# TEU00311

## What is the Internet doing to me? (witidtm)

Stephen Farrell
stephen.farrell@cs.tcd.ie

https://github.com/sftcd/witidtm
https://down.dsg.cs.tcd.ie/witidtm

# (Mostly) About Passwords

- Background on passwords and their uses
- Password handling and a bit on password cracking
- Exercise for you today: think about how you handle your passwords

# More detail exists...

- In 2018/2019 I taught a 4th year/MSc module on scaleable computing where the students spent a lot of time cracking password hashes
- These slides evolved from a lecture from that module, which is similar but more technical:
  - https://github.com/sftcd/cs7ns1/blob/master/lectures/about-passwords.pdf
- Hopefully I’ve adjusted the content correctly for you, but do let me know
  - I’ve left in some bits that we’ll just skim over to give a flavour of what’s possible (for an attacker) and in case your future self has to care about that kind of thing
  - I’ve added some content on password managers

# Passwords are horrible (1)

- Weak (guessable) passwords are inevitable – implicit in allowing “human memorable” values
  - “123456” almost always the most-used
- Re-use of (related) passwords is inevitable
  - Das, Anupam, et al. "The Tangled Web of Password Reuse." NDSS. Vol. 14. 2014. https://www.cs.cmu.edu/~anupamd/paper/NDSS2014.pdf
- Attacker often does not need all passwords, just a few good ones
  - e.g. belonging to an admin or manager

# Passwords are horrible (2)

- Password entry user interfaces lend themselves to phishing
  - Distinguishing browser “chrome” from web content is very hard for a user
- Mandatory “hard” password policies or password rotation force users to game the system
- Accessibility? What if you can’t use a keyboard?

# But... passwords are also great!

- Can be human memorable
  - Try that with your SSH private key! (SSH == secure shell, a command line thing)
- No need for h/w tokens or special s/w tools
- People can change passwords (even if they don’t)
- Passwords can link authentication between diverse systems
  - E.g. IPsec VPN access governed by ActiveDirectory login
- Fallback is required in any system – and you can fallback to closing a loop for a password reset
  - Main fail of a scheme I helped with called HOBA – RFC 7468
    - https://tools.ietf.org/html/rfc7486

# But... passwords leak (1)

- Attackers very rarely, if ever, try to grab passwords as they go by in a network packet (but they might, so don’t allow that)
  - Careful of man-on-the-side attacks!
- Attack password entry (phishing, keylogging)
  - Can be done at scale, if you can get malware to host
- Masquerade as server, e.g. via borked DNS in coffee shop
  - Recall the HTTP->HTTPS demo in the lab
- Grab a copy of the password verifier database
  - And then dictionary attack that – 1% success rate can be enough!

# But... passwords leak (2)

- Trickle brute-force attacks on online services
  - Esp. sshd but anything really – that happens **all** the time for all services exposed to the Internet
- Access/purchase a DB of leaked passwords and try those elsewhere or on the original leaky site
  - If joe.bloggs@accounts.example.com has password “123456” then it’s worth trying variants of that password with a possible account like joe.bloggs@example.net
- Bugginess: user enters password in username field; system logs failed login by user “123456”; “oops!” says user, then successfully logs in as “joeblow”; system logs get centralised; logs contain cleartext passwords easily correlated with usernames
- How else might passwords leak?

# Firefox (nightly) sez...

- It has 273 “logins” stored for me (was 270 a year ago, 265, 259 the years before that)
- Many are duplicates, e.g. same login for different cs.tcd.ie web pages, where URLs change from time to time
- Many are outdated, e.g. my home-router before last
- Many are for conference technical programme committees that change from year to year
- Almost all have auto-generated crap for passwords (so not human memorable), some also for usernames (if the password isn’t memorable, maybe the username also doesn’t need be)
- None are (IMO) highly sensitive: Not banking, not github, etc
- Of my other browsers:
  - Opera has home network logins and one online service that uses certificate-based TLS client authentication
  - Chromium, Brave, Vivaldi have zero stored logins (I hope!)

# Your passwords?

- How many? What kinds? How chosen? How protected? How long-lived?
- <your input here>

# What’s a person to do? (1)

- Use password managers
  - Pros/cons?
- Avoid new accounts
  - Can you? Do you? Why? Why not?
- Avoid passwords where possible
  - SSH, USB tokens, even HOBA:-)
  - Key management?
- Two-factor authentiction (2FA) if you can and are willing/able

# What’s a person to do? (2)

- Try hard to never use a terribly weak password
  - You never know if the system for which you create/update a password will end up being important for you
- Firefox (nightly) and maybe other browsers now warn when you access a site that (they reckon) has had a password DB leak or other similar incident
  - Collaboration with https://haveibeenpwned.com/
- Do not kick the bucket!
  - Post-mortem credential handling is kinda hard (but a real issue)

# Server side considerations

- It’s maybe useful to think a bit about the sysadmin view, or server side, here because:
  - You’ll hear some of these terms, e.g. if there’s a data-leak from some service you use
  - You may end up being a sysadmin or the boss of some sysadmins some day
    - For your home network, you almost certainly kind-of will be a sysadmin
  - It might help you choose between services when you have a choice
  - It might help you whine at a sysadmin if they’re being dumb:-)
- Don’t worry if the detail here is too much...

# What’s a sysadmin to do? (1)

- Try not use passwords, esp. for admin purposes
  - Does a user **really** need to create an a/c? Is the minimal marketing benefit worth the risk of adding possibly toxic data to your DB?
- Try hard to insulate users from client-side attacks: CORS, XSS, etc.
  - You won’t ever know all possible attacks, so just make sure it’s someone’s job to be on top of that
- Monitor and protect your systems
  - fail2ban, denyhosts, other intrusion detection systems (IDSes)
- Try (but fail) to deploy universal single-sign-on (SSO)

# What’s a sysadmin to do? (2)

- Avoid holding the password verifier DB, e.g. outsource to “IT” or a mega-scaler or service provider
  - But – centralisation of the web is a real problem, as is control
- Ensure best-practices for password verifier DB
  - More on that in a minute
- Maybe: use password authenticated key exchange (PAKE) schemes where that makes sense
  - Caveat: I’m a skeptic for many claimed uses of PAKEs – the hard problems with passwords are **not** really cryptographic ones
  - But... some service providers are getting keen on PAKEs

# What’s a sysadmin to do? (3)

- Use two-factor authentication (2FA)... which does help
- Need caution in ensuring authentications are really out-of-band of one another
  - SMS messages – SS7 protocol attacks: Holtmanns, Silke, and Ian Oliver. "SMS and one-time-password interception in LTE networks." Communications (ICC), 2017 IEEE International Conference on. IEEE, 2017. https://ieeexplore.ieee.org/document/7997246/
- Google USB token claiming success against phishing
  - https://krebsonsecurity.com/2018/07/google-security-keys-neutralized-employee-phishing/

# What’s a sysadmin not to do?

- Do not follow “traditional” password policies
  - Read this instead: Florêncio, Dinei, Cormac Herley, and Paul C. Van Oorschot. "An Administrator's Guide to Internet Password Research." LISA. Vol. 14. 2014. https://www.usenix.org/system/files/conference/lisa14/lisa14-paper-florencio.pdf
  - Main result is there’s a huge gap between online guessable and offline dictionary attackable – do require systems/user-pwds to not be online guessable but no more, and do make sure offline dictionary attacks (and hence passwords) are hard-enough but don’t care much more than that
- Do not enforce password “quality” requirements
  - Do encourage (not require) higher-entropy passwords e.g. via meters: Egelman, Serge, et al. "Does my password go up to eleven?: the impact of password meters on password selection." Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 2013. https://www.guanotronic.com/~serge/papers/chi13b.pdf
- NIST recanted on decades-old guidance recently
  - https://www.passwordping.com/surprising-new-password-guidelines-nist/

# Biometrics eh?

- Beware of biometrics!
  - You cannot easily change your fingerprint, retina, toe-smell!
  - And biometric verifiers can be fooled as much as anything (and haven’t been tested near as much as some things)
- CCC 2017: 55 minute video of breaking biometrics
  - Fingerprint stuff about 24 mins in
  - https://www.youtube.com/watch?annotation_id=annotation_2684251971&feature=iv&src_vid=pIY6k4gvQsY&v=VVxL9ymiyAU
- Fiebig, Tobias, Jan Krissler, and Ronny Hänsch. "Security Impact of High Resolution Smartphone Cameras." WOOT. 2014.
  - https://www.usenix.org/system/files/conference/woot14/woot14-fiebig.pdf

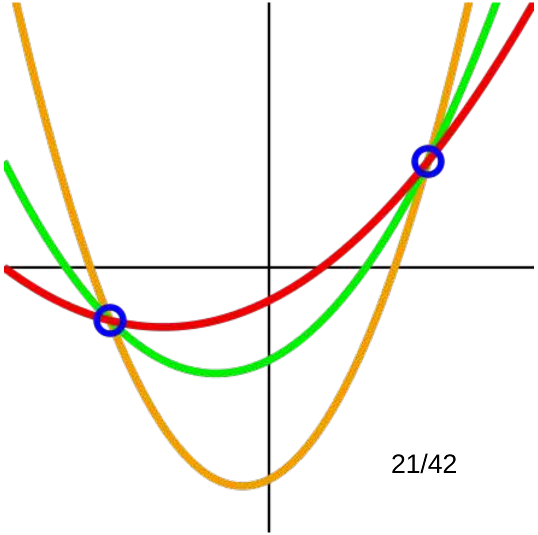
# Aside: secret sharing

# Aside: shamir secret sharing

- Nice function to give intuiton into how cryptographic functions tend to work
- HOWTO create “n shares” so that combining any k-of-n allows you to re-calculate a secret
- Shamir, Adi. "How to share a secret." Communications of the ACM 22.11 (1979): 612-613.
  - According to Google scholar: “Cited by 17484”
  - https://web.mit.edu/6.857/OldStuff/Fall03/ref/Shamir-HowToShareASecret.pdf

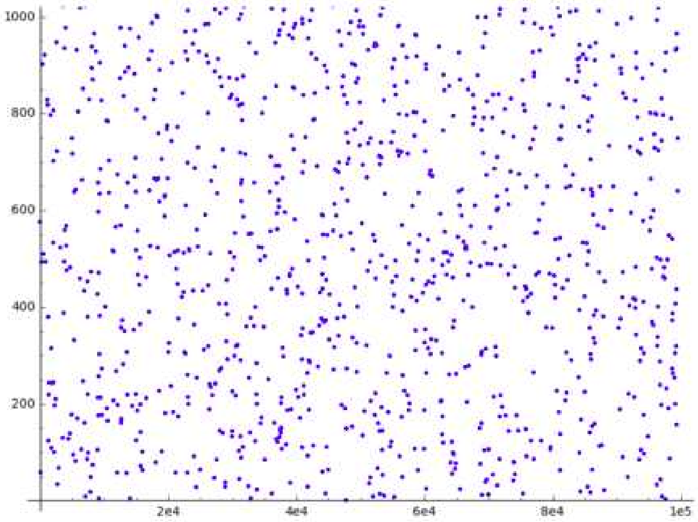
# Shamir Secret Sharing

- Given a secret, how can I give n people a value such that once at least k (<=n) people get together they can reconstruct the secret?
- Shamir's scheme: If I have a polynomial of degree k-1, and I give each person one point (e.g. "i,f(i)" for i=1..n) then if any k of them get together they can find the formula for the polynomial and hence the secret
  - Usually the secret is "f(0)"
- Intuition: I need two points to know the formula for a line. I need three points to find the formula for a quadratic, etc.
  - https://en.wikipedia.org/wiki/Shamir%27s_Secret_Sharing
  - Figures on this and next slide from that Wikipedia page



# More on Shamir

- For security reasons we choose polynomials over a finite field e.g. F(p) with p a prime that’s big enough for the given k-of-n scenario
  - With a polynomial over the reals, k-1 points can allow guessing of the k-th point a bit too easily, e.g. if secret value were “small” guessing may be cryptographically efficient
- Intuition: polynomial curves over finite fields are more “random” looking
- We end up dealing with polynomical coefficients that are maybe 64 or 128 bit values
  - Hey, it’s crypto:-)



Ok, here comes the password hashing nitty-gritty....

Again, don’t worry:-)

Our goal is that you properly understand stories such as: https://arstechnica.com/information-technology/2019/09/doordash-hack-spills-loads-of-data-for-4-9-million-people/

# Password verifiers

- User enters username (u) and password (p)
- System transmits u & p to verification system
  - Rarely sends a processed password – could do but system problems often mean p is in clear at the application layer even if encrypted via TLS at the transport layer – what system problems might those be?
- System uses u to retrieve password verifier (pv) value from database (call that PVDB)
- System checks if f(p,pv)==’ok’ for some function ‘f’
  - You need to be able to replace ‘f’ without changing all passwords so really PVDB contains some form: of: u,f,pv

# Salts

- PVDB has many u,f,pv entries
- What if two users have the same password?
- Don’t want u1,f,pv1 and u2,f,pv1 in the same PVDB as that’d help an attacker quite a bit
  - New attack enabled: if I can read *“/etc/passwd/”* then I could keep changing my password until my pv is the same as someone else’s
- So we use a salt – a randomly chosen string that’s set whenever the password changes
  - Now we’re storing some form of u,f,s,pv
- Longer salts make dictionary attacks harder
- One possibility is to use a cryptographic hash function as part of f, to generate pv

# PVDB Protection

- Is it useful to encrypt the entire PVDB?
- What else might we do to protect the PVDB?
  - Hint: consider the risk as being something like:

    probability(PVDB leaks) x cost of the leak

# Cryptographic Hashes (1)

- Cryptographic hashes are one-way functions that take arbitrary input and produce a fixed-size output
  - Reversing hash should be cryptographically “hard” - say 2^128 units of work for some sensible unit
- Many uses in cryptography, usually we want hash functions to be highly efficient
  - Signature on LARGE file...
- Hash functions should be:
  - Collision resistant: finding x,y s.t. H(x)==H(y) is hard
  - Pre-image resistant: given x, s.t. x==H(y) finding y is hard
  - 2nd-pre-image resistant: given x, finding y s.t. H(x)==H(y) is hard

# Cryptographic Hashes (2)

- Finding collisions is **much** easier than pre-images due to birthday paradox
  - https://en.wikipedia.org/wiki/Birthday_problem
- If hash output length is n, then 2^(n/2) work to find a collision, and 2^n to find a pre-image for a perfect hash function
  - It can be important to understand that difference
  - Note: 2^128 is a **lot** less than 2^256!
- Hash function names:
  - MD5, SHA-1, **SHA-256**, SHA-512, SHA-3 family, ...

# Properties of ‘f’?

- Do we want ‘f’ to be speedy?
- Do we want ‘f’ to use as little memory as possible?
- Do we want ‘f’ to be easy to parallelise?

- ‘f’ is often called a password hashing algorithm but is really a verifier, the password hashing alg produces pv given p and s (and sometimes u)
  - It’s ok to not be terminologically pure:-)
- See https://password-hashing.net/ for much more on a recent competition related to that kind of function

# MD5

- MD5 is an old hash function, probably older than most in this room:-)
  - See RFC 1321 (https://www.rfc-editor.org/rfc/rfc1321)
  - MD5 has 128 bit output, is very fast and has been broken for collisions (with ~2^18 work)
- But let’s say we base f on a simple use of the MD5 hash function...
  - That’s really dumb! But is done all the time.
- In that case ‘f’ is something like:
  - (pv==md5(salt||p)?”ok”:”not-ok”)
    - Where || is catenation
- Unsalted versions are also used (OMG!)
  - (pv=md5(p)?”ok”:”not-ok”)
- Really easy to reverse via dictionary attack

# Dictionary Attack (1)

- Say you have md5(x), what’s x?
  - While MD5 is broken for collisions, pre-images are still much harder so we won’t try reverse the hash directly (yet!)
- But we can guess x, esp if x is human memorable
  - Human memorable => 40 bits or less of entropy
    - => 2^40 search space => easy
- Algorithm:
  - Define the search space; guess=first_guess();
  - while f(guess,s,pv)!=”ok”) guess=next_guess();
- Note: next-guess() might do more than just take the next word from a list, e.g. if current guess==”password” next_guess() might return “password01” or “passw0rd”

# Dictionary Attack (2)

- Can be easier still if:
  - We know about the possible/likely alphabet
  - We have a set of substrings that may be (part of) the password
  - We know something about the length of the password
- Dictionary attacks: The set of algorithms that base guesses on a dictionary of words, guessing the next variant and keep going ‘till we’ve run out of search space, computational resources or we’ve won the game.
- If the “words” used are just random strings from an alphabet less than some length then we’d call that a **brute force** attack
- If ‘f’ uses a salt, then we need to explore the space of ‘s’ via brute force, but the space of ‘p’ could still use a dictionary
  - So the salt slows down the dictionary attack, in proportion to the length of the salt

# So MD5 is crap, how’s SHA-512?

- Standard linux hashes of the “sha-512” (or “$6”) variety:
- See ``man 3 crypt`` on your local linux
- Uses SHA-512 hash, iterated 5000 times
  - ‘s’ and ‘p’ are chars from [a-zA-Z0-9/]
  - ‘s’ is 16 chars, default random per ‘p’
- Output from ``mkpasswd -m sha-512 foo`` has format:

  $6$<salt>$<hash> and could be :

  $6$m45hbNT1w/f$gSX6x7nnEwkYTWskeNmz.j7XALhcOVcLL/
  c5oxMfrZy4bbYZsKa2la2yQGPfs0zgSQnPjCtW3mDkPgVqTFqHh.
- Details are gnarly and may be described by:
  - https://www.akkadia.org/drepper/SHA-crypt.txt
  - Seems like a less clean PBKDF2 (RFC8018, https://www.rfc-editor.org/rfc/rfc8018)

# So we had crap, then messy, ...

- Unsalted MD5 is terrible because it’s so quick
- SHA-512 flavour crypt is slow but attacks can benefit from parallelism, e.g. multiple GPUs
- Argon2 won the password hashing competition and is explicitly designed to be a better ‘f’ that’s memory intensive and time-memory trade-off resistant
  - RFC9106 - https://datatracker.ietf.org/doc/html/rfc9106
- All very nice, but after PHC win some issues discovered, “fixed” by Argon2d (Argon2i won the PHC), and deployment is (so far) limited

# A good password recovery paper...

- Hranický, Radek, Martin Holkovič, and Petr Matoušek. "On Efficiency of Distributed Password Recovery." Journal of Digital Forensics, Security and Law 11.2 (2016): 5.

  https://commons.erau.edu/cgi/viewcontent.cgi?article=1380&context=jdfsl

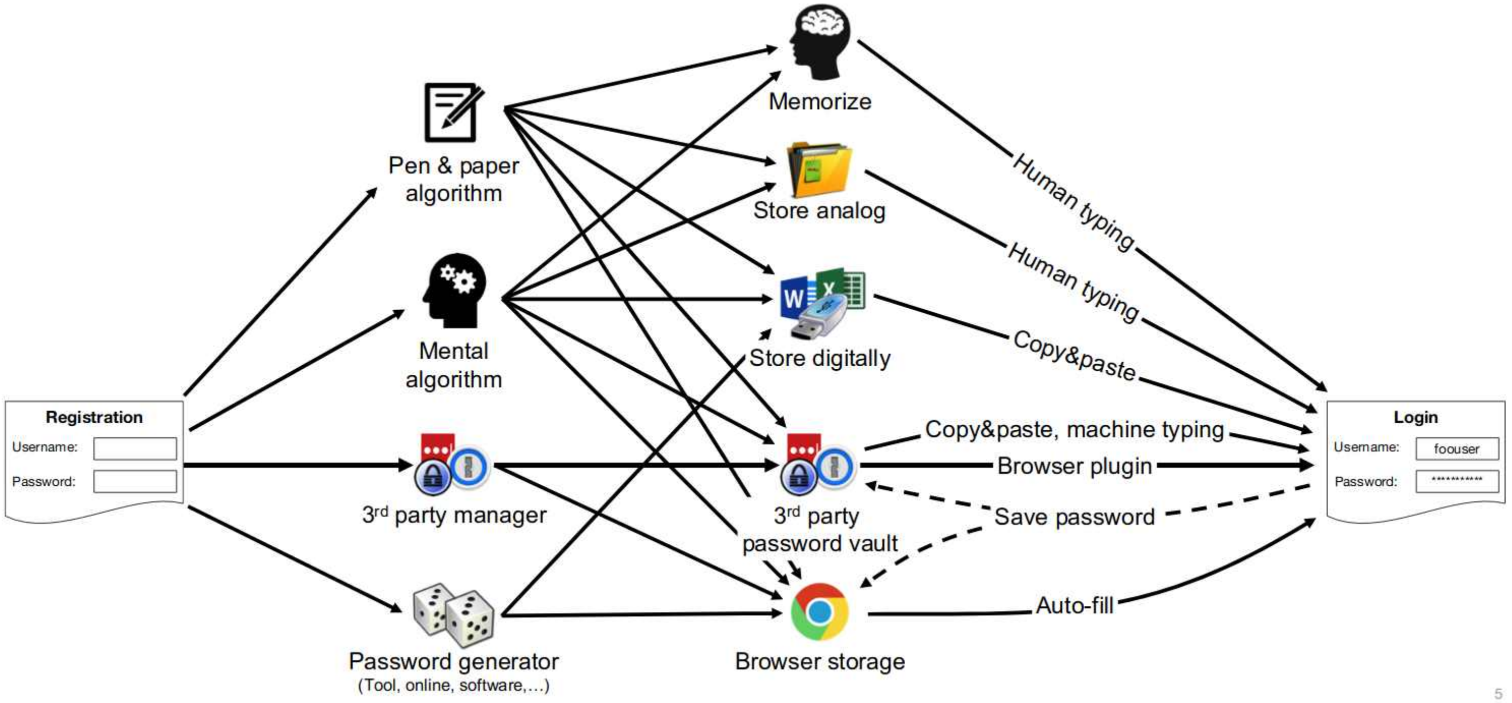
- Describes challenges/opportunities in distributed computation for hash cracking with a nice description of implementation and measurement issues

# Password Managers

# Password Managers

- Basic idea: humans are crap at managing usefully complex passwords and services are crap at not letting PVDB’s leak, so why not have a bit of client-side software handle all your passwords?
- This can make sense, but there are trade-offs
- For me, so far, I’ve not gone down this route, but I might, depending...
  - My current setup works, but would make for a lot of work if my laptop were stolen

# Password Handling Strategies



Lyastani, Sanam Ghorbani, et al. "Better managed than memorized? Studying the Impact of Managers on Password Strength and Reuse." 27th {USENIX} Security Symposium ({USENIX} Security 18). 2018. https://www.usenix.org/system/files/conference/usenixsecurity18/sec18-lyastani.pdf

# Some Resources (accessed 2022-10-18)

- Wikipedia page with a list and nice characterisation of products and features:
  - https://en.wikipedia.org/wiki/List_of_password_managers
- More commercial lists/reviews:
  - Caveat: I am not recommending specific products!
  - Some of the article authors here make money from people buying these products/services
  - Tom’s guide:
    - https://www.tomsguide.com/us/best-password-managers,review-3785.html
  - CNET “best of”:
    - https://www.cnet.com/tech/services-and-software/best-password-manager/
  - PC mag “best of”:
    - https://www.pcmag.com/picks/the-best-password-managers

# Factors to consider

- Are you ok with just letting your browser(s) do it? Some can sync over >1 device within the browser (e.g. if you create a Firefox account or are a dedicated Apple-fan)
- How much time do you want to invest in start-up/testing costs?
  - **BUT** how much might you lose if some of your passwords leak?
- Support for your preferred current/future platforms (OSes, browser prefs, ...)
- Cost, limitations (e.g. syncing)
- Form filling for the forms you care about (usually via browser extensions)
- Open/closed source (important for me)
- Developer has history of fixing problems quickly?
- Server sync needed or just client-side?
- How many eggs do you like in how many baskets?
  - https://www.zdnet.com/article/lastpass-bug-leaks-credentials-from-previous-site/

# Conclusion

- Passwords are unavoidable and crap
- They can be handled more or less well at a systems level and cryptographically
- Dictionary attacks (of various forms) will likely have some percentage success
- You should think about whether you ought use a password manager
- Re-use passwords less!

# Questions? Things to add?

- <your text here>