# *Practical Privacy-Preserving Authentication for SSH*

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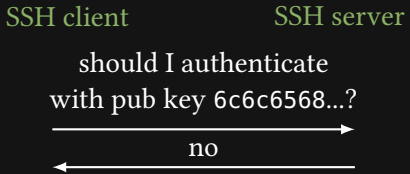
Stanislav Lyakhov
Yeongjin Jang
Mike Rosulek

Oregon State University

NIST Crypto Reading Club
ia.cr/2022/740

2022-08-23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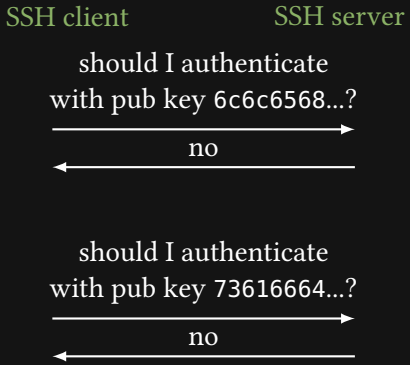
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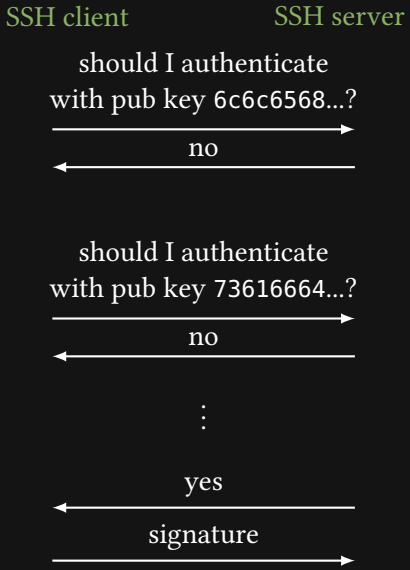
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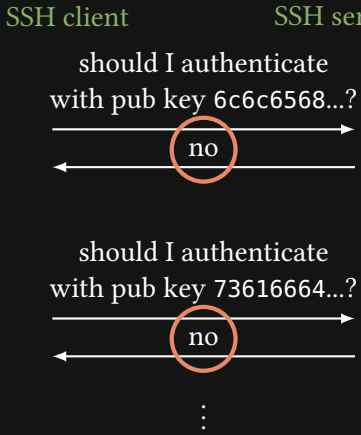
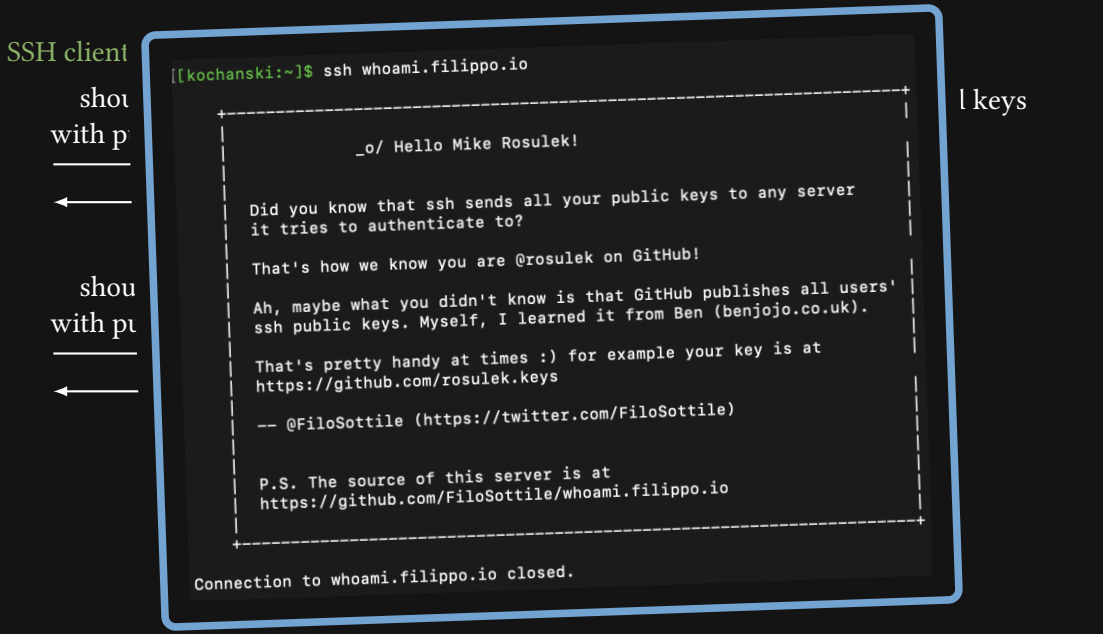



**problem:** server can fingerprint client:

- refuse all advertisements ⟹ learn all keys


SSH client
SSH server
problem:
shou
with p
shou
with pu
l keys
04 Aug 2015
SSH WHOAMI.FILIPPO.IO
Here's a fun PoC I built thanks to Ben's dataset.
I don't want to ruin the surprise, so just try this command. (It's harmless.)
ssh whoami.filippo.io
For the security crowd: don't worry, I don't have any OpenSSH oday and even if I did I wouldn't burn them on my blog. Also, ssh is designed to log into untrusted servers.
Filippo Valsorda https://words.filippo.io/ssh-whoami-filippo-io/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Did you know that ssh sends all your public keys to any server
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That's how we know you are @rosulek on GitHub!
Ah, maybe what you didn't know is that GitHub publishes all users'
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That's pretty handy at times :) for example your key is at
https://github.com/rosulek.keys
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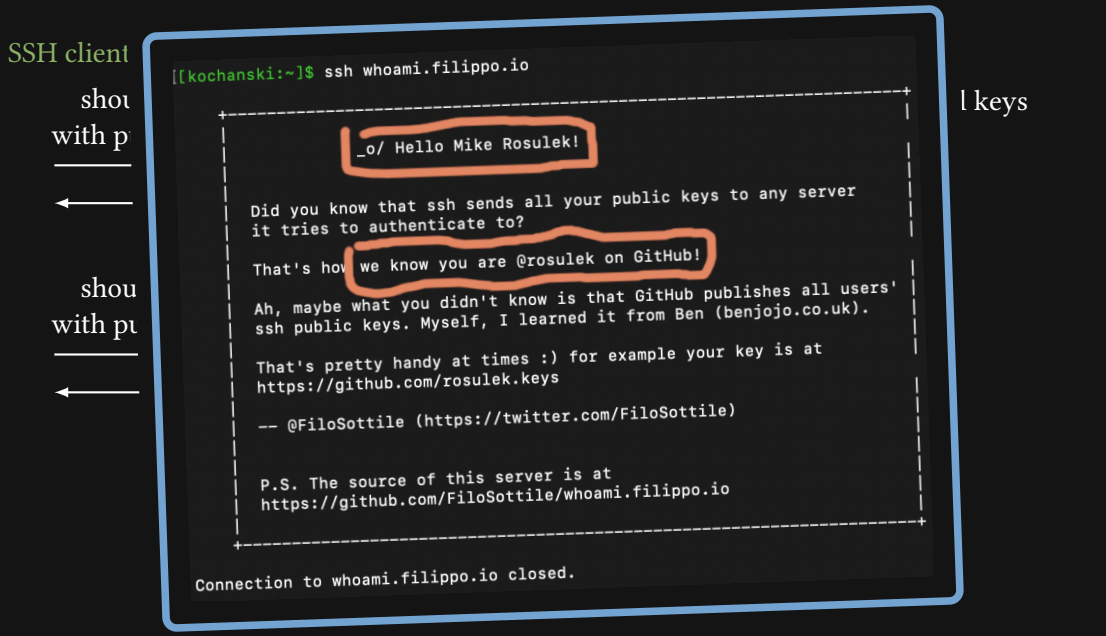
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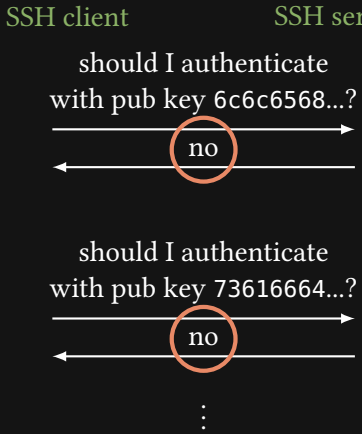


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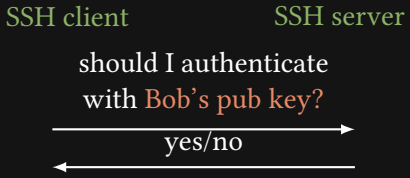


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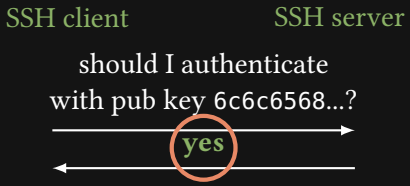
- fundamental to protocol

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**problem:** server can act as honeypot:

- accept *any* key, even ones never seen before
- fundamental to protocol

# *goals of this work*

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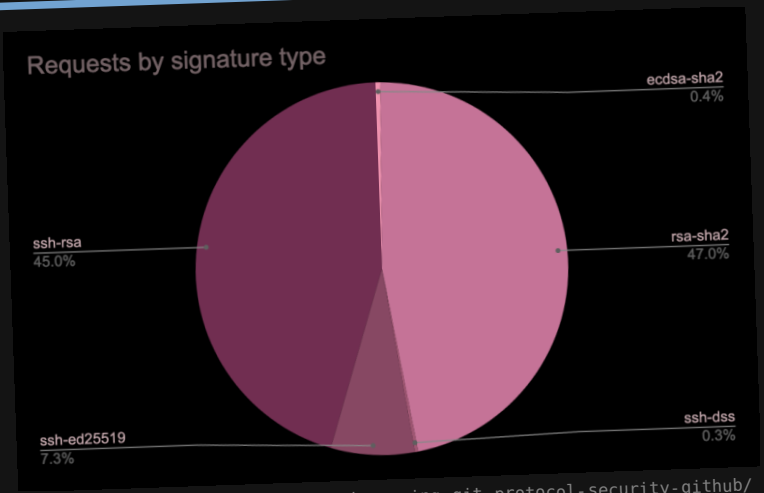
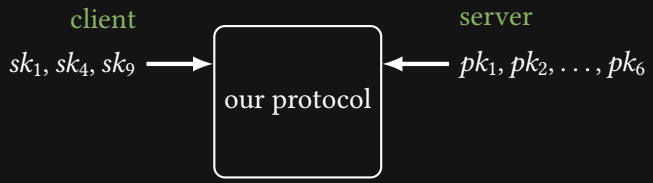



https://github.blog/2021-09-01-improving-git-protocol-security-github/

# *goals of this work*

1. server & client should learn minimal information
2. authenticate with respect to existing SSH keys
3. minimize reliance on per-site configuration

# *our new authentication method:* big picture

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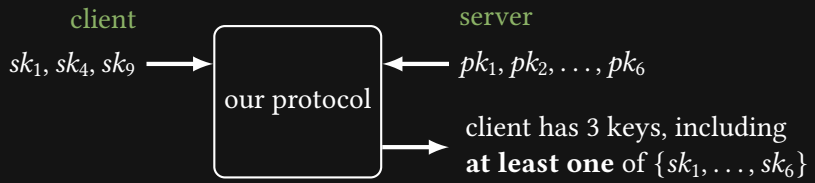


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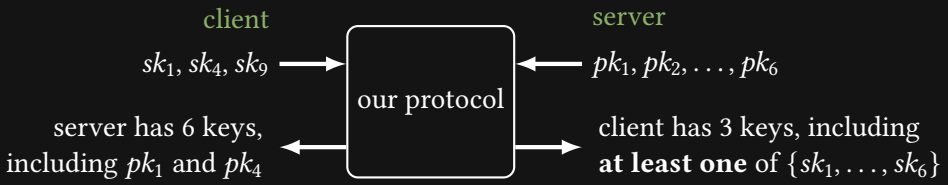


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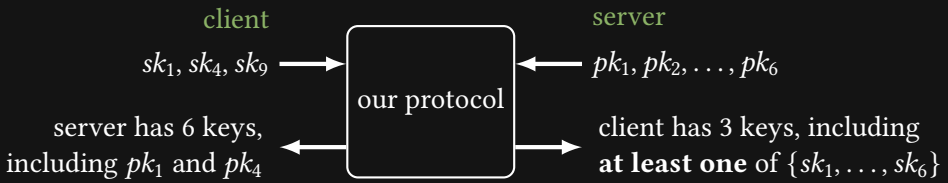


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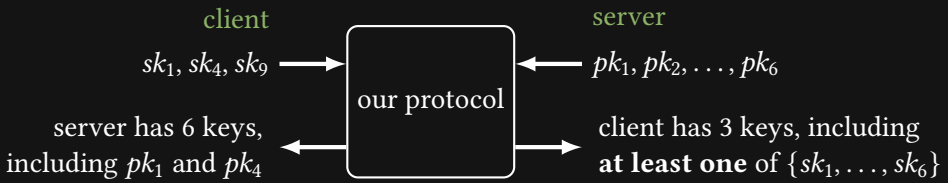


- any **mixture** of existing RSA, ECDSA, EdDSA keys, in a single authentication attempt
- does not depend on site-specific configuration; safe to use **all keys** in every authentication attempts
- client won't connect unless server **knows** and **explicitly includes** one of client's keys

# *technical overview*

client (with $\{sk_i\}_i$):

server (with $\{pk_j\}_j$):

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$c, \{m_j\}_j \leftarrow \mathsf{Enc}\Big(\{pk_j\}_j\Big)$

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address ciphertext to $\{pk_j\}_j$;
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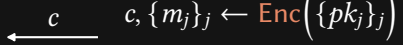


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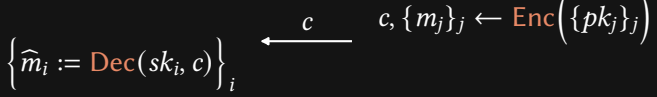


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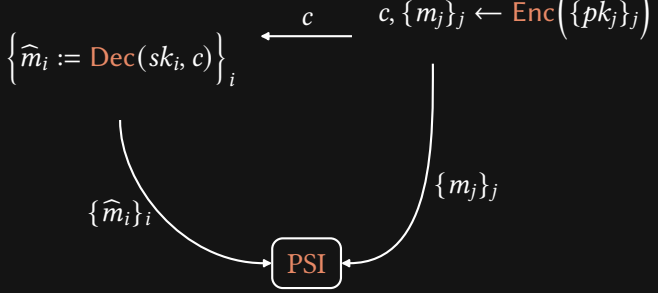


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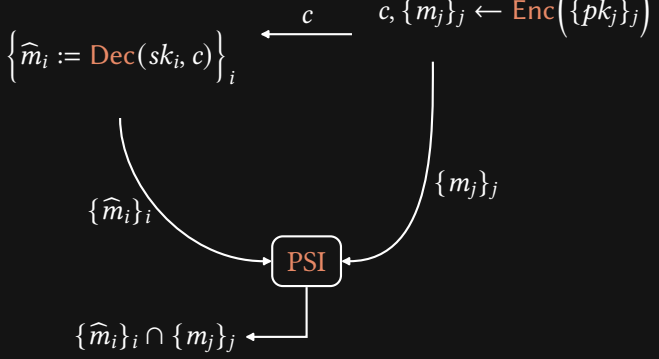


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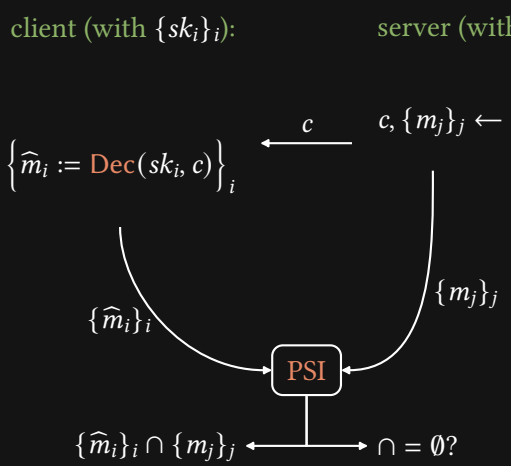


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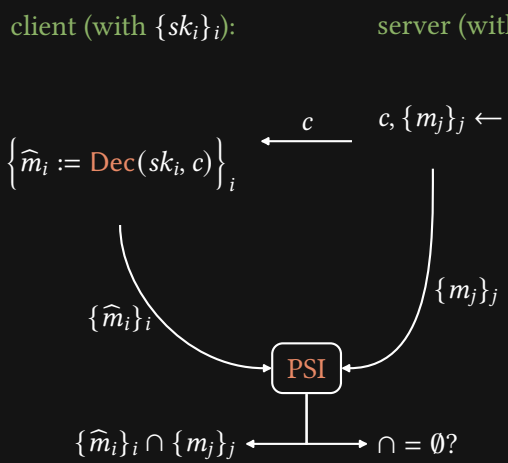
# *technical overview & contributions*

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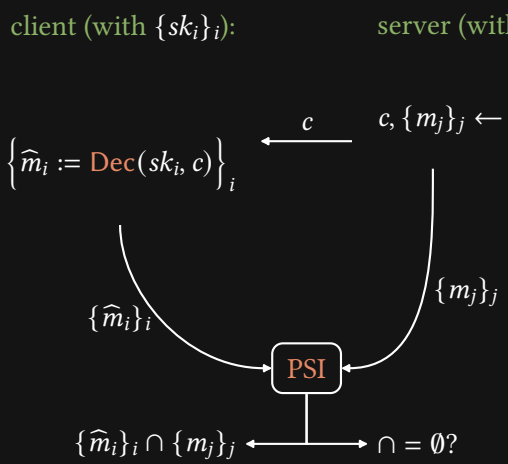


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add "proof of nonempty intersection" to [RosulekTrieu21] PSI

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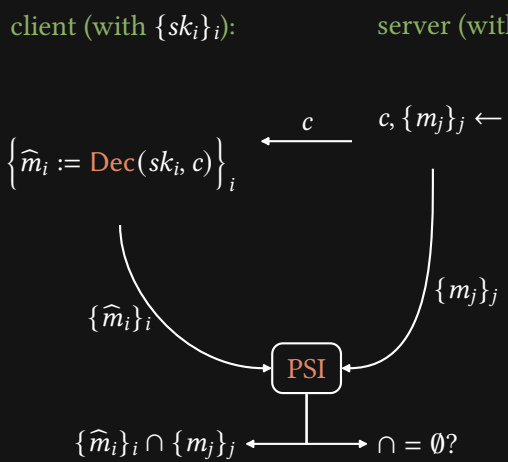


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+ full UC security analysis

# *concrete performance (in OpenSSH):*

| # of keys | | RSA keys only (worst case for us) | | {EC,Ed}DSA keys only (best case for us) | |
|---|---|---|---|---|---|
| client | server | time | comm | time | comm |

`github.com/osu-crypto/PSIPK-ssh`

2 commodity desktop computers on LAN

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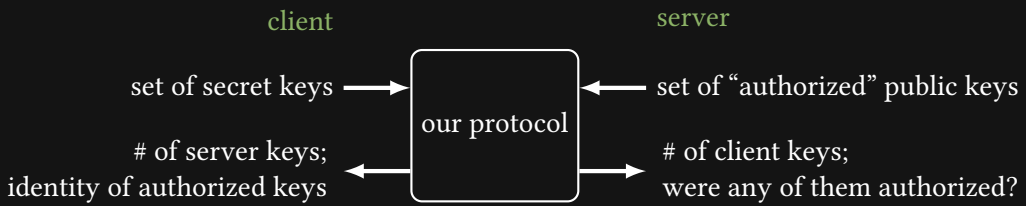


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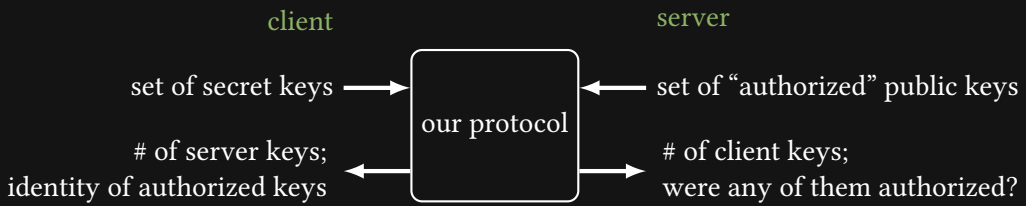
- ✓ mixture of existing RSA & EC keys
- ✓ safe without special per-site configuration

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*(backup slides)*

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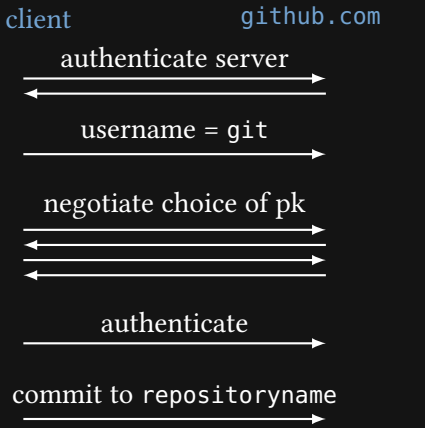

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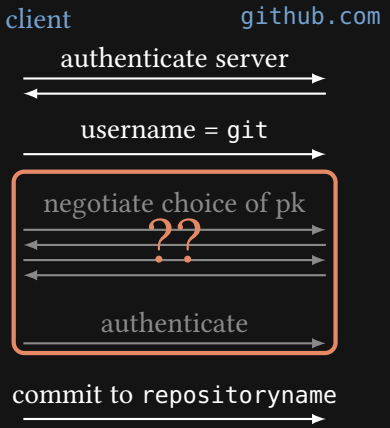

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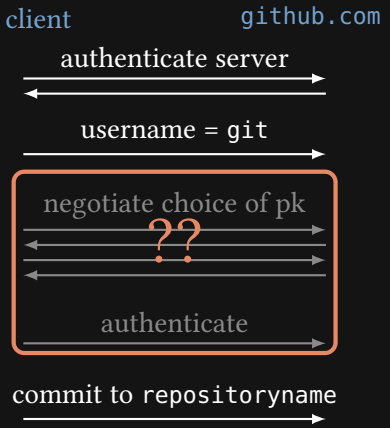


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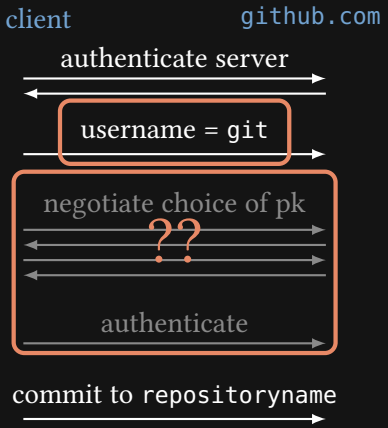


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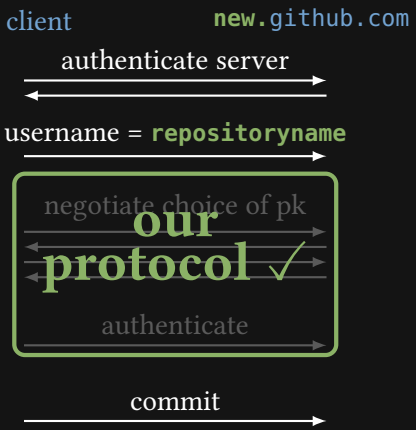


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- server does not know repository name yet!
- use repository name as `username`

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address ciphertext to $\{pk_j\}_j$;
$sk_j$ decrypts $c$ to $m_j$;
$c$ hides $pk_j$ recipients

# *the case of EdDSA/ECDSA*

Alice: $pk_A = g^a$

Bob: $pk_B = g^b$

Charlie: $pk_C = g^c$

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*ciphertext hides set of recipients; even # of them!*

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Alice: $pk_A = (N_A, e_A)$

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encrypt $(r_A)^{e_A} \bmod N_A$

encrypt $(r_B)^{e_B} \bmod N_B$

encrypt $(r_C)^{e_C} \bmod N_C$

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Alice: $pk_A = (N_A, e_A)$

Bob: $pk_B = (N_B, e_B)$

Charlie: $pk_C = (N_C, e_C)$

encrypt $(r_A)^{e_A} \bmod N_A$

encrypt $(r_B)^{e_B} \bmod N_B$

encrypt $(r_C)^{e_C} \bmod N_C$

interpolate poly $P$:

$P(N_A) = (r_A)^{e_A}$

$P(N_B) = (r_B)^{e_B}$

$P(N_C) = (r_C)^{e_C}$

**1. anonymous multi-KEM**

address ciphertext to $\{pk_j\}_j$;
$sk_j$ decrypts $c$ to $m_j$;
$c$ hides $pk_j$ recipients

# *the case of RSA*

Alice: $pk_A = (N_A, e_A)$

Bob: $pk_B = (N_B, e_B)$

Charlie: $pk_C = (N_C, e_C)$

encrypt $(r_A)^{e_A} \bmod N_A$

encrypt $(r_B)^{e_B} \bmod N_B$

encrypt $(r_C)^{e_C} \bmod N_C$

interpolate poly $P$:

$P(N_A) = (r_A)^{e_A}$

$P(N_B) = (r_B)^{e_B}$

$P(N_C) = (r_C)^{e_C}$

ciphertext = $P$ ←

**1. anonymous multi-KEM**

address ciphertext to $\{pk_j\}_j$;
$sk_j$ decrypts $c$ to $m_j$;
$c$ hides $pk_j$ recipients

# *PSI with proof of nonempty intersection*

**2. private set intersection**

each party has set of items;
client learns intersection;
server learns whether empty

# *oblivious PRF (OPRF) paradigm for PSI*

[FreedmanIshaiPinkasReingold05]

Alice:

$X = \{x_1, x_2, \ldots\}$

Bob:

$Y = \{y_1, y_2, \ldots\}$

# *oblivious PRF (OPRF) paradigm for PSI*

[FreedmanIshaiPinkasReingold05]

Alice:

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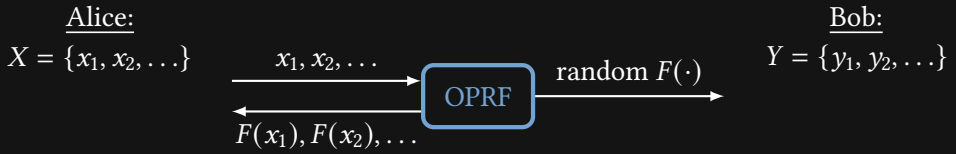
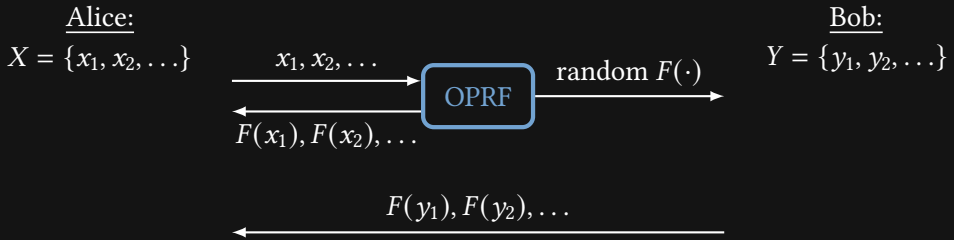
# *oblivious PRF (OPRF) paradigm for PSI*

[FreedmanIshaiPinkasReingold05]



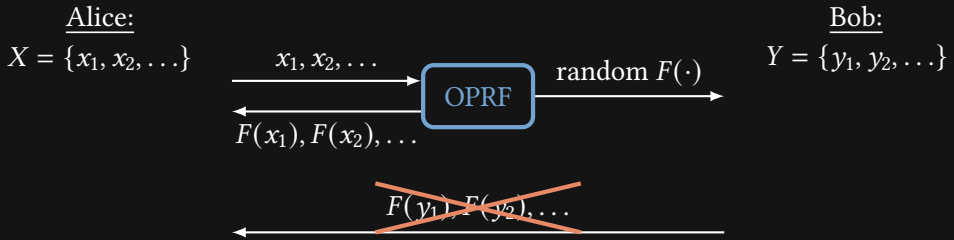
# *oblivious PRF (OPRF) paradigm for PSI*

[FreedmanIshaiPinkasReingold05]



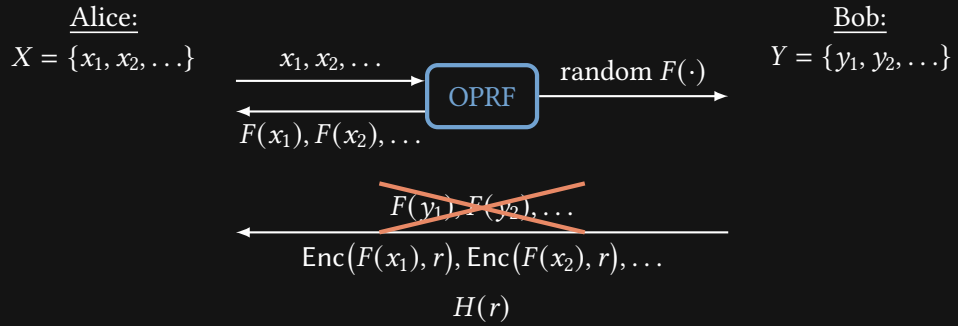
# *oblivious PRF (OPRF) paradigm for PSI*

[FreedmanIshaiPinkasReingold05]



# *oblivious PRF (OPRF) paradigm for PSI*

[FreedmanIshaiPinkasReingold05]



# *oblivious PRF (OPRF) paradigm for PSI*

[FreedmanIshaiPinkasReingold05]