Two-Server Password-Authenticated Secret Sharing UC-Secure Against Transient Corruptions

Jan Camenisch, Robert R. Enderlein, Gregory Neven
IBM Research – Zurich & ETH Zurich

Our Goal: Protect Your Data

- Protect user data = provide access to authenticated users.
- How to authenticate users? Usually: with passwords.
- Most users choose easy-to-remember, insecure passwords.
  - Low entropy: 16 character passwords have only approx. 30 bits of entropy [NIST].
  - Password databases compromised = attacker can recover passwords (even if hashed and salted).
    - A rig of 25 GPUs can test 350 billion passwords/second.
    - 60% of LinkedIn passwords cracked within 24 hours (2012).

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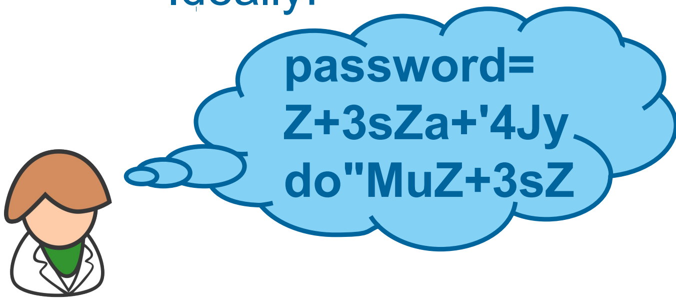

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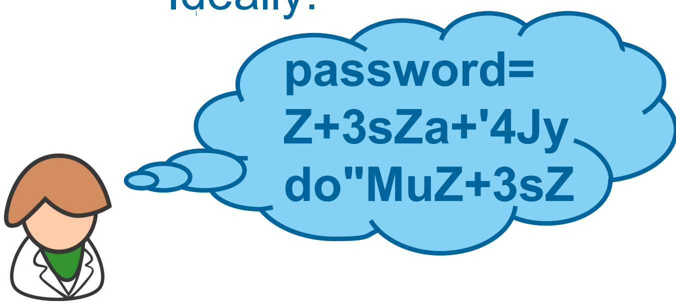

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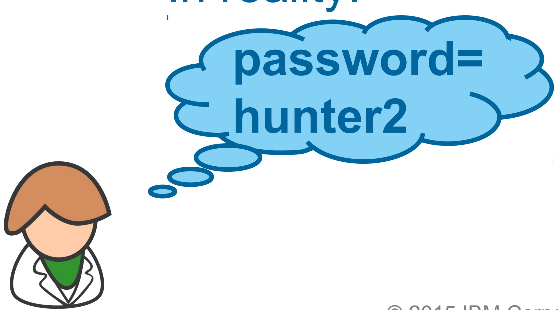

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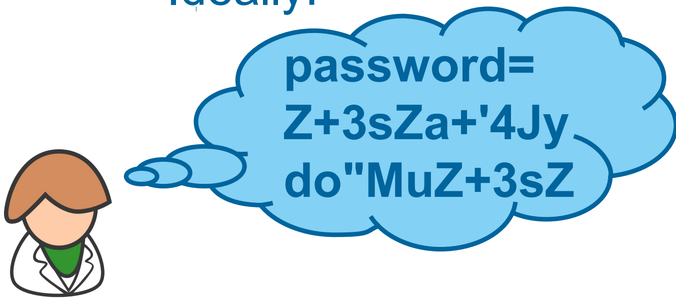

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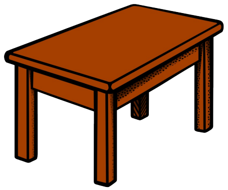

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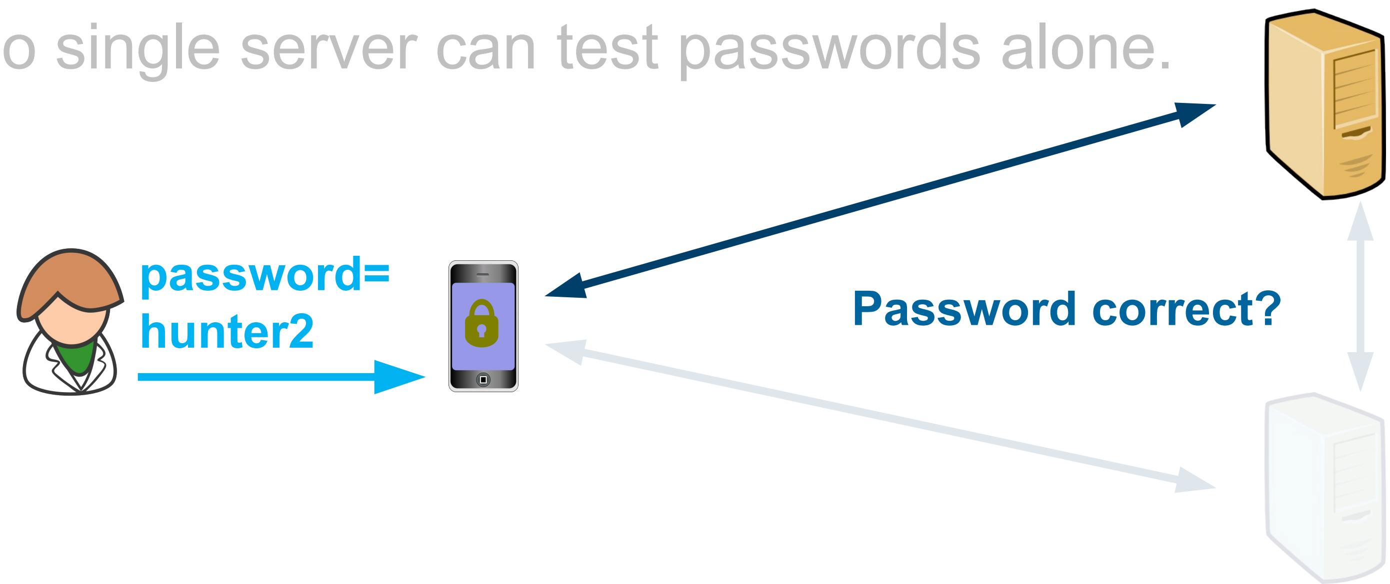
- No! We are using them incorrectly.
- Single-server solutions inherently vulnerable to offline-guessing attack if compromised.
- Instead use two server solution where no single server can test passwords alone.



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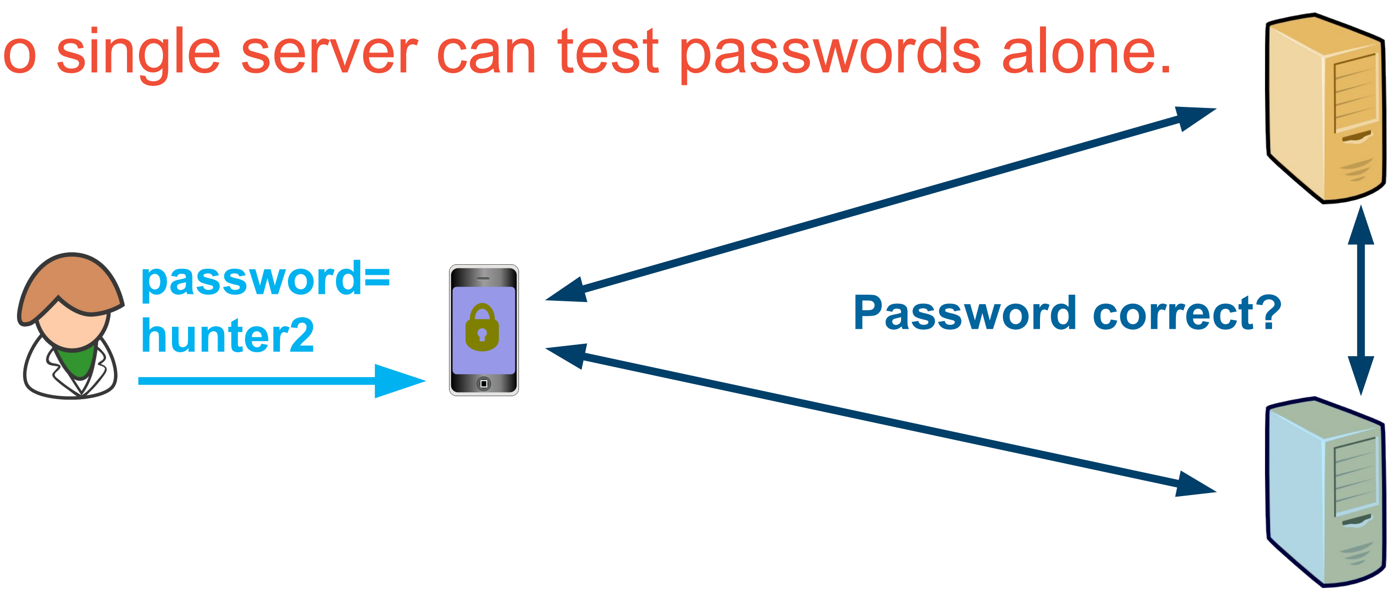
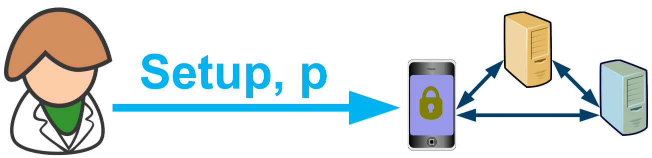
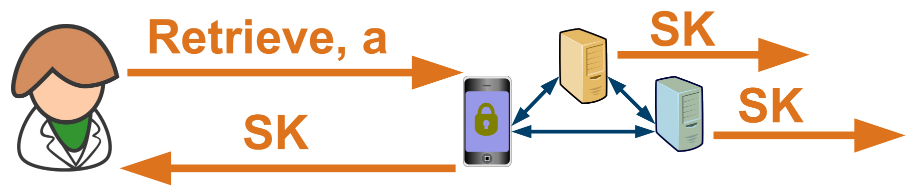


Two-Server Password-Authenticated Protocols

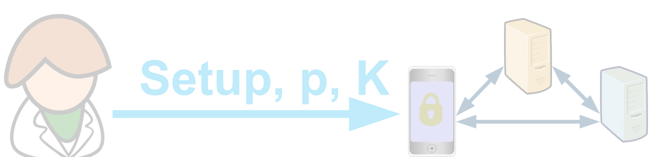
- Threshold Password-Authenticated Key Exchange (T-PAKE):

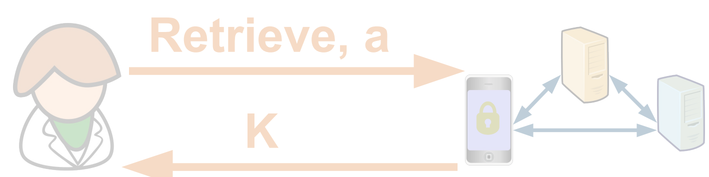




  – If password attempt is correct, share a random session key.

- Password-Authenticated Secret Sharing (PASS):





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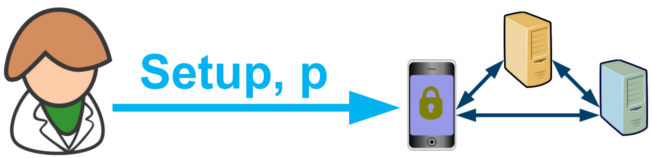

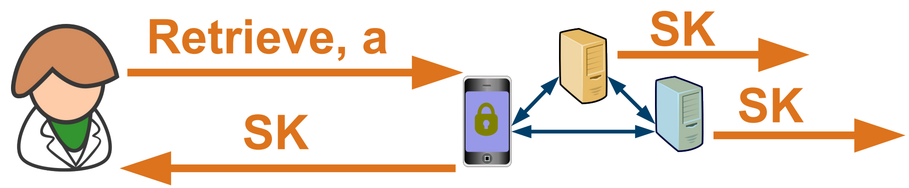

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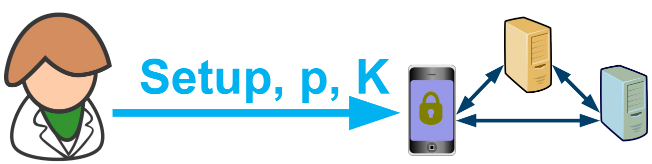

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- User remembers weak password, user name, server names.
- User deposits and later reconstruct a strong secret K.
  (K can then be used to encrypt further data.)
- One server compromised:
  - Cannot perform an offline attack on the password.
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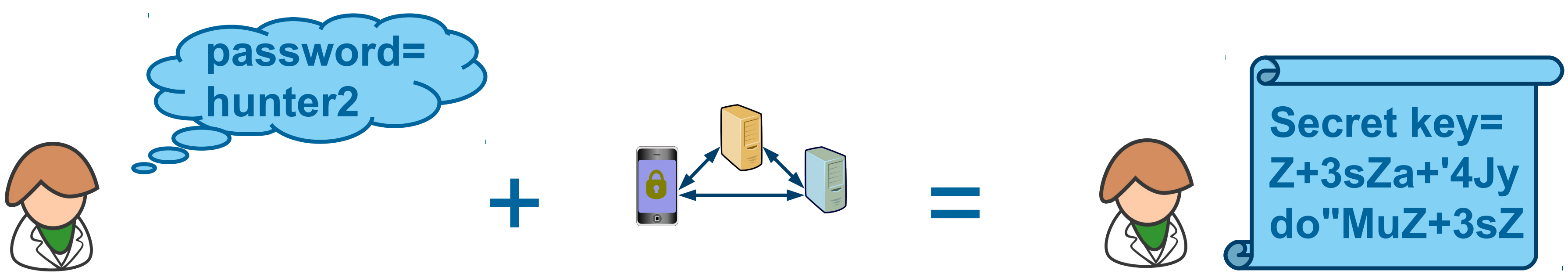
- Servers can recover from being compromised.



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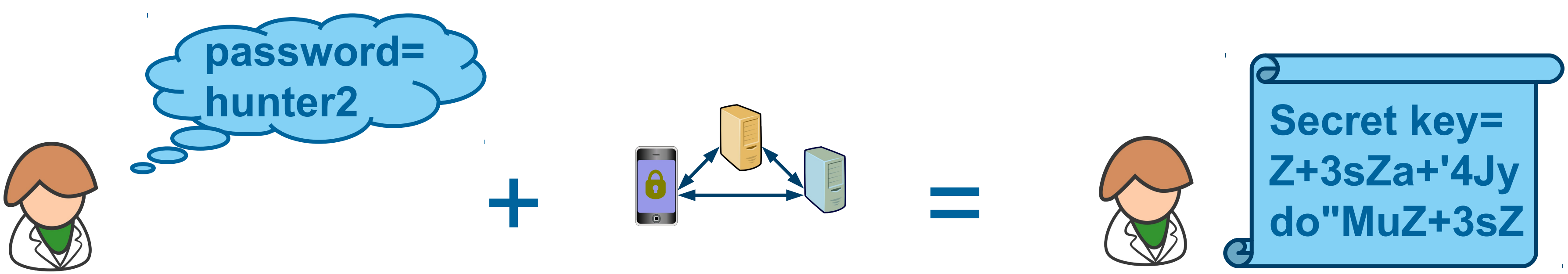

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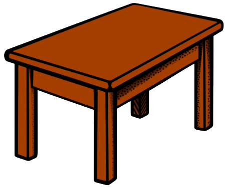

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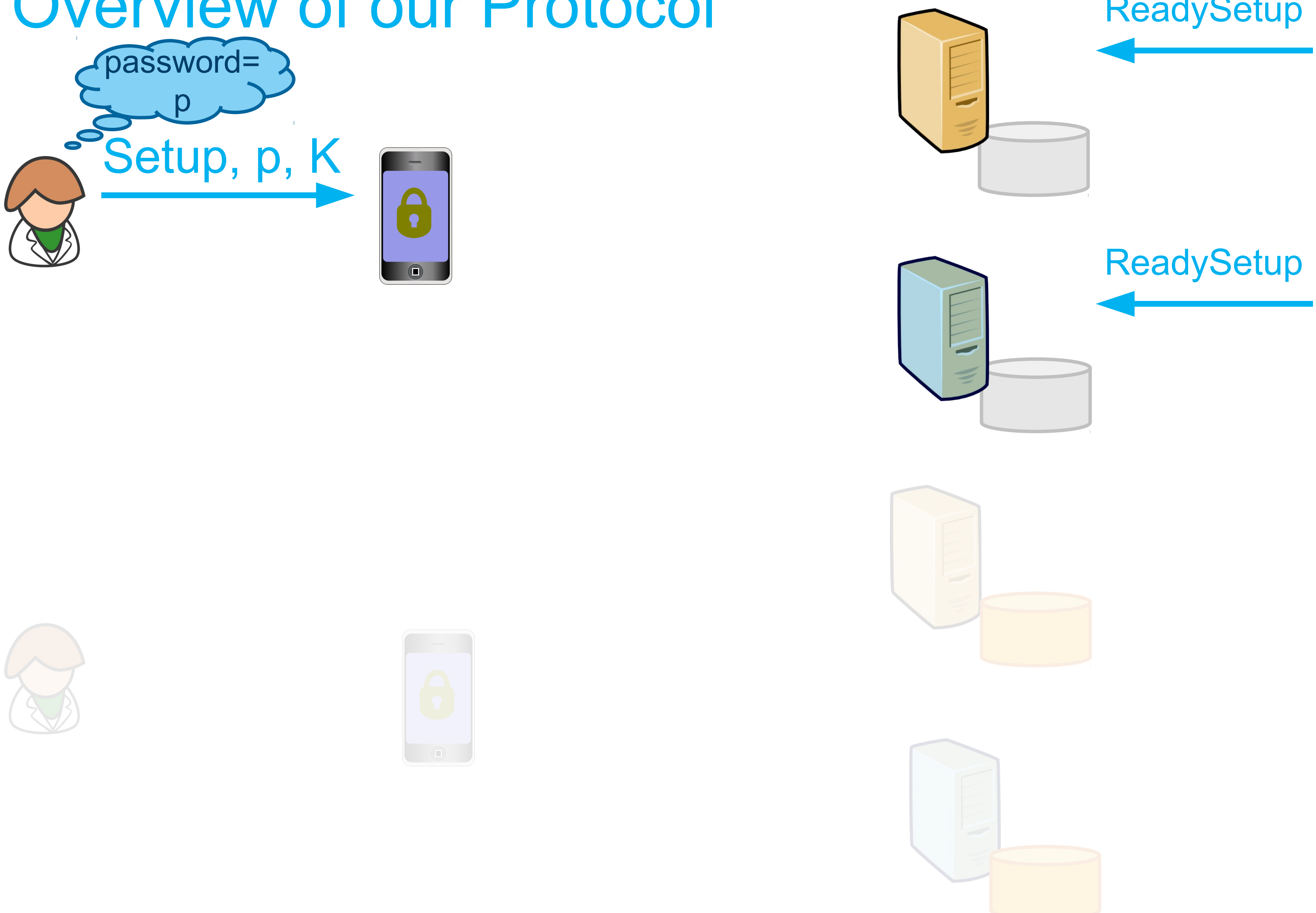

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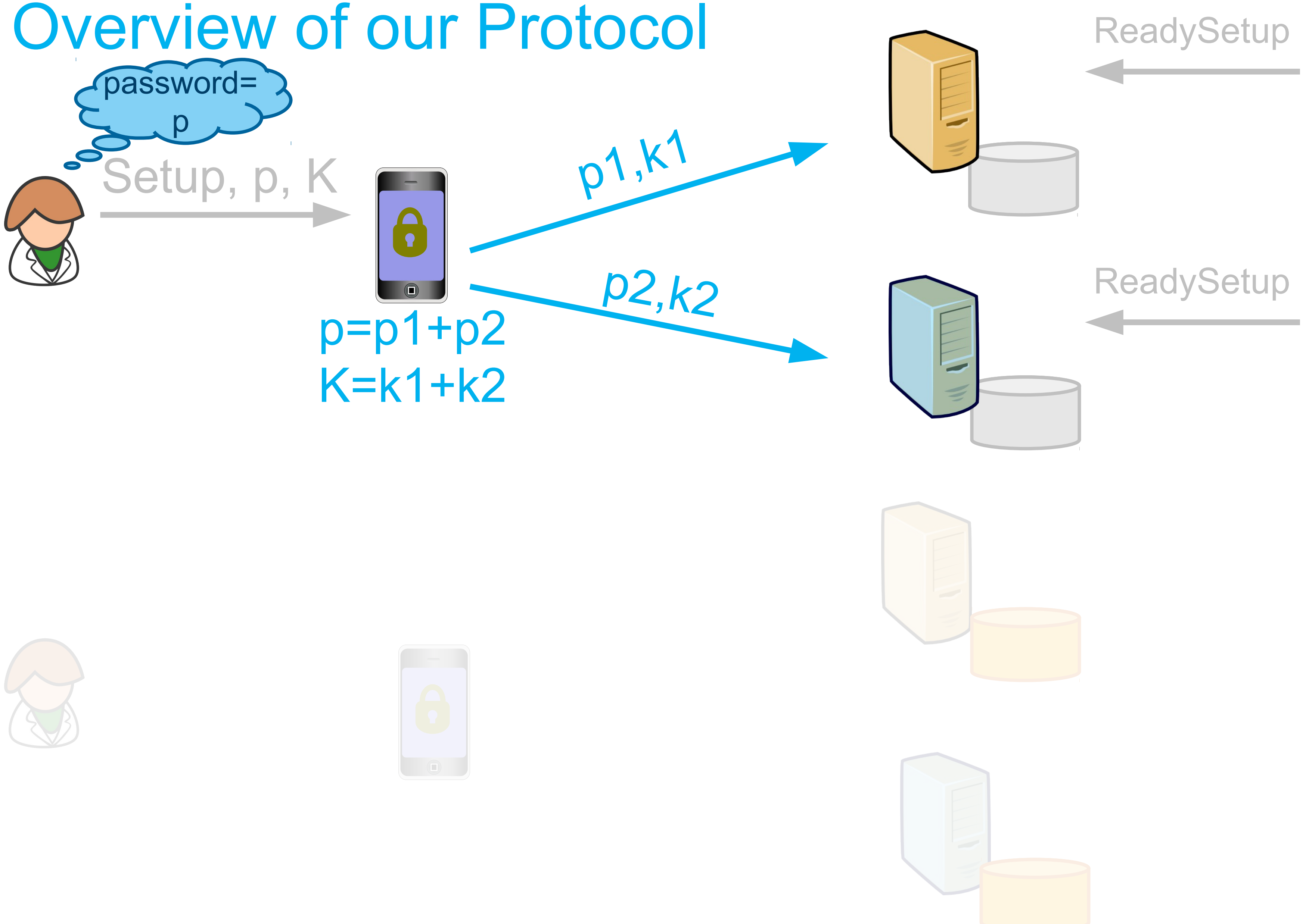

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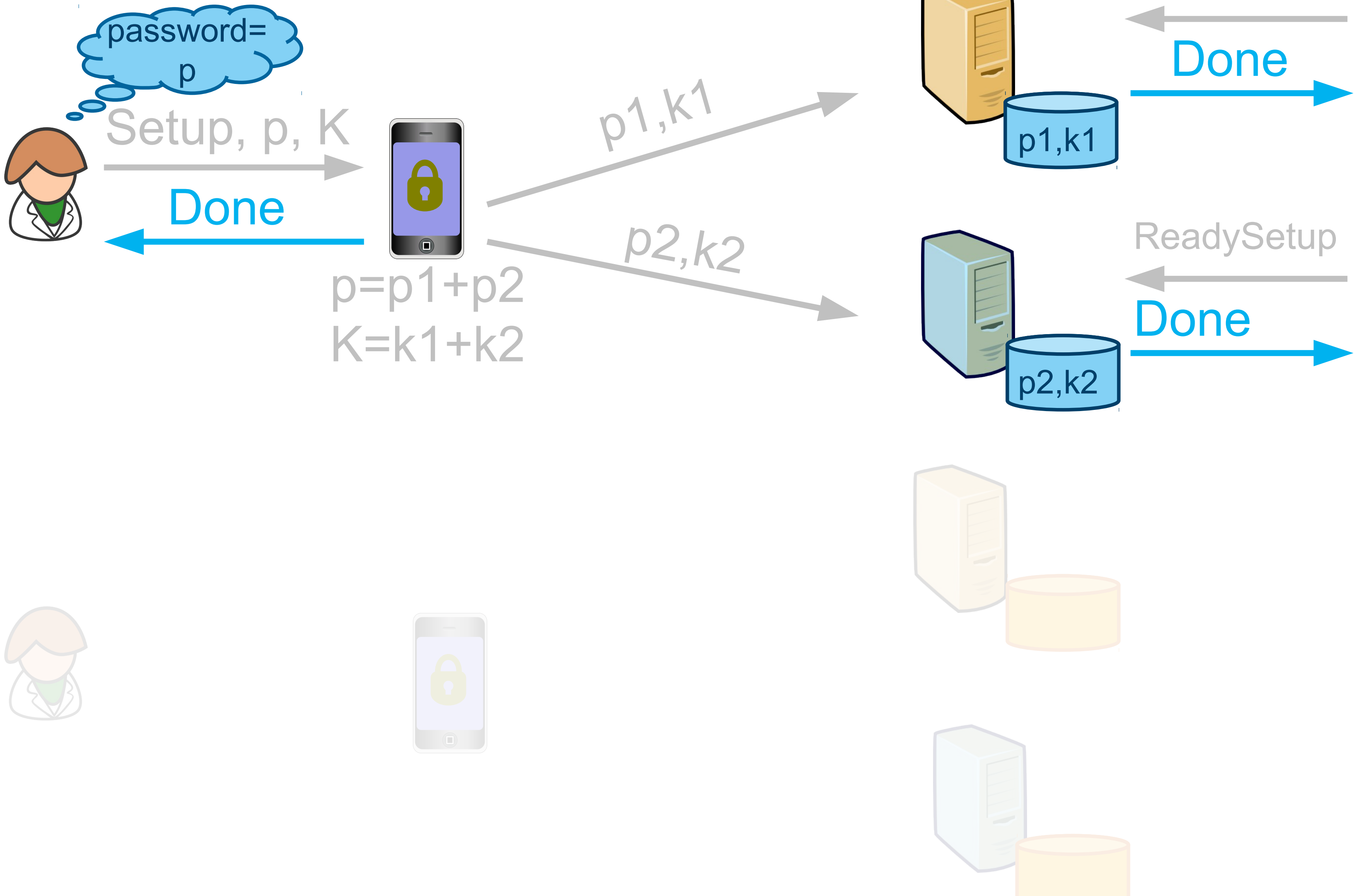

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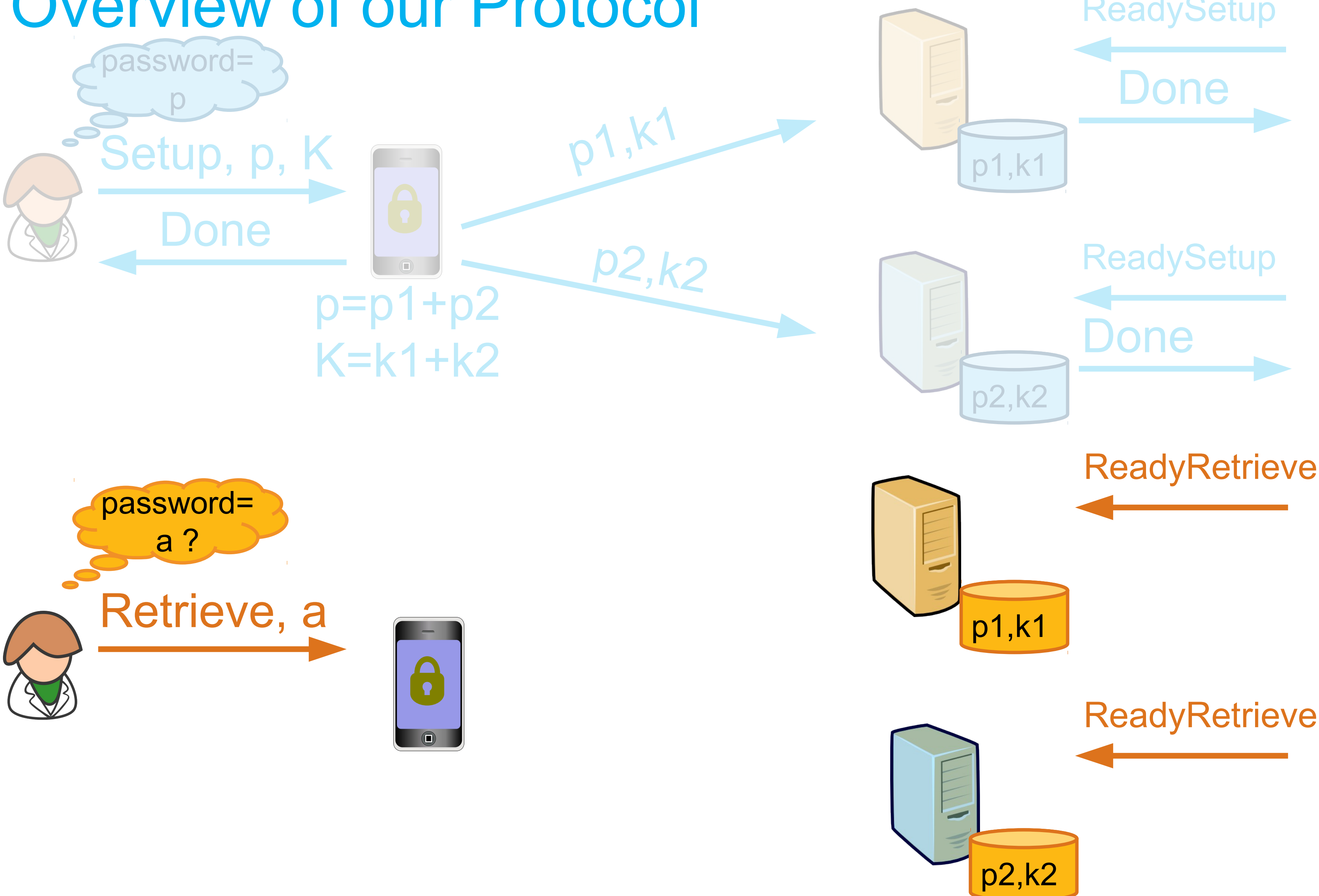

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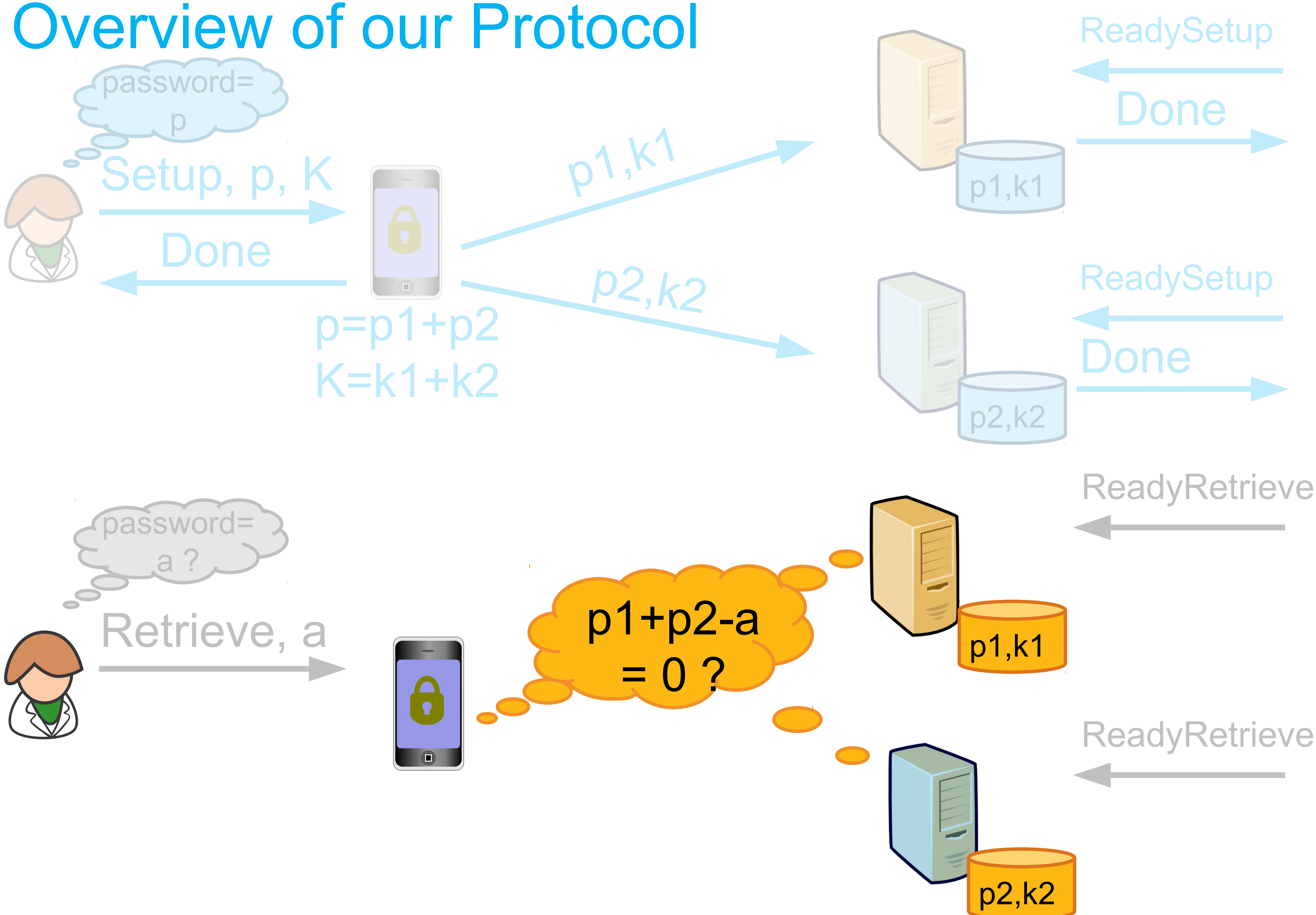

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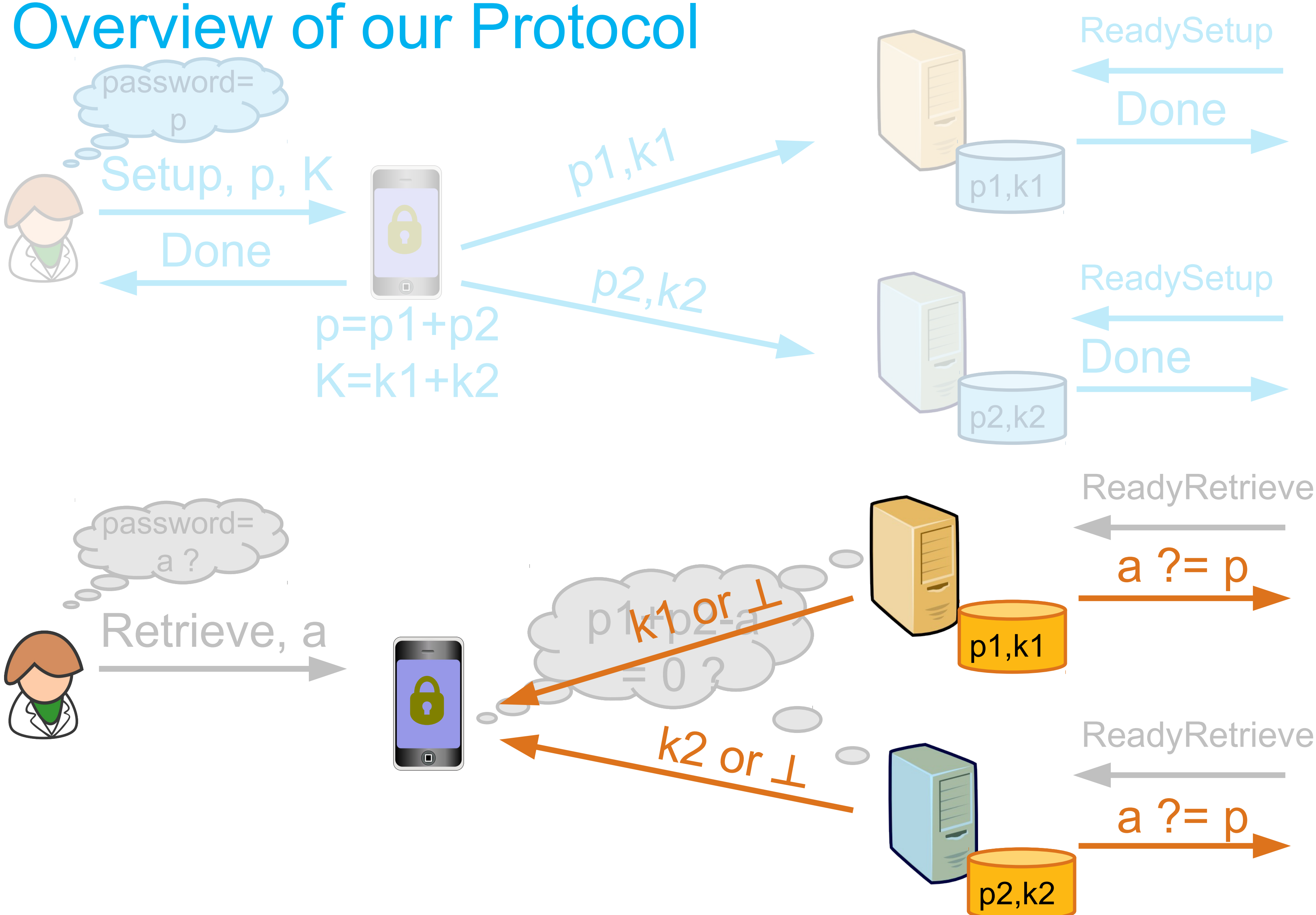

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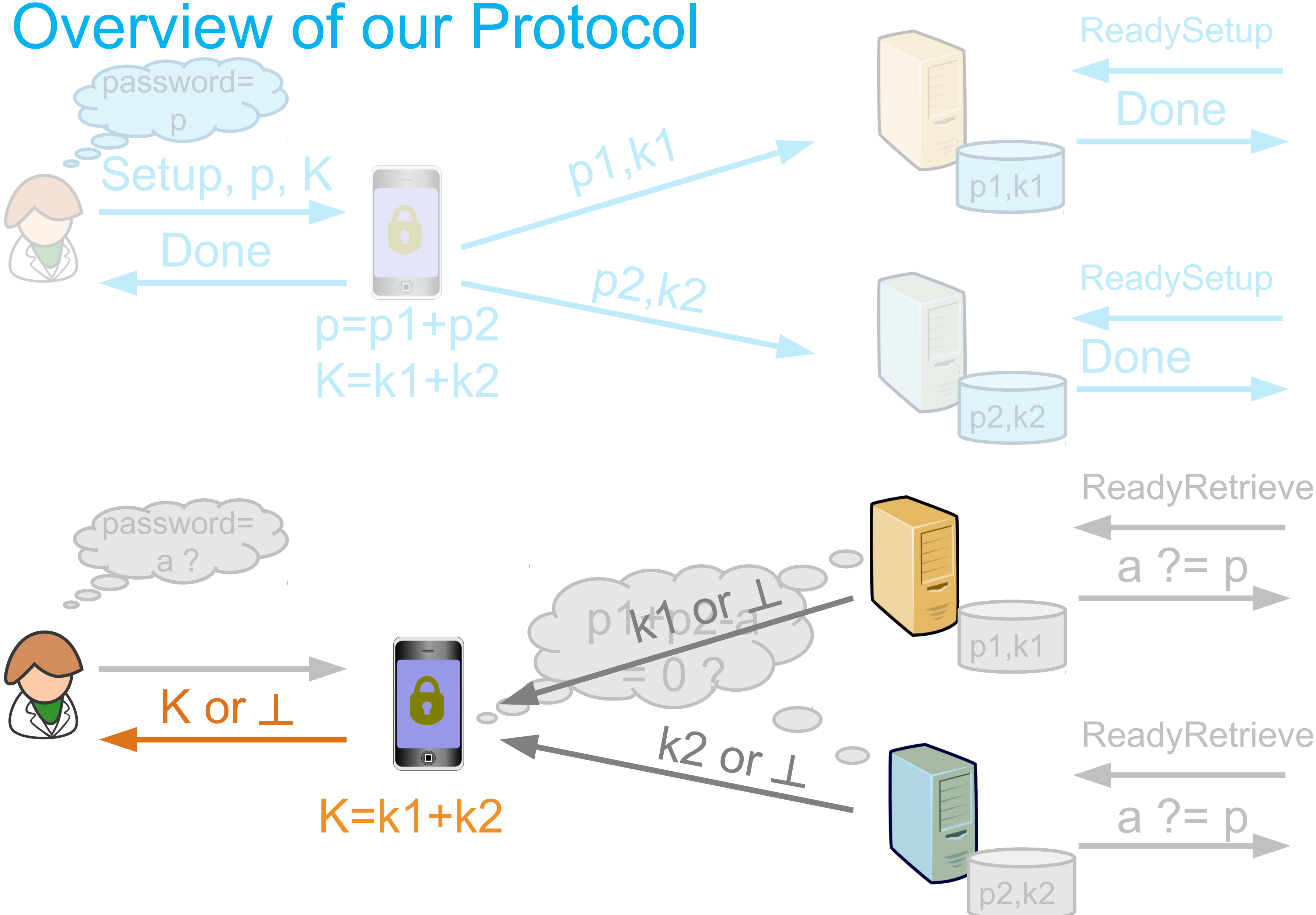
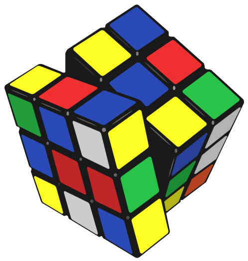


Difficulties with Security Against Dynamic Corruptions



- Selective decommitment problem:
  parties must never be committed to their input.
  - A party cannot send a ciphertext containing their input to another party: unsimulatable when recipient is then corrupted.
- We must work around this limitation,
  e.g., by using non-committing encryption based on one-time pads and secure erasures [BH91].
- Further modifications so that ZK proofs are still possible.

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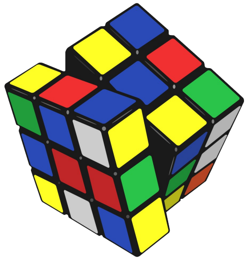

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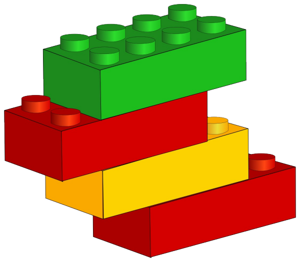
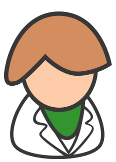
Building Blocks of Protocol



- Functionalities:
  - –One-sided authenticated channels (user ↔ servers), where only the servers are authenticated.
  - –Authenticated channels (server 1 ↔ server 2).
  - –(Local) common reference strings (CRS).
- Cryptographic schemes:
  - –Zero-knowledge proofs.
  - –Perfectly-hiding commitments (of special form).
  - –Non-committing encryption based on OTP and erasures.

High-level Idea of Protocol: Setup

- User splits (p, K) into additive shares.
- Commits to shares. Sends all commitments to servers.
- Sends encrypted shares and openings to respective server.
- Servers prove to each other they know their shares.



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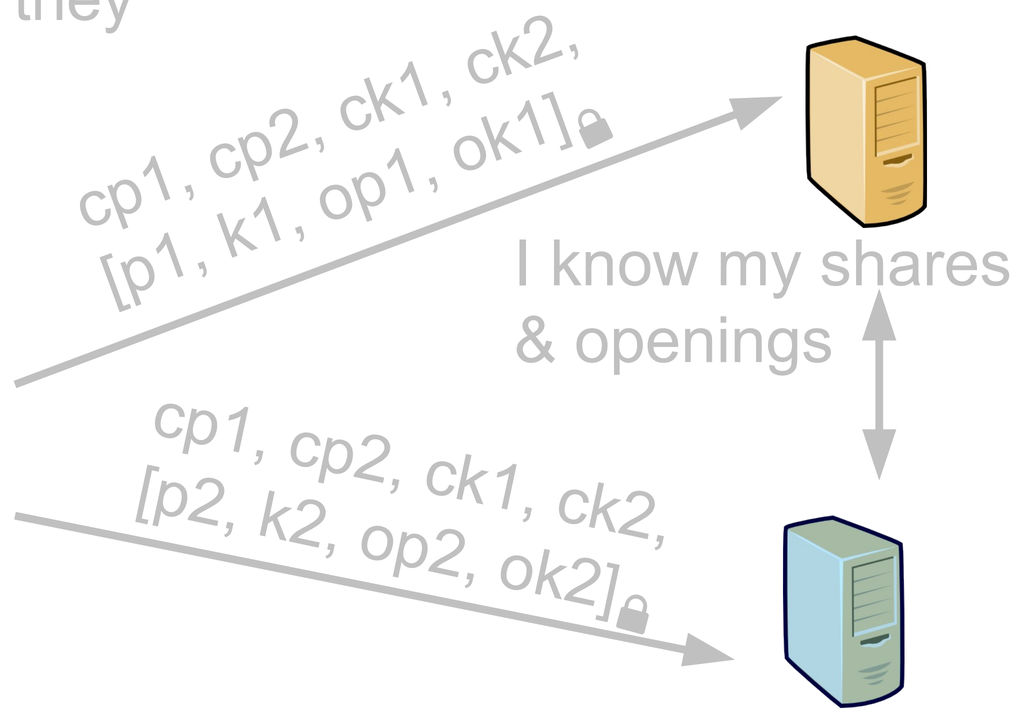

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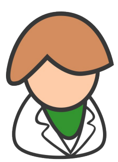

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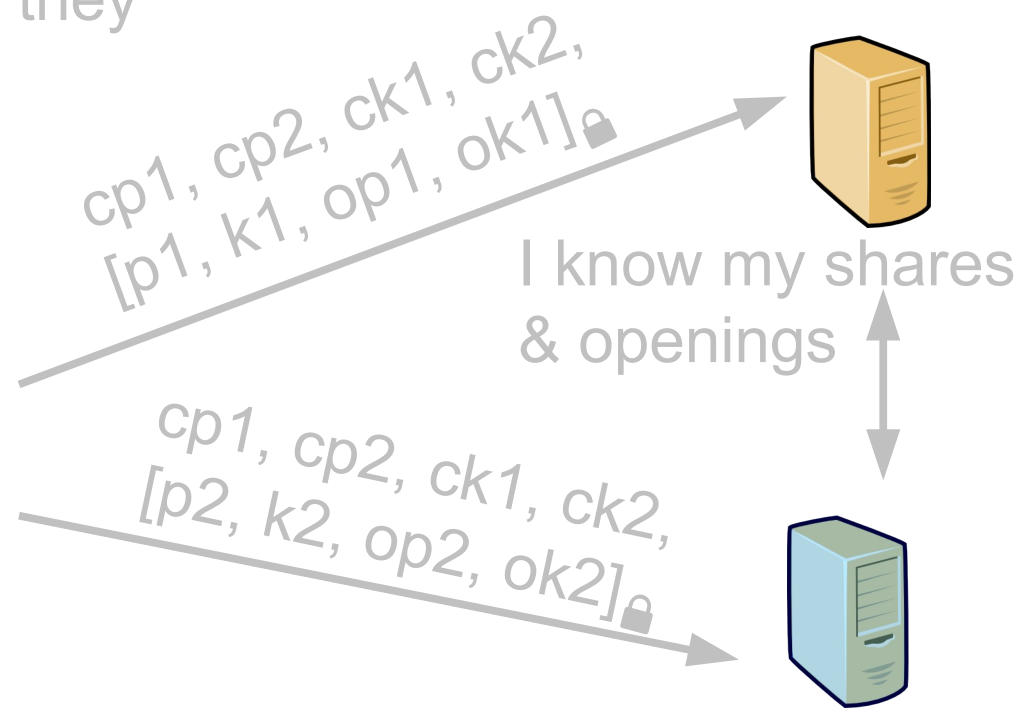

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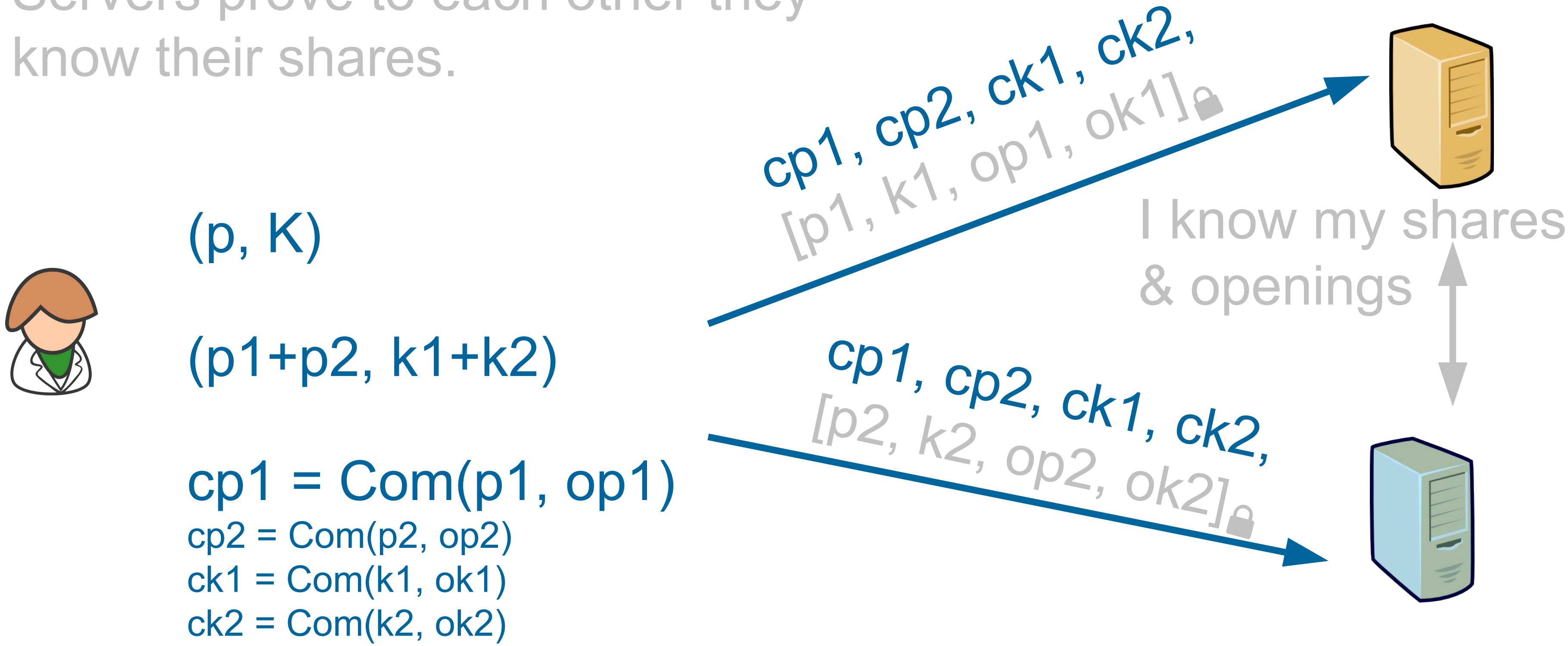

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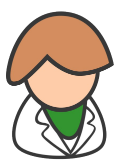

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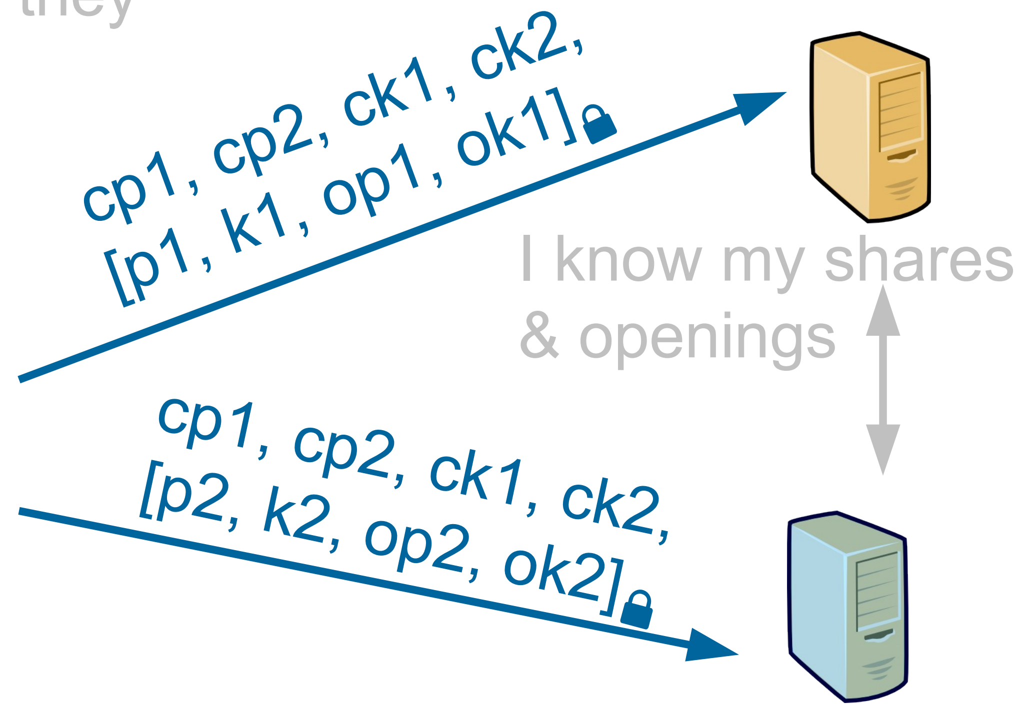

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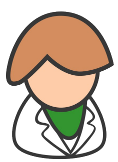

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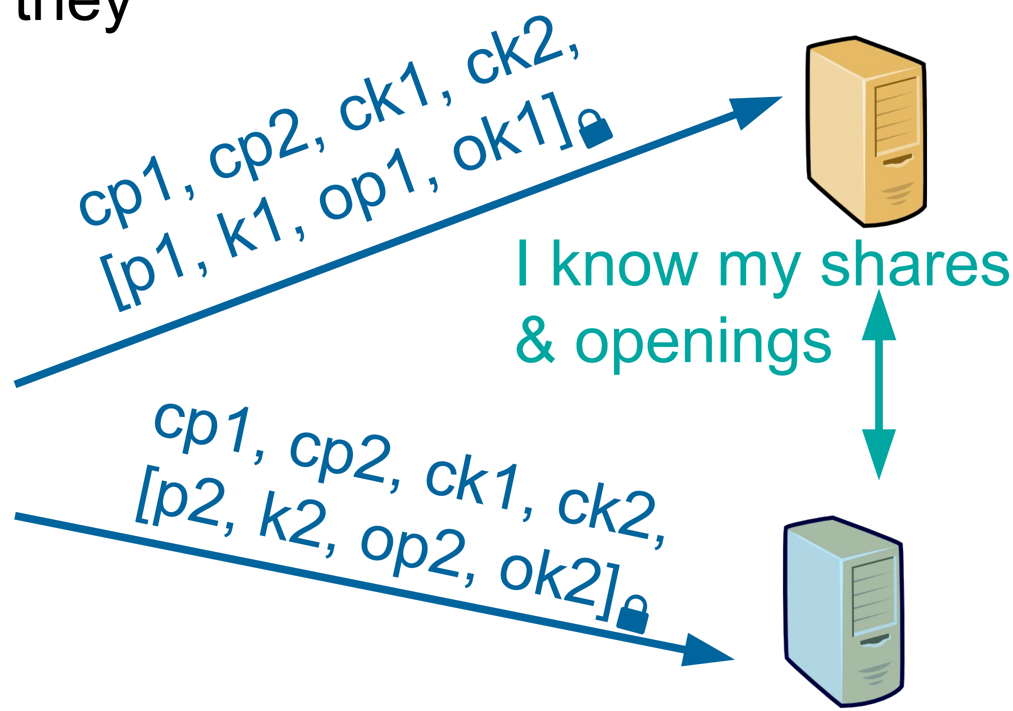

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- Servers send commitments to user & prove they know shares.
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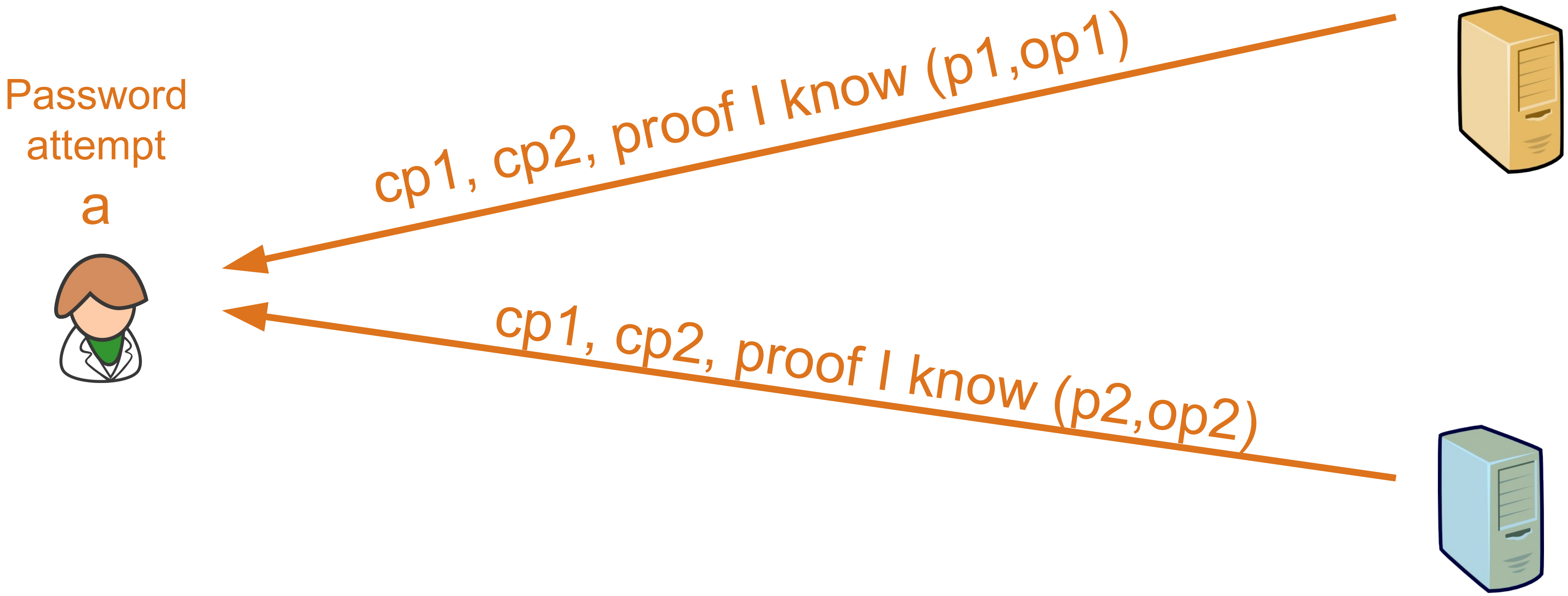

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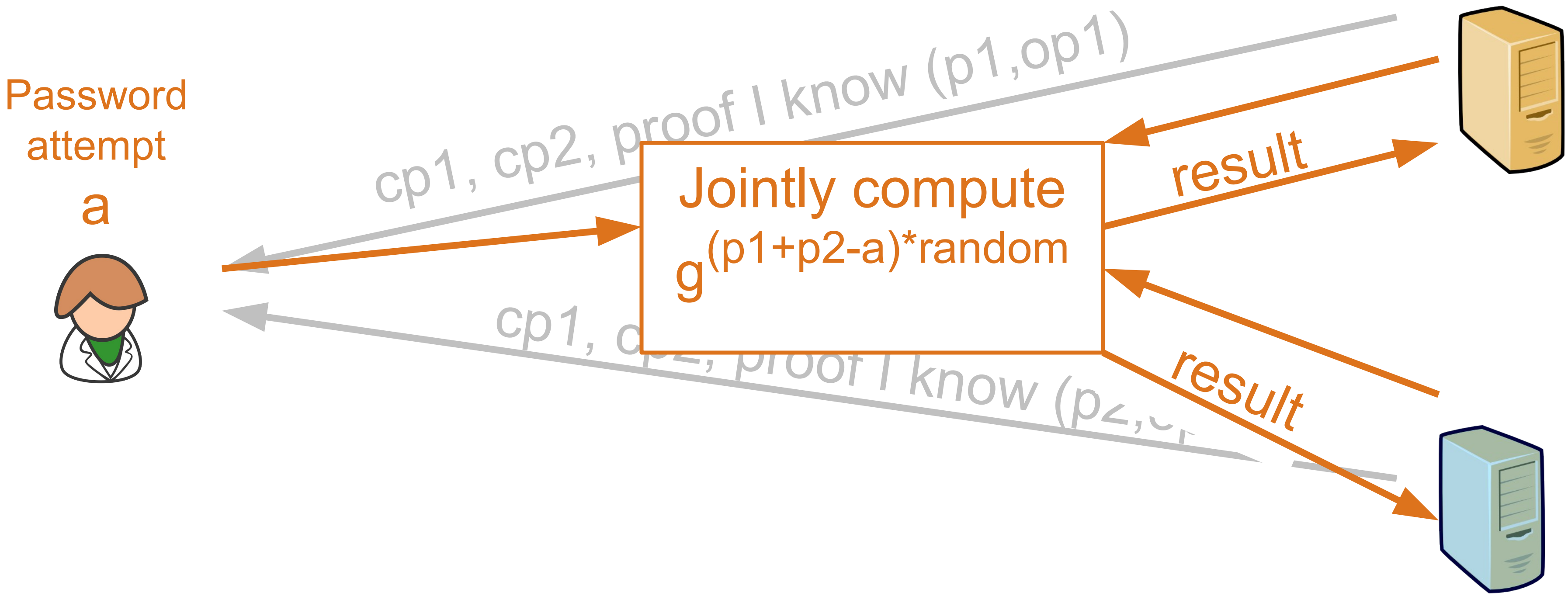

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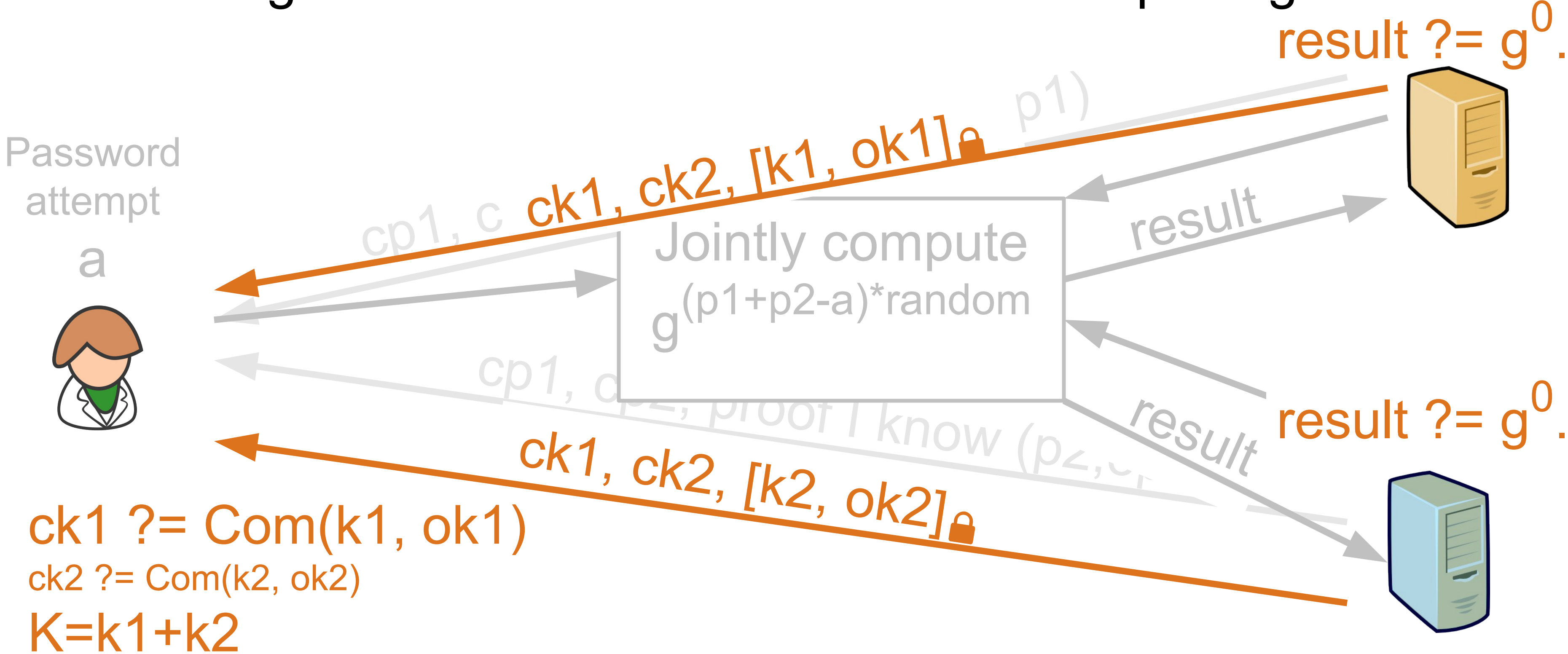

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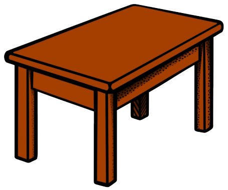

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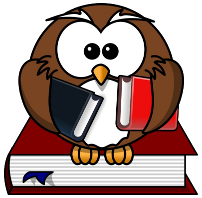
Related Work



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- Other non-UC secure PASS protocols:
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- Our paper: UC-Secure, transient corruptions, standard model.

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- Previous solutions secure only against malicious servers (i.e., against static corruptions).
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- Our solution is secure also if servers are hacked (UC-secure against dynamic corruptions).
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  - The non-negligible success probability of adversary guessing the password is handled correctly.
  - Our protocol composes nicely with itself and other protocols.

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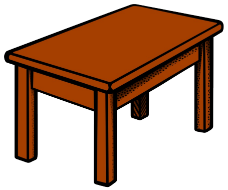

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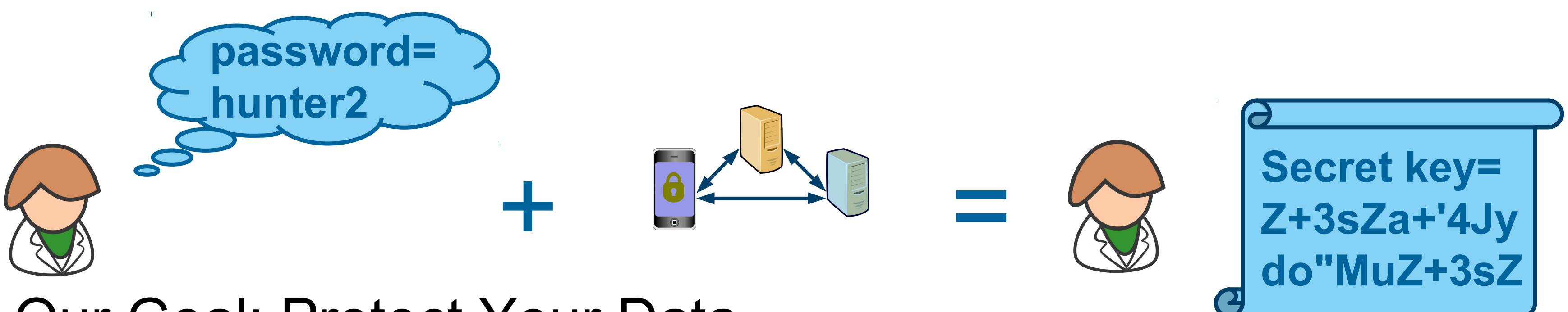
Conclusion

- First efficient 2-PASS that is UC-secure against dynamic corruptions.
  - Password protected from offline attack when ≥ 1 server honest.
  - Secret K protected when ≥ 1 server honest.

- Servers can recover from corruption.
- Efficient construction in standard model (w/ erasures). (A few hundred exponentiations ; ≤ 0.2 seconds total.)

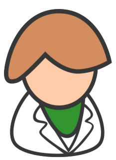


Our Goal: Protect Your Data

Backup slides: Protocol Detail

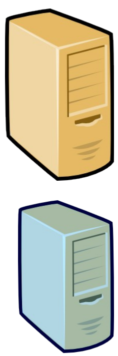
First Idea: Compute $g^{\delta\text{*random}}=g^{\text{(p1+p2-a)*random}}$

- Basic idea: use homomorphic properties of ElGamal.
- Let Elg[plaintext, rand, shkey]=$(h^{\text{rand}}, g^{\text{plaintext}}h^{\text{rand*shkey}})$.
  where $\log_g(h)$*shkey is the El-Gamal secret key.



From a, cp1, cp2 extract Elg[δ, -1, -op1-op2].

Exponentiate by random r0: → Elg[δ*r0, -r0, (-op1-op2)*r0].



Remove op1 & exp by r1: → Elg[δ*r0*r1, -r0*r1, -op2*r0*r1].

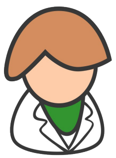
Remove op2 & exp by r2: → Elg[δ*r0*r1*r2, -r0*r1*r2, 0] =

$(h^{\text{-r0*r1*r2}}, g^{-\delta\text{*r0*r1*r2}})$.

- Parties additionally use zero-knowledge proofs throughout.

Final Idea: Compute $g^{\delta * random} = g^{(p1+p2-a)*random}$

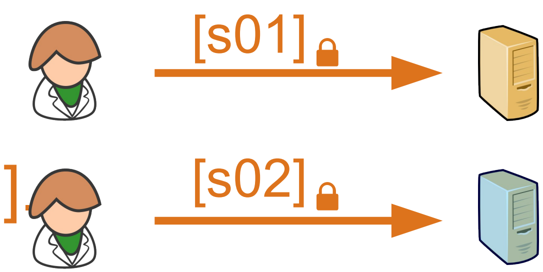
- Doesn't work: we need non-committing ciphertexts for dynamic corruption.
- Idea: add shared keys s01, s02, s12 (& send in a non-committing way).



From a, cp1, cp2 extract Elg[δ, -1, -op1-op2].

Add s01, s02 & exponentiate by r0:

→ Elg[δ*r0, -r0, (-op1-op2+s01+s02)*r0].



Add s12 & remove op1, s01 & exponentiate by r1:

→ Elg[δ*r0*r1, -r0*r1, (-op2+s02+s12)*r0*r1].

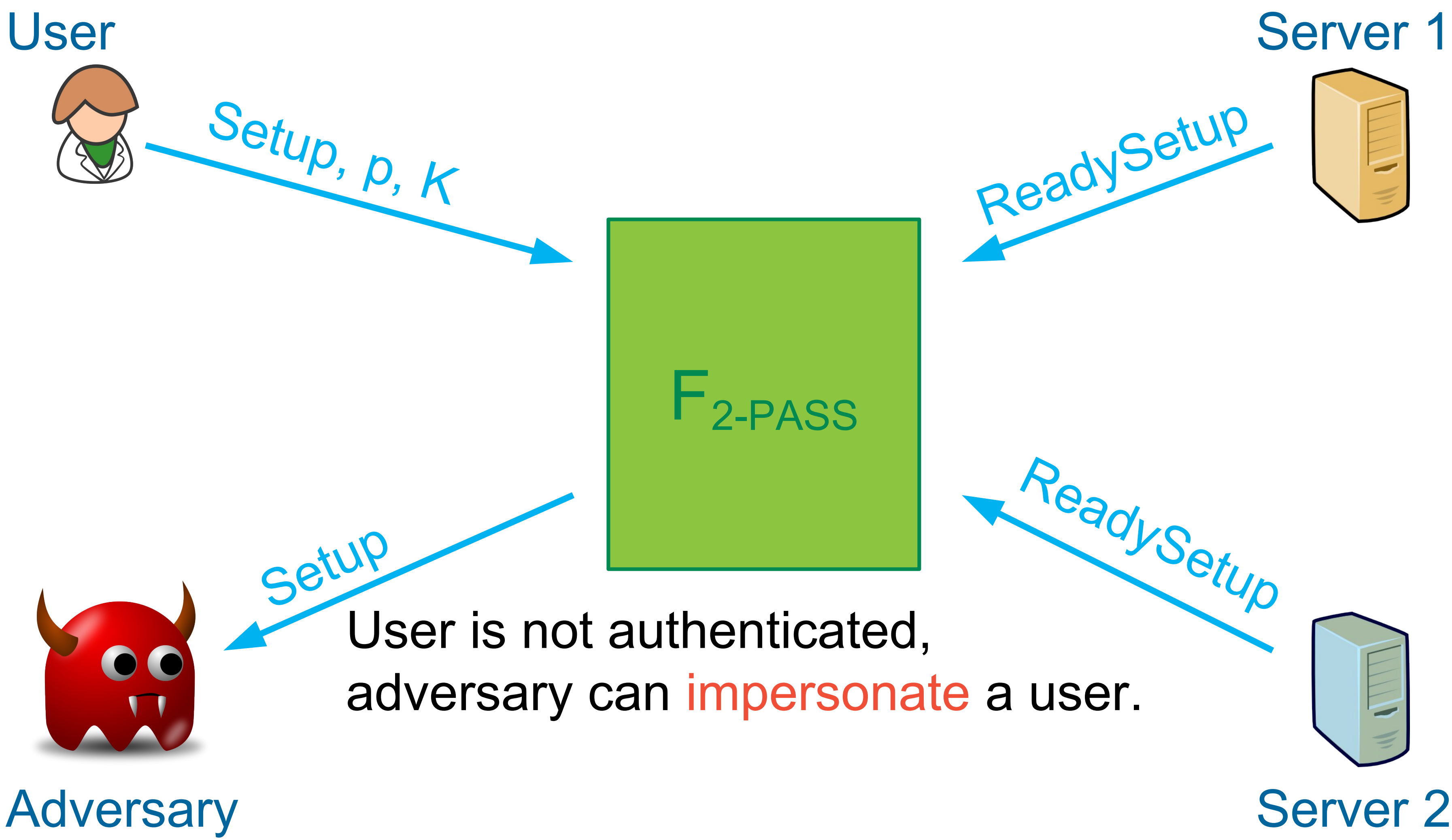
Remove op2, s02, s12 & exponentiate by r2:

→ Elg[δ*r0*r1*r2, -r0*r1*r2, 0] =(..., $g^{-\delta * r0 * r1 * r2}$).

- Parties additionally use zero-knowledge proofs throughout, and use perfect-hiding commitments to keep track of s01, s02, s12.

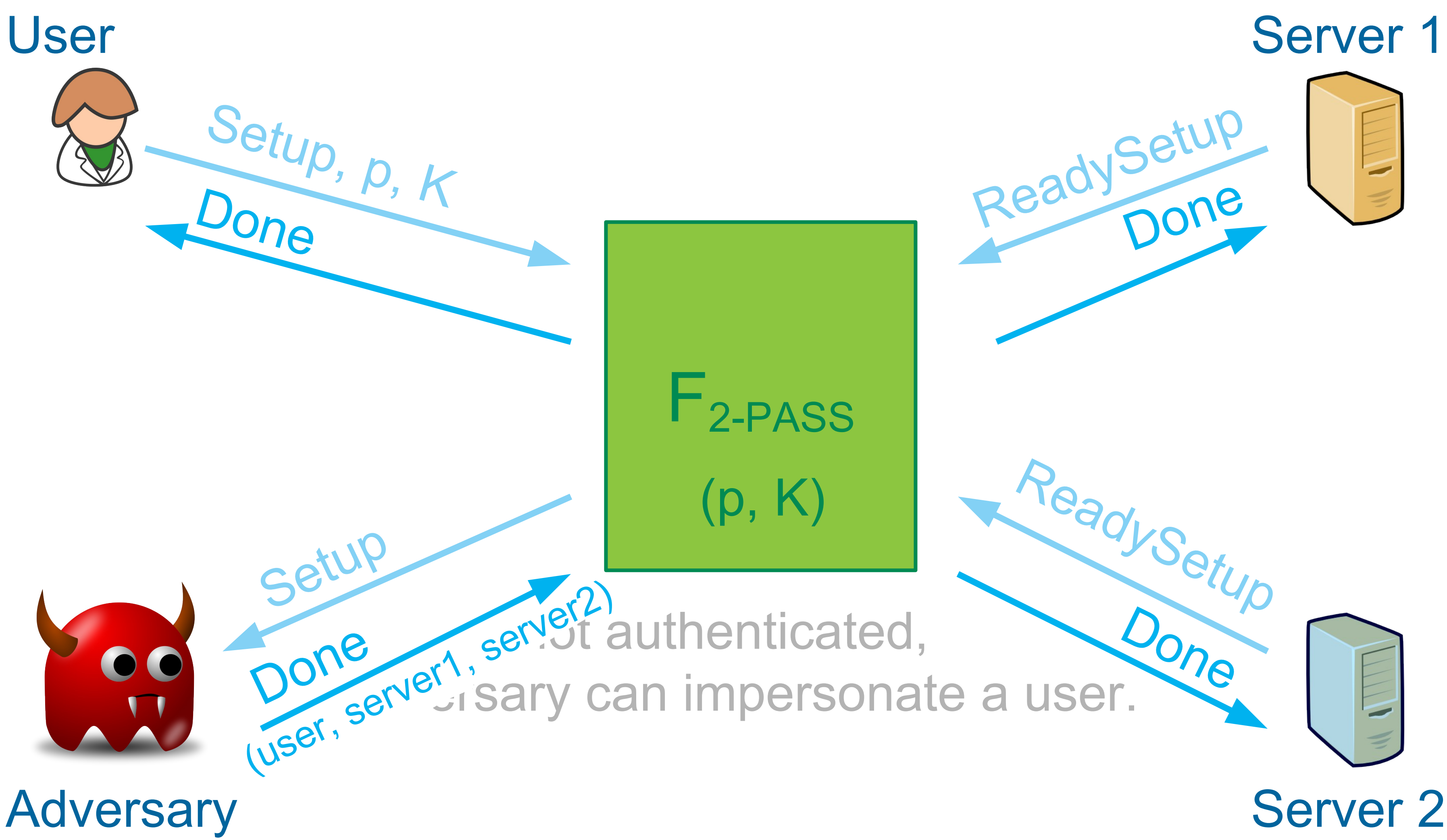
Backup slides: Ideal Functionality

Ideal Functionality $F_{2\text{-PASS}}$: Setup

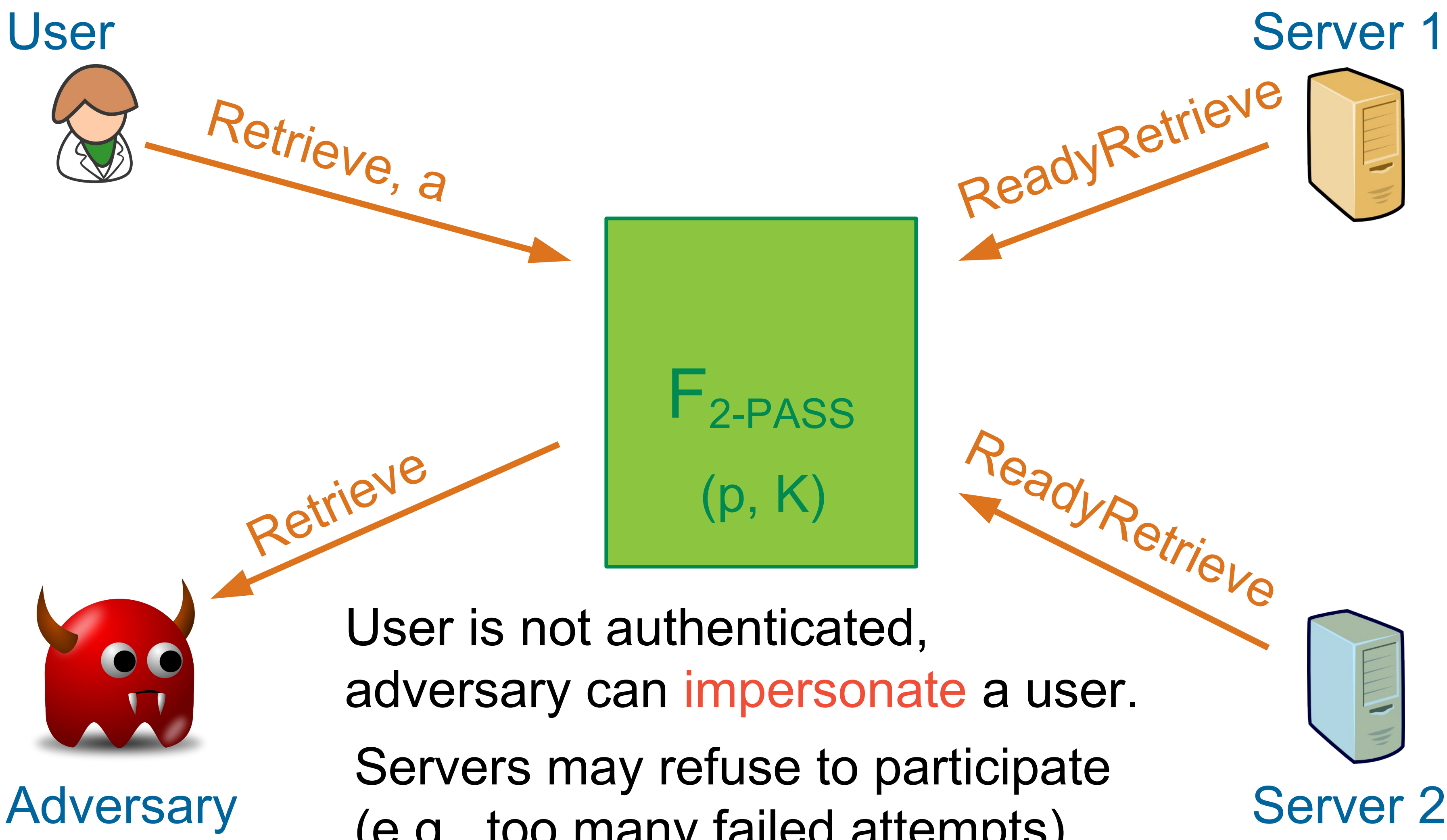


User is not authenticated,
adversary can impersonate a user.

Ideal Functionality $F_{2\text{-PASS}}$: Setup



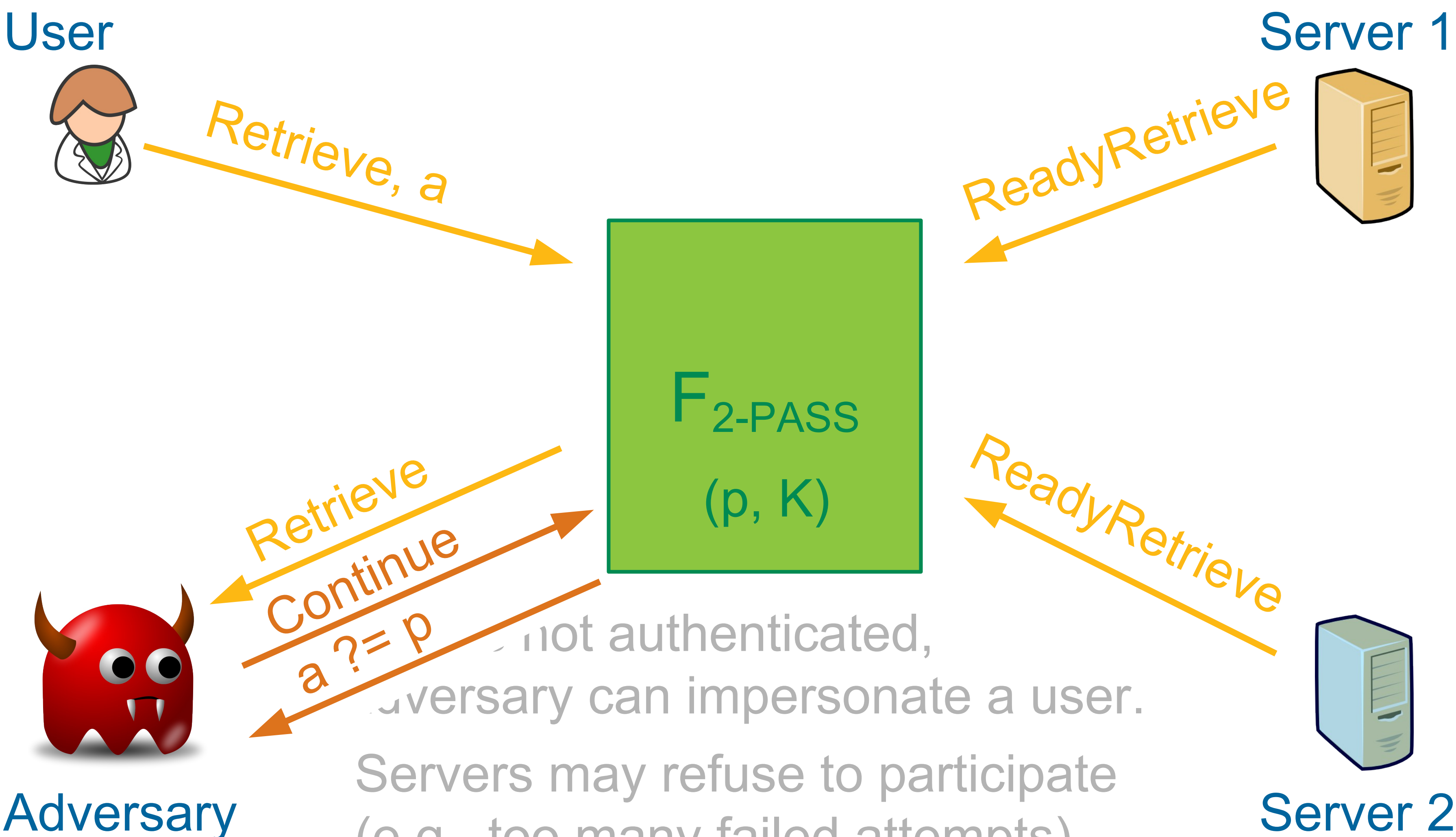
Ideal Functionality $F_{\text{2-PASS}}$: Retrieve



User is not authenticated, adversary can impersonate a user.

Servers may refuse to participate (e.g., too many failed attempts).

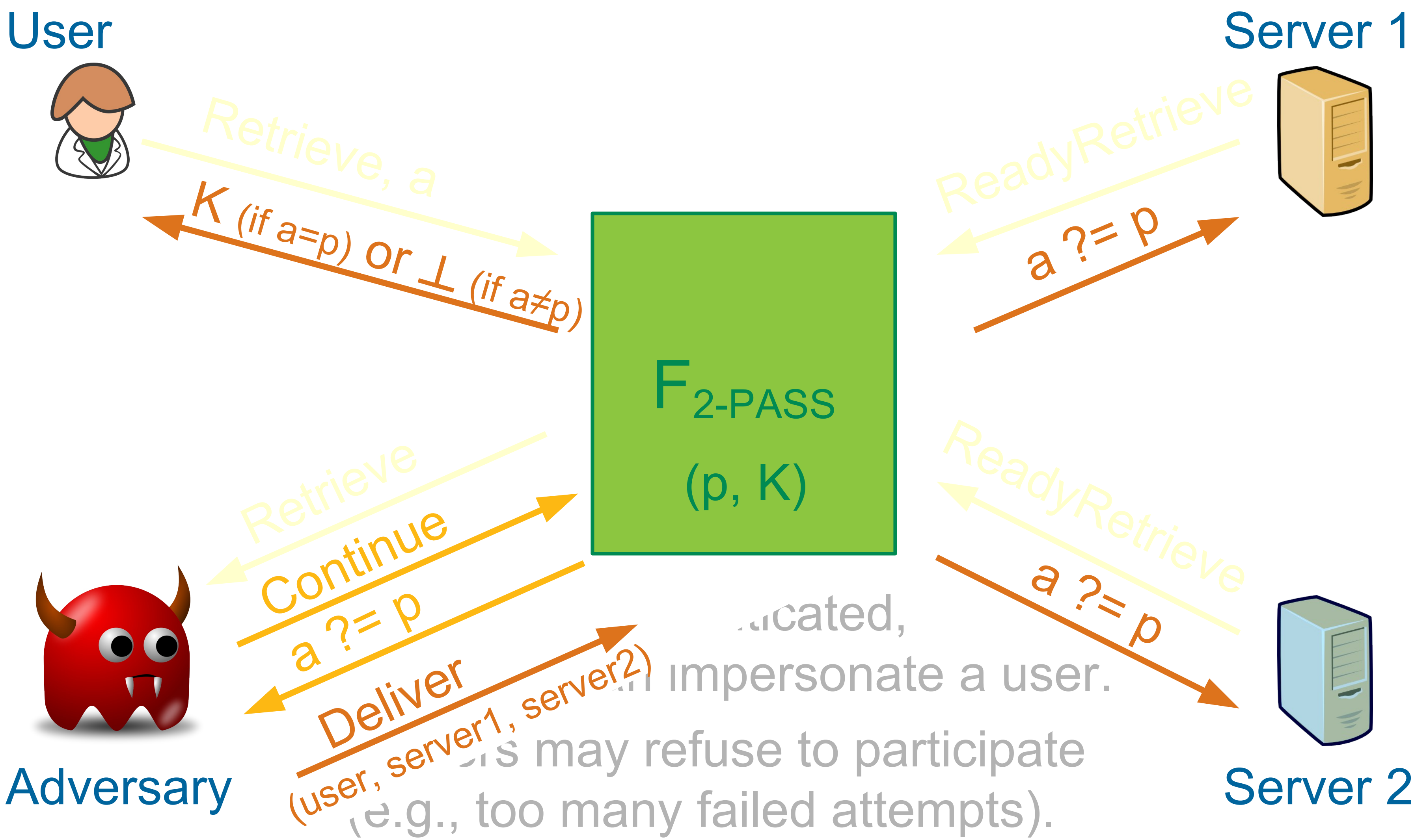
Ideal Functionality $F_{2\text{-PASS}}$: Retrieve



not authenticated,
versary can impersonate a user.

Servers may refuse to participate (e.g., too many failed attempts).

Ideal Functionality $F_{2\text{-PASS}}$: Retrieve



$F_{2\text{-PASS}}$: Modelling corruption

- Modelling corruption is necessary to be realistic.
- Corruption of user (per query):
  - –Adversary controls input & output.
  - –Adversary sees previous inputs for that query.
- Corruption of one server:
  - –Adversary controls input & output.
- Corruption of both servers:
  - –Adversary also learns (p, K) from $F_{2\text{-PASS}}$.
  - –Adversary can set (p, K) in $F_{2\text{-PASS}}$ for every query or permanently.

$F_{2\text{-PASS}}$: Recovery from Corruption

- Models that server detects it was hacked and takes remedial action (e.g., recovers from backup).
- Adversary may leave a corrupted server.
  - Both servers then run a Refresh protocol.
    - This aborts all currently running queries.
  - Afterwards, server is then not corrupted anymore (adversary doesn't control input & output).

2-PASS Ideal Functionality.

- Servers can refuse to service Retrieve queries (to defend against on-line brute force attacks).
- Servers and adversary learn if p = a (password attempt).
- If only one server compromised:
  - Adversary doesn't learn anything about the p, K, & a.
  - Cannot cause user to get wrong K.
- Two servers compromised: adversary gets (p, K), but not password attempts. (Also if user contacts wrong servers.)