 |

# Honeywords example

Bob

Database

| User | Salt 1 | H(PW 1) | Salt 2 | H(PW 2) | Salt 3 | H(PW 3) |
|---|---|---|---|---|---|---|
| Bob | aB | y4DvF7 | fI | bHDJ8l | 52 | Puu2s7 |
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# Honeywords example


SHA512(“fl” | “p4ssW0rd”) → bHDJ8l

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| Bob | aB | y4DvF7 | fl | bHDJ8l | 52 | Puu2s7 |
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# Honeywords example


SHA512(“fl” | “p4ssW0rd”) → bHDJ8l

Cracked Passwords

| User | PW 1 | PW 2 | PW 3 |
|---|---|---|---|
| Bob | 123456 | p4ssW0rd | Turtles! |
| sandi | puppies | iloveyou | blizzard |
| Alice | coff33 | 3spr3ss0 | qwerty |

Database

| User | Salt 1 | H(PW 1) | Salt 2 | H(PW 2) | Salt 3 | H(PW 3) |
|---|---|---|---|---|---|---|
| Bob | aB | y4DvF7 | fl | bHDJ8l | 52 | Puu2s7 |
| sandi | 0x | plDS4F | K2 | R/p3Y8 | 8W | S8x4Gk |
| Alice | 9j | 0F3g5H | /s | 03d5jW | cV | 1sRbJ5 |

Honeyserver

| User | Index |
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# Honeywords example


SHA512(“fl” | “p4ssW0rd”) → bHDJ8l

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|---|---|---|---|---|---|---|
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| sandi | 0x | plDS4F | K2 | R/p3Y8 | 8W | S8x4Gk |
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Honeyserver

| User | Index |
|---|---|
| Bob | 2 |
| sandi | 3 |
| Alice | 1 |

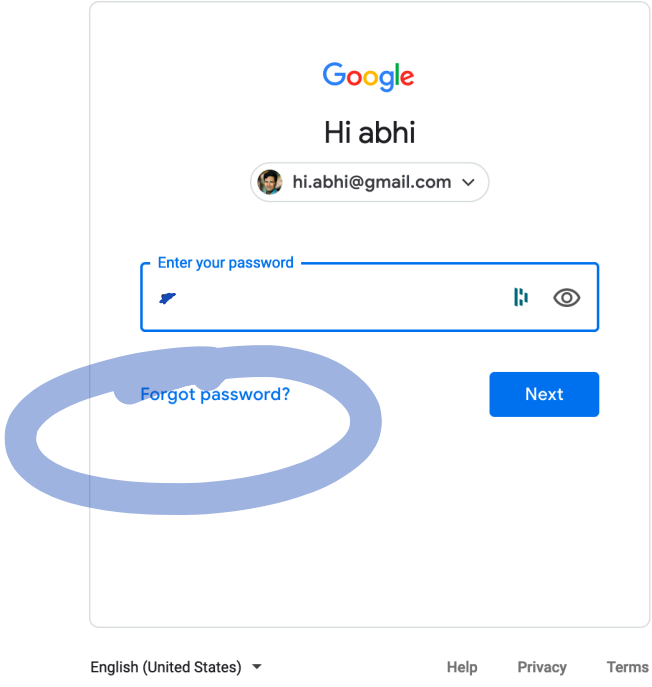
# Multiple layers of storage

# Password Storage Summary

1. **Never store passwords in plain text**
2. **Always salt and hash passwords before storing them**
3. **Use hash functions with a high work factor**
4. **Implement honeywords to detect breaches**

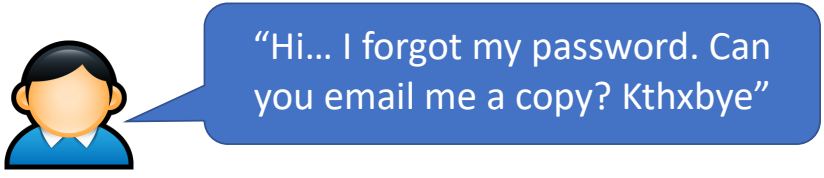
- These rules apply to any system that needs to authenticate users
  - Operating systems, websites, etc.

# Still one problem?



# Password Recovery/Reset

- Problem: hashed passwords cannot be recovered (hopefully)




- This is why systems typically implement password reset
  - Use out-of-band info to authenticate the user
  - Overwrite hash(old_pw) with hash(new_pw)
- Be careful: its possible to crack password reset

# Cracking Password Reset

- Typical implementations use Knowledge Based Authentication (KBA)
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- Experts recommend that services not use KBA
  - When asked, users should generate random answers to these questions