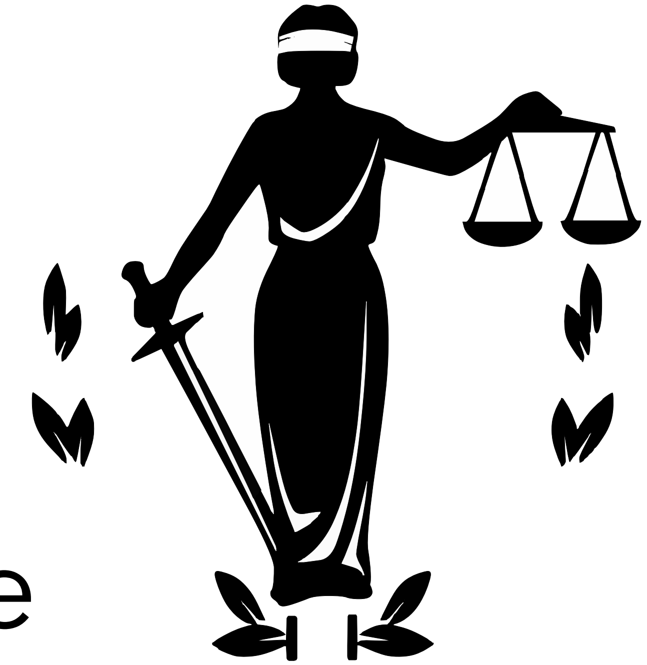

# Quantum-secure message authentication via blind-unforgeability

Gorjan Alagic, Christian Majenz, Alexander Russell and Fang Song

Eurocrypt 2020, in Cyberspace

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# Introduction

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Nowadays: digital signature schemes, message authentication codes (MACs).

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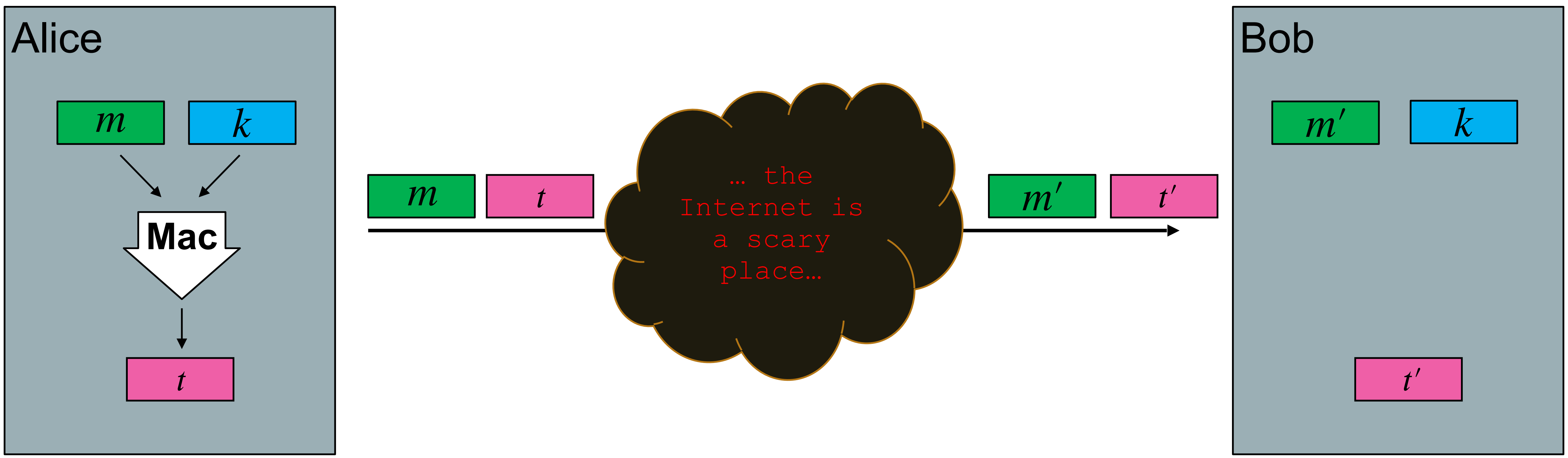

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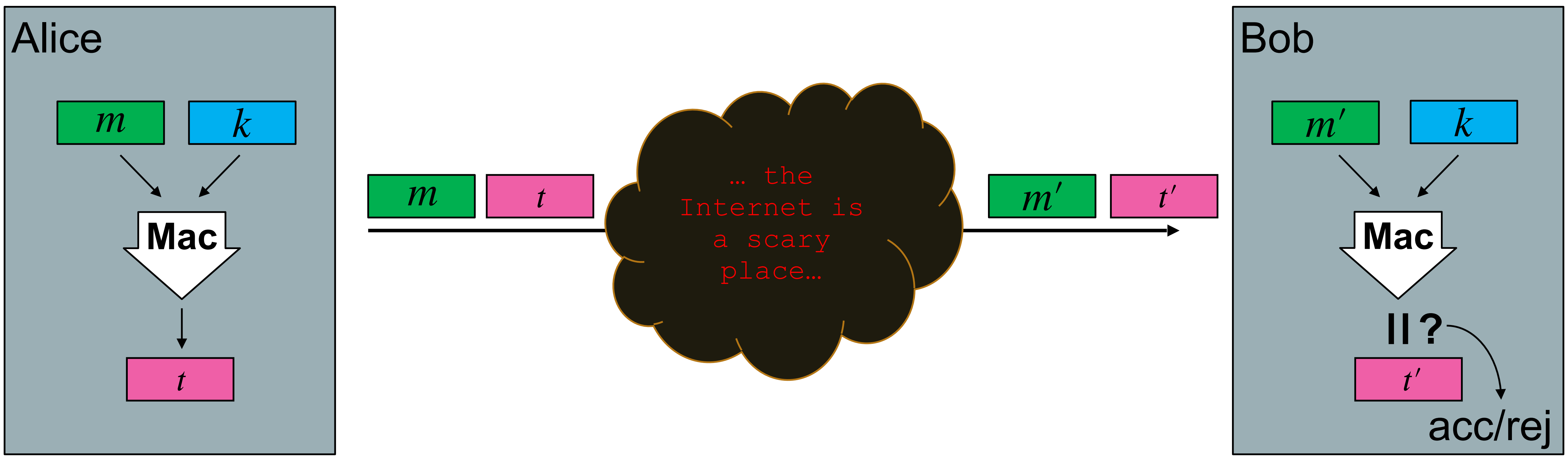
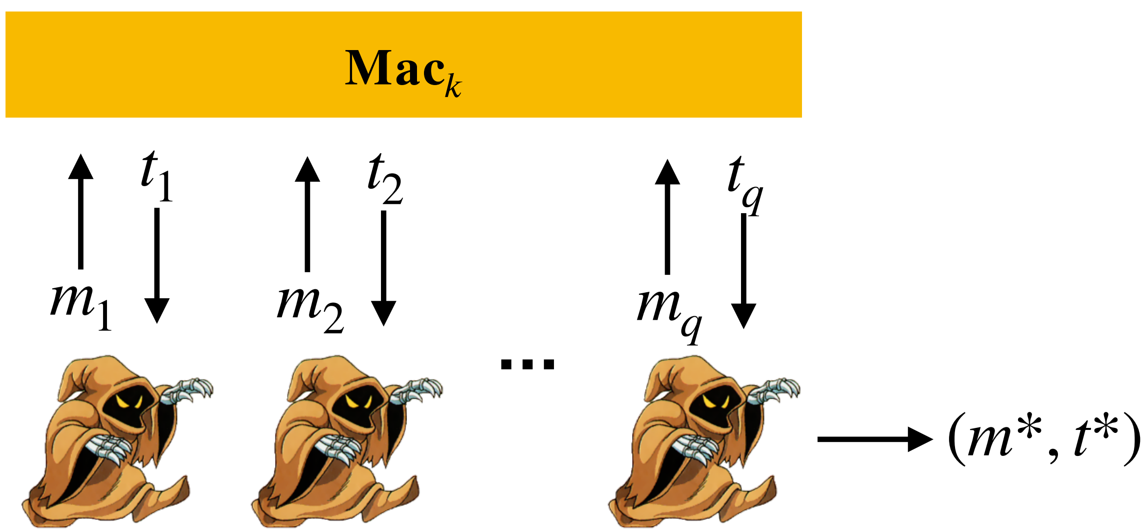


# Security: UF-CMA

Definition: Unforgeability under chosen message attacks (**UF-CMA)**

A message authentication code is secure, if no successful forger exists:




Success:

$i)$ $m^* \neq m_i$ for all $i = 1, \ldots, q$

$ii)$ $\mathbf{Mac}_k(m^*) = t^*$

# Quantum Access Security

Stronger security model: quantum oracle access to $\mathbf{Mac}_k$:

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**UF-CMA** doesn't make sense anymore…

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What does it mean for a function to be unpredictable against quantum?

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We should be worried about:

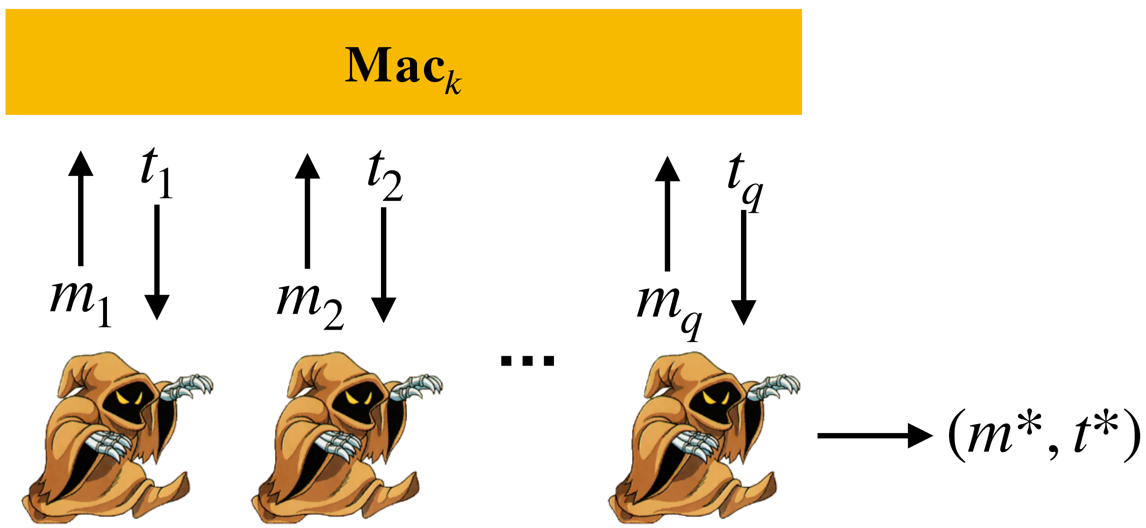
key $k$ specifies a random periodic function $f_k$ with period $p_k$

$\mathbf{Mac}_k(p_k) = 0$ , and $\mathbf{Mac}_k(x) = f_k(x)\ \forall x \neq p_k$

i) run period finding (a subroutine of Shor's algorithm) to find $p_k$

ii) output $(p_k, 0)$

# Quantum problems

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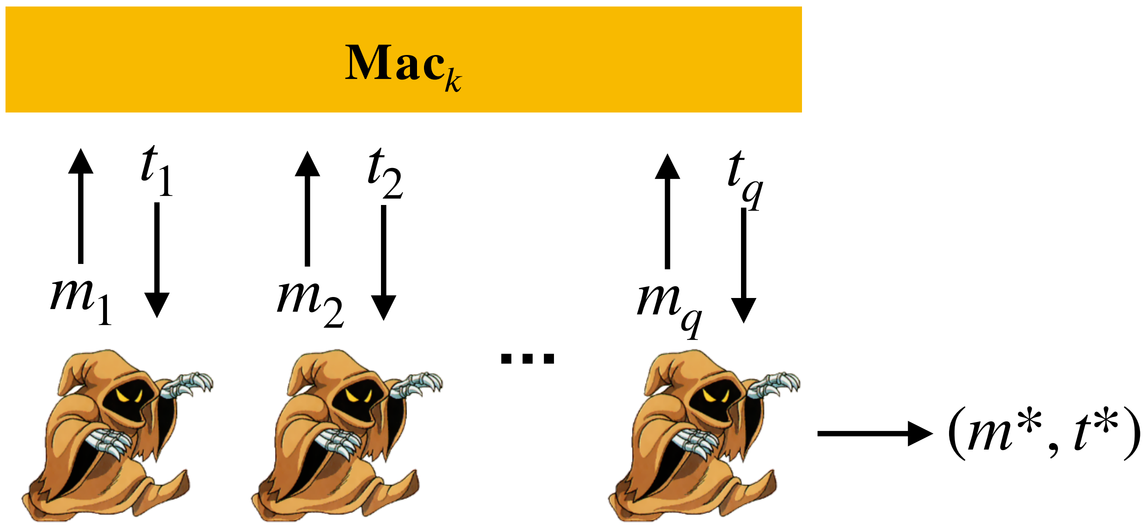


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- No-cloning principle: can't keep a transcript
- Measurement causes disturbance!

# Results

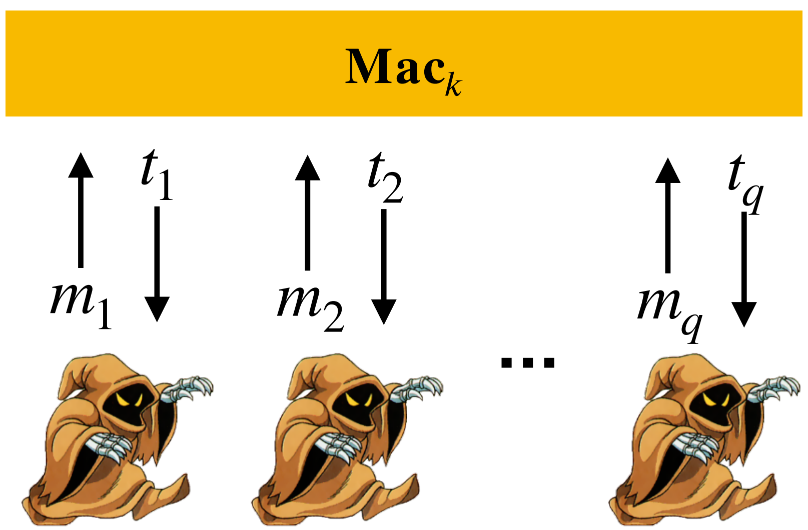
# Our results

- We study unforgeability under **quantum** chosen message attacks
- We propose a new security definition: **blind unforgeability (BU)**
- We exhibit a MAC that is secure under a previous definition by Boneh and Zhandry (Eurocrypt 2013) but clearly broken, and BU-insecure
- We characterize BU
  - It implies the previous definition
  - Random functions, Lamport signatures are BU secure
  - Hash-and-Mac/Hash-and-Sign preserves BU security for appropriate hash functions

# Boneh Zhandry unforgeability

Boneh and Zhandry (Eurocrypt 2013) propose:

Ask $q+1$ forgeries for $q$ queries!

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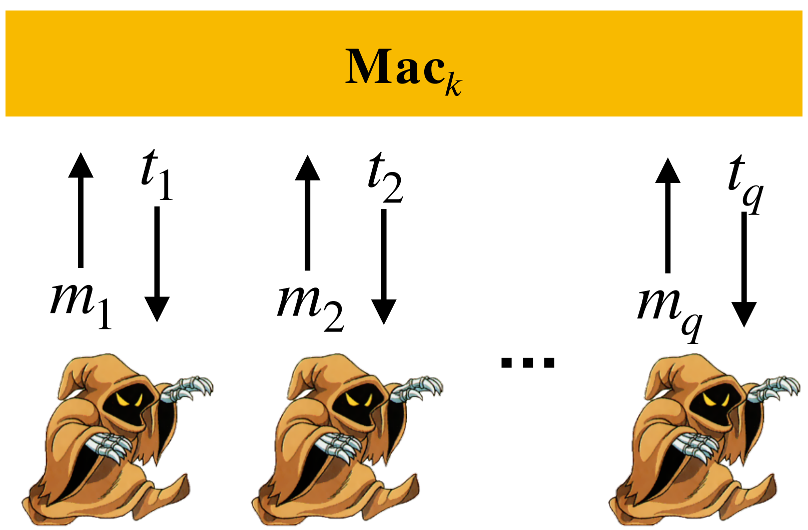


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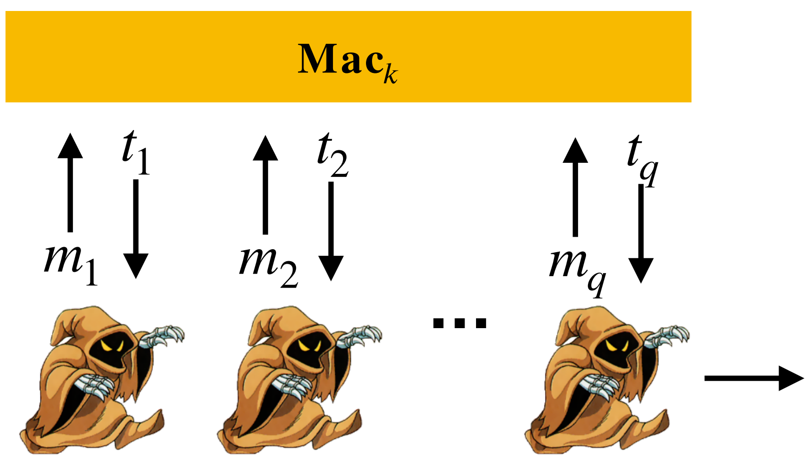
Has some nice properties:

- Equivalent to **UF-CMA** for classical oracle
- A random oracle is BZ-unforgeable (BZ '13)

# The right definition?

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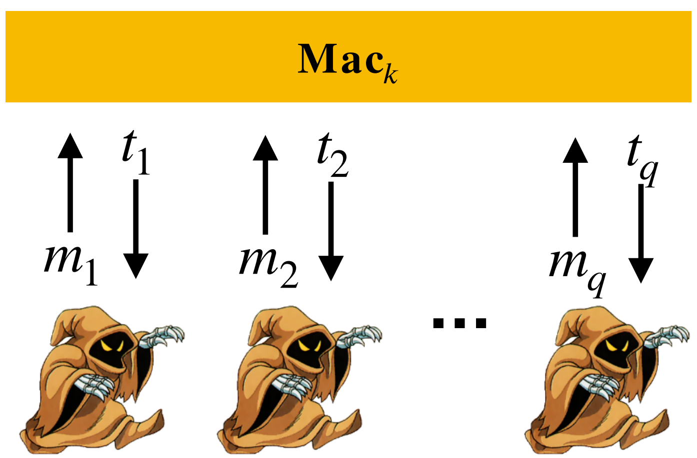


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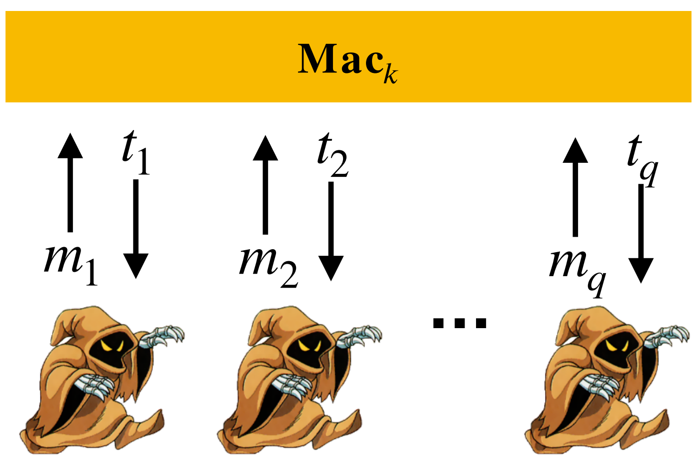


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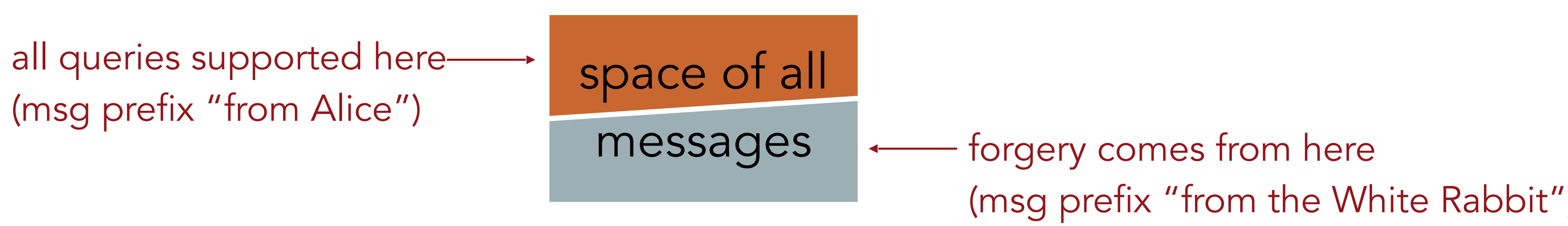

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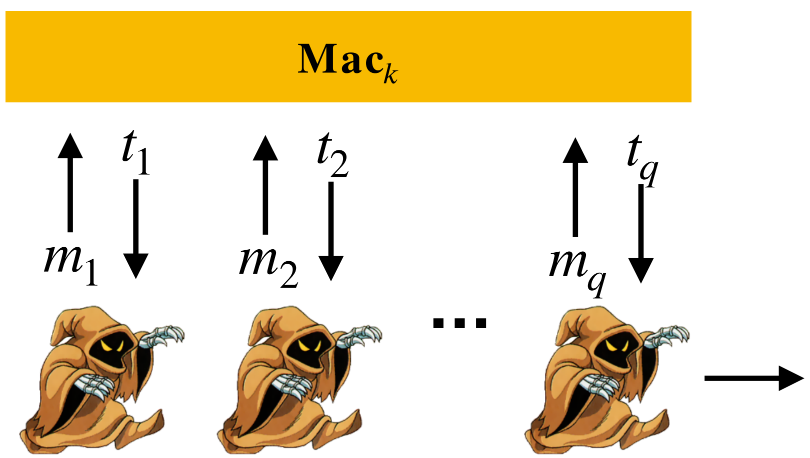


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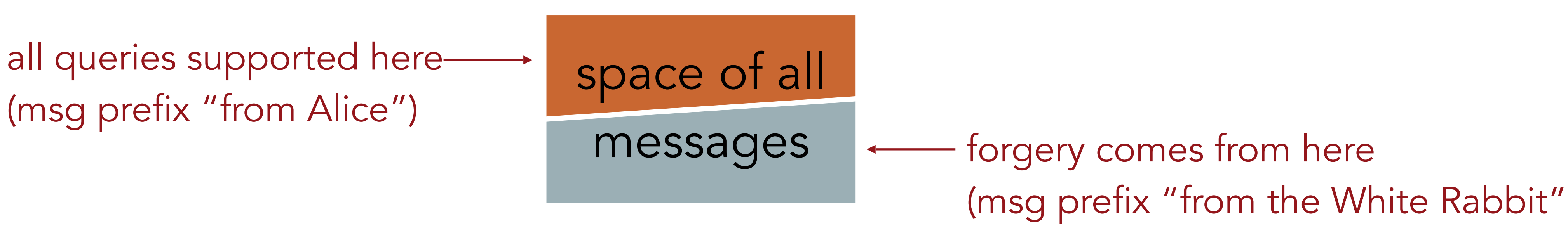


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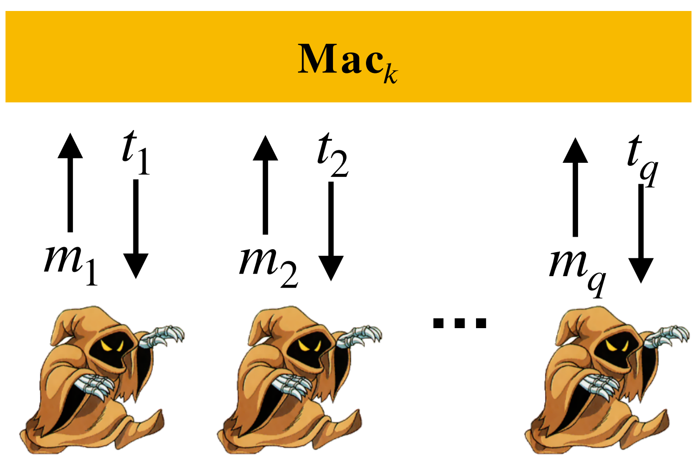


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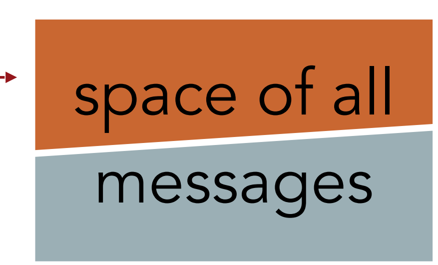
all queries supported here
(msg prefix "from Alice")




forgery comes from here
(msg prefix "from the White Rabbit")

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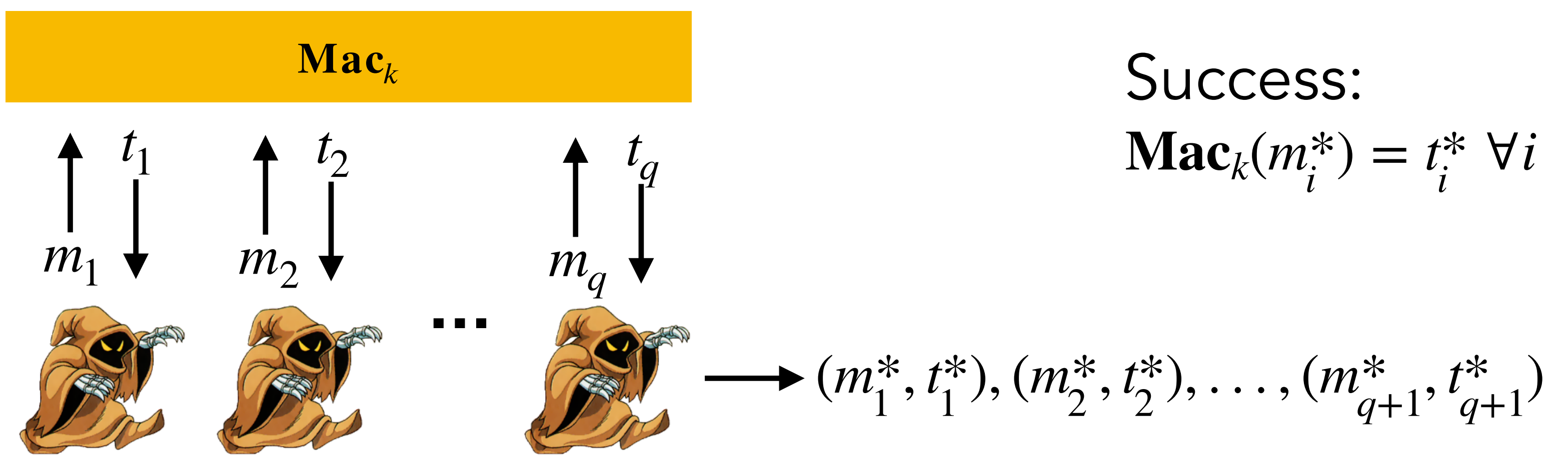


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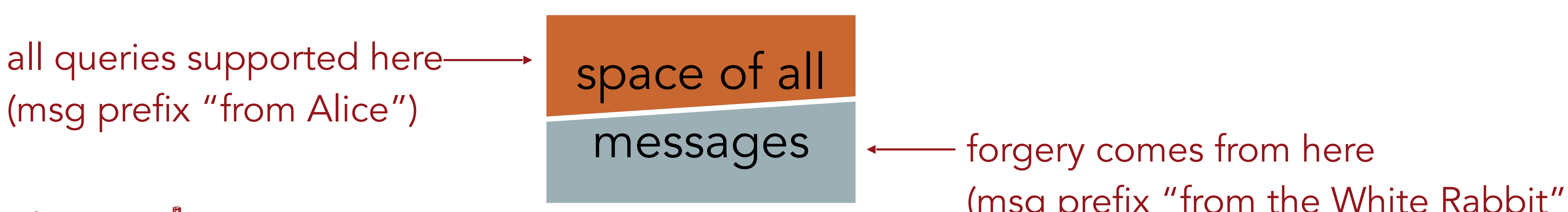


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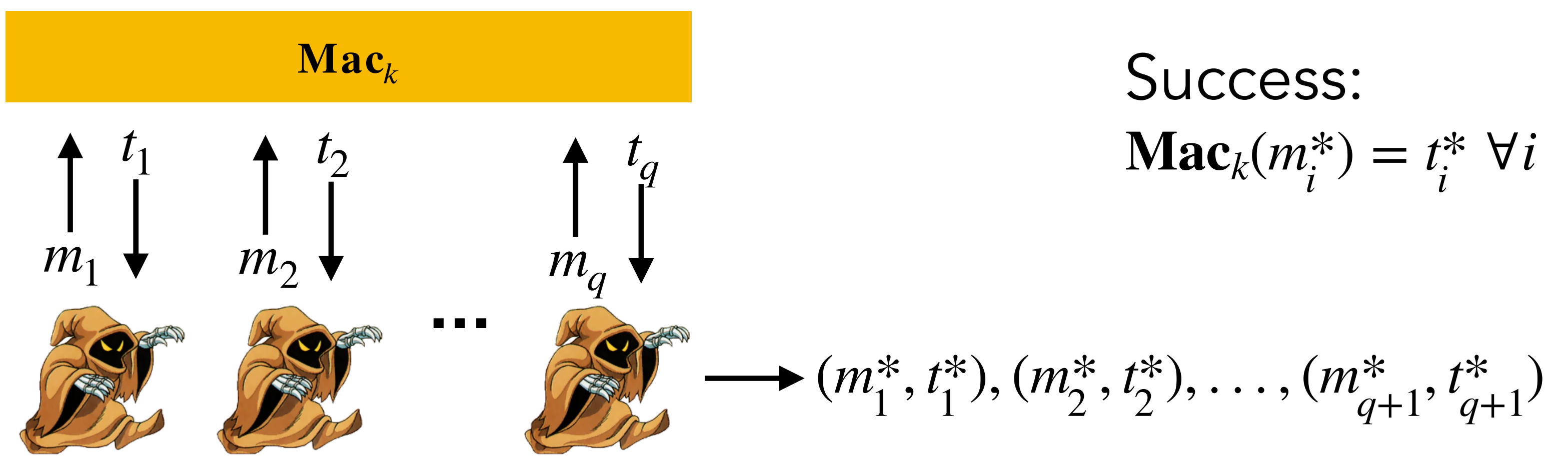


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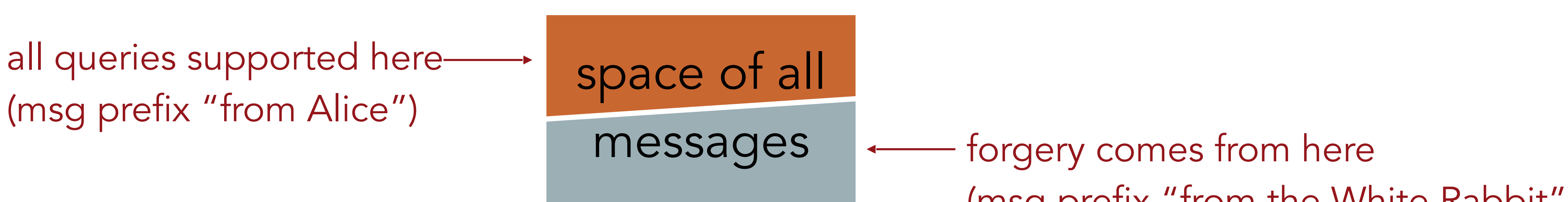


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One-time Mac that's BZ secure, GYZ (Garg, Yuen&Zhandry, Crypto '17) insecure, assuming iO (Zhandry, Eurocrypt '19)

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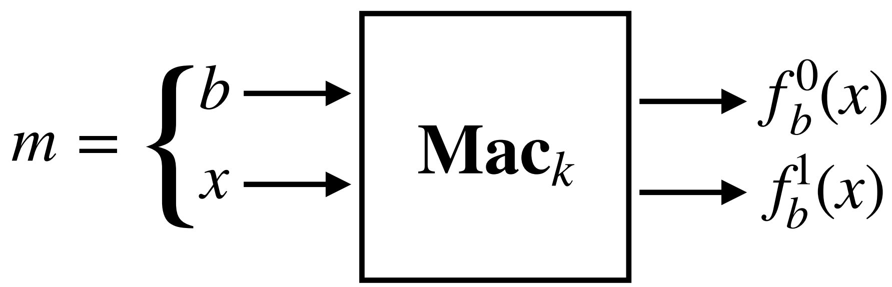


- $\hat{f}_b^i : \{0,1\}^n \to \{0,1\}^n$ random functions
- $f_0^0(x) = \hat{f}_0^0(x \bmod p)$ for random $p$, $f_0^1 = \hat{f}_0^1$
- $f_1^0 = \begin{cases} 0^n & x = p \\ \hat{f}_1^0(x) & \text{else} \end{cases}, f_1^1 \equiv 0^n$

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Key step: ignorance is necessary

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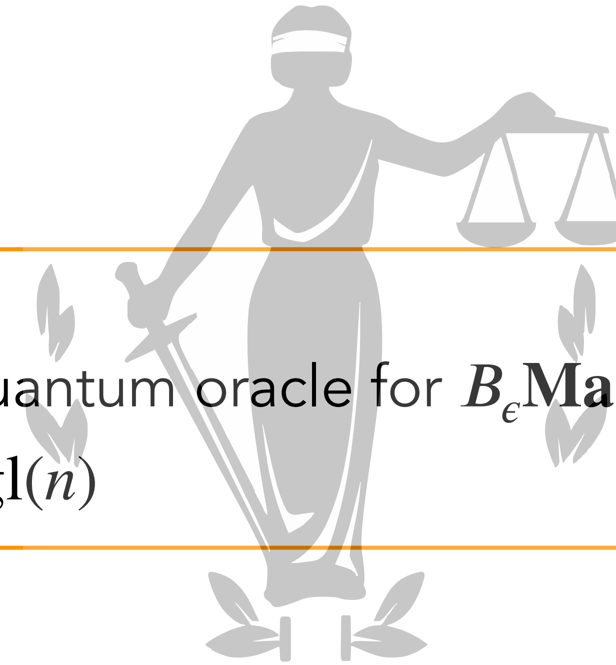

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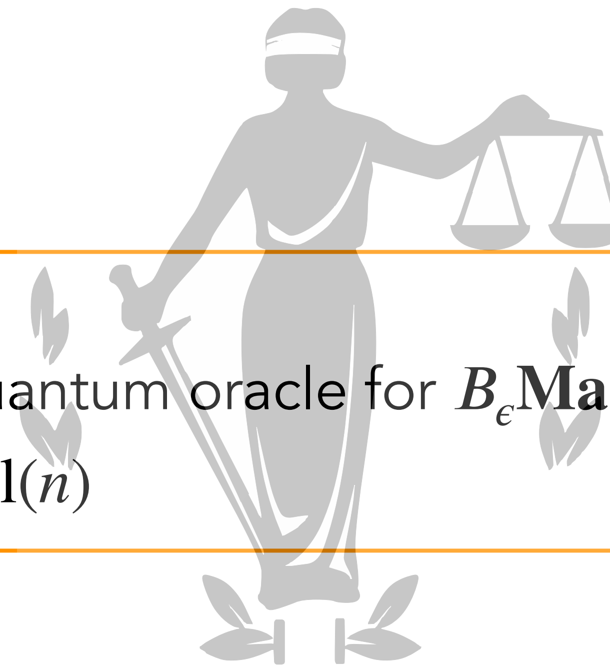

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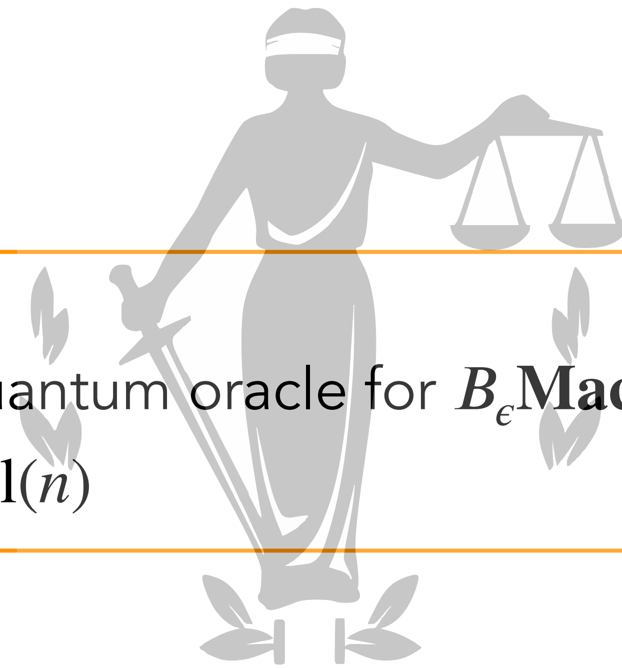

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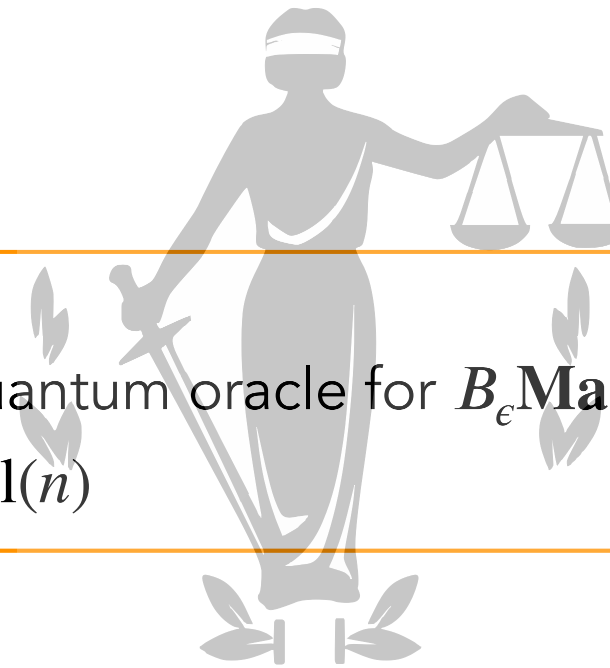
Check, e.g., for random functions:

- if oracle is blinded…
- … $\mathbf{Mac}_k(m)$ for blinded $m$ is *independent* of post-query state,
- this adversary fails.



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Definition (Blind-Unforgeability):
A MAC $\mathbf{Mac}_k$ is blind-unforgeable if for every adversary $\mathscr{A}$ with a quantum oracle for $B_\epsilon \mathbf{Mac}_k$ ,

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**Does this work?**

- equivalent to **UF-CMA** in classical setting;
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- Implies previous defintion by Boneh and Zhandry;
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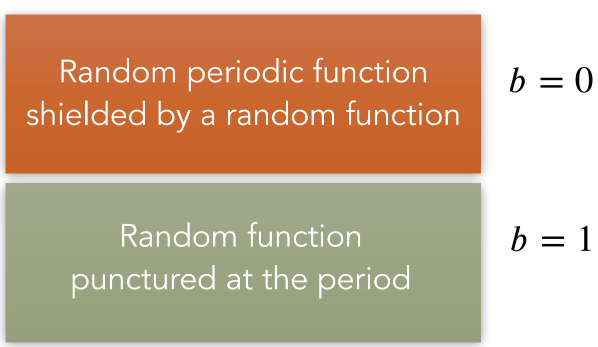


One-query attack: Find period in orange part,
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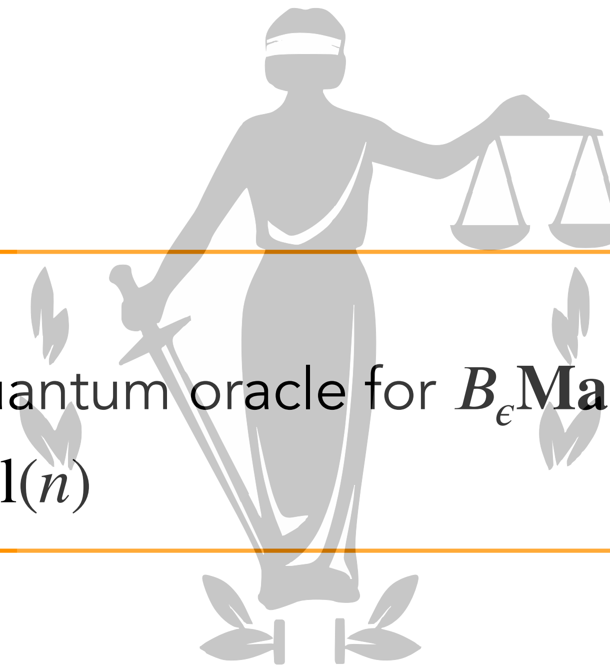

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2.

| | |
|---|---|
| Random periodic function shielded by a random function | $b = 0$ |
| Random function punctured at the period | $b = 1$ |

Check, say for $\varepsilon = 0.0001$,

- *oracle is blinded only on few random inputs…*
- *…post-query state won't change too much;*
- $(1p,0)$ is blinded with *independent* probability $\varepsilon$;
- so this adversary succeeds!

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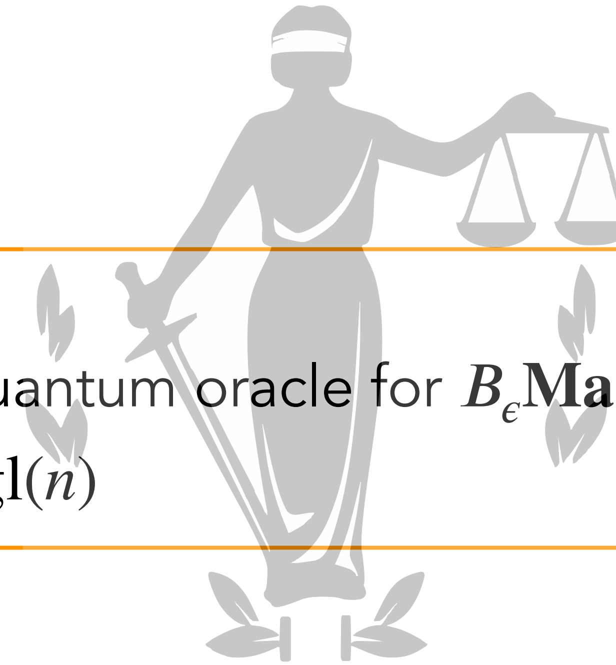

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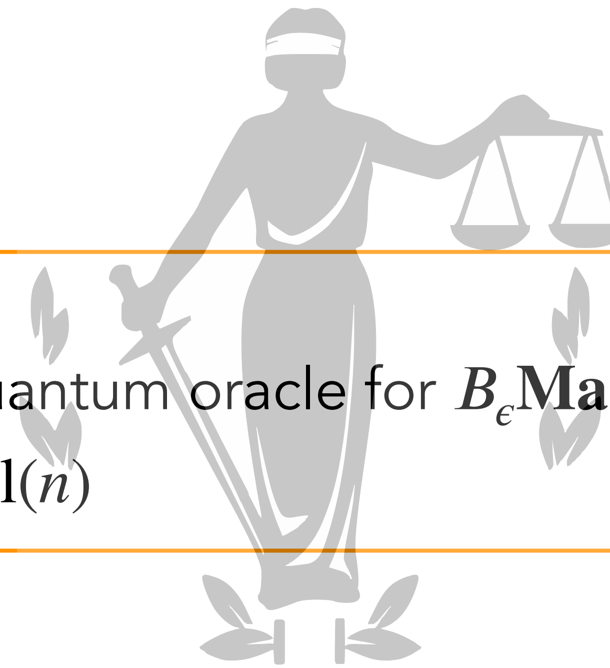

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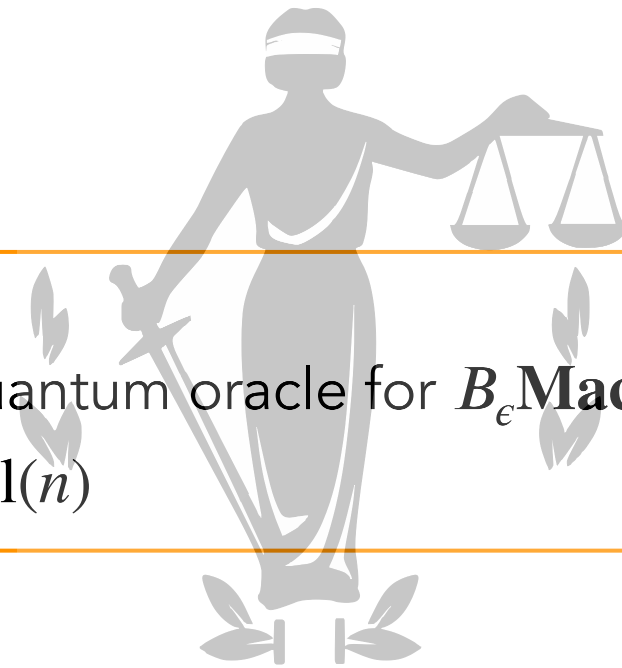

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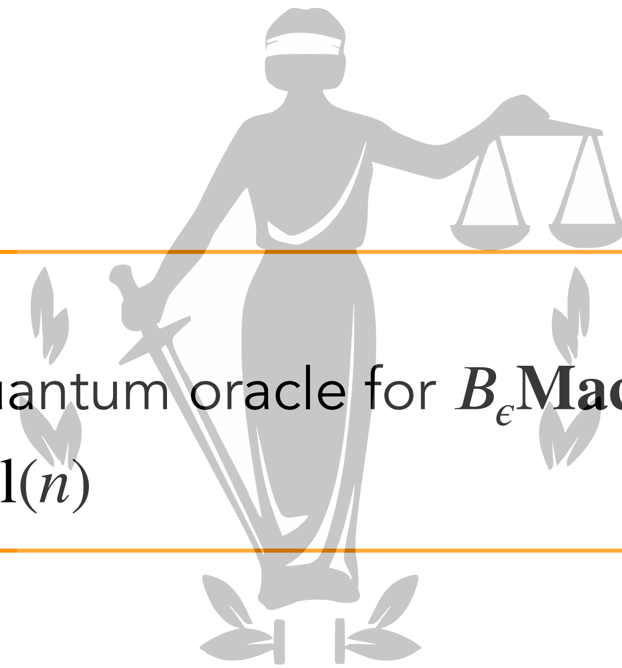

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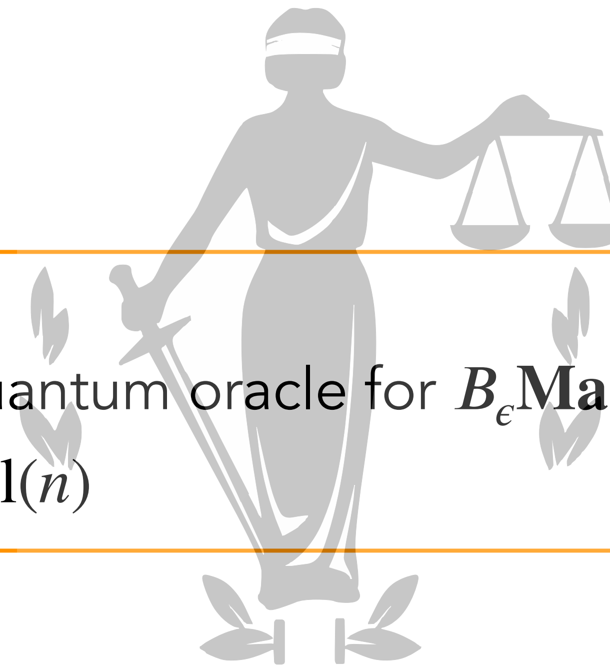

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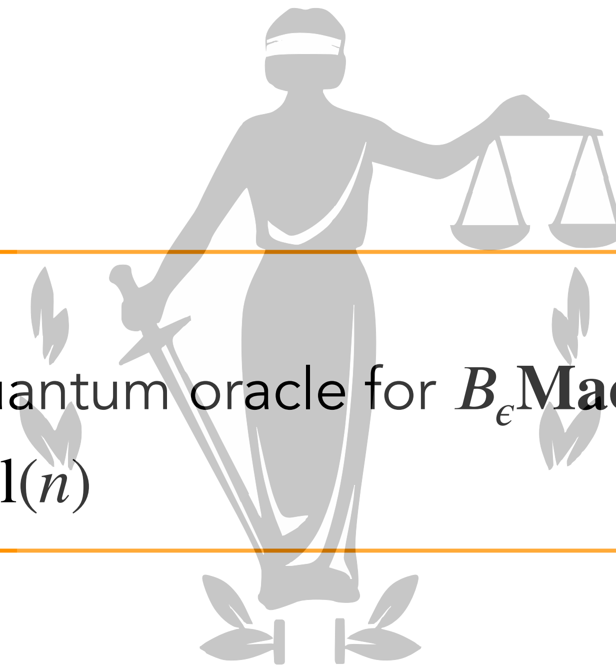

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- Zhandry's superposition representation of quantum random oracles

# Summary, open questions

**Summary:**

- We exhibit a MAC that is secure according to a definition by Boneh and Zhandry but allows for an intuitive forgery attack.
- We propose a replacement definition: Blind Unforgeability
- Blind unforgeability has a lot of nice properties and classifies all known examples correctly.

**Open questions:**

- The security game for blind unforgeability is not natural. Can this be fixed?
- Are popular schemes (MACs and DSS) blind-unforgeable? We only have NMAC, HMAC and Lamport in the QROM for now…