Knock Yourself Out

Secure Authentication with Short Re-Usable Passwords

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Knock Yourself Out (KYO)...

- Is neither a password manager, nor a password generator, but something of both
- Allows short passwords and password re-use
- Protects against
  - password manager loss
  - multiple, simultaneous disclosure of server databases
  - computationally unbounded adversaries

Authentication - Acceptable Risk

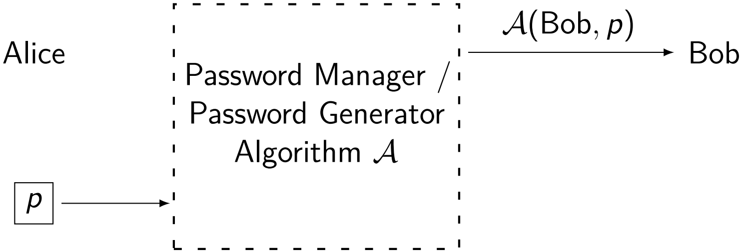
- What is an "acceptable (individual) risk"?
- Look at ATM cards: 4 digits (0-9), three attempts allowed
- $\rightarrow$ Probability to guess PIN correctly is

$$\Pr[\text{guess PIN}] = 3 \cdot 10^{-4} = 0.0003.$$

- To break the scheme, attacker needs to steal ATM card (first factor), and guess the correct PIN (second factor)

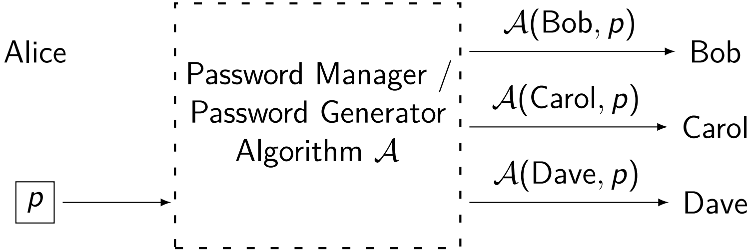
$$\Pr[\text{break ATM scheme} \mid \text{stolen card}] = \Pr[\text{guess PIN}]$$

Authentication - Security and Safety



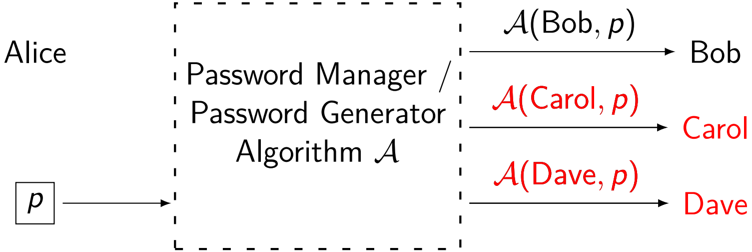
- Alice uses her PW p and PW manager / -generator to create a **secret** $\mathcal{A}(\text{Bob}, p)$
- **Security Threat**: Adversary finds p or predicts $\mathcal{A}(\text{Bob}, p)$
- **Safety Threat**: Bob blocks Alice due to a wrong secret

Authentication - Security Threats



Adversary might learn:

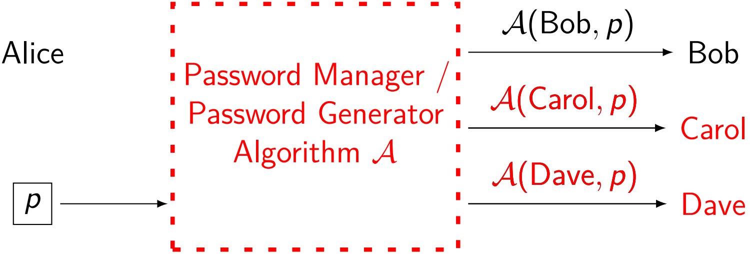
Authentication - Security Threats



Adversary might learn:

- up to N out of Bob, Carol or Dave: e.g. (virtual) servers

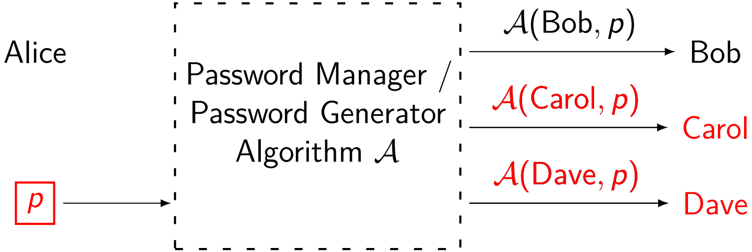
Authentication - Security Threats



Adversary might learn:

- up to N out of Bob, Carol or Dave: e.g. (virtual) servers
- **either** PW manager: $\{$stolen, lost$\}$ $\{$computer, phone$\}$

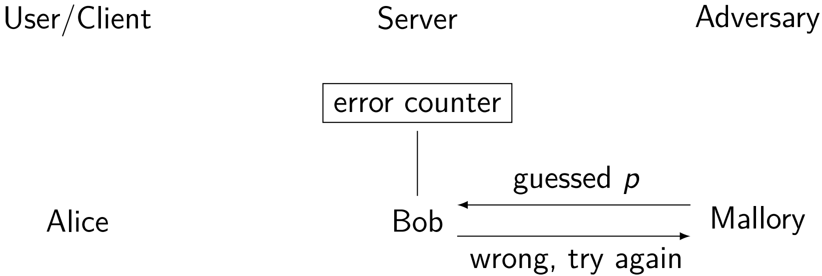
Authentication - Security Threats



Adversary might learn:

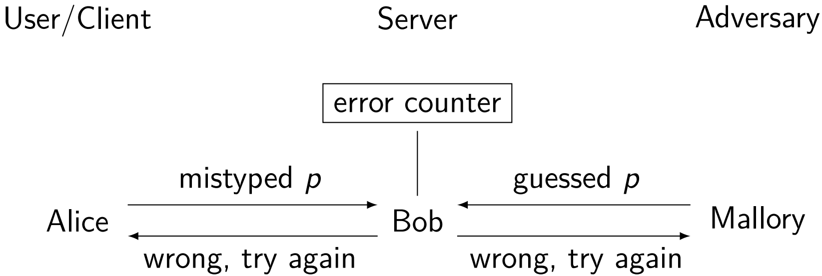
- up to N out of Bob, Carol or Dave: e.g. (virtual) servers
- **either** PW manager: {stolen, lost} {computer, phone}
- **or** password p (e.g. shoulder surfing)

Authentication - Security Threats: Guessing



- Mallory tries to guess Alice's PW, repeatedly.
- To limit Mallory's tries, Bob blocks Alice's account once a critical limit of failed attempts is reached (e.g. three)

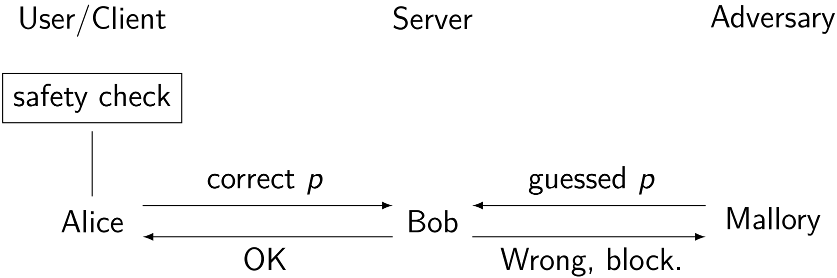
Authentication - Safety Threat: Input Errors



- Did Alice mistype her PW? Allowing Alice to retry is a **safety mechanism**
- Does Mallory know the PW? Limiting Mallory's tries is a **security mechanism**.

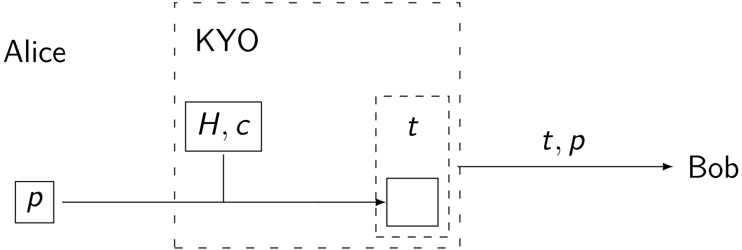
KYO: safety check

KYO: Input Errors



- KYO catches input errors client-side
- Bob blocks Alice's account **immediately**, once Mallory shows a wrong password

KYO - Safety Check



- Generic safety check: For some H, is $H(p) = c$?
- Q1: How "good" is the safety check?
- Q2: What does an adversary learn through H, c?

- (Token t prevents DOS attacks: see paper for details.)

Q1: How good is the safety check?

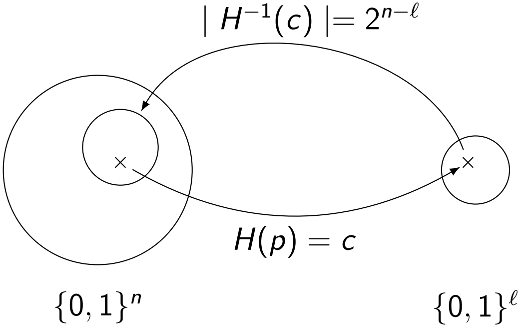
- Measure the probability that safety checks fails, assuming a wrong password P was entered:

$$\Pr[H(P) = c \mid P \neq p]$$

- Unknown: types of errors a user might make
- ($\rightarrow$: users may need a custom solution)
- Idea: if H is a randomly selected function, the probability is the same for every distribution of P

Q2: Adversary learning H, c

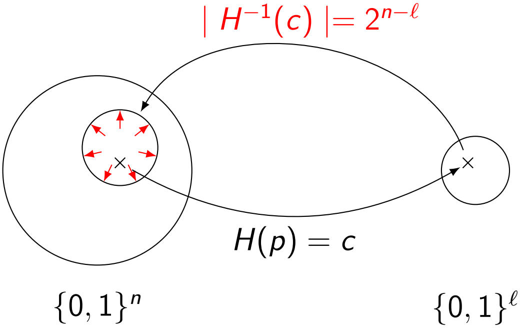
- For a randomly chosen function $H : \{0,1\}^n \to \{0,1\}^\ell$, $\mid H^{-1}(c) \mid$ is binomial distributed with average value $2^{n-\ell}$



Conceptually similar to "collisionful hash functions", PolyPassHash, Kamouflage, Honeywords

Q2: Adversary learning H, c

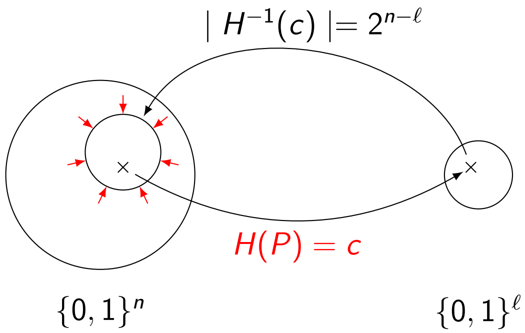
- For KYO **security**: Make $\mid H^{-1}(c) \mid$ **large** enough



$$\Pr[\text{guess } p \mid \text{stolen KYO}] \leq \Pr[\text{guess PIN}]$$

Q1: How good is the safety check?

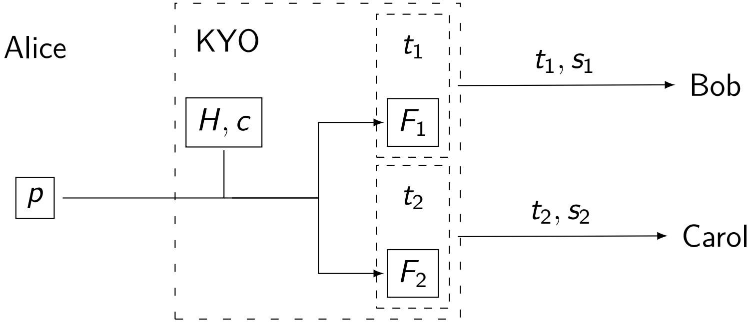
- For KYO **safety**: Make $| H^{-1}(c) |$ **small** enough



$$\Pr[\text{KYO check fails} \mid \text{input error}] \leq \Pr[\text{guess PIN}]$$

KYO: re-using and managing passwords

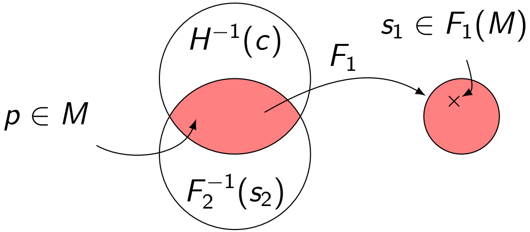
KYO - re-using passwords



- Randomly choose functions F_1 and F_2
- Secrets: $s_1 = F_1(p)$ and $s_2 = F_2(p)$
- What does an adversary learn about p and s_1, given H, c, F_1, F_2, s_2?

KYO - re-using passwords

- Set $M := H^{-1}(c) \cap F_2^{-1}(s_2)$
- For randomly selected $H, F_2 : \{0,1\}^n \to \{0,1\}^\ell$, the size of M is binomial distributed with average value $2^{n-2\cdot\ell}$.



- $F_1(M)$ is a bit smaller

KYO - managing passwords

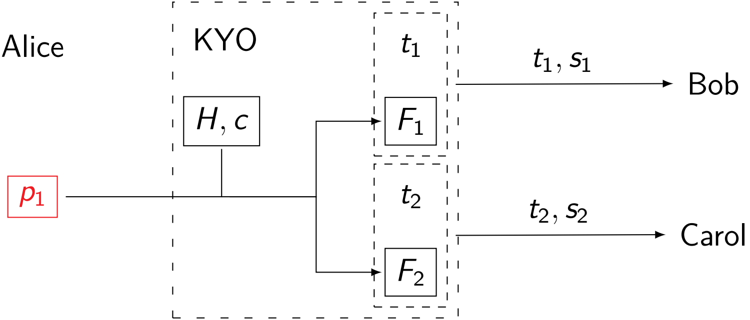
- Given p, s, it is easy to **select** a $F : \{0,1\}^n \to \{0,1\}^\ell$ with $n > \ell$ randomly, so that

$$F(p) = s.$$

- Random sampling works well
- Make use of that for flexible password management

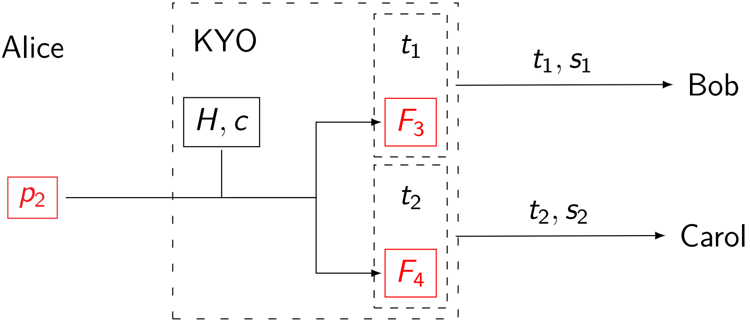
- (Intuitively, this seems like a really bad idea. But, the information that F was selected to give $F(p) = s$ is of little use to an adversary. See paper for details.)

KYO - managing passwords



Renew Alice's password p_1:

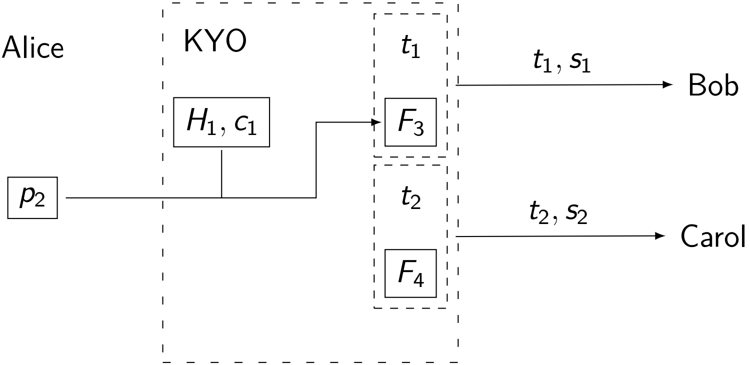
KYO - managing passwords



Renew Alice's password p_1:

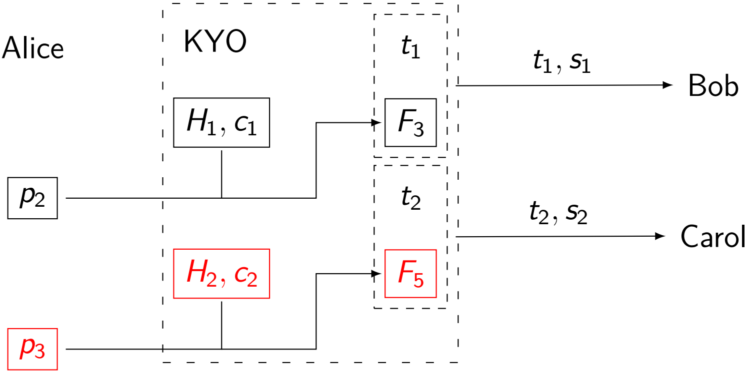
- choose a new p_2
- select F_3, F_4 with $F_3(p_2) = s_1$ (Bob), $F_4(p_2) = s_2$ (Carol)

KYO - managing passwords



Different password for Carol:

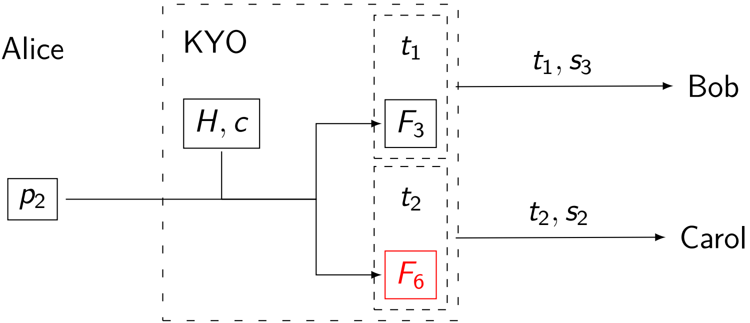
KYO - managing passwords



Different password for Carol:

- choose a new p_3
- choose H_2, set $c_2 := H(p_3)$
- select F_5

KYO - managing passwords

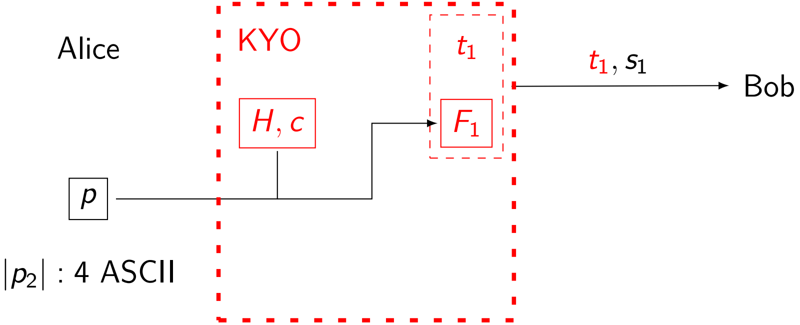


To merge passwords:

- dispose of H_2, c_2
- select F_6

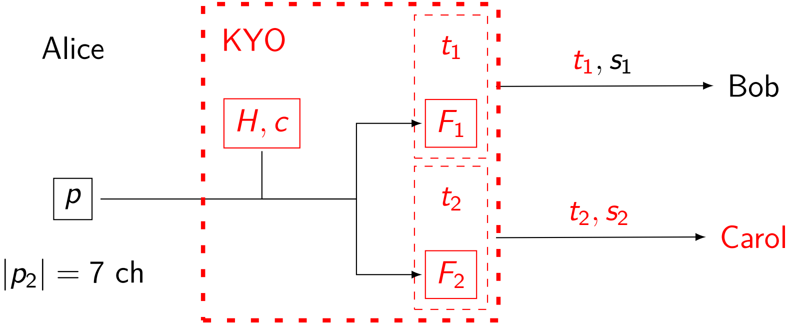
KYO: evaluation results

Theoretical results



- minimum password length for baseline risk $3 \cdot 10^{-4}$.
- 4 ASCII (5 alphanumeric) chars withstand KYO loss.
- Each server breach costs about 2 characters ($\sim$ 10 bit)

Theoretical results



- What the average user could get:
- Florencîo found 6-7 alphanum. chars average ($\sim$ 40 bit)
- 7 alphanum. chars withstand KYO loss and 1 breach

From theory to practice

- In analysis: functions are chosen uniformly at random
- But: descriptions of H, F_i too large to store in practice:

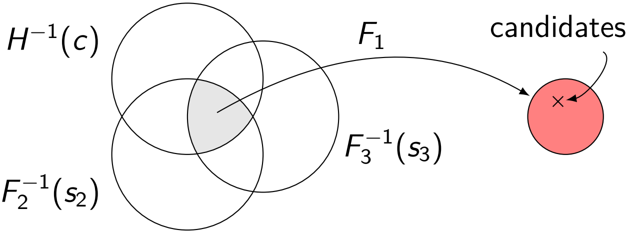
$$13 \cdot 2^{38} \text{ bit} \sim 200 \text{ gigabytes } \textbf{each}$$

- $\rightarrow$ use decent hash functions (But: neither collision-resistance nor pseudorandomness required)

- (One would usually just assume H, F output "random" values. However, it is better to assume H, F are taken from a **random subset** of all functions instead)
- For details: talk to me afterwards

Implementation and preliminary results

- 2-Univ: $F_\sigma(p) = (a(\sigma) \cdot p + b(\sigma) \bmod p) \bmod 2^\ell$
- E.g. 30 bit password, three 6-bit secrets:
  - Avg candidate probability: 0.016 ± 0.011 (0.015 pred).
  - Best candidate probability: 0.019 ± 0.005 (0.015 pred).



Outlook

- Interested in easy-to-invert hash functions
- Pen & paper KYO?

(Thank you)

Acknowledgements: The first author and the third author were supported by the CONFINE project while doing this research.