Passwords, or the "Weakest Link"
3 February 2016

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Spring 2016
User authentication today is a mess.
The case of Mat Honan
3 August 2012

- 4:33 p.m., “Mat Honan” called AppleCare reporting lost me.com e-mail password. Apple issued temporary password.
- “Mat” couldn’t answer his own security questions.
- Apple required only last four digits of a credit card and a billing address.
- 4:50 p.m.: Password reset e-mail arrived in Honan’s me.com e-mail box; used to reset Honan’s AppleID password
- 4:52 p.m.: GMail password recovery e-mail arrived in Honan’s me.com mailbox
- 4:54 p.m.: Honan’s Google account password changed.

Matt Honan, Wired correspondent
The case of Mat Honan
3 August 2012

• 5:00 p.m.: iCloud “Find My” tool used to wipe Honan’s iPhone
• 5:02 p.m.: Honan’s Twitter password reset
• 5:05 p.m.: Honan’s MacBook wiped
• 5:10 p.m.: The real Honan calls AppleCare
• 5:12 p.m.: Hackers post message on Honan’s Twitter account taking credit for the hack

Matt Honan, Wired correspondent
How did it happen?

- Attackers started by compromising Honan's Amazon account.
- Needed credit card number for Honan’s Amazon account. How did they learn it?
- Attackers called Amazon and **added** a new credit card number to Honan’s account. (Name, e-mail, and billing address sufficed.)
- Attackers called Amazon to reset Honan’s password. For identity verification, Amazon asked for a credit card number...

Matt Honan, *Wired* correspondent
How did it happen?

- Once logged in to Honan’s Amazon account, attackers learned last four digits of real credit card numbers.

- “The very four digits that Amazon considers unimportant enough to display in the clear on the web are precisely the same ones that Apple considers security enough to perform identity verification.”

Matt Honan, *Wired* correspondent
How did it happen?

- Then they called AppleCare…
- “It turns out, a billing address and the last four digits of a credit card number are the only two pieces of information anyone needs to get into your iCloud account. Once supplied, Apple will issue a temporary password, and that password grants access to iCloud.”
The result?

- Honan hadn’t backed up his data.
- He lost all of it, e.g., irreplaceable photos young daughter
- Why did hackers wipe his devices?
  - Just to prevent his regaining control of accounts!
- Honan’s suggested remedy… maybe in a later class…
- Honan got in touch with one of the hackers, Phobia, via instant messaging…

Quoth Phobia:
- “yea i really am a nice guy idk why i do some of the things i do.”
- “idk my goal is to get it out there to other people so eventually evry1 can over come hackers”
- “even though i wasnt the one that did it i feel sorry about that. Thats alot of memories im only 19 but if my parents lost and the footage of me and pics i would be beyond sad and im sure they would be too.”
And yet, last year...
User authentication

User authentication is proving your identity to a system (or another person).

- The starting point of nearly any security protocol.
The different mechanisms for user authentication:

- **The traditional three factors:**
  - Something you know: Passwords, PINs, answers to life questions, credit card numbers
  - Something you have: Authentication tokens, mobile phones, smartcards
  - Something you are: Fingerprint, voiceprint, iris code, gait analysis

- **Other possibilities:**
  - Somebody you know: Facebook “Trusted Contacts”
  - Contextual authentication

2015 Verizon Data Breach Investigations Report (DBIR): More than 50% of web app attacks were executed using stolen credentials.
How do people pick their passwords?
Often they don’t!

- In April 1994, English teenager ("Datastream Cowboy") penetrated Pentagon computers via the Air Force Rome (New York) Laboratory, started probing Korean nuclear facilities.
  - Deemed “No. 1 threat to U.S. military”.
  - How did he do it?
    - Guessed default guest password!
- Surveys show that half of users leave the default password in place for their routers at home.
- Canary: cybersecurity@home
Often they don’t!

- Examples from Kevin Mitnick’s *Art of Intrusion*
- NY Times employee database: pwd = last 4 SSN digits
- “Dixie bank”: 99% of employees used password “password123”
- What’s the most important thing in the world to prevent unauthorized access to?
  - Nuclear missiles!
    - From 1962 to 1977, the passcode for launching Minuteman missiles was… 00000000.
    - Strategic Air Command was more afraid of lost passwords than of Armageddon!
How might a researcher collect passwords?

**Passwords revealed by sweet deal**

More than 70% of people would reveal their computer password in exchange for a bar of chocolate, a survey has found.

It also showed that 34% of respondents volunteered their password when asked without even needing to be bribed.

A second survey found that 79% of people unwittingly gave away information that could be used to steal their identity when questioned.
Another way

• “Social gaming” site RockYou hacked in December 2009
  • SQL injection attack; good example of how breaches occur—more in a later lecture
• Disclosed 32 million user passwords; posted to internet
• Passwords were in clear (not hashed or encrypted)
• Main source today of research / knowledge about user password composition
Some findings

Worth even a candy bar?

Top 10 RockYou passwords

<table>
<thead>
<tr>
<th>Rank</th>
<th>Password</th>
<th>Number of Users with Password (Absolute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>123456</td>
<td>290731</td>
</tr>
<tr>
<td>2</td>
<td>12345</td>
<td>79078</td>
</tr>
<tr>
<td>3</td>
<td>123456789</td>
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</tr>
<tr>
<td>4</td>
<td>Password</td>
<td>61958</td>
</tr>
<tr>
<td>5</td>
<td>iloveyou</td>
<td>51622</td>
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<tr>
<td>6</td>
<td>princess</td>
<td>35231</td>
</tr>
<tr>
<td>7</td>
<td>rockyou</td>
<td>22588</td>
</tr>
<tr>
<td>8</td>
<td>1234567</td>
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<td>9</td>
<td>12345678</td>
<td>20553</td>
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<tr>
<td>10</td>
<td>abc123</td>
<td>17542</td>
</tr>
</tbody>
</table>

From Ashley Madison breach

- Result of cracking 4007 passwords
  - Top 20 worst passwords…
- Very similar to RockYou
  - Just a rather less polite…
  - And no 'iloveyou'

Measuring password strength

• Many ways to measure password strength

• “Entropy”: intuitively, the “randomness” of passwords over a population, and thus how hard for attacker to guess

• One important type:
  • Min-entropy: related to commonness of most popular password

• We’ll let “guessing probability” or GP denote probability of most probable password over a population; and GPP denote the (unique) password with the GP

  • Formally, for random variable Y with probability distribution \( P_Y(y) \), min-entropy (in bits) is \( H_{\text{min}}(Y) = -\log_2 \max_{y \in Y}(P_Y(y)) \). Max probability is \( 2^{\{-H_{\text{min}}(Y)\}} \).
Guessing probability

GP = 0.9%; i.e., 0.9% of users, about 1 in 111, have this password!

*In 2013 Adobe breach, GP = 1.6%, and GPP was "123456"!

Why is GP important?

- Measures vulnerability of the weakest accounts, which can be best for an attacker to target.
- If you get only a single guess at a password, you should guess the GPP.
  - Prob. of success is GP (about 0.9% for RockYou).
- If you can attack multiple accounts, best strategy is to try GPP against them sequentially.
  - Success in an expected (average) $1 / \text{GP}$ tries (about 111 for RockYou!)
People also choose poor PINs

- GP for PINs is 10%+!
  - i.e. you have a 1/10 chance of guessing a random person’s PIN correctly!
- GPP is…
  - 1234 (of course!)
- Another popular PIN:
  - 2580 (Why?)

<table>
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<th>PIN</th>
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</tr>
<tr>
<td>#2</td>
<td>1111</td>
</tr>
<tr>
<td>#3</td>
<td>0000</td>
</tr>
<tr>
<td>#4</td>
<td>1212</td>
</tr>
<tr>
<td>#5</td>
<td>7777</td>
</tr>
<tr>
<td>#6</td>
<td>1004</td>
</tr>
<tr>
<td>#7</td>
<td>2000</td>
</tr>
<tr>
<td>#8</td>
<td>4444</td>
</tr>
<tr>
<td>#9</td>
<td>2222</td>
</tr>
<tr>
<td>#10</td>
<td>6969</td>
</tr>
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<td>#11</td>
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<tr>
<td>#18</td>
<td>4321</td>
</tr>
<tr>
<td>#19</td>
<td>2001</td>
</tr>
<tr>
<td>#20</td>
<td>1010</td>
</tr>
</tbody>
</table>

Other interesting insights into how people think about PINs...

Repeated couplets (e.g., 0101) on diagonal

Years 19YY are here

DDMM dates are in this mass

But maybe users aren’t stupid after all…

- A recent paper…

- Recall **incentives**.
- Remembering passwords imposes **cognitive load**
  - Burden on memory
- To optimize security *and* cognitive load, Florencio et al. observe need for weak passwords in portfolio
How are passwords protected on servers?

And why are strong ones important?
Not all that well…

some losses…

Plus LivingSocial, Last.fm, eHarmony, etc. etc. etc.

Adobe
130 million (ECB-encrypted) passwords
Oct. 2013

Yahoo
273 million passwords
2014

Evernote
50 million passwords
March 2013

Ashley Madison
36 million passwords
August 2015
Passwords are generally protected via hashing.

\[ P = \text{“CatPajamas”} \]
To verify an incoming password…

\[ H(P') = H(P) \]
Hashing

• A hash function $H(P)$ applied to password $P$ has a one-wayness property:
  • It is possible to verify whether $P'$ is the correct password, i.e., $P' = P$.
    • Compute $H(P')$ and see if $H(P') = H(P)$
  • Otherwise, nothing can be learned about $P$ from $H(P)$.

• This seems great. If the system gets breached and hashes are leaked, passwords aren’t leaked.

• At least, not directly…
Hashing

• Unfortunately, the ability to check $P'$ leaks a lot of information…

• An attacker that learns $H(P)$ can keep testing guesses $P'$ until she guesses $P$ itself.

• This kind of brute-force guessing is known as *password cracking*. 
The art of password cracking

• Password crackers are software that performs brute-force guessing attacks against password hashes
• Basic password crackers guess common passwords, trying:
  • Dictionary words
  • Dictionary words spelled backwards
  • Proper names—people, streets, cities
  • License plate numbers
• Plus various manipulations:
  • Upper case / lower case
  • LEET substitutions
    • E.g., a <- @, etc.

If you’ve thought of it, they can too…
The art of password cracking

The tools just keep getting better:

- John the Ripper
  - Developed originally for Unix hash; now available for many hash types
  - GUIs such as Johnny bring tool within reach of nonspecialists
- Weir et al. (2009) cracker
  - Uses probabilistic context free grammars to model user password selection in the wild
  - 28% to 129% faster than John the Ripper
- RockYou was a boon for cracking!
...and they're getting faster

- Custom GPU-based hardware
  - A 5-server rig with 25 Radeon GPUs
  - 77 million md5crypt-hashed passwords per second
    - md5crypt() is used by FreeBSD and Linux

- Cloud-based cracking tools
  - CloudCracker, Cloud Cracking Suite (CCS)
  - Can use cloud-based browsers to do MapReduce jobs (almost) for free

Password attack path

(1) Steal $H(P)$

(2) Crack $H(P)$; get $P$

(3) Impersonate user

"Alice"
Given password risks, why can’t users follow short, sweet, sensible advice like this?


- Don’t use your login name in any form (as-is, reversed, capitalized, doubled, etc.).
- Don’t use your first or last name in any form.
- Don’t use your spouse's or child's name.
- Don’t use other information easily obtained about you. This includes license plate numbers, telephone numbers, social security numbers, the brand of your automobile, the name of the street you live on, etc.
- Don’t use a password of all digits, or all the same letter. This significantly decreases the search time for a cracker.
- Don’t use a word contained in (English or foreign language) dictionaries, spelling lists, or other lists of words.
- Don't use a password shorter than six characters.
- Do use a password with mixed-case alphabets.
- Do use a password with nonalphabetic characters, e.g., digits or punctuation.
- Do use a password that is easy to remember, so you don't have to write it down. [My emphasis]
- Do use a password that you can type quickly, without having to look at the keyboard. This makes it harder for someone to steal your password by watching over your shoulder.
Times have changed

• Note missing advice:
  • Don’t use the same password on multiple websites.

• Average user has many passwords now
  • At least 25 per user (probably higher today) [Florencio & Herley, 2007]
Some key points

- Strong passwords serve two goals.
  - They prevent online guessing attacks.
  - They prevent offline cracking attacks.
- Mainly useful for the latter. Why?
  - Online guessing can be throttled, i.e., slowed / stopped by service provider
  - Offline guessing can be performed arbitrary number of times
- Users are being required to protect themselves in case password hashes leak when systems get breached.
- The industry is basically forcing users to protect themselves against its mistakes!
Password advice comes from... xkcd

**Tr0ub4dor & 3**

- Uncommon (non-gibberish) base word
- Order unknown
-caps?
- Common substitutions
- Numerals
- Punctuation

(you can add a few more bits to account for the fact that this is only one of a few common patterns)

~28 bits of entropy

- $2^{29} = 3$ days at 1000 guesses/sec
- (Plausible, attack on a weak remote web service, yes, cracking a stolen hash is faster, but it’s not what the average user should worry about)

Difficulty to guess: EASY

Was it trombone? No, troubador, and one of the Os was a zero?

And there was some symbol...

Difficulty to remember: HARD

**Correct horse battery staple**

- Four random common words

~44 bits of entropy

- $2^{44} = 530$ years at 1000 guesses/sec

Difficulty to guess: HARD

That’s a battery staple.

Correct!

Difficulty to remember: You’ve already memorized it

Through 20 years of effort, we’ve successfully trained everyone to use passwords that are hard for humans to remember, but easy for computers to guess.
Other common ways passwords get compromised

- Social engineering
  - 2007 study by Treasury Dept. found that 61 of 102 employees could be convinced by “IT help desk” to change passwords.

- Password reuse across sites
  - Users average about 6 sites per password! (Florencio and Herley (2007))
Other common ways passwords get compromised

- Default passwords
- Illustrated by Gary McKinnon
  - Self-labeled “bumbling computer nerd”
  - In 2001 and 2002, hacked into 97 US military and NASA computers searching for evidence of free energy suppression and UFO coverups
    - “… shut down the entire US Army’s Military District of Washington network of over 2000 computers for 24 hrs”
    - “… rendered [US Naval Weapons Station Earle]’s entire network of over 300 computers inoperable at a critical time immediately following 11 September 2001”
- Method: Perl script randomly looking for blank and default passwords to administrator accounts
Other common ways passwords get compromised

- Malware
- Phishing
  - $1.5 billion lost to phishing in 2012 (RSA Feb. 2013 Fraud Report)
  - Can be highly sophisticated, as we’ll discuss in a lecture on social engineering…
- How did RSA get breached in 2010?
...and some exotic ones

E.g., reflections

- Raguram et al. iSpy: automatic reconstruction of typed input from compromising reflections. ACM CCS, 2011.

Figure 1: Some example threat scenarios that we investigated. Video was recorded in both indoor and outdoor environments, using various consumer video cameras. Top: shoulder surfing, bottom: reflection surfing, bottom right: key pop-out event.
and some exotic ones

Vibrations

- Philip Marquardt et al. iPhone: Decoding Vibrations From Nearby Keyboards Using Mobile Phone Accelerometers. ACM CCS, 2011.
And there’s a vast market for stolen passwords

• Online retailer account passwords can go for $1-$5.
• Social media account passwords can now be worth more than stolen credit card numbers.
• Reports of $325+ prices for Twitter usernames / passwords.

• Why?

The “Pentagon” store
Password recovery

How your dog Max threatens your identity
What happens when you forget your password?

Two popular recovery mechanisms:

• E-mail
  • Risks exemplified by Mat Honan’s story

• Personal questions
  • Also called “security questions,” “personal knowledge questions,” or “life questions”
  • Another something-you-know factor
Sarah Palin’s password recovery

- On 16 Sept. 2008, then Gov. Palin’s Yahoo! account was hacked. How?
- Password reset
  - Zip code?
    - Only 2 in Wasilla
  - Date of birth?
    - Wikipedia: February 11, 1964
  - Where did you meet your spouse?
    - Wikipedia: met Todd in high school...
- Password posted to /b/ on 4chan.
- When everyone tried to log into Palin’s account, Yahoo! finally detected attack
- 20-year-old hacker David Kernell (a.k.a. Rubico) caught
  - Sentenced to one year of federal prison
Problems with security questions

- What’s your high school mascot?
- Name of favorite elementary school teacher?
- Name of college you applied to but did not attend?
- Who is your favorite president? What is your favorite color? (Um, is it Calvin Coolidge?)
- Which college did you attend?

Answers easy to guess or find out...

- Name of your first / favorite pet?

- First name of your best friend?
  - 10% of men: James/Jim, John, Robert/Bob/Rob
  - Top 500 names achieve 65% coverage
  - Information available from Facebook, etc.
  - Where you went to school, college athletic rivals, favorite book/movie/pastime, high school mascot

Bella, Max top list of most popular dog names in 2013

Michelle Healy, USA TODAY  8 p.m. EST December 20, 2013
or hard to remember...

- Name of the street you grew up on?
  - There can be more than one.
- Name of your best friend?
  - Depends on my mood.
- City where you were born?
- People lie to increase security… then forget their answers.

Slide source: V. Shmatikov, 2014
Federal:
• What is a relative's telephone number that is not your own?
• Type a significant date in your life?
• What is the name of the manager at your first job?

Individual states:
• What is your youngest child's birth weight?
• What color was your first bicycle?
• If you needed a new first name, what would it be?
• What band poster did you have on your wall in high school?
• How many bones have you broken?
One password defense: Expiration
Password expiration

• Common interval: 90 days
• May help sometimes, but…
  • Helps users forget passwords
    • Estimated $150 cost per user per year
    • META group estimate: 1.75 help desk calls a month; Gartner group: 30% of calls are for password resets; Forester research: $25 / call
• Makes social engineering worse

8 glasses of water / day and 90 days between password resets
Password expiration

How do users change their passwords?

Password1
Password2
Password3
Pa$sword1
Password expiration

UNC Experiment:

- Obtained password hashes (MD5, no salt) from 10374 defunct UNC accounts
- Cracked password other than last one in 7752 accounts
  - Call these "eligible" accounts
- Defined set $T(P)$ of transformations ("tweaks") on password $P$
  - E.g., `s' <- '$' (LEET), '1' <- '2', etc.
- Given cracked password, found future password in $T(P)$ for 41% of eligible accounts
  - Most effective algorithm tried expected 481607.44 elements of $T(P)$

Password managers to the rescue!
Password managers

• Why should users have to remember passwords?
• Password managers solve this problem.
  • LastPass, RoboForm, Dashlane, KeePass, etc.
Password managers

• Idea: Encrypt all of your passwords under a single, master password

• One password to rule them all…

Password = 123456
Password managers

• The good:
  • Vault makes it easy to use strong passwords
  • E.g., automatically generated passwords
    • See lastpass.com/generatepassword.php
    • Passwords like "1UjCQMd8d0"

<table>
<thead>
<tr>
<th>Web site</th>
<th>Login</th>
<th>Password</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://www.ifca.org">www.ifca.org</a></td>
<td>Alice</td>
<td>SleepyGrumpy</td>
</tr>
<tr>
<td><a href="http://www.mybank.com">www.mybank.com</a></td>
<td>Alice</td>
<td>HappyDopey</td>
</tr>
<tr>
<td><a href="http://www.iacr.org">www.iacr.org</a></td>
<td>Alice</td>
<td>DocBashful</td>
</tr>
</tbody>
</table>
Password managers

• The bad
  • Why might a master password be weaker than an ordinary one?
    • You have to type it *often*
    • You often have to type it on a mobile device
  • How is a master password cracked?
    • Slight modification of John the Ripper, etc.

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</tr>
</tbody>
</table>
Password managers

• The ugly
  • Password vaults backed up in cloud
  • Effectively protected only by master password
  • Why? Synchronization / recovery
  • What does this mean?
    • Bad master password 🚭 all your vault passwords vulnerable to cracking attack
Password managers

• The ugly

• Of course, password management services are a nice target for hacking

• LastPass has been breached *twice*!

• 2011: LastPass asks users to change master passwords

• 2015: "LastPass account email addresses, password reminders, server per user salts, and authentication hashes were compromised"
Implementation issues

- Password vaults can be buggy—like any other software.
- Recent study found serious vulnerabilities in five popular managers
  - Analyzed five popular password managers

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<th>User Interface Vulnerabilities</th>
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<td>✓ ([4.2.1])</td>
<td></td>
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<td>✓ ([27])</td>
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<td>✓ ([4.4])</td>
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<td>✓ ([4.3.1])</td>
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<td>✓ ([4.3.2])</td>
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<td></td>
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</tr>
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</table>

Table 2: Summary of Vulnerabilities Discovered. NA identifies vulnerabilities not applicable to the particular password manager because it does not provide the relevant functionality.
Passwords are very interesting anthropological artifact!

Keepsake passwords... ritualize a daily encounter with personal memories

"Fiona Moriarty, a competitive runner... often used "16:59" — her target time for the 5,000 meters in track"

"To help quell his anger at his ex-wife soon after their divorce, Estrella had reset his password to "Forgive@h3r."

"[H]e moved on to other goals: “Quit@smoking4ever” (successful); “Save4trip@thailand” (successful); “Eat2@day” (“it never worked, I’m still fat,” Estrella wrote); “Facetime2mom@sunday” (“it worked,” he said, “I’ve started talking with my mom every week now”)."

Lecture takeaways

User authentication is a mess because of...

• Weak secrets
  • Users choose weak passwords or…
    they don’t change defaults or…
    they give passwords away for candy.
  • “Life questions” encourage weak answers—or forgettable ones.
  • Guessing probability GP (or min-entropy) is a key measure of strength.

• Password cracking
  • Password hashes can be “cracked” when passwords are weak.

• Password managers are a good idea, but need work.