Leakage-Resilient Key-Dependent Message Secure Encryption Schemes

Mahesh Sreekumar Rajasree
Post-Doctoral Researcher
CISPA Helmholtz

Joint work with Dhairya Gupta (IITD) and Harihar Swaminathan (IITD)

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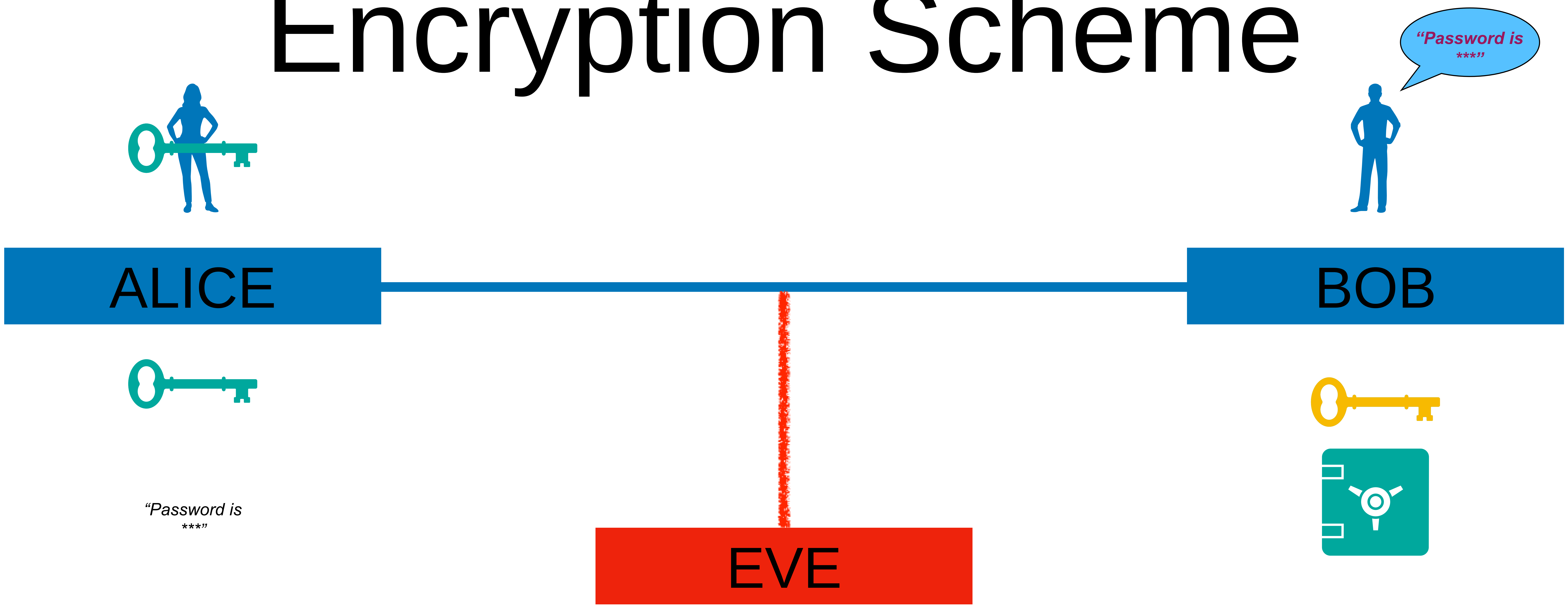
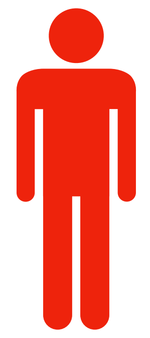
Introduction

Encryption Scheme





2 types :

- secret key (SKE) - Both Alice and Bob have the same key.
- public key (PKE) - Encryptor has public key and decryption has secret key.

Consists of 3 algorithms :

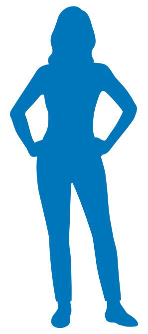
- $Setup()$: Outputs the keys
- $Enc(pk/sk, m)$: Outputs ciphertext
- $Dec(sk, c)$: Outputs message or error

Public-Key Encryption

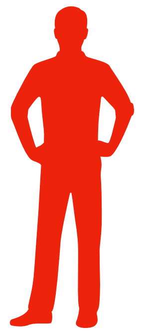
- Diffie,Hellman-76 presented the first key exchanged photocol.
- RSA cryptosystem was introduced in 1977.
- Goldwaser,Micali-84 proposed semantic security.

Security Definitions

Standard Security [Goldwaser,Micali-84]



Challenger



Adversary

$(pk, sk) \leftarrow Setup()$ — pk →

← m_0, m_1

$b \leftarrow \{0,1\}$

$c \leftarrow Enc(pk, m_b)$

c →

← $b' \in \{0,1\}$

Adversary wins if $b = b'$

More Security Notions

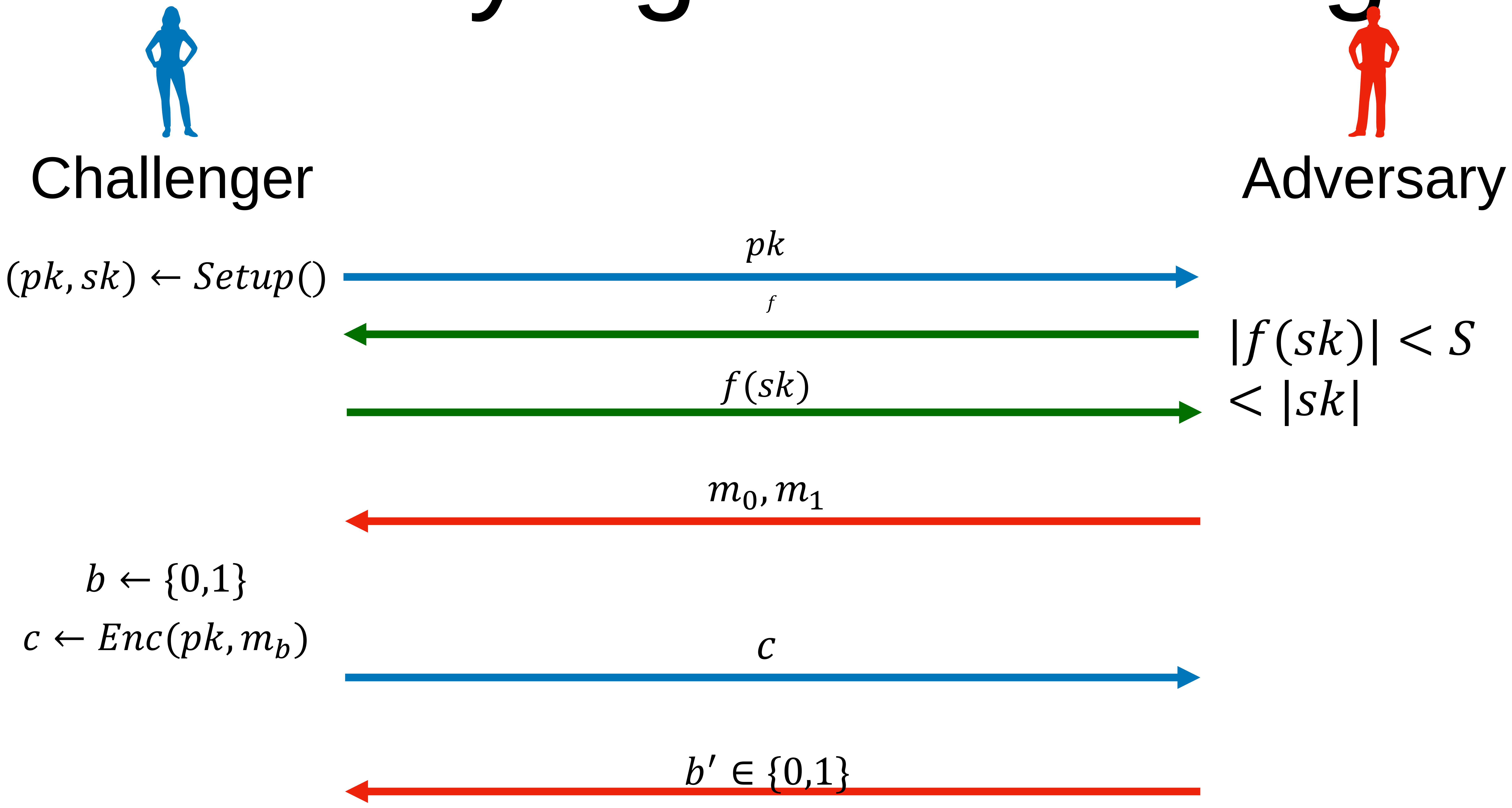
- Chosen-Ciphertext Attacks
- Non-malleable
- Leakage-Resilient
- Key-Dependent Message
- Selective Opening
- Incompressible

Can Secret Key be leaked?

- Standard security says that adversary cannot distinguish between encryptions of two different message provided **no** information of secret key is leaked.
- In practice, secret key can be leaked using side-channel attacks.

Leakage-Resilience

Security against Leakage



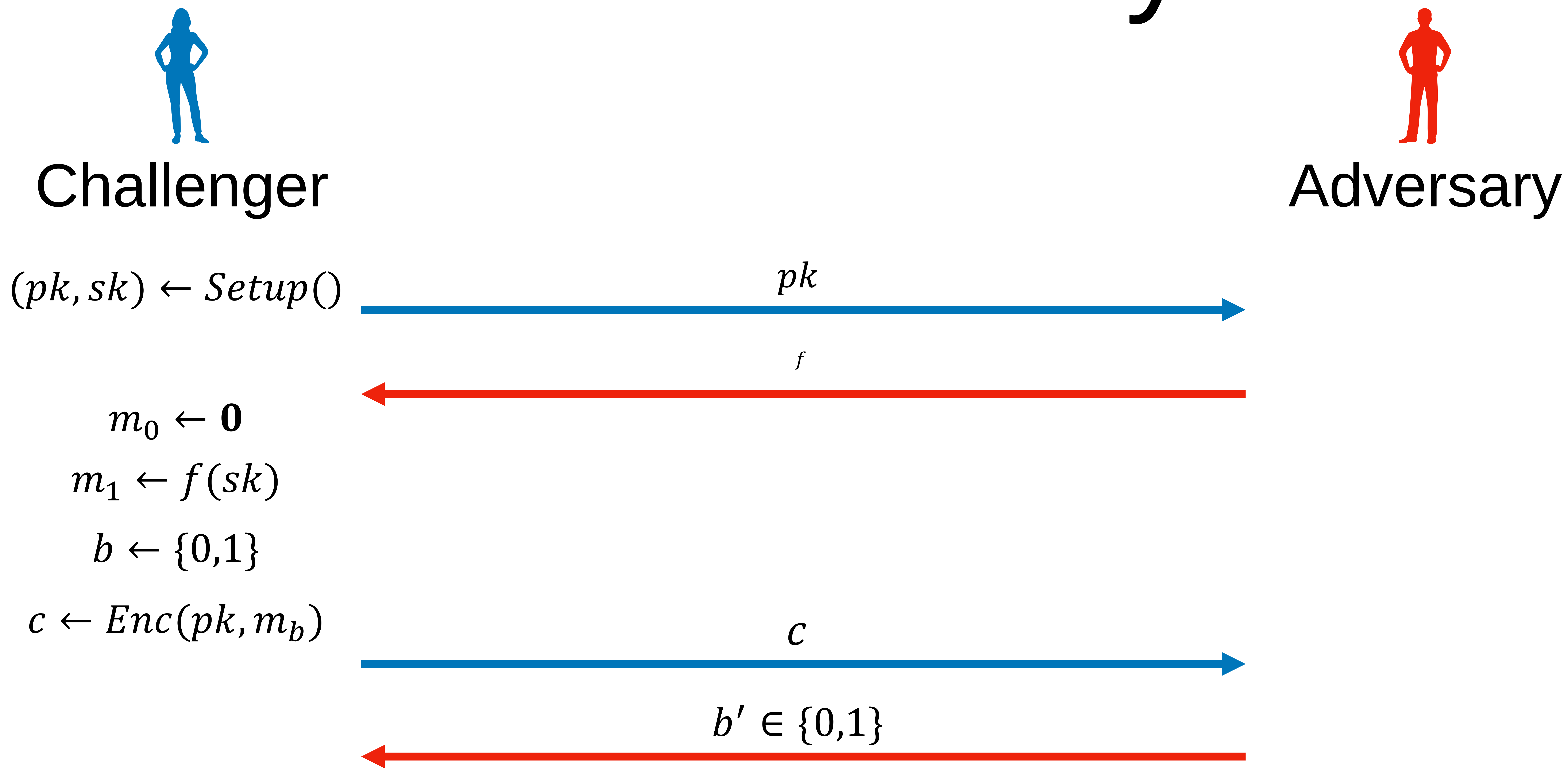
Adversary wins if $b = b'$

Leakage Resilient Schemes

- Canetti et al.-00 and Dodis et al.-01 gave construction where f returns bits of sk.
- Dziembowski-06, Di Crescenzo et al.-06, Akavia et al.-09, etc. considered arbitrary function f.
- Other works include Dodis et al.-09, Brakerski et al.-10, Dodis et al.-10, Faonio et al.-15 and many more.

Key-Dependent Message Security

KDM Security



Adversary wins if $b = b'$

Function Classes

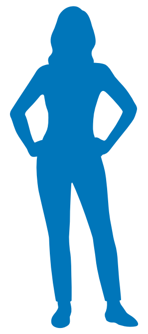
- **Circular**: $f_i(x_1, \ldots, x_n) = x_i$.
- **Projection**: if each of its output bits depends on at most a single input bit.
- **Affine**: can be represented as $f(x) = Ax + b$ where A is a matrix and b is a vector.
- **Circuits** of a-priori bounded size s: described by a circuit of size s.

KDM Schemes

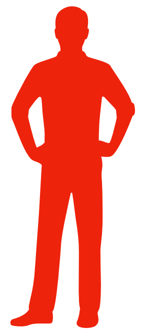
- Black, Rogaway,Shrimpton-03 formalised KDM security.
- Boneh, Halevi, Hamburg, Ostrovsky-08 developed the first KDM-secure PKE scheme from DDH assumption.
- Applebaum, Cash, Peikert, Sahai-09 gave construction for KDM-secure PKE from LWE.

Leakage-Resilient Key Dependent Message Secuity

LR-KDM security



Challenger



Adversary

$(pk, sk) \leftarrow Setup()$ — pk →

← h

$h(sk)$ →

$|h(sk)| < S < |sk|$

← f

$m_0 \leftarrow \mathbf{0}$

$m_1 \leftarrow f(sk)$

$b \leftarrow \{0,1\}$

$c \leftarrow Enc(pk, m_b)$ — c →

← $b' \in \{0,1\}$

Adversary wins if $b = b'$

Prior Works

- Naor and Segev-09 showed that BHHO construction is LR.
- Brakerski and Goldwasser-10 constructed schemes that are LR and KDM scheme from QR and DCR assumptions.
- Hajiabadi, Kapron, Srinivasan-16 developed a scheme that are LR and KDM secure schemes using homomorphic hash proof systems.
- Brakerski, Lombardi, Segev, Vaikuntanathan-18 used batch encryption to construct scheme that are LR and KDM secure schemes based on DDH, LPN and other standard assumptions.
- Dodis, Karthikeyan, Wichs-21 defined CS+LR Security which is stronger than LR-KDM and used it to construct updatable PKE schemes.

Separation

Result

There exists schemes that are LR and KDM secure,
but isn't LR-KDM secure.

Construction

- Let SKE' be LR and circular-KDM.
- PRF be a pseudorandom function.
- $Setup$: Run $ske.sk \leftarrow SKE'.Setup()$ and generate PRF key k. Output $sk = (k, ske.sk)$
- $Enc(sk, m)$: If $m = ske.sk$, set $c_0 = PRF(k, 1)$. Else, $c_0 = PRF(k, 0)$. Generate $c_1 \leftarrow SKE'.Enc(ske.sk, m)$. Output $ct = (c_0, c_1)$.
- $Dec(sk, ct)$: Output $SKE'.Dec(ske.sk, c_1)$.

LR and KDM security

- If adversary A breaks LR security, the LR security of SKE' is broken.
  - Reduction B on receiving h from A, generates k and relays $h(k,\cdot)$ to challenger.
  - It generate $c_0 = PRF(k,0)$.
- If adversary A breaks f-KDM security, the KDM security of SKE' is broken.
  - Here, $f(x,y) = y$.
  - B generates a random c_0.

Not LR-KDM secure

- Adversary can leak the entire k in the leakage phase.
- Using k, it checks whether $c_0 = PRF(k, 0)$ or not.

Constructions and Amplifications

Constructions

- Wee-16 showed that homomorphic HPS gives KDM secure schemes.
  - We defined LR homomorphic HPS and constructed LR-KDM secure schemes.
- We showed that batch encryption schemes are also LR-KDM secure.

Amplifications

- Waters and Wichs-23 showed that PKE + (existence) circular-KDM SKE gives circuit-KDM PKE.
- Applebaum-14 showed projection-KDM PKE + garbled circuits implies circuit-KDM PKE.
- We showed these can be used in the LR-KDM setting.

Future Works

- Multi-Key LR-KDM security where adversary interacts with multiple pairs of public-secret keys.
- LR-KDM security under Chosen-Ciphertext Attacks.
- LR-KDM in advanced primitives such as IBE and ABE.

Thank You!