Reset-Sampling: Fine-tuning the Security of Standardized MACs

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Reset-Sampling: Fine-tuning the Security of Standardized MACs

- MACs and their security
- LightMAC & OMAC
- Observations on the Security
- Some fine-tunings

Message Authentication Codes (MAC)

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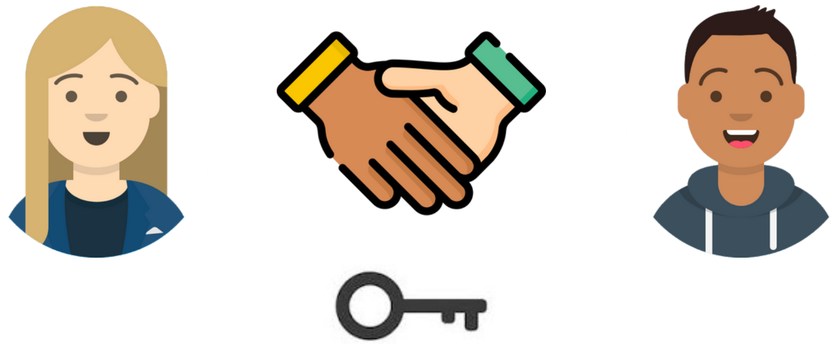

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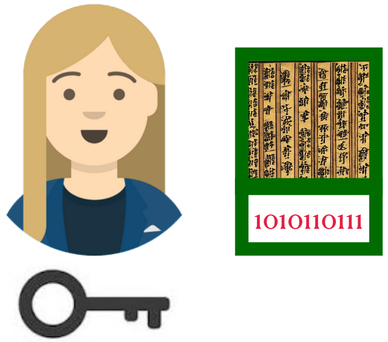

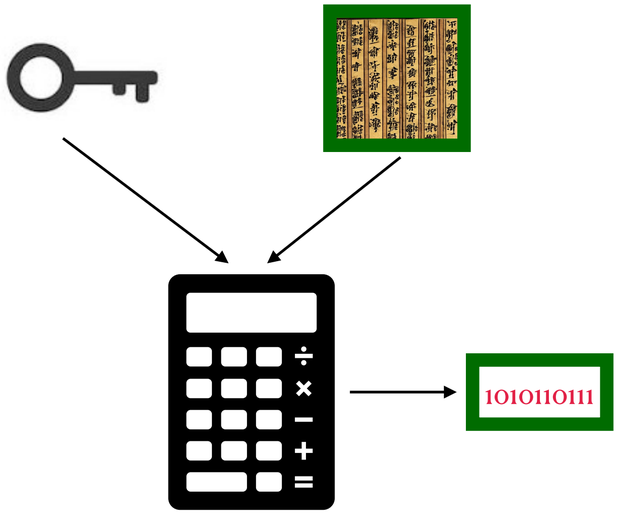

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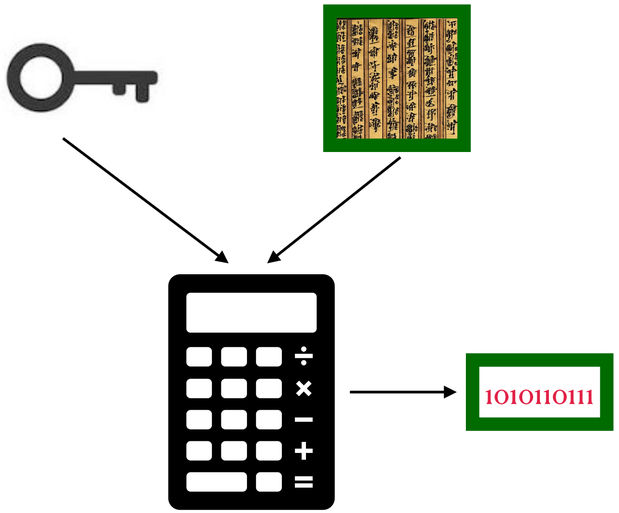

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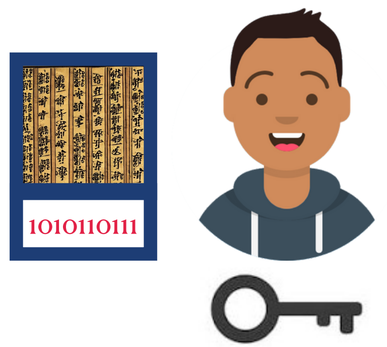
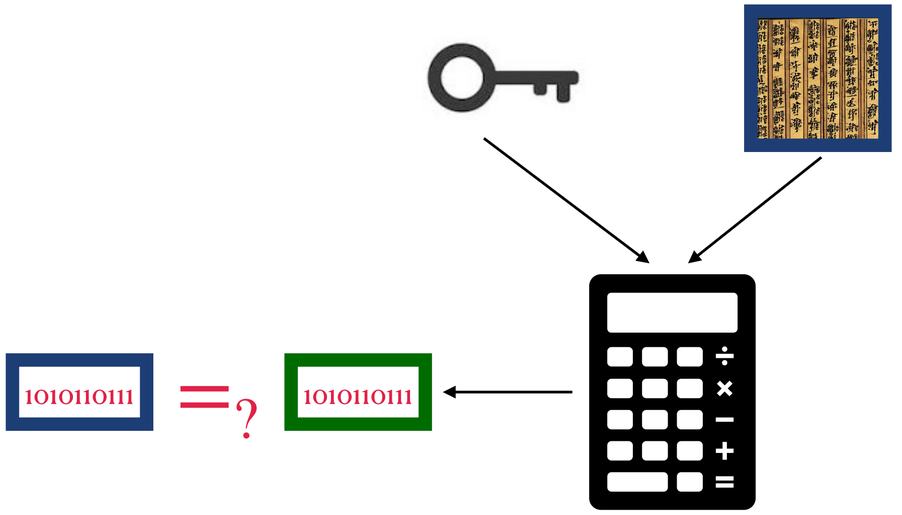
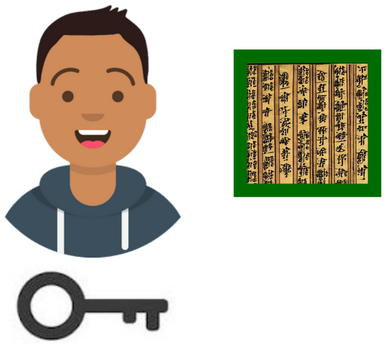
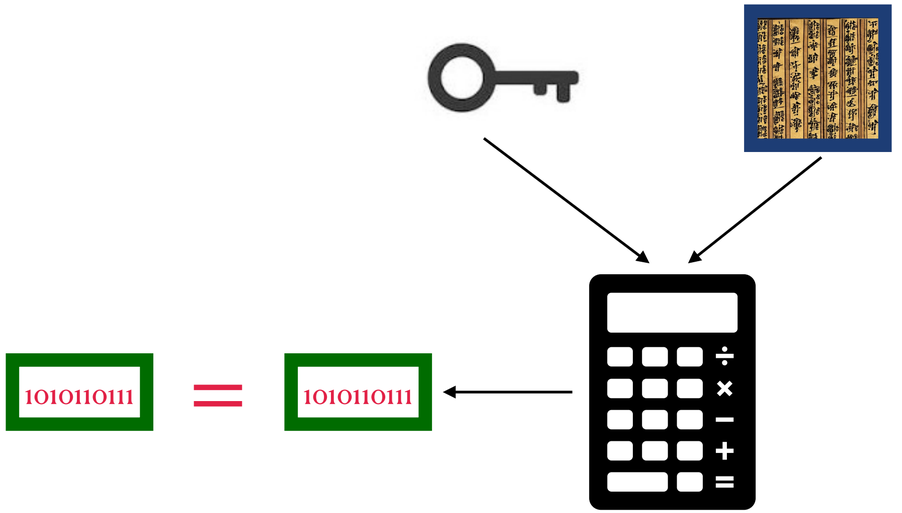




Message Authentication Codes (MAC)

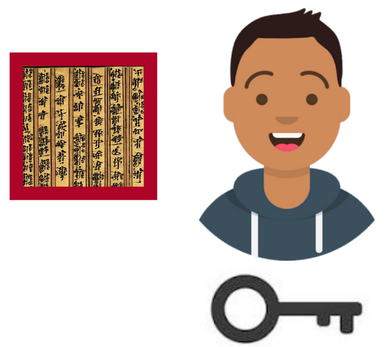
Authentication Succeeds

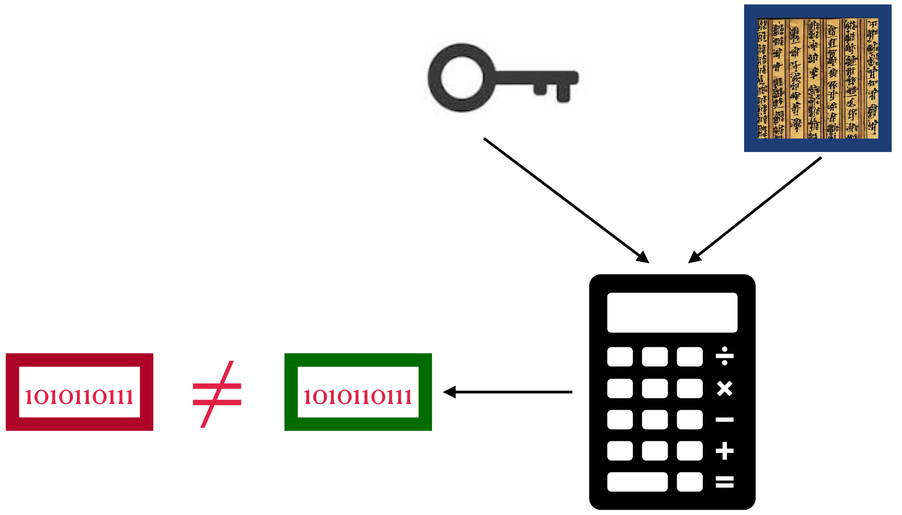




Message Authentication Codes (MAC)

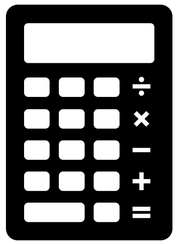
Authentication Fails





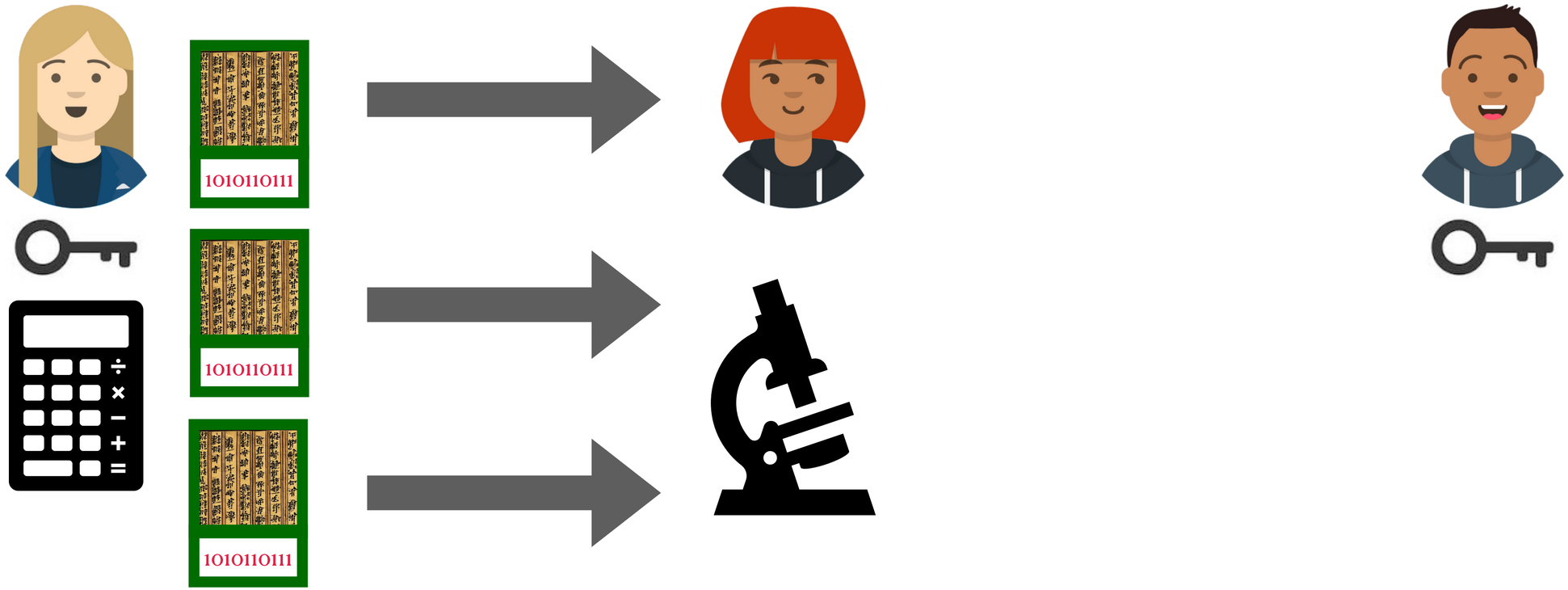
MAC Security

Unforgeability Game



MAC Security

Unforgeability Game: Passive Adversary



MAC Security

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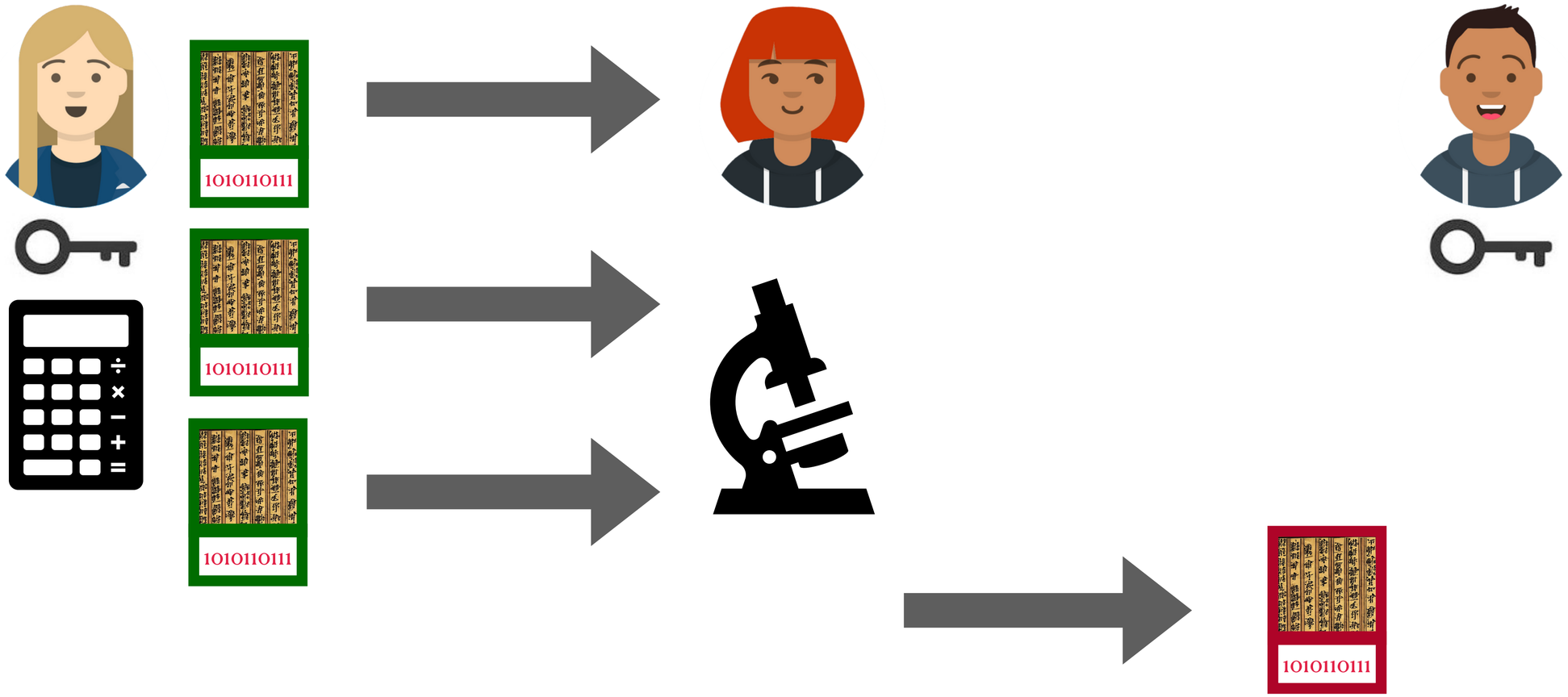
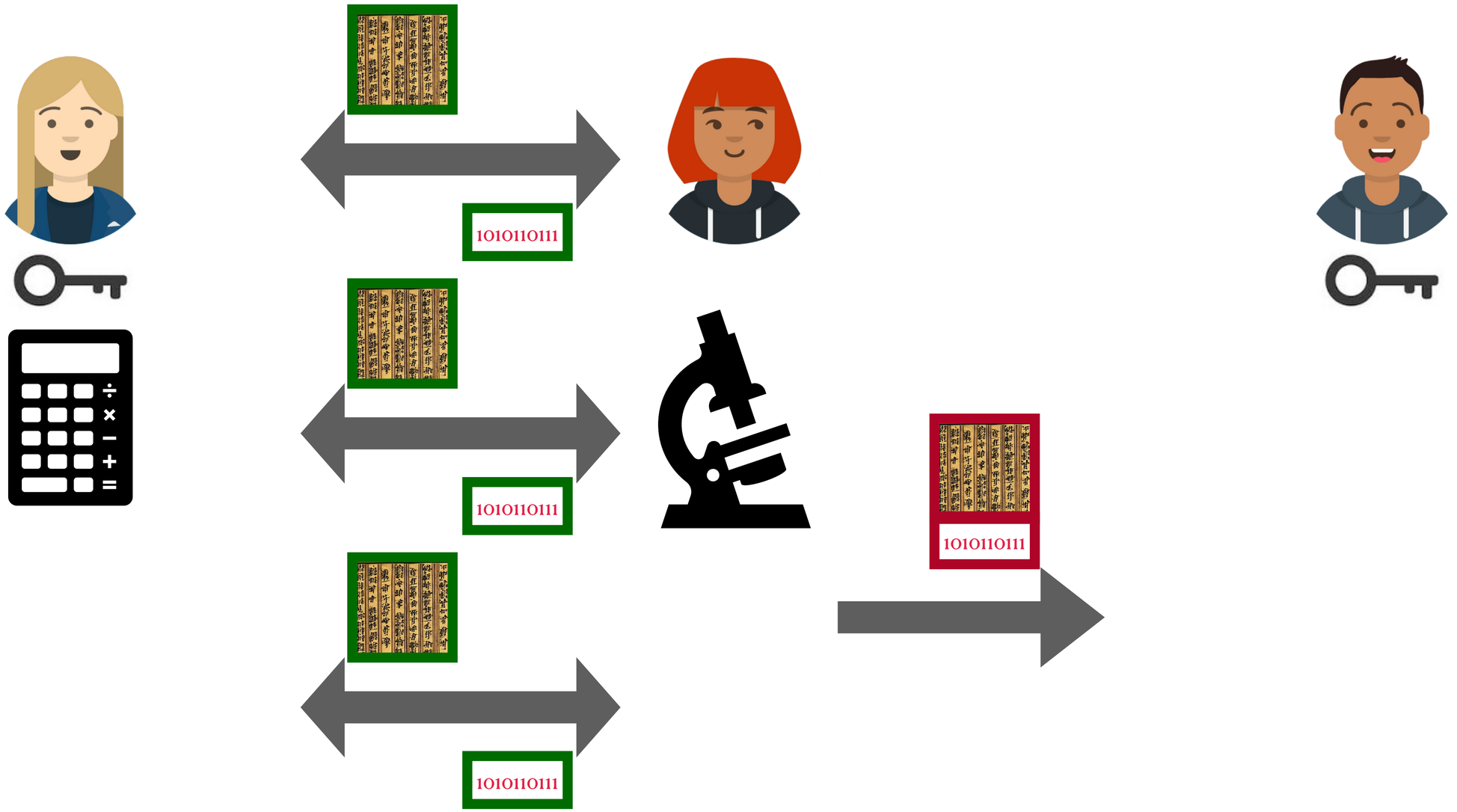


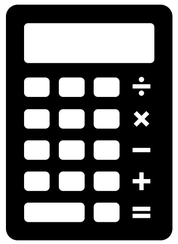
MAC Security

Unforgeability Game: Active Adversary



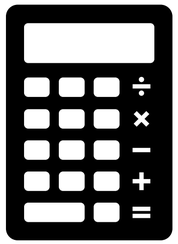
MAC Security

Unforgeability Game: Forgery Succeeds



MAC Security

Unforgeability Game: Forgery Succeeds



$$\Pr(\text{Forgery Succeeds})$$

MAC Security

Random Functions are Good MACs

$$\Pr\left(\texttt{Forgery Succeeds}\right) = \Pr\left(\texttt{Guessing}\right)$$

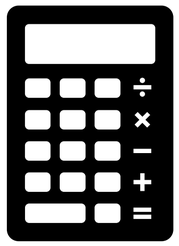
Pseudorandom Function Security

Ideal World (0)

Pseudorandom Function Security

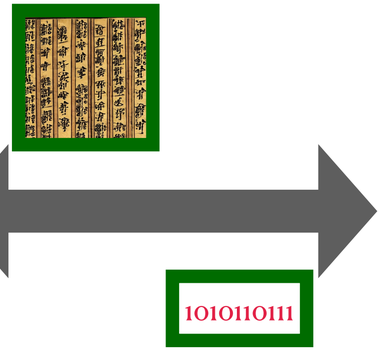
Ideal World (0)

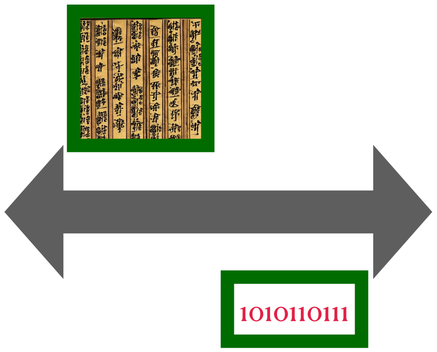
Real World (1)



Pseudorandom Function Security

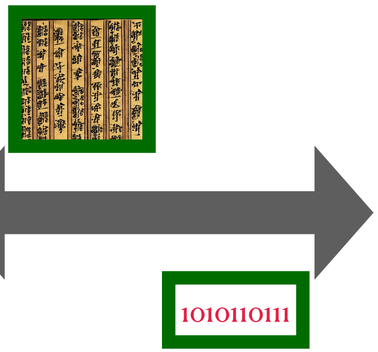
Ideal World (0)

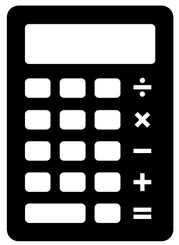


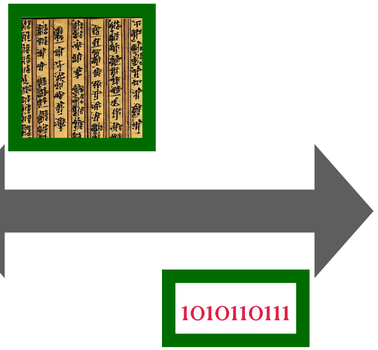


b

Real World (1)







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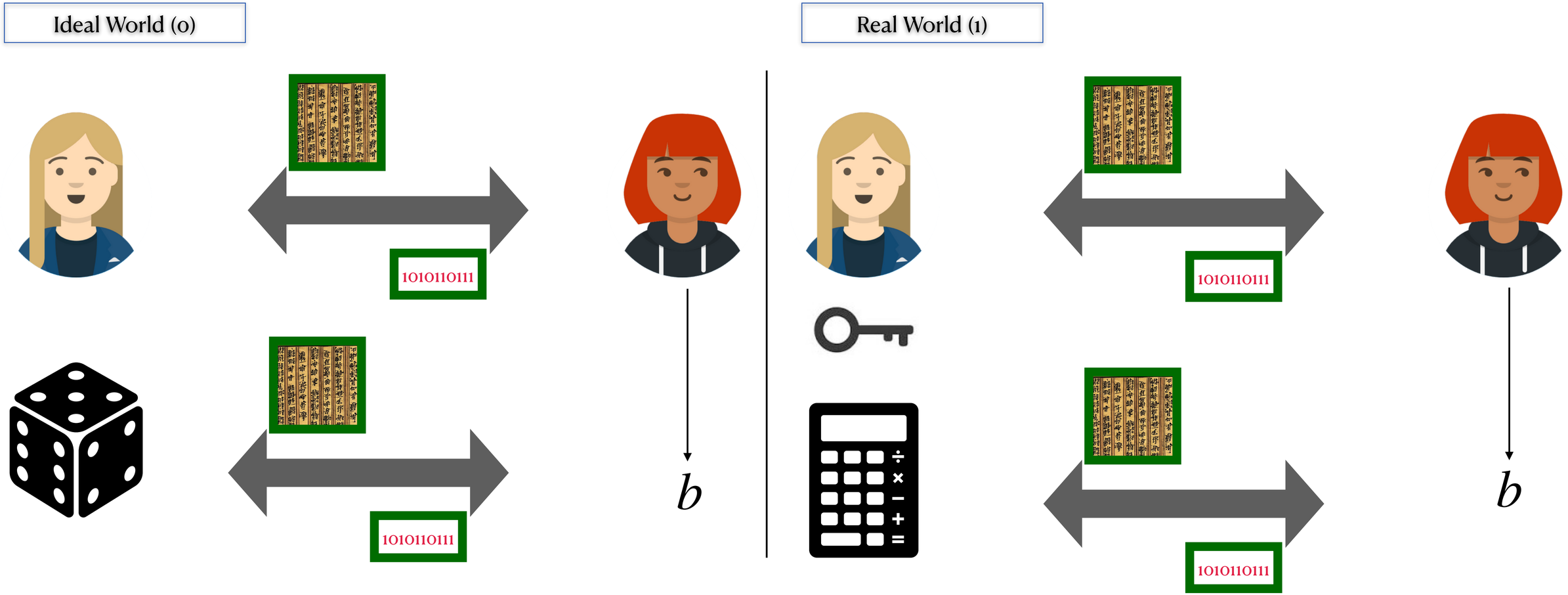
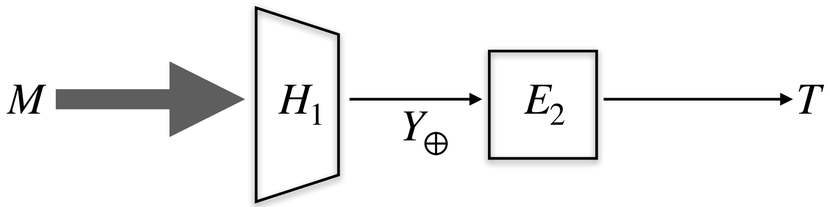
Pseudorandom Function Security



$$\mathbf{Adv}^{\mathrm{prf}}_{\mathbf{Alice}}(\mathbf{Eve}) := \left|\Pr\left(b = 1 \text{ in the real world}\right) - \Pr\left(b = 1 \text{ in the ideal world}\right)\right|$$

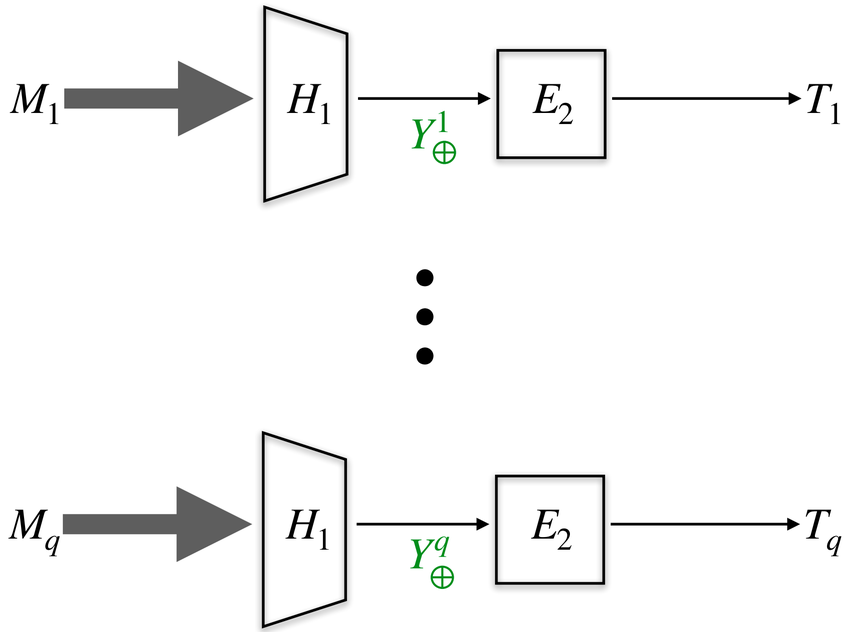
Hash then PRF



- $H_1 : \{0,1\}^* \rightarrow \{0,1\}^n$
- E_1 a permutation of $\{0,1\}^n$
- $H_1 \perp E_1$

Hash then PRF

High Level Security Argument



$Y^1_\oplus \neq \cdots \neq Y^q_\oplus \implies T_1, \ldots, T_q$ are independent and uniform

$$\mathbf{Adv}^{\mathrm{prf}}_{\mathsf{HtPRF}}(\mathbf{Eve}) \leq \overbrace{\Pr\left(\exists i \neq j \ : \ Y^i_\oplus = Y^j_\oplus\right)}^{\text{Maximum Collision Probability of } H_1}$$

LightMAC

LuykxPTY, IACR FSE 2016; ISO/IEC 29192-6:2019

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$(M[1], \ldots, M[\ell + 1]) \xleftarrow{n-s} M$

LightMAC

LuykxPTY, IACR FSE 2016; ISO/IEC 29192-6:2019

$(M[1], \ldots, M[\ell + 1]) \xleftarrow{n-s} M$

$\langle 1 \rangle_s \| M[1] \qquad \langle 2 \rangle_s \| M[2] \qquad \langle \ell \rangle_s \| M[\ell] \;\; M[\ell + 1] \| 10^d$

LightMAC

LuykxPTY, IACR FSE 2016; ISO/IEC 29192-6:2019

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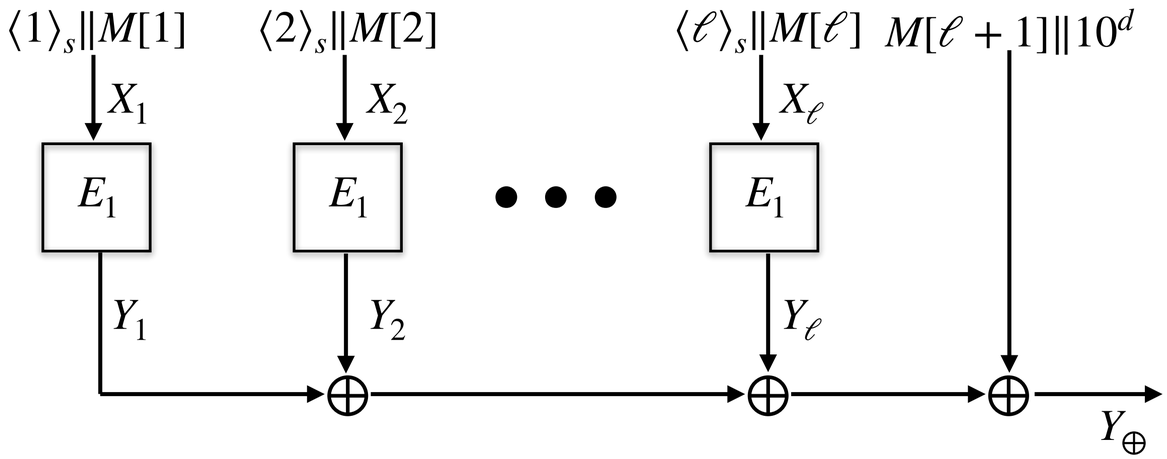

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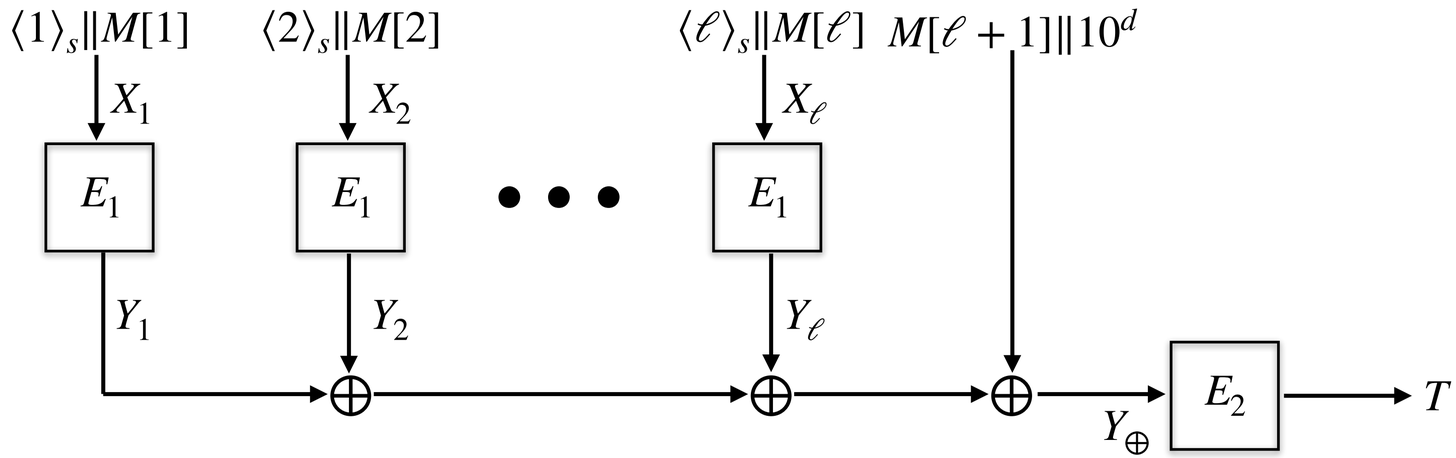

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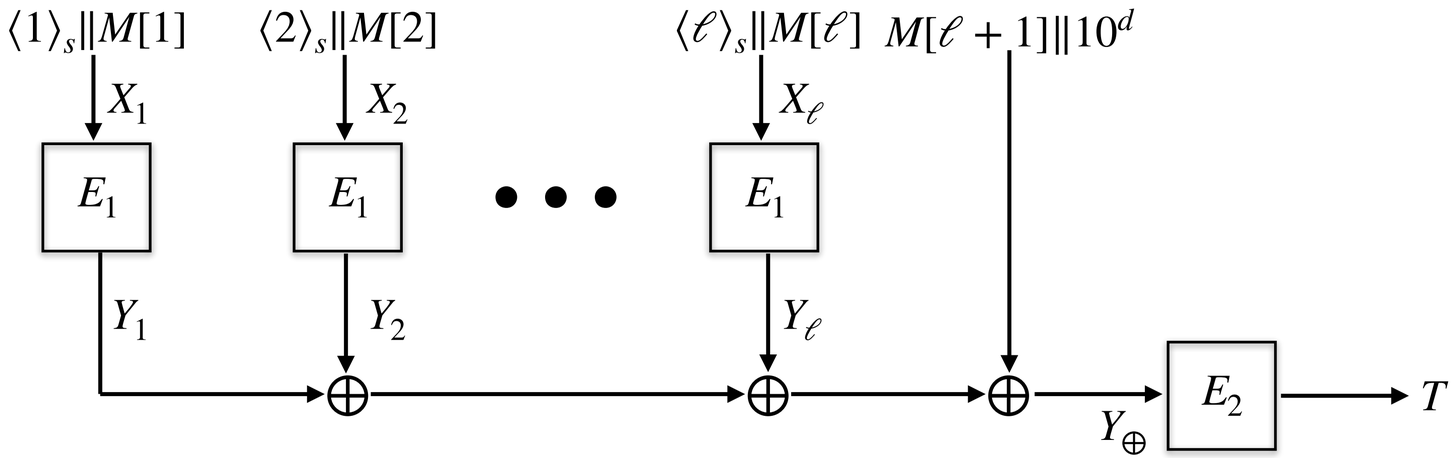

- Parallelizable yet compact.
- Birthday bound security: $\mathbf{Adv}^{\mathrm{prf}}_{\mathsf{LightMAC}}(\mathbf{Eve}) = O\left(\frac{q^2}{2^n}\right)$

LightMAC

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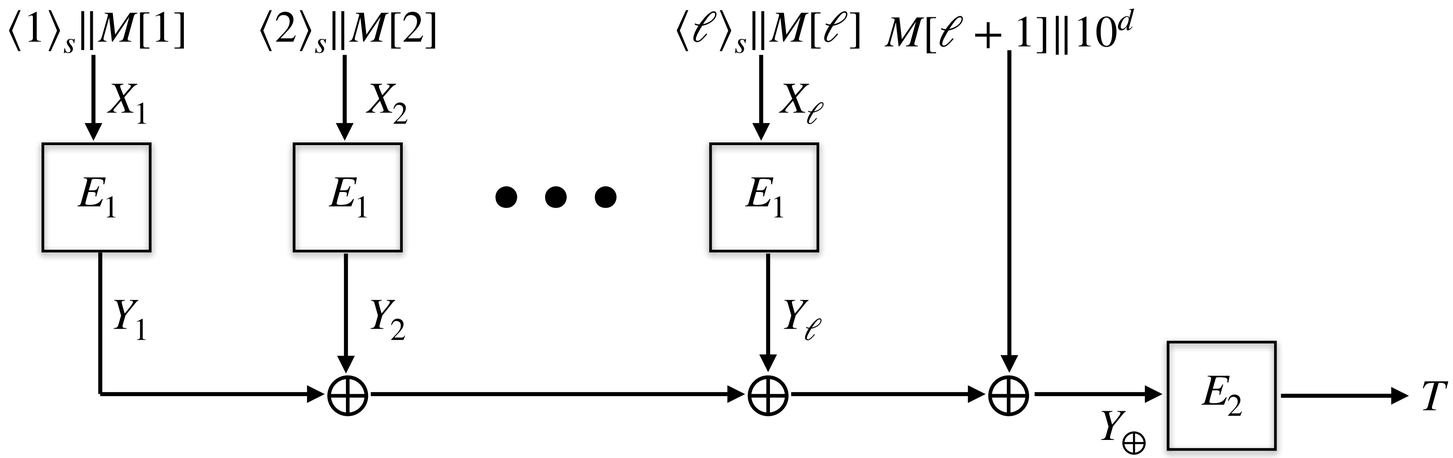
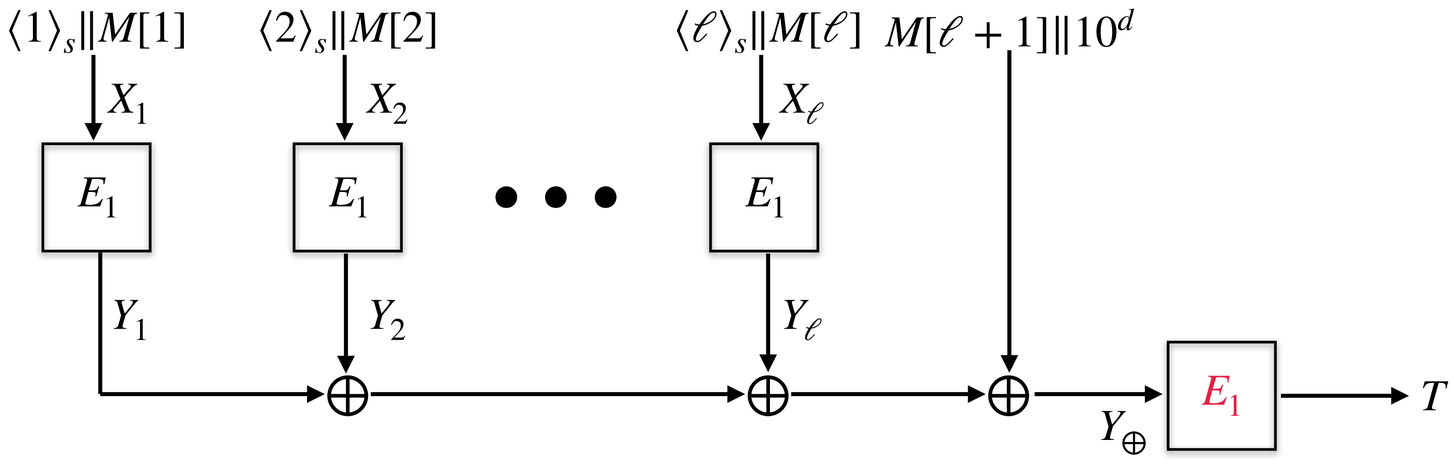


- Parallelizable yet compact.
- Birthday bound security: $\mathbf{Adv}^{\mathrm{prf}}_{\mathsf{LightMAC}}(\mathbf{Eve}) = O\left(\frac{q^2}{2^n}\right)$
- Two independent block cipher keys.

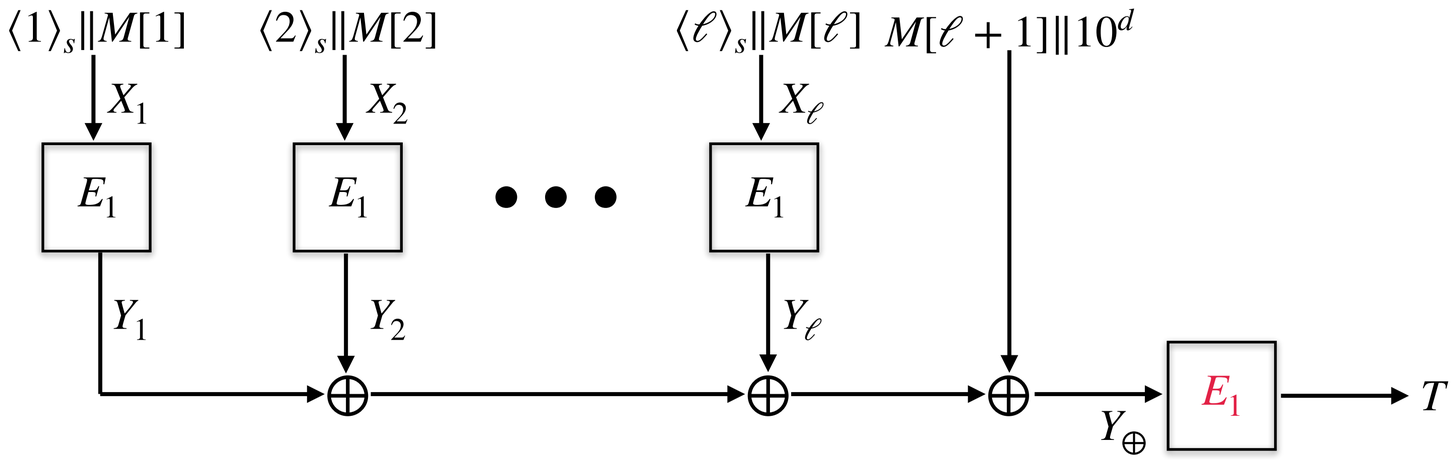
One-key LightMAC

ChattopadhyayJN, IACR ASIACRYPT 2021



One-key LightMAC

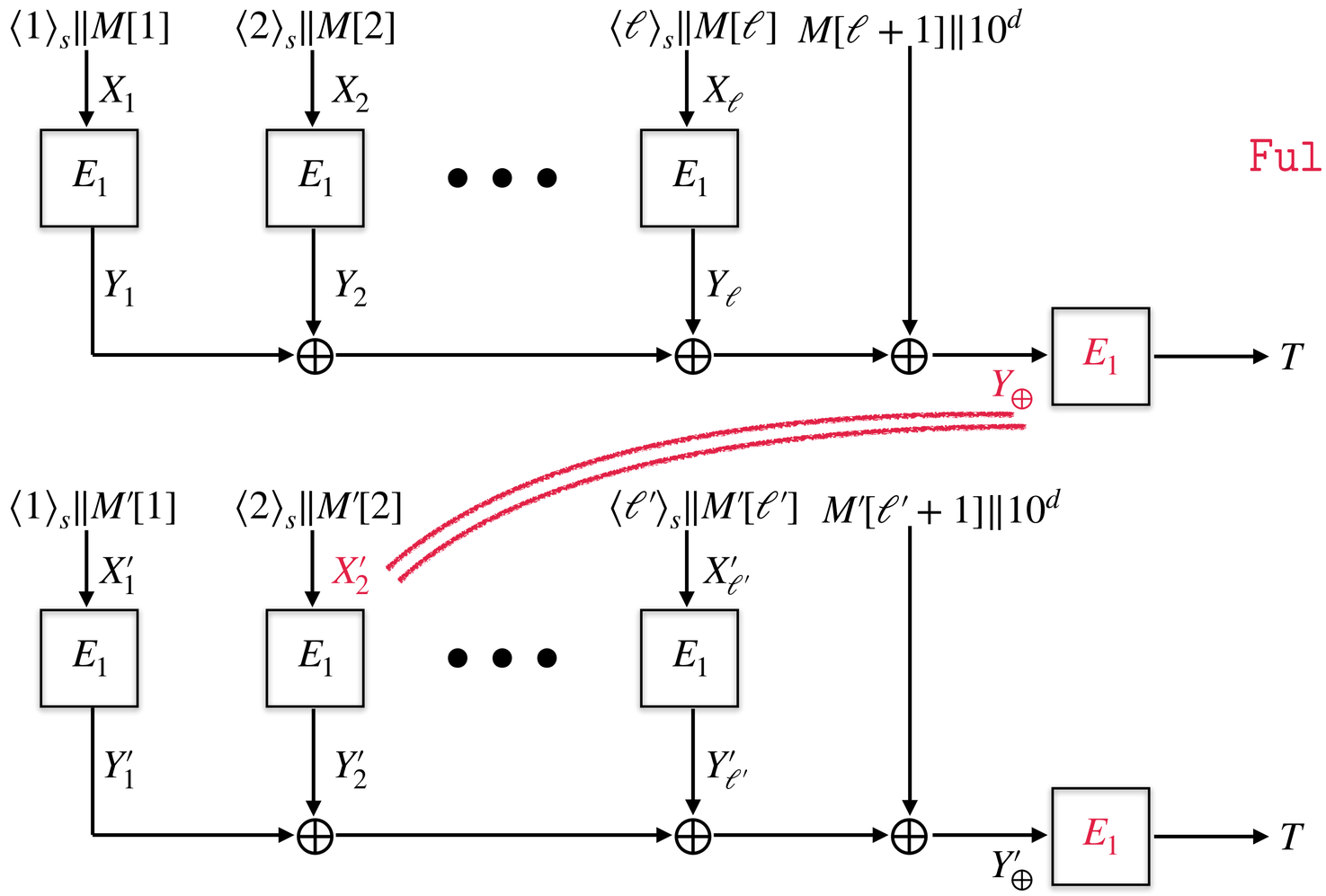
ChattopadhyayJN, IACR ASIACRYPT 2021



Is this secure?

One-key LightMAC

Full Collision Event

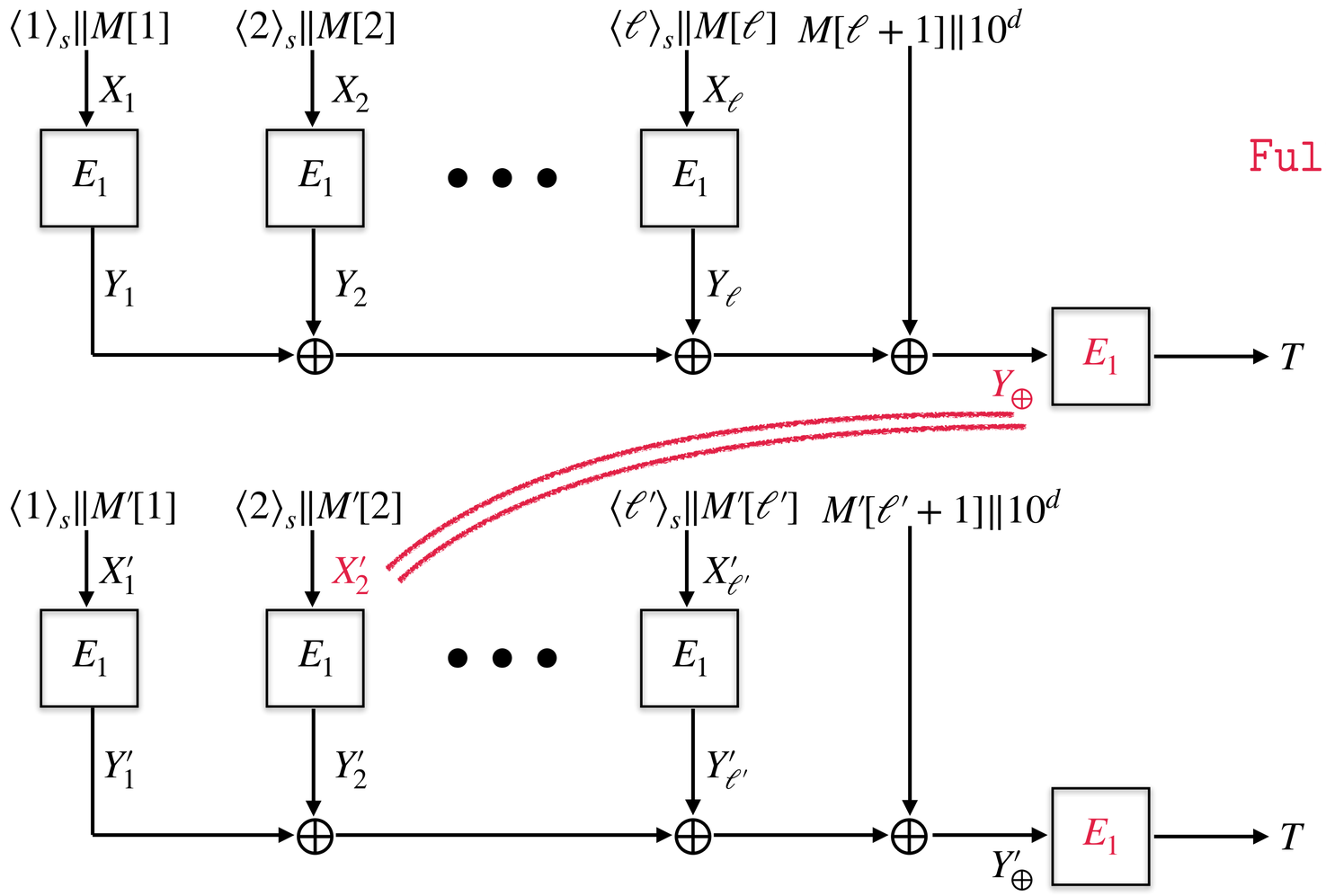


$$\texttt{Full Collision}: \quad \exists i, j, a, b \ : \ X_a^j = Y_\oplus^i$$

$$\Pr(\texttt{Full Collision}) = O\left(\frac{q^2\ell}{2^n}\right)$$

One-key LightMAC

Full Collision Event



$\texttt{Full Collision}: \quad \exists i, j, a, b \ : \ X_a^j = Y_\oplus^i$

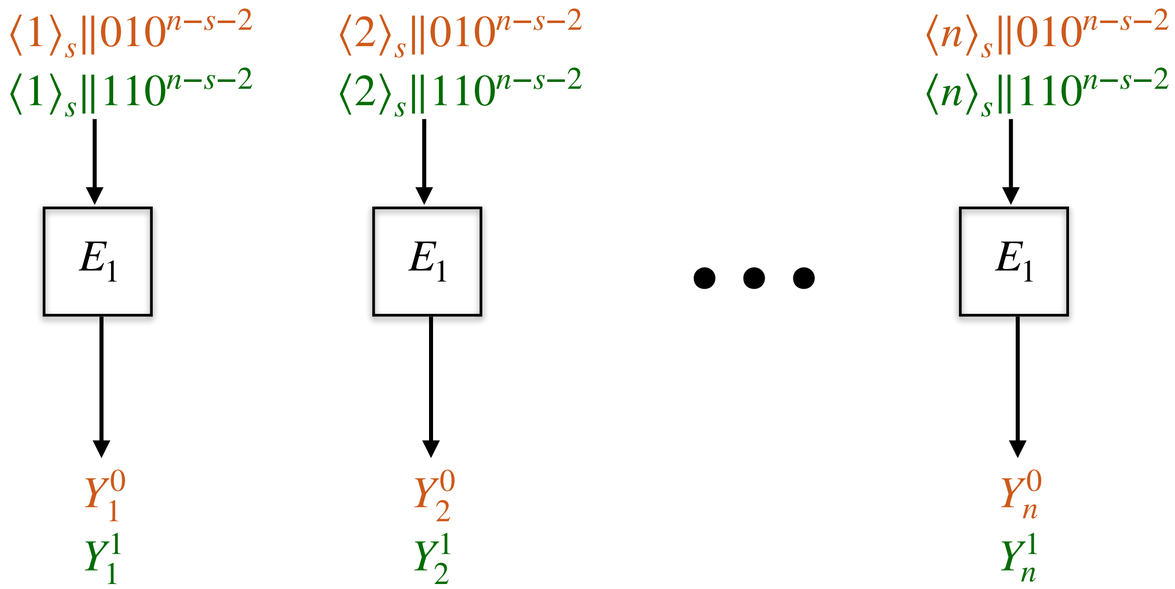
Is it even important?

One-key LightMAC

A Short Message Attack

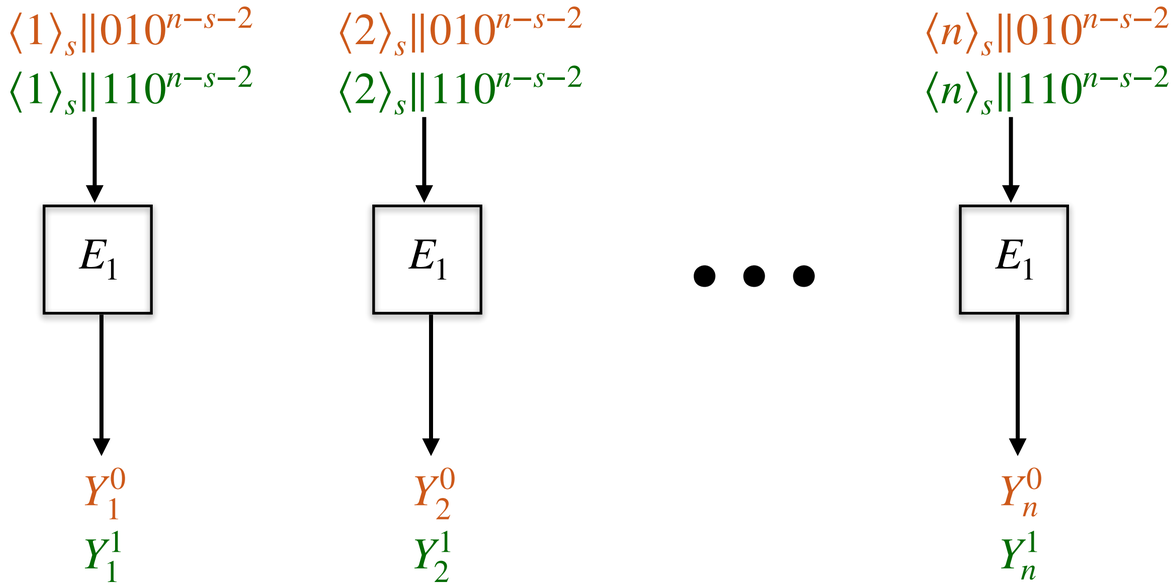
One-key LightMAC

A Short Message Attack



One-key LightMAC

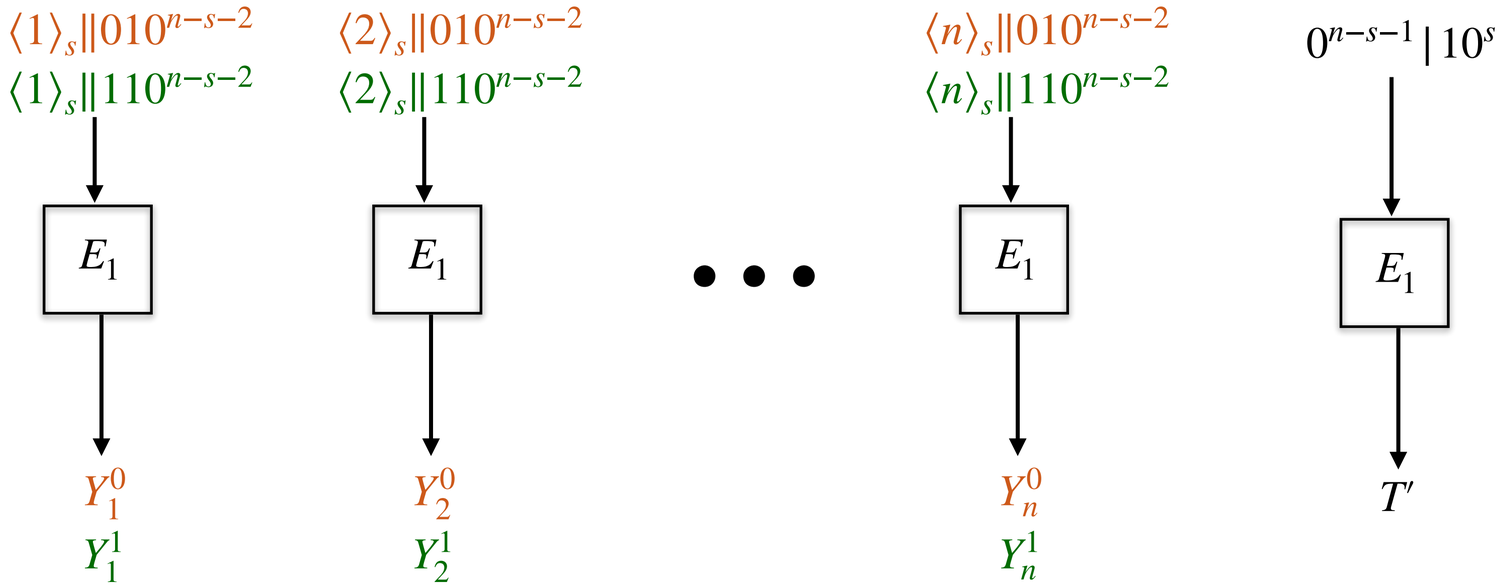
A Short Message Attack



- n lists each containing exactly 2 elements
- Using Generalized Birthday Problem: $\exists j_1, \ldots, j_n \in \{0,1\}$ such that $Y_1^{j_1} \oplus \cdots \oplus Y_n^{j_n} = 0^n$

One-key LightMAC

A Short Message Attack



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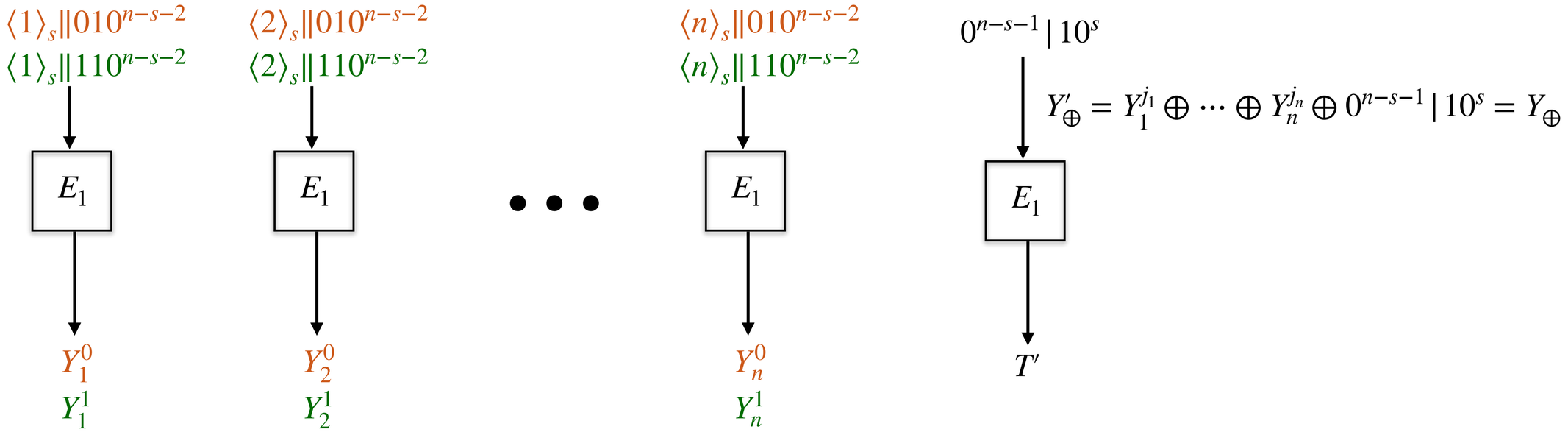
- Using Generalized Birthday Problem: $\exists j_1, \ldots, j_n \in \{0,1\}$ such that $Y_1^{j_1} \oplus \cdots \oplus Y_n^{j_n} = 0^n$
- Construct $M = j_1 \| 10^{n-s-2} \| \cdots \| j_n \| 10^{n-s-2} \| 0^{n-s-1}$ and $M' = 0^{n-s-1}$

One-key LightMAC

A Short Message Attack



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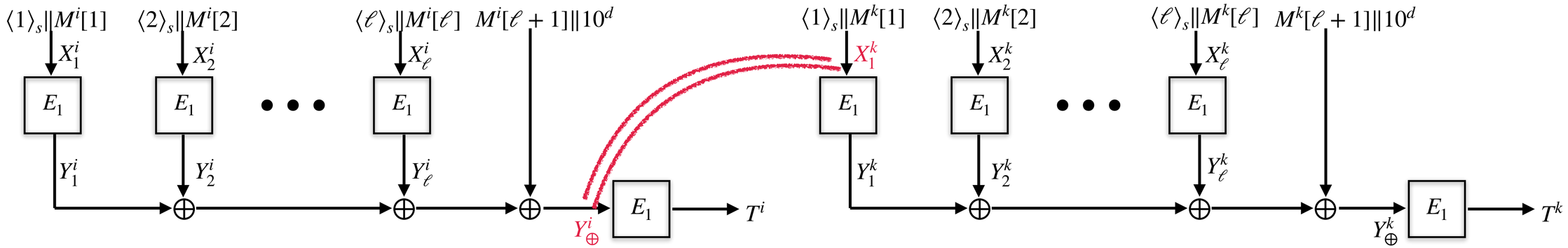
- Construct $M = j_1 \| 10^{n-s-2} \| \cdots \| j_n \| 10^{n-s-2} \| 0^{n-s-1}$ and $M' = 0^{n-s-1}$
- $Y_\oplus = Y'_\oplus \implies T = T'$ (Collision on output leads to forgery)

One-key LightMAC

Reset-Sampling



One-key LightMAC

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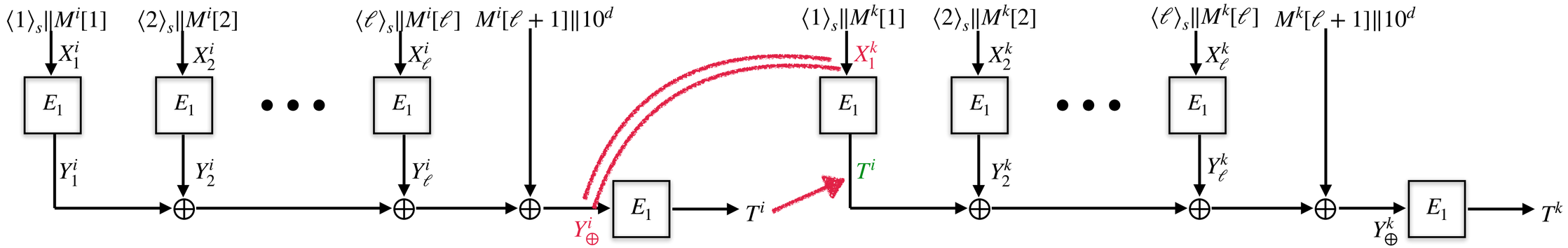

One-key LightMAC

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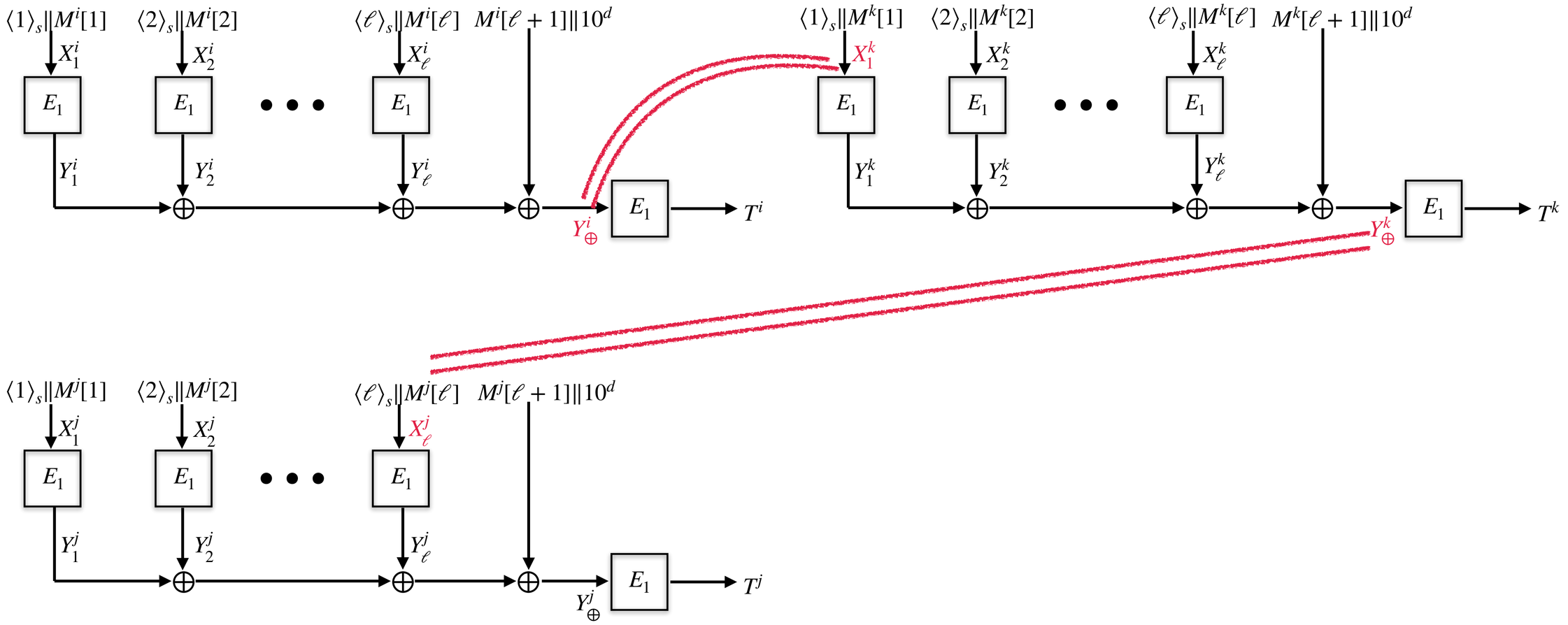

One-key LightMAC

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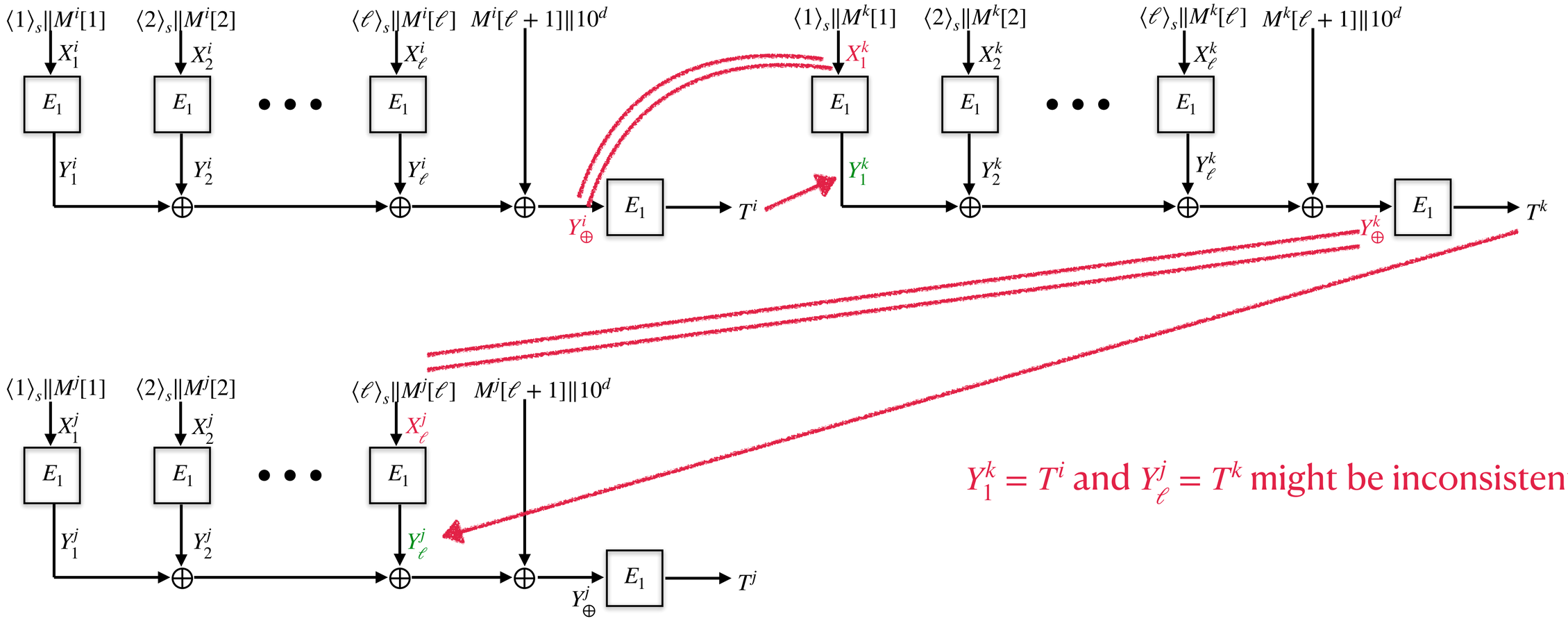

$Y_1^k = T^i$ and $Y_\ell^j = T^k$ might be inconsistent

One-key LightMAC

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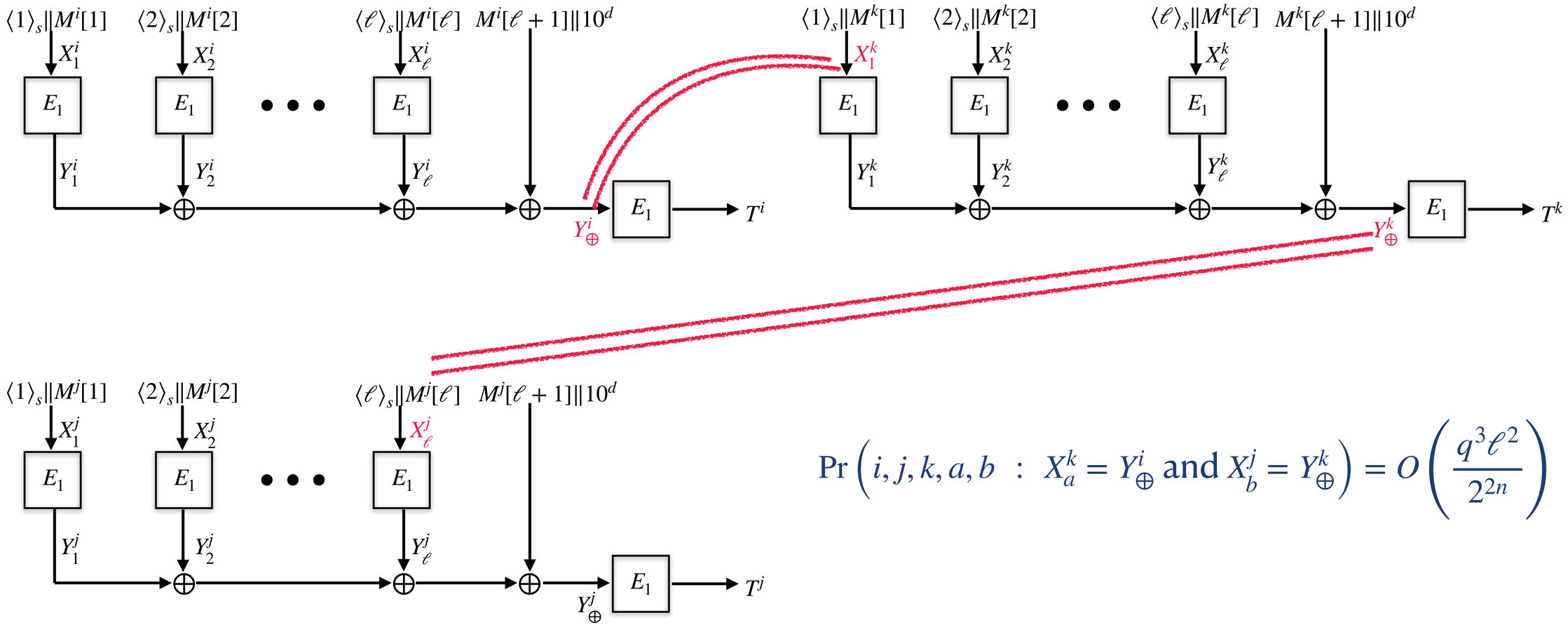

$$\Pr\left(i,j,k,a,b \ : \ X_a^k = Y_\oplus^i \text{ and } X_b^j = Y_\oplus^k\right) = O\left(\frac{q^3\ell^2}{2^{2n}}\right)$$

One-key LightMAC

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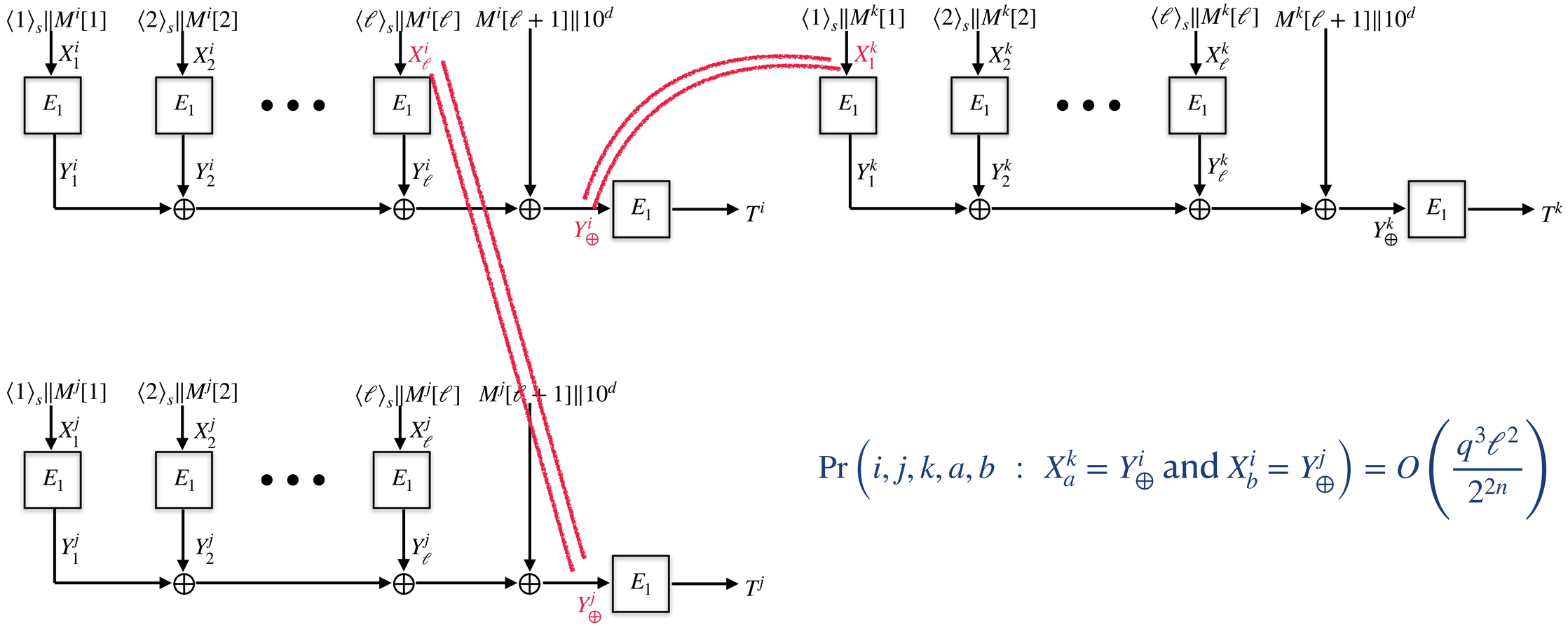

$$\Pr\left(i,j,k,a,b \ : \ X_a^k = Y_\oplus^i \text{ and } X_b^i = Y_\oplus^j\right) = O\left(\frac{q^3\ell^2}{2^{2n}}\right)$$

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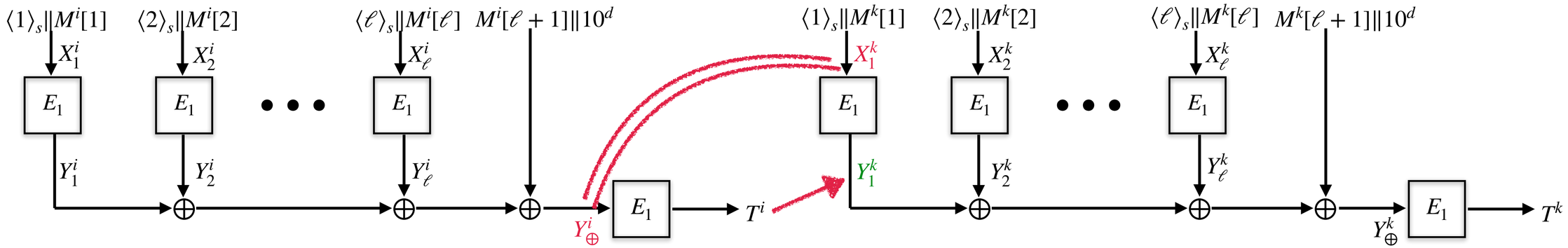

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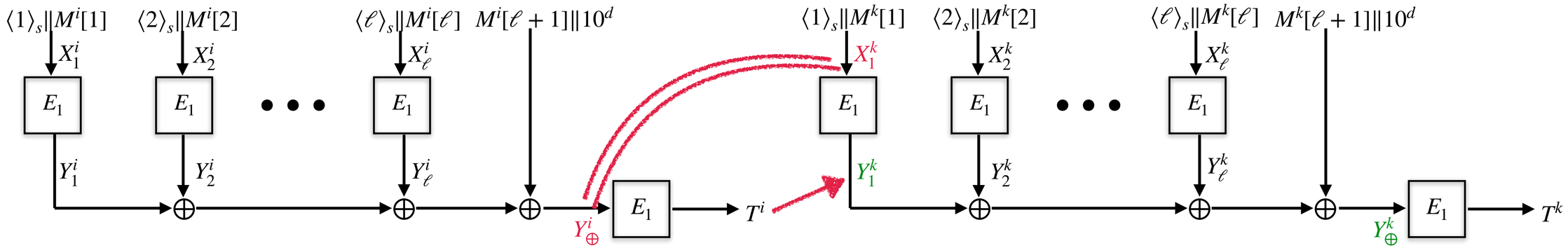
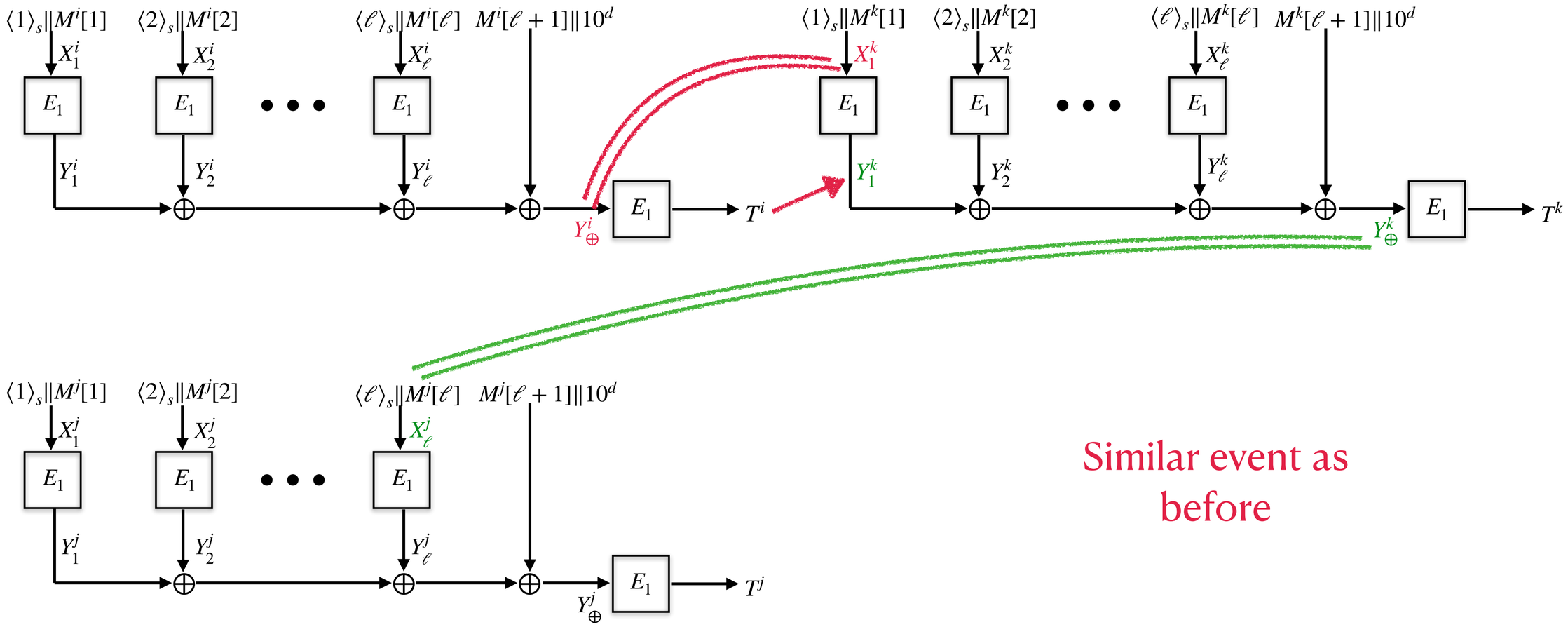


One-key LightMAC

Reset-Sampling



Similar event as before

One-key LightMAC

ChattopadhyayJN, IACR ASIACRYPT 2021

$$\mathbf{Adv}^{\mathrm{prf}}_{\text{1k-LightMAC}}(\mathbf{Eve}) = O\left(\frac{q^2}{2^n}\right), \qquad \text{while } \ell \ll 2^{n/4}$$

One-key LightMAC is identical in security up to acceptable restrictions on message length

OMAC

Iwata and Kurosawa, IACR FSE 2003; NIST FIPS 800-38B; ISO/IEC 29167-10:2017

$(M[1], \ldots, M[\ell]) \xleftarrow{n} M$

OMAC

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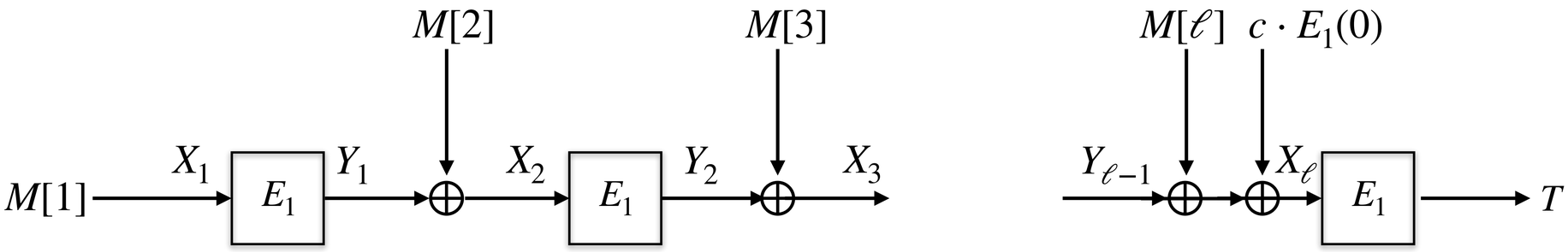
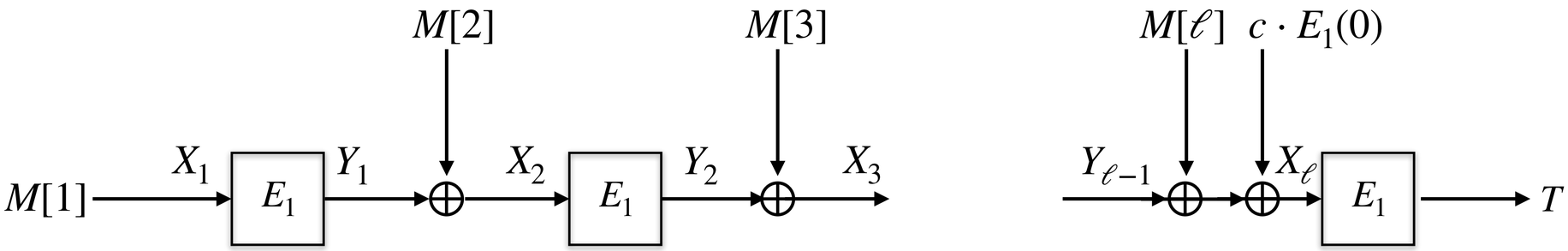


OMAC

Iwata and Kurosawa, IACR FSE 2003; NIST FIPS 800-38B; ISO/IEC 29167-10:2017

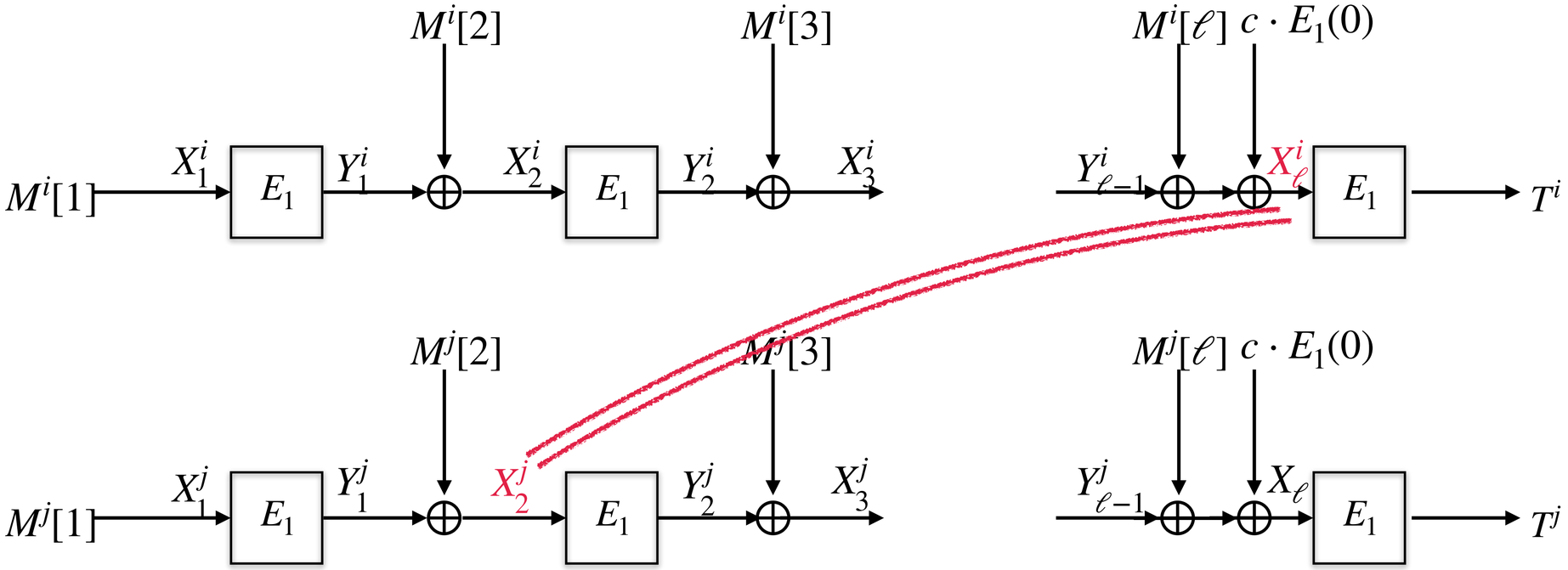
$(M[1], \ldots, M[\ell]) \xleftarrow{n} M$



- Sequential and single-key CBC-MAC.
- Best security bound: $\mathbf{Adv}^{\text{prf}}_{\text{CBC-MAC}}(\mathbf{Eve}) = O\left(\frac{q^2\ell}{2^n}\right)$
- No matching attack.

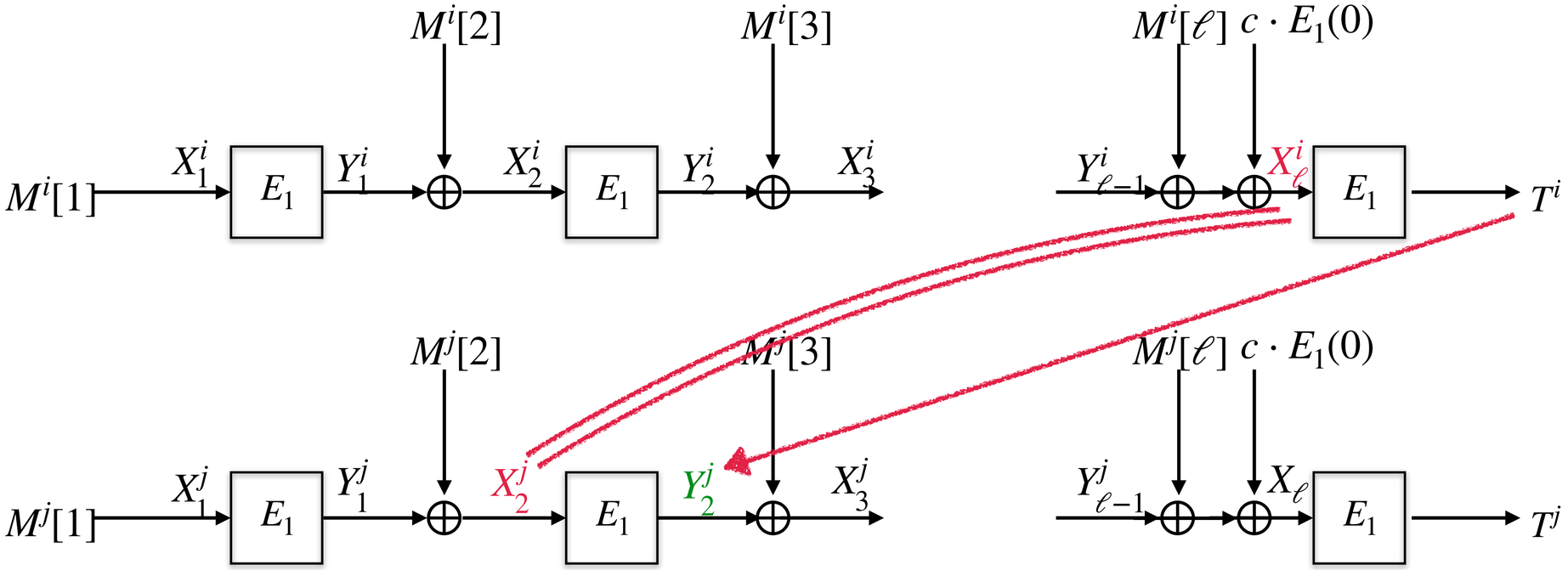
OMAC

Full Collision Event



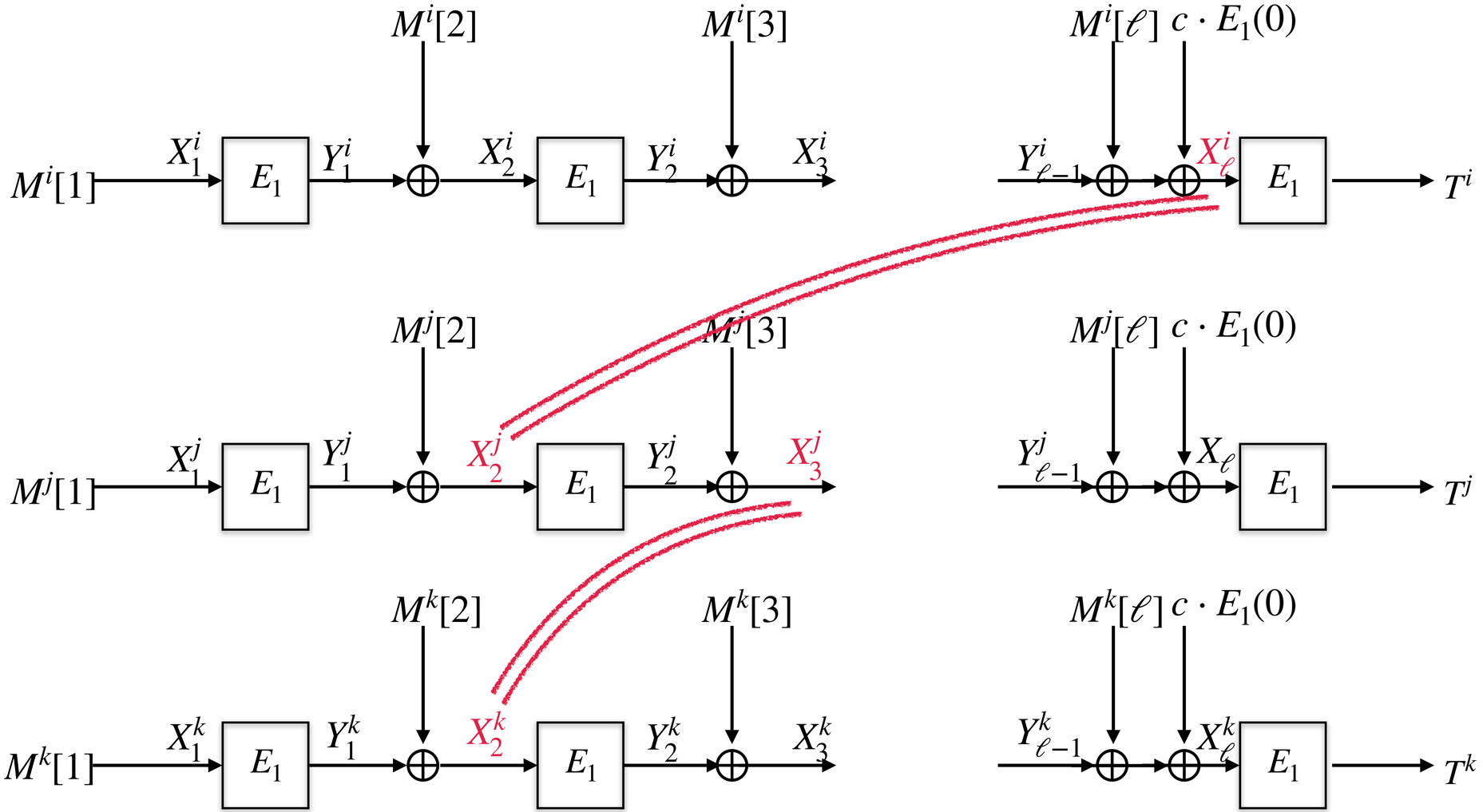
OMAC

Reset-Sampling



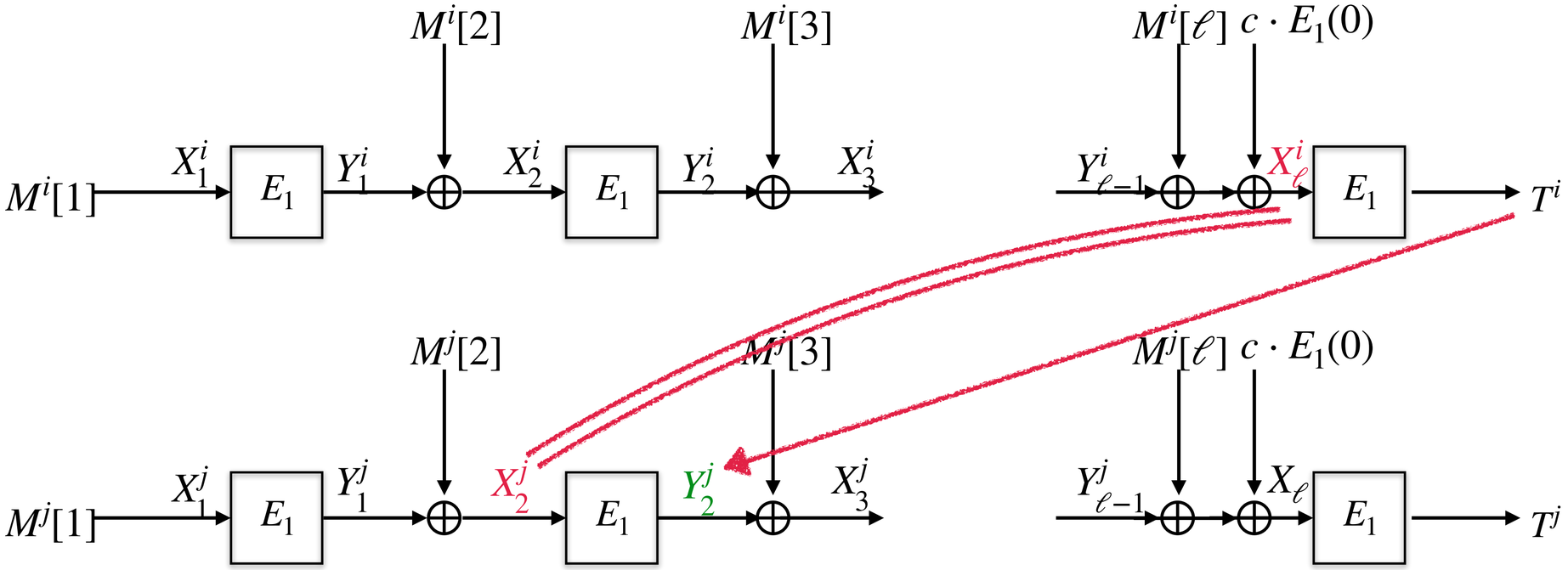
OMAC

Reset-Sampling



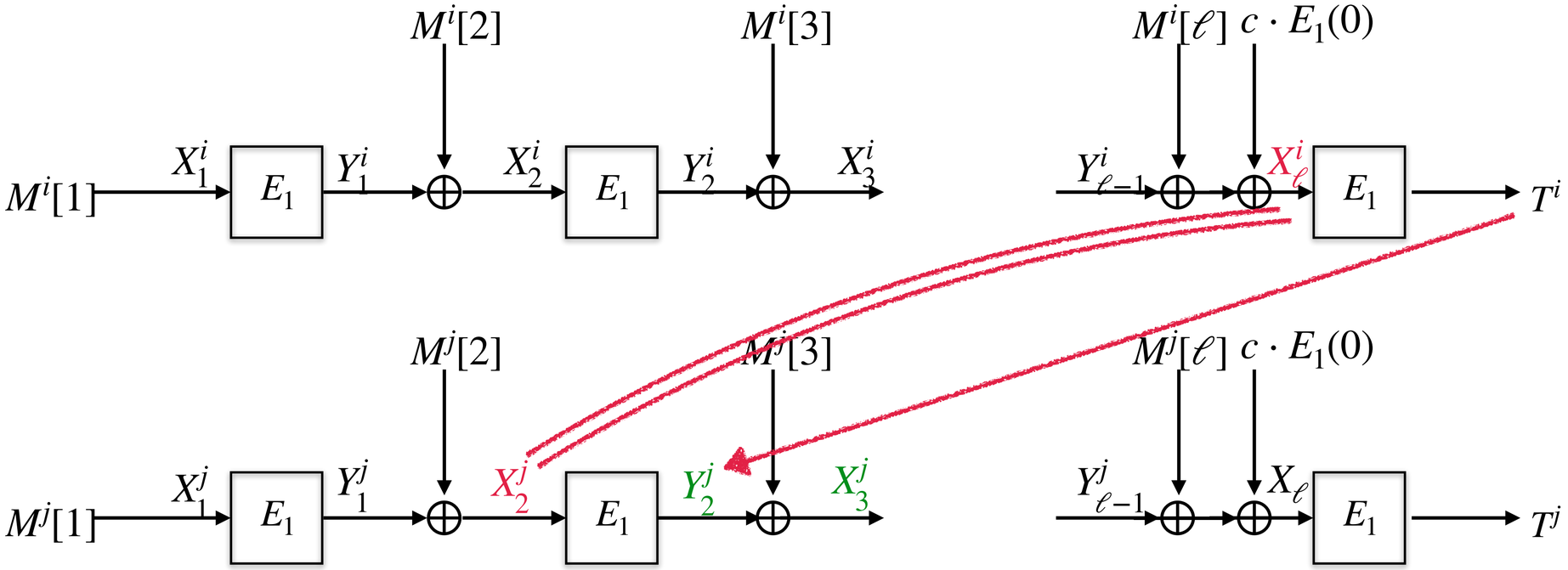
OMAC

Reset-Sampling



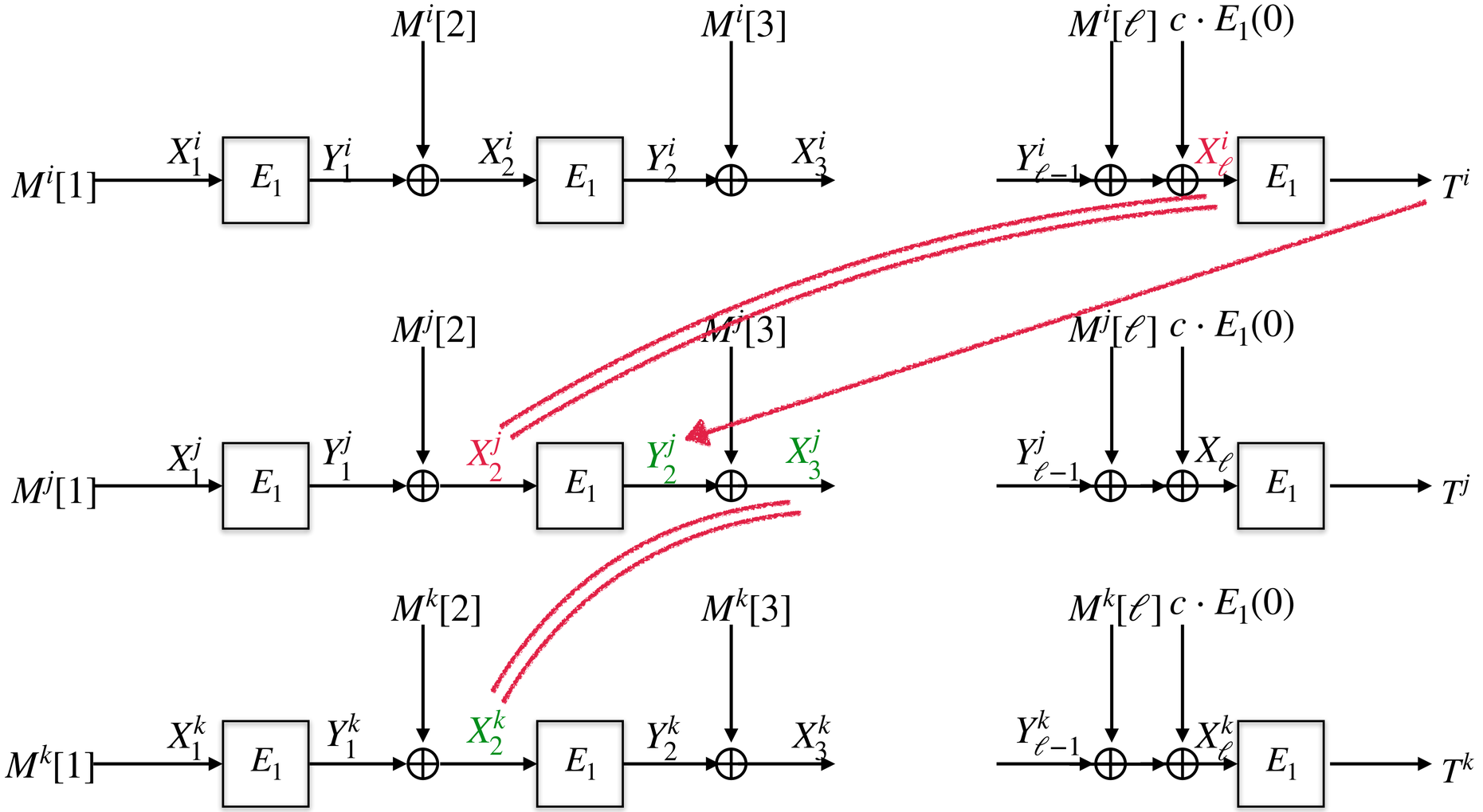
OMAC

Reset-Sampling



OMAC

Reset-Sampling



OMAC

ChattopadhyayJN, IACR ASIACRYPT 2022

$$\mathbf{Adv}^{\mathrm{prf}}_{\mathrm{OMAC}}(\mathbf{Eve}) = O\left(\frac{q^2}{2^n} + \frac{q\ell^2}{2^n}\right)$$

OMAC

ChattopadhyayJN, IACR ASIACRYPT 2022

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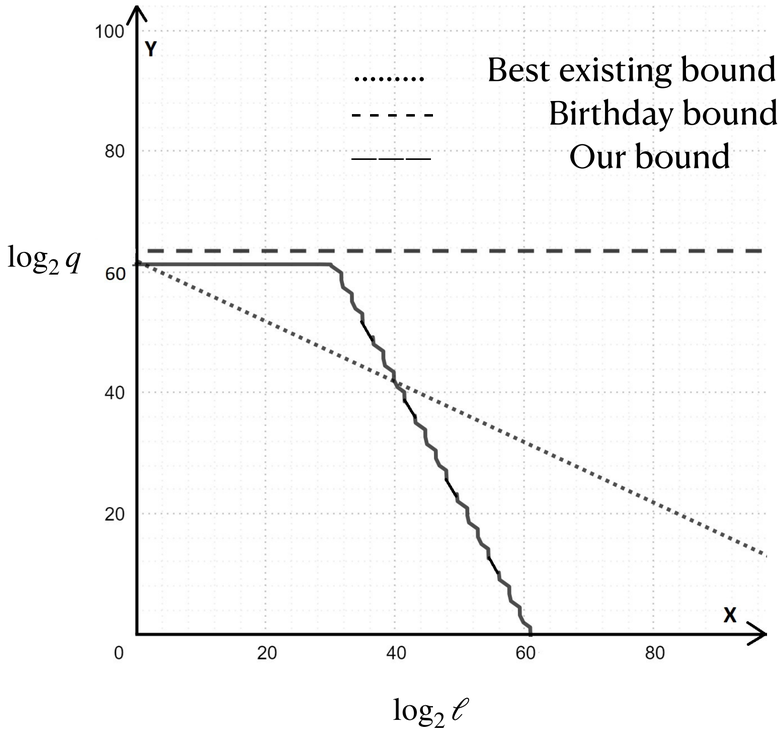

OMAC is (almost) birthday bound secure.

Future Directions

- New applications of reset-sampling.
- Relaxation in the restriction on message lengths.
- An abstract formalization of the reset-sampling philosophy.

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Thank you