



Is Password InSecurity Inevitable?

Cryptographic Enhancements to Password Protocols

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Password (In)Security

- Passwords: **MAIN** authentication tool in the digital era
- Protect our lives and social order, *conveniently* and **Insecurely**
- **BILLIONS** of passwords stolen
 - Yahoo ~~500M~~^{1B}, MySpace 360M, LinkedIn 165M, eBay 145M,..., Ash-Mad 11M
 - ... Twitter, RSA, Google, Dropbox, PayPal, Sony, ...
- <https://www.leakedsource.com>:
 - 2,918,283,623 accounts at your service.
 - "Check for free to see if your email or account was hacked."

An Unacceptable State of Affairs (but do we have a choice?)


- Unacceptable, really! Our social order depends on passwords
- But do we have a choice?
 - Get rid of passwords all together: Not realistic, too convenient, massively deployed.
 - Ask users to memorize (multiple) high-entropy passwords: No way
 - Stop choosing same/related password: No way

Can Cryptography Help?

- Yes!
- We show strong password protocols for a variety of problems in a variety of settings.
- Using simple, well-established techniques
 - Mostly blinded DH [Chaum, Ford-Kaliski, Boyen, ...] (“oblivious PRF”)
- Efficient. Mature. Ready for deployment in the real world.
- I will go over three such solutions very briefly.
- Pointers to papers at the end; and please talk to me if you are interested to learn more (esp. if you can transfer this to practice).

Offline Dictionary Attacks

- Main source of password compromise:
 - *Deadly combination* of human memory limitation (→low entropy passwds) and server compromise
 - Attacker that gets hold of "password file" can test candidate passwords against stored hashes; cost proportional to dictionary size
- The most effective attack on passwords
 - Millions++ of passwords tested per second (from s/w to dedicated h/w)
- ☹ Offline attacks upon server compromise are **unavoidable**
 - If the server can check, so does the attacker



Hope: Make these unavoidable exhaustive attacks ineffective
(High-entropy passwords or additional devices/servers)



Part I:

**Take the burden of choosing and
memorizing passwords off humans**

A simple solution: Password Store (a.k.a. password manager)

- Carry strong independent passwords stored
- ... in your phone, your smart watch, ..., or retrievable online
- ... encrypted under *a master password*
 - Just remember the one master password (hopefully non-trivial)



Password store: Not without problems

- A list of user passwords encrypted under the user's master password
 - Attacker obtains the list → offline attack on master password (all the user's passwords compromised)
 - "Inside compromise": Attacker learns master password as user types it
 - User-device communication compromise (master password leaked)
 - Furthermore: Typical password managers keep *user-chosen passwords* (hence, weak and related/repeated)
- Can we do better?

A dream password store

- All passwords kept in a password store in a *user's device or online*
- User memorizes a *single* master password
- All passwords are *random* and *independent* of each other
- And: An attacker getting hold of store or even in full control of the device... **learns nothing**
 - **About the individual stored passwords**
 - **Or the master password**

What do you mean by *nothing* ?

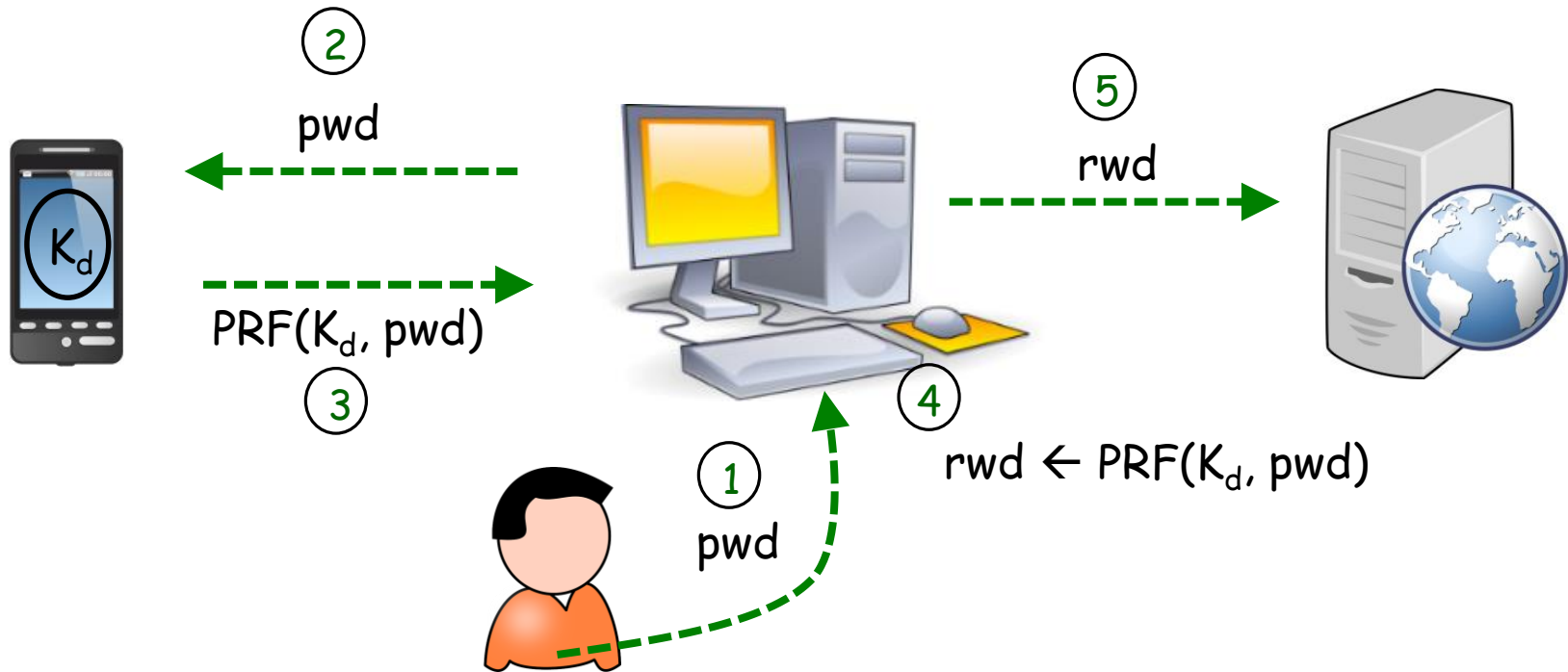
- Well... *nothing*. As in information-theoretic nothing!
 1. Information stored in the device is *independent of the user's individual passwords and independent of the master password*
 2. Cleartext master password is *never entered* into the device!
 - An eavesdropper or active attacker on the link to the device learns nothing
 - An attacker inside the device, w/full control, even when user enters the master password does not learn anything either (not even at init!)

**SPHINX: A password Store that Perfectly Hides from Itself
(No Xaggeration)**

SPHINX

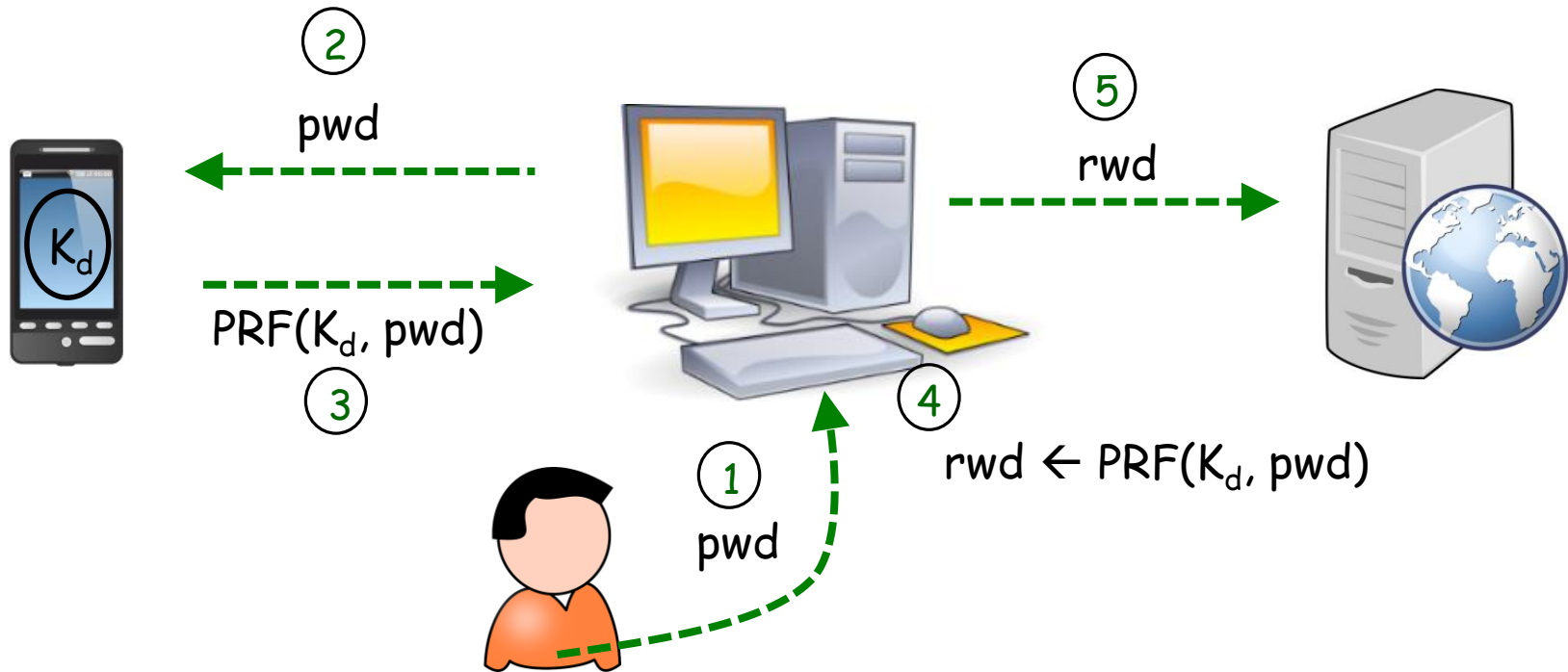
- A password Sore that Perfectly Hides from Itself
- Really? Let me show you.

PRF-based Solution



- rwd is a (pseudo) random password that user registers with server
- There is an independent rwd with each service, e.g. $\text{PRF}(K_d, \text{pwd} \mid \text{url})$
- **Works with *any* password protocol between client and server**

PRF-based Solution

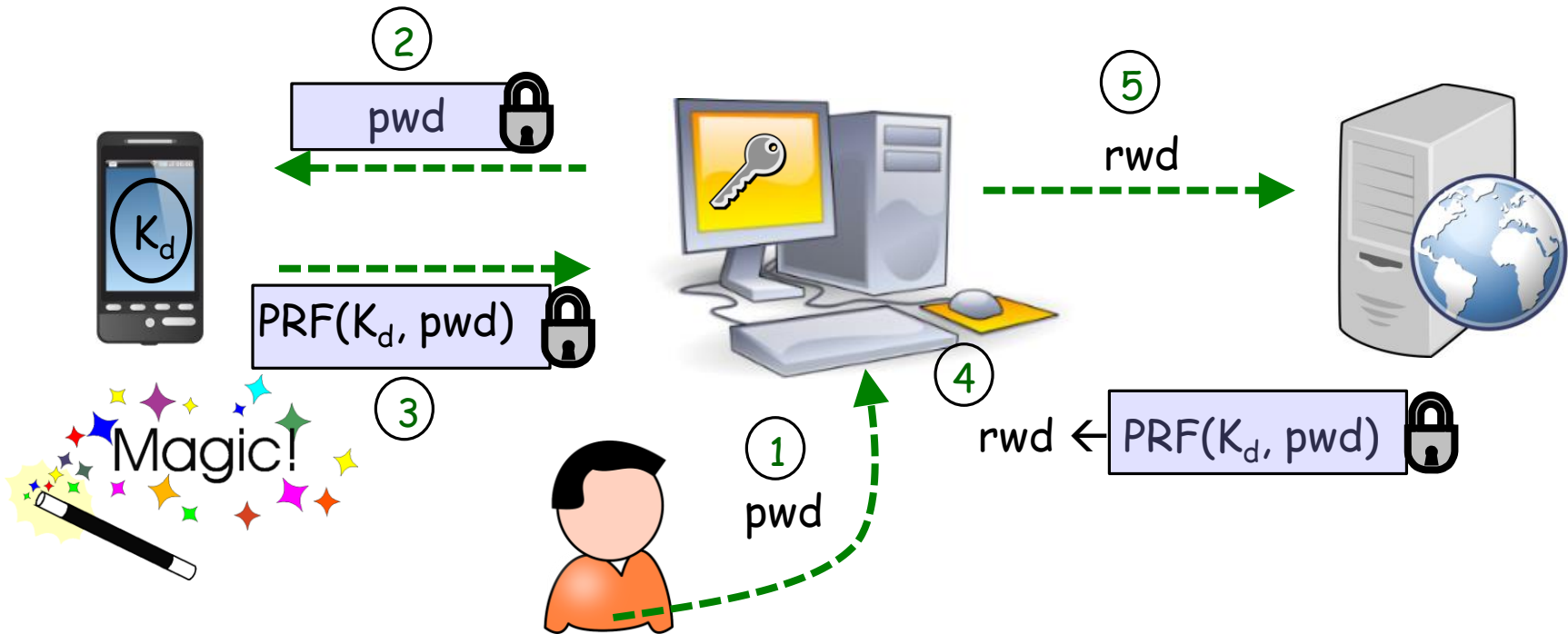


☺ rwd is a (pseudo) random password \rightarrow *offline attacks are infeasible*

☺ Storage in device (K_d) is *independent* of master pwd and of rwd 's

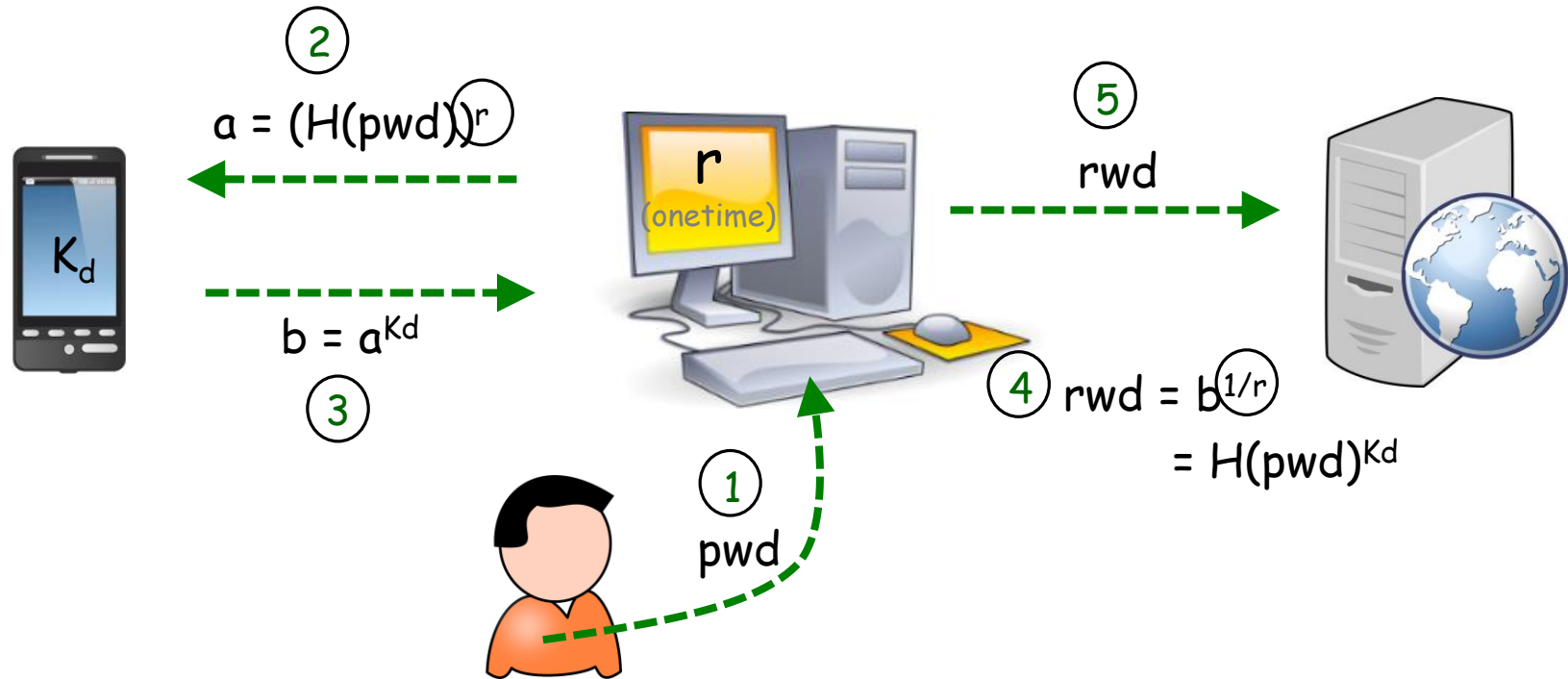
☹ Master pwd is sent unprotected to device

Oblivious PRF ← OPRF-based Solution



- ☺ rwd is a (pseudo) random password \rightarrow *offline attacks are infeasible*
- ☺ Storage in device is *independent* of master pwd and of individual rwd 's
- ☺ **Master pwd hidden over the wire and from the device!**

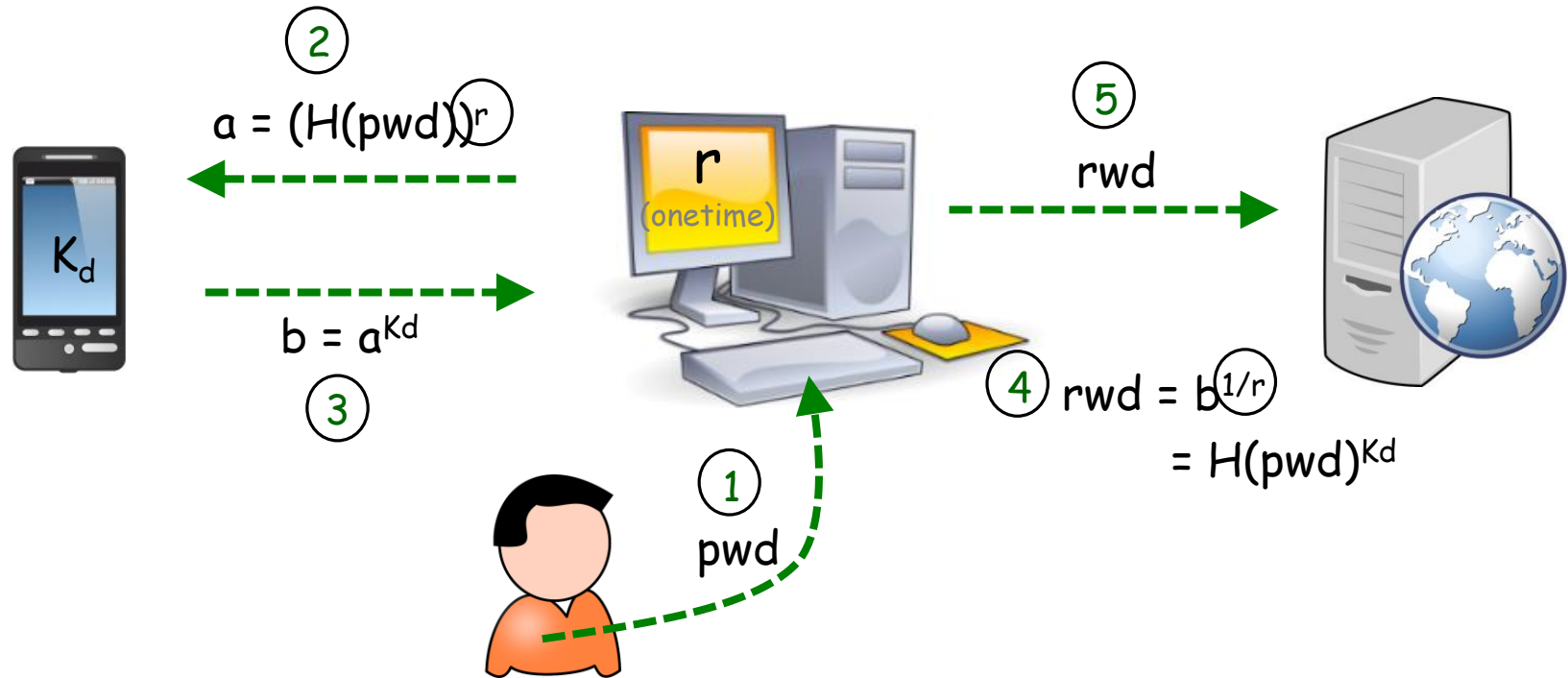
Implementation: $OPRF(K_d, \text{pwd}) = (H(\text{pwd}))^{K_d}$



☺ ☺ rwd is pseudo-random and K_d fully independent of pwd and of rwd

☺ ☺ *master pwd is perfectly hidden on the wire and from device!!*

Implementation: $OPRF(K_d, \text{pwd}) = (H(\text{pwd}))^{K_d}$



☺ ☺ rwd is pseudo-random and K_d fully independent of pwd

☹ ☹ CAN WORK WITH ANY CLIENT-SERVER PASSWORD PROTOCOL (SERVER TRANSPARENT) *from the wire and from device!!*

Not only secure...

- **Performance:** Single round C-D, 1 exponentiation for D, 2 for C, and one hash into group for C (any DH group works, no bilinear, etc)
 - SPHINX pwd manager: Implementation as Android app + usability study (user only inputs master pwd, rest is automated) - see references
- **Server transparent** (works with Google, Facebook, your employer...)
- No need for C-D channel protection (self-protected by SPHINX),
 - can use *any* communication channel (WiFi, Bluetooth, Internet)
- *Can replace D with online service* (pwd, rwd never seen by server, no need to "secure" communication with server!)

SPHINX Security

- Device compromise: Unconditional secure pwd/rwd (online-only att'ck)
- Network attacks: Unconditional security device-client communication
 - No PKI or externally enforced secure channels (great for **online** SPHINX)
- Offline dictionary attacks: Infeasible (random rwd)
 - Offline against master pwd *ONLY* if *both server and device compromised*
- Online dictionary attacks: Infeasible (random and independent rwd's)
- Password leakage: Partial defense (rwd useless in another server, master pwd useless w/o device, url hashing prevents phishing)



Two-factor authentication with improved security and usability (see ref's)

Part II:

How to Protect* a *Valuable** Secret*

When all You Remember is a Password

* Protect: Secrecy and Availability

** Bitcoin wallet, user-controlled cloud backup, secure msging keys, private key for a PK credential, corporate keys,...

How to store a secret

- Protect *secrecy* and *availability* of information while remembering a *single* password
 - Need a multi-server solution
 - Single server → Single point of failure for secrecy (offline dict attacks) and availability (server gone → secret gone).
- Natural cryptographic solution: keep the secret encrypted in multiple locations; *secret share the encryption key* in multiple servers
 - Share among n servers, retrieve from $t+1$ servers (e.g. $n=5$, $t=2$)
- Protects *availability* and *secrecy*.
 - Available: As long as $t+1$ available
 - Secret: As long as no more than t corrupted

Wait, but how do you authenticate to each server for share retrieval?

- Server needs to authenticate the user before delivering a share
- All we have is a user and a password
 - A strong independent password with each server? Not realistic
 - Same (or slight-variant) password for each server? Not good
- *Each server as a single point of failure!*
 - From one point of failure to n. We didn't achieve much, did we?

What we really want: PPSS [BJSL'12] (Password Protected Secret Sharing)

- Init: User secret shares a secret among n servers; forgets secret and keeps a single password.
- Retrieval: User contacts $t + 1$ servers, authenticates using the single password and reconstructs the secret.
- Security: Attacker that breaks into t servers learns nothing about secret or password
 - Even if it and finds all the server's secret information (shares, long-term keys, password file, etc.)
 - Only adversary option: Guess the password, try it in an online attack.
 - Offline attacks with $\leq t$ corrupted servers are useless.
- + Soundness: User reconstructs the correct secret or else rejects.

A surprisingly efficient PPSS scheme

- Computation:
 - Single exponentiation for each server
 - Only two exponentiations *in total* for the client (independent of t and n)
 - t multiplications (additions in ECC) for client and for each server
- Communication: Single parallel message from user to $t+1$ servers, one message back from each server. No inter-server communication.
- *No assumed PKI or secure channels* (other than for initialization)
- Any t, n ($t \leq n$)
- See papers
- Note: Extension to Threshold-PAKE.

Part III: X-PAKE*

Enhanced Password Security for the
Single-Server Setting (without PKI)

*Follows from (1,1)-PPSS, ~ Boyen'09

Single-Server PAKE (asymmetric/augmented PAKE, aPAKE)

■ Desiderata:

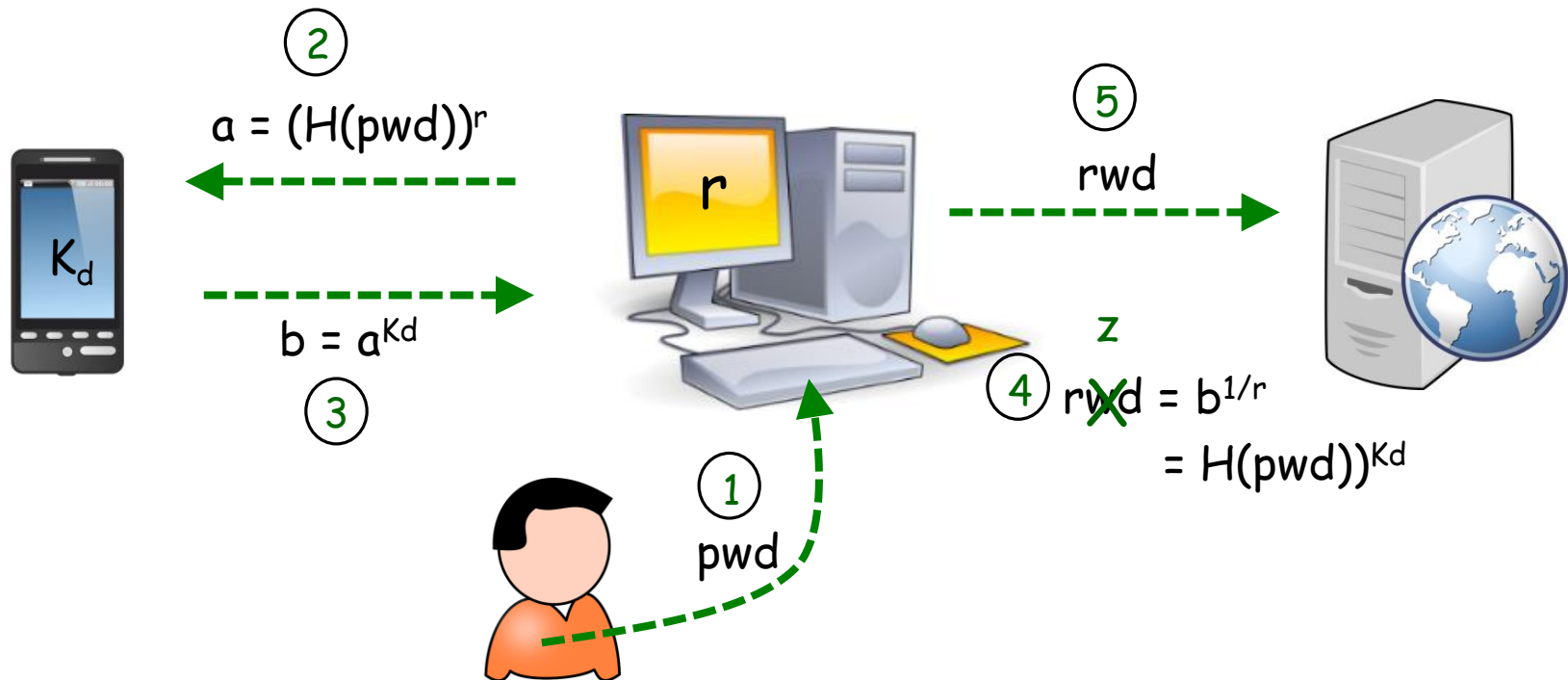
1. Force attacker to run a dictionary attack upon server compromise
2. No pre-computation prior to server compromise should help
3. Server should never see the password in plaintext
4. Reduce/eliminate reliance on PKI
5. Performance: Offload hash iterations to client ("key stretching")

■ Password-over-TLS:  1, 2  3, 4, 5

■ PKI-free aPAKE:  1, 3, 4  2, 5

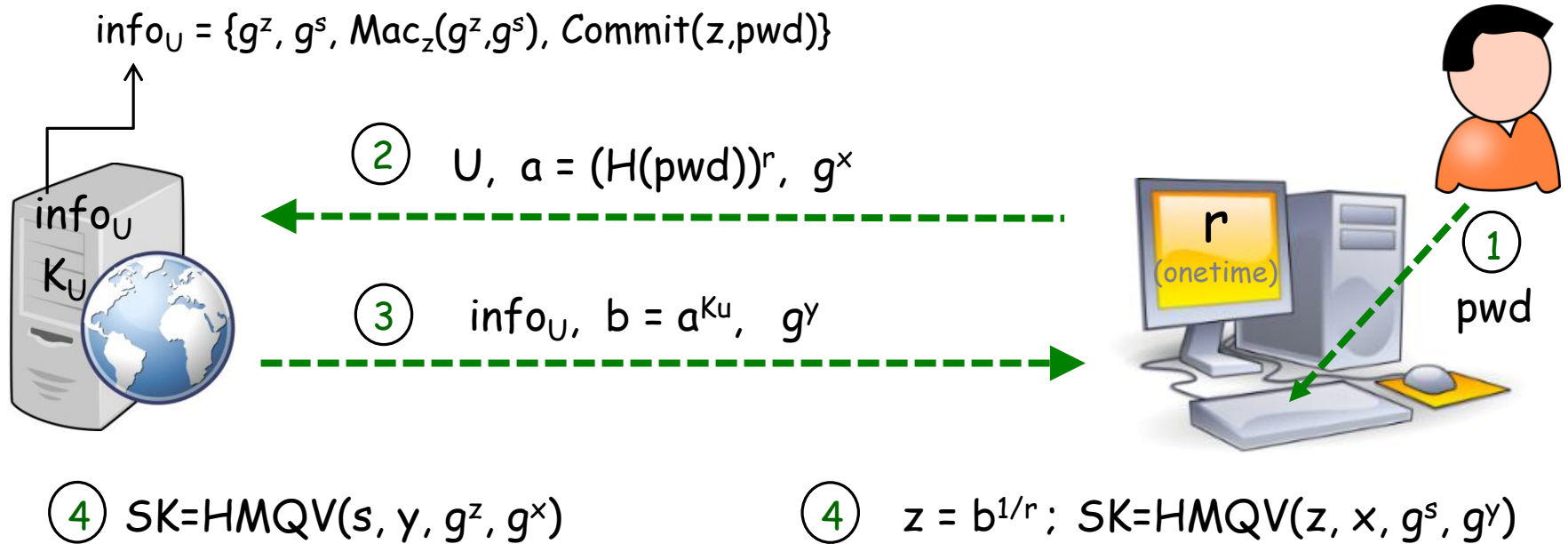
■ X-PAKE:  1, 2, 3, 4, 5

X-PAKE



- z is a secret only U knows; can be used to bootstrap a AKE with S
 - E.g., S stores public keys $PK_U = PK(z)$, $PK_S = PK(s)$ which it sends to U
 - U and S use their PK 's and private keys (z and s) with any PK -based AKE (note: AKE and mutual authentication)

X-PAKE with HMQV (single round)



- Single round (one message per party, add'l one for explicit auth)
- HMQV complexity (\sim plain DH) + 1 exp for S, 2 exp for U

X-PAKE

- X-PAKE: X is for "ECS" (Enhanced Client-Server) PAKE
- No reliance on PKI
- Server never sees password, *not even at init* (good against pwd reuse)
- Private salt: Attacker cannot pre-compute dictionary
 - Afaik, no other PKI-free aPAKE achieves this!
- Hash iterations can be offloaded to user [Boyen'09]
 - Afaik, no other aPAKE w/private salt (incl PKI-based) achieves this!
- Hedged PKI: TLS-protected PAKE vs PAKE-protected TLS (+ hidden pwd + offload iterations)
 - If PKI acceptable can use z as client signature key and TLS client auth

Summary

- Password vulnerabilities: A serious problem endangering everything from our privacy to social well-being to national security.
- Yet, we showed that password insecurity is not inevitable.
- Blinded DH to the rescue in three important applications:
 - Password store with perfect security (device-based and/or online)
 - Password protected secret sharing (multi-server secret protection with a single memorized password)
 - X-PAKE: Asymmetric PAKE with extra (ordinary) properties (PKI-free, private salt, client iterated, ...)
- All schemes backed by security models and proofs of security

**Mature, efficient, simple technology,
just waiting to be deployed...**

Thanks!

Annotated references:

<http://webee.technion.ac.il/~hugo/rwc17.html>

<http://alturl.com/aaxev>