# How to (not) Share a Password:

## Privacy preserving protocols for finding **heavy hitters** with **adversarial** behavior

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# Passwords

- First “modern” use in MIT's CTSS (1961)
- “Passwords are dead”?
- User tend to choose passwords with **low** min–entropy
  - Easy to guess

# Compromise a User, Attack the Eco System

- Bad passwords do not only compromise the users
- Weak and popular passwords can be used for large scale attack
  - E.g. the Mirai attack
  - Easy to find IoT devices with Shodan like search engines
  - Unique weak passwords might be ok, popular passwords are bad
- Service provider liability?
  - Force users to change passwords, but to what?

# California Guideline for IoT

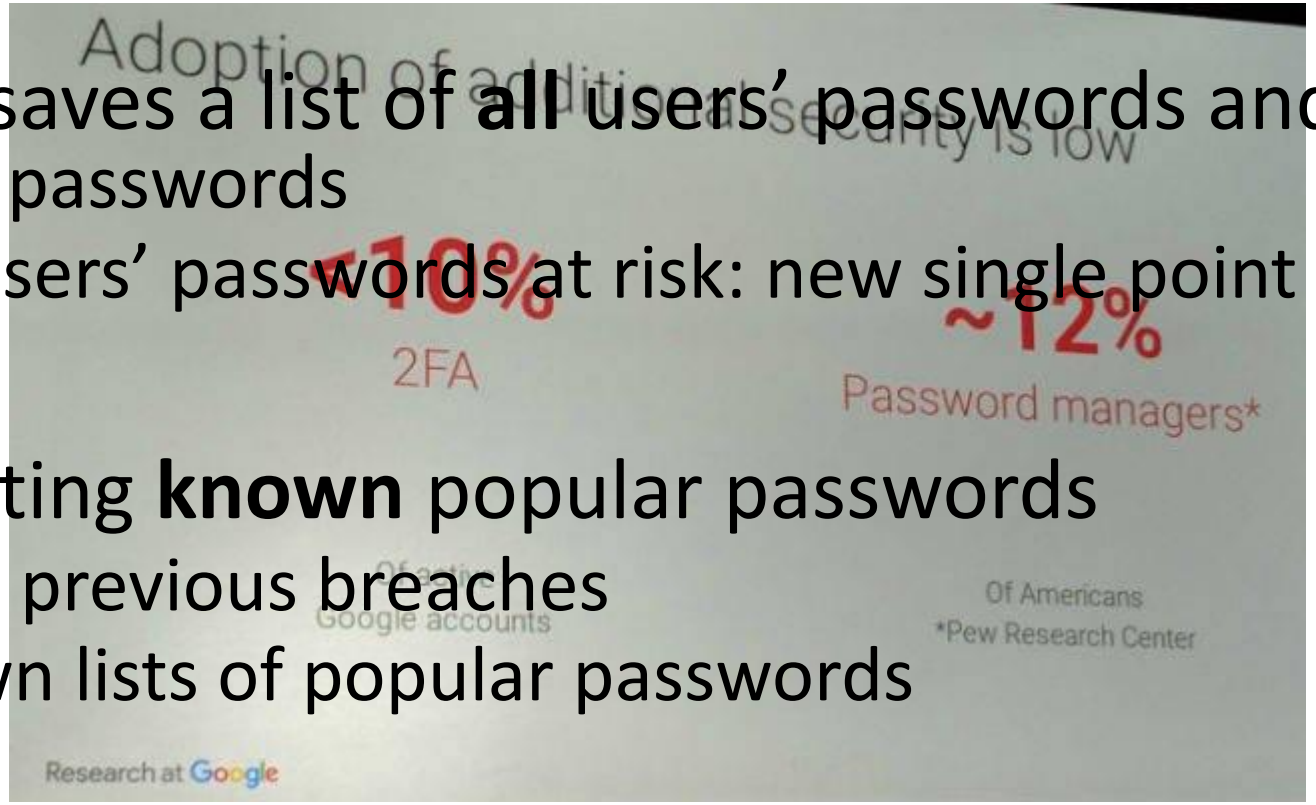
- “Security of Connected Devices” signed in California Law October 2018

As of 2020 manufacturers required to either include :

- "a preprogrammed password unique to each device manufactured" or
- "a security feature that requires a user to generate a new means of authentication before access is granted to the device for the first time."

# Possible solutions

- Two factor authentication (2FA)
- Server saves a list of **all** users' passwords and blacklists the popular passwords
  - Put users' passwords at risk: new single point of failure
- Blacklisting **known** popular passwords
  - From previous breaches
  - Known lists of popular passwords



# Passwords over time

- password -> passw0rd -> p@assw0rd->password
- superman -> wonderwoman
- Different populations

# Primum non nocere

First do (almost) no harm

- Publishing passwords blacklist can also help attackers
  - Attacker can use **auxiliary data** to guess password distribution
  - Publishing the blacklist is like publishing a **code vulnerability**
- Leaking password information can hurt the user
  - Gathering statistics requires some password information
  - One bit leakage doesn’t hurt the user a lot (next slide)
  - Differential privacy can also help

# The Password Game

- PGame(L): Attacker A wants to attack device D
  - Publishes a list with L guesses for passwords
  - Wins if the password of D is in the list
- Effect of one bit leakage on password:
  - If A wins PGame(L) w.p at least $\delta$ using a 1 bit leak

  **implies**
  - There is A' wins PGame(2L) w.p $\delta$ without a leak

- $\epsilon$-Differential Privacy
  - If A wins PGame(L) w.p at least $\delta$ using $\epsilon$-DP information

  **then**
  - There is A' wins PGame(L) w.p $> \delta \cdot e^{-\epsilon}$ without a leak

# How to (not) share a Password: **Desiderata**

- Identify and **blacklist** popular passwords (heavy hitters)
  - those were chosen by more than a fraction $\tau$ of the users
- Server should not learn ``more than 1 bit'' on any user's password
  - At most halves  the number of password guesses
- Probability of False Negative (pFN) must be **negligible**
  - **No popular password is missed**
- Probability of False Positive (pFP) should be a small value
  - A legitimate password **may** be rejected with **low probability**

# Previous work

- Finding **heavy hitters** in many settings - [DNP+10,DNPR10,CSS11,CLSX12, HKR12,DNRR15]
- Semi-honest version [BS15,BNST17]
- Non colluding mix servers – [MS17]

- DP password list with trusted server – [BDB16]
- Similar motivation, no DP – [SHM10]

# The Malicious World


- **Both** users and server might be malicious
- A malicious server wants to learn the passwords
- Malicious users want to “hide” popular passwords
  - **Adversary controls a coalition of users**
    - **Want to hide weak passwords by other users**

# MPC meets DP in the Malicious World

- Asymmetric security requirements from the parties in the protocol
  - Relatively easy to protect users' privacy from server
  - Harder to protect against **colluding malicious** users

- Use **efficient 2PC protocol tailored to the system's correctness requirements**

# Correctness

- Password used by at least a $(1+\delta)\tau$ fraction of the users: **identified as a heavy hitter** w.p **at least** (1-pFN)
  - Even at the presence of malicious user coalition

- Password used by at most a $(1-\delta)\tau$ fraction of the users: identified as a heavy hitter w.p **at most** pFP

# The semi honest solution

Bassily, Nissim, Stemmer, Thakurta

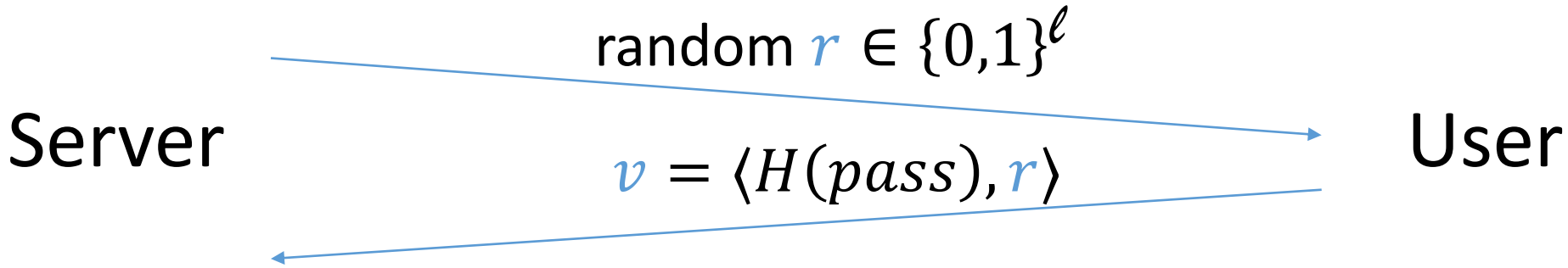
- Similar to the **heavy hitters** solution of [BNSTS17]

- Hash the passwords to $\ell$ bits values
  - "Naïve" hash function
  - May have collisions
    - OK if $1/(1-\delta)\tau \ll 2^l$

- Server initializes to zero a **counter histogram** T of size $2^\ell$

# The semi honest Protocol

- For every user:




- Server iterates over all possible value of $x \in \{0,1\}^{\ell}$
  - If $v = \langle x, r \rangle$: $T[x] \mathrel{+}= 1$
  - Else: $T[x] \mathrel{-}= 1$

# The semi honest solution

- $T[x] = N * Prob(x) + Noise$
  - $Noise \sim Bin(N * \big(1 - Prob(x)\big), 0.5)$
- $E[T[x]] = N * Prob(x)$

- **Blacklist** the hash value if $T[x] > \tau N$

- Define $\tau$ as a function of N and $\delta$ such that:

$$Prob[|Noise| > \tau N \delta] < pFN$$

# The undercount attack

- A user wants to “hide” a popular password pass
- The user simply sends: $1 - \langle H(pass), r \rangle$

# The required functionally

- Input
  - The server sends to the Trusted Third Party (TTP) an $\ell$ bit input r
  - The user sends to the TTP an $\ell$ **bit input v**
- Output
  - The TTP sends to the server $\langle v, r \rangle$
  - The user gets no output

- Two approaches:
  - QR based
  - Yao's **garbled circuit based**

# A naïve QR based solution

For **N=pq** hard to distinguish squares (QR) from non-squares (nQR) among those with Jacobi Symbol 1

- Based on the **intractability** of the quadratic residuosity (QR) **assumption**

0 encrypted as a QR and 1 as nQR

- Encrypt the r vector **as in the Goldwasser-Micali public encryption** scheme
  - The server generates an RSA modulus N=pq, p and q primes
  - Encrypt the bits of r=$r_1, r_2 \ldots, r_\ell$ into $r_1{}^p, r_2{}^p, \ldots, r_\ell{}^p$
    - 0 as QR and 1 as nQR mod N

$$e = d^2 \cdot \prod_{i=1}^{\ell} (r_i^p)^{V_i^s} \quad \text{where} \quad d \xleftarrow{R} \mathbb{Z}_N$$

Is it secure?

**Not if adversary knows an nQR**

# The nQR generation assumption

- Is it hard to generate a nQR number w.h.p?
  - With probability better than $\frac{1}{2} + negl$?

*Remarks about Theorem* 2. When the factorization of $n$ is secret, no efficient algorithm for selecting a quadratic nonresidue mod $n$ is known. Thus it may be that revealing, say, the smallest quadratic nonresidue in $Z_n^1$ may endanger the secrecy of the factorization of $n$ or make deciding quadratic residuosity modulo $n$ easy.

- Simple reduction from protocol security
  - Assuming Unique N for each device

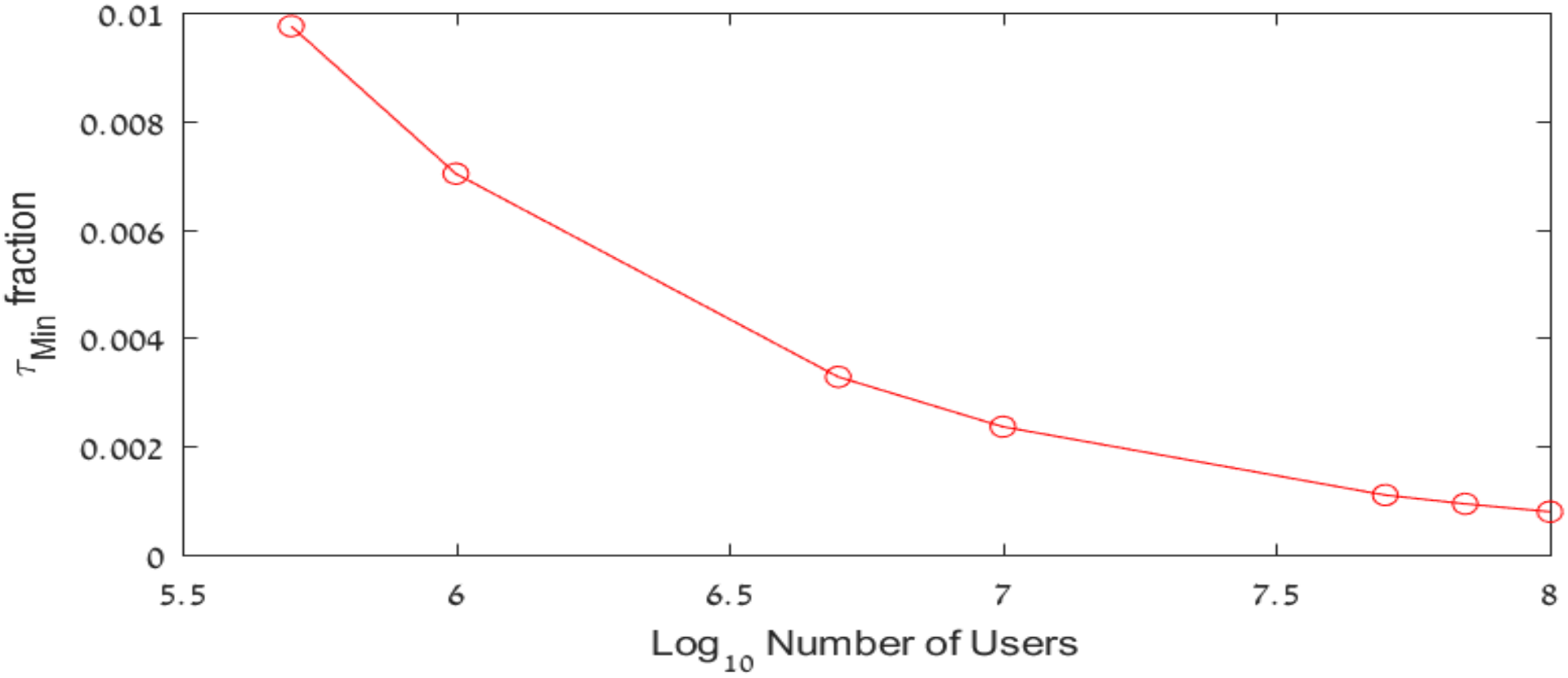
# Reduction to nQR generation assumption

- The honest algorithm $A(v, r^p)$ return e=$\langle v, r \rangle$
- The adversary algorithm $A'(v, r^p)$ return e=1-$\langle v, r \rangle$ w.p $\frac{1}{2} + \delta$
- Generate $r^p$ by random sample from $\mathbb{Z}_N$ with Jacobi symbol 1
- Generate random $v$
- Return $A(v, r^p) \cdot A'(v, r^p)$, result nQR w.p $\frac{1}{2} + \delta$

# Solution based only on QR assumption

- Adding an Interactive zero knowledge proof that the inner product was computed correctly
- Non interactive version based on Fiat-Shamir
- Requires proof that N=pq where p and q are primes
- Another garbled circuit solution

# Malicious bounds on $\tau$




Blacklist top 3 passwords of the Yahoo! Leak, and top 5 passwords of the RockYou leak

# Implementation and other usages

- Implemented the full malicious QR protocol on a RPi
  - Non interactive version runs in about 15 seconds, can run in background
  - Server computer  can verify in about 0.5 seconds

- Same solution can be used in any heavy hitters problem with possible malicious setting
  - **TOR network statistics**
  - **Device PIN/Pattern**
  - **Large service providers dynamic passwords statistics**

# Open questions

- Do we need Crypto?
  - For non-malicious users – no (computational based) crypto needed!
- Research on the nQR assumption
- Can the attacker really use the leaked information from the blacklist publications?