The 9 Lives of Bleichenbacher's CAT: New Cache ATtacks on TLS Implementations

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מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

UNIVERSITY OF MICHIGAN

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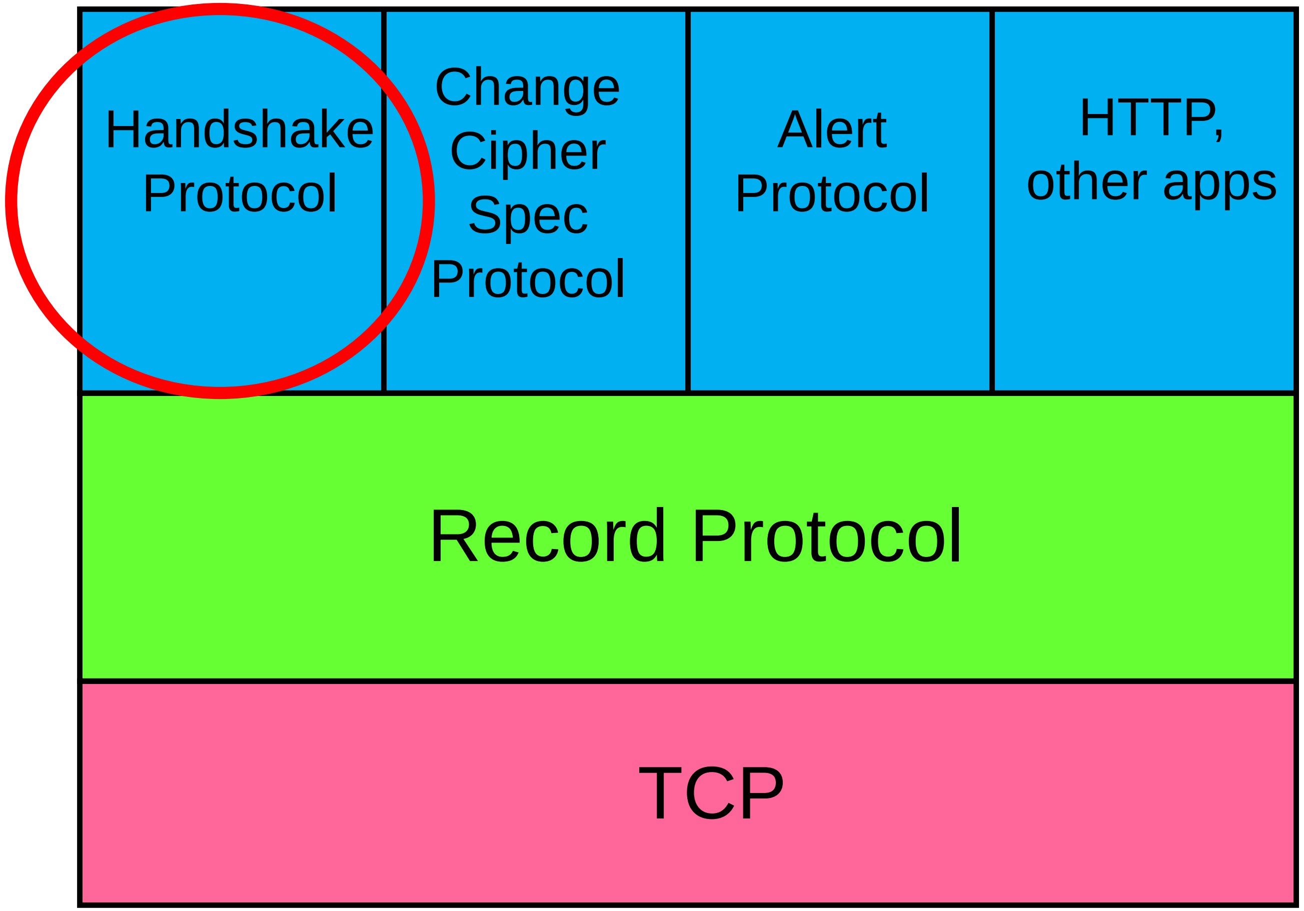
Talk Outline

1. Background
2. Attacking TLS and downgrade attack
3. RSA padding attack parallelization using CVP
4. Cache attacks on RSA padding
5. Conclusions

Transport Layer Security (TLS)

- The most widely used cryptographic protocol
- Provides communication security (https, VPN, etc.)
  - TLS handshake is used for authentication and secure key exchange
  - TLS Record layer protects the communication
  - Allows for cryptographic agility using different cipher suites

Transport Record Layer



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  - Better alternatives now available (e.g. Ephemeral ECDH)
  - Supported for backwards compatibility

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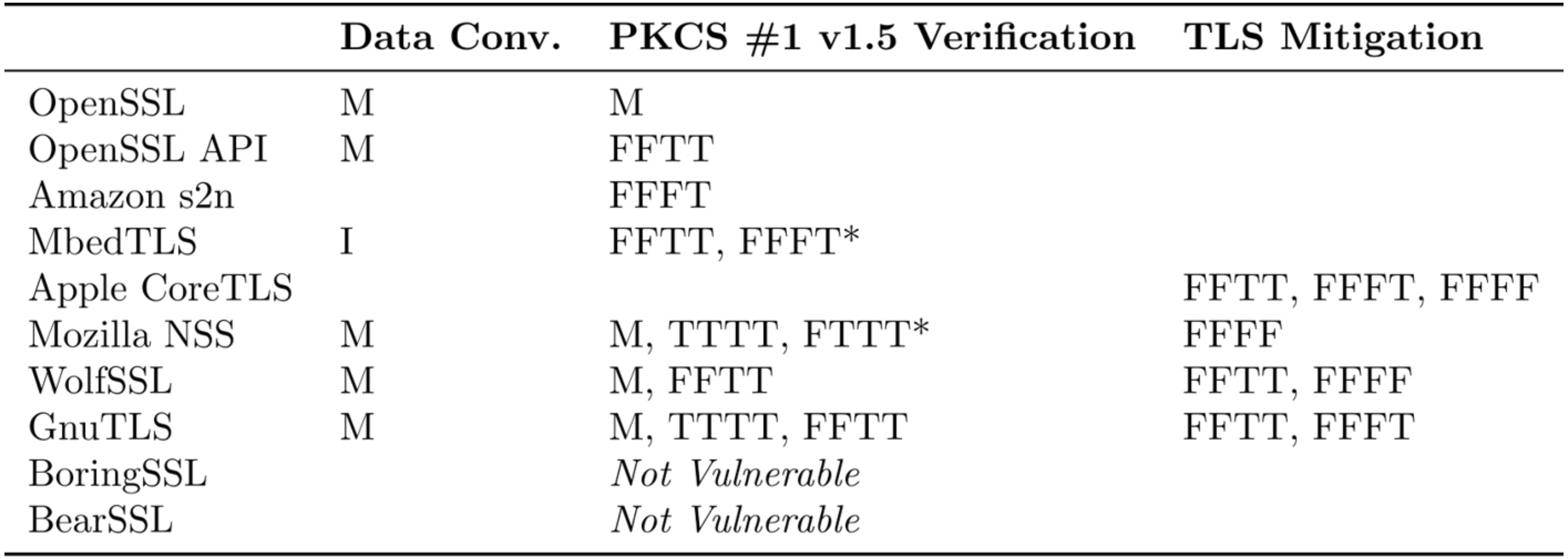

	Data Conv.	**PKCS #1 v1.5 Verification**	**TLS Mitigation**
OpenSSL	M	M	
OpenSSL API	M	FFTT	
Amazon s2n		FFFT	
MbedTLS	I	FFTT, FFFT*	
Apple CoreTLS			FFTT, FFFT, FFFF
Mozilla NSS	M	M, TTTT, FTTT*	FFFF
WolfSSL	M	M, FFTT	FFTT, FFFF
GnuTLS	M	M, TTTT, FFTT	FFTT, FFFT
BoringSSL		*Not Vulnerable*	
BearSSL		*Not Vulnerable*	

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- We show the feasibility of MiTM downgrade attack
  - Novel parallelization technique for RSA padding oracle attacks
  - Assume cache attack against multiple TLS servers
  - Use BEAST to boost success probability
  - Break 100% of the connections that use vulnerable implantations

RSA Encryption

$$N = p \cdot q \qquad (p, q) \text{ are primes}$$

$$d \cdot e = 1 \mod \phi(N)$$

$$c = m^e \mod N$$

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- Nice math, but how can we use it on real data?
  - There are several real world problems

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- Assume I want to encrypt the answer to a Yes/No question – value 0 or 1
    - Vulnerable to dictionary attack
    - Easy to detect repetitions
    - We need to make sure m is random

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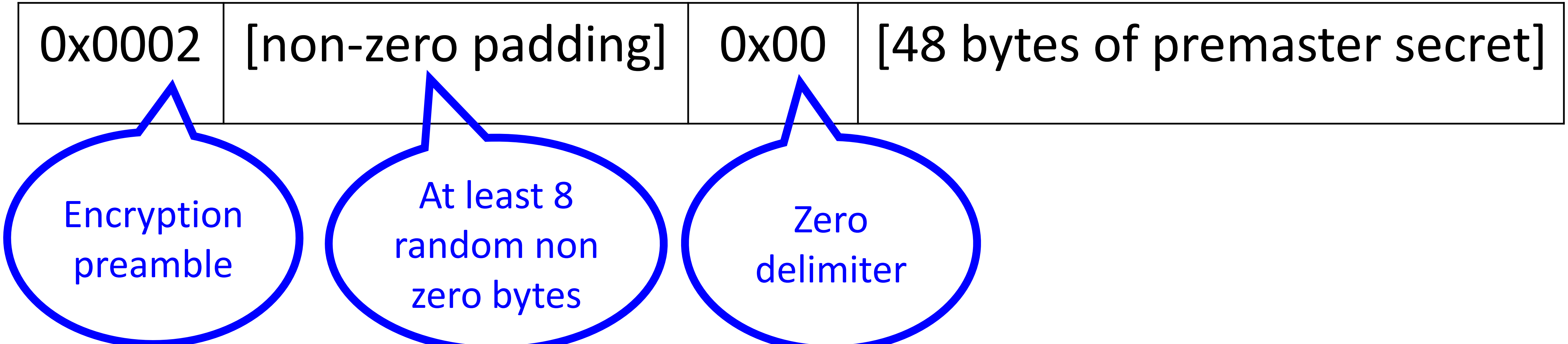

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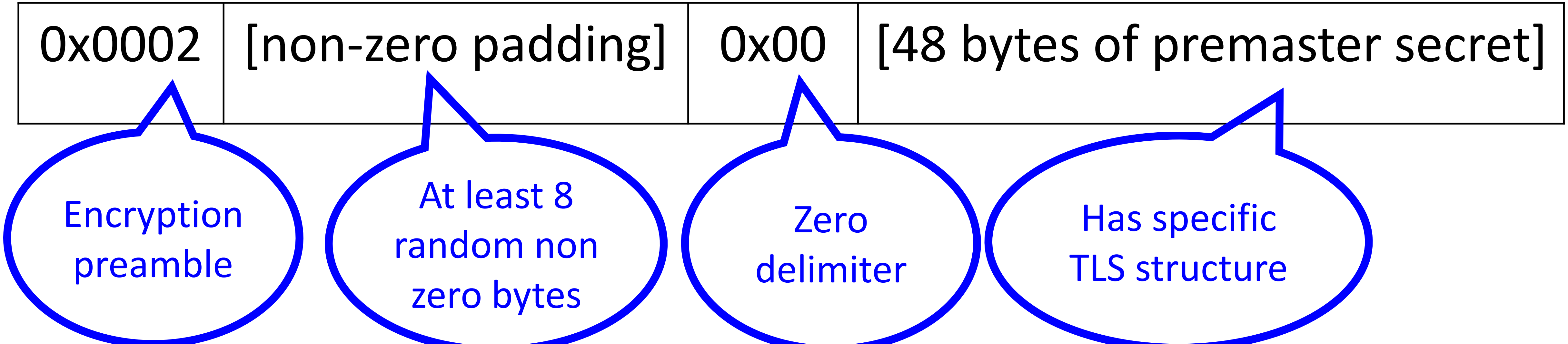

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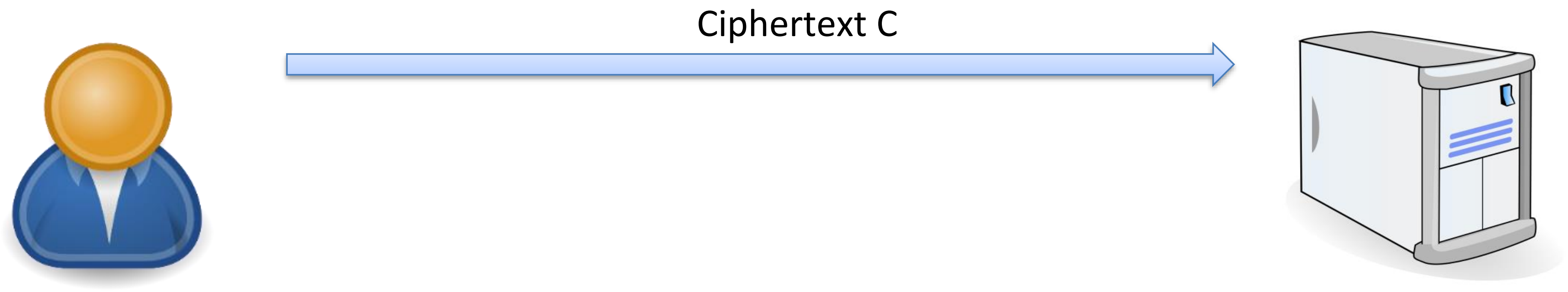

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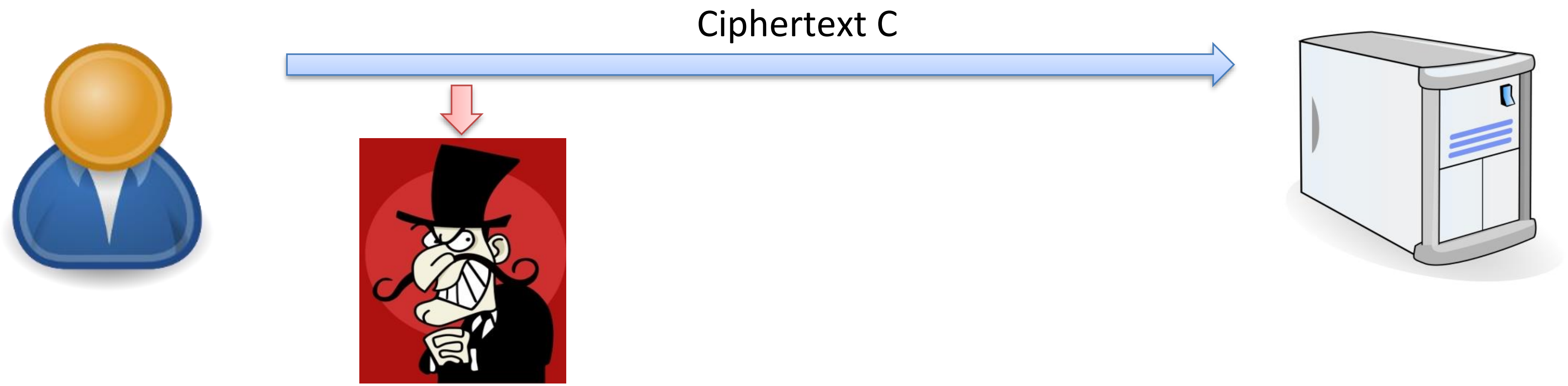

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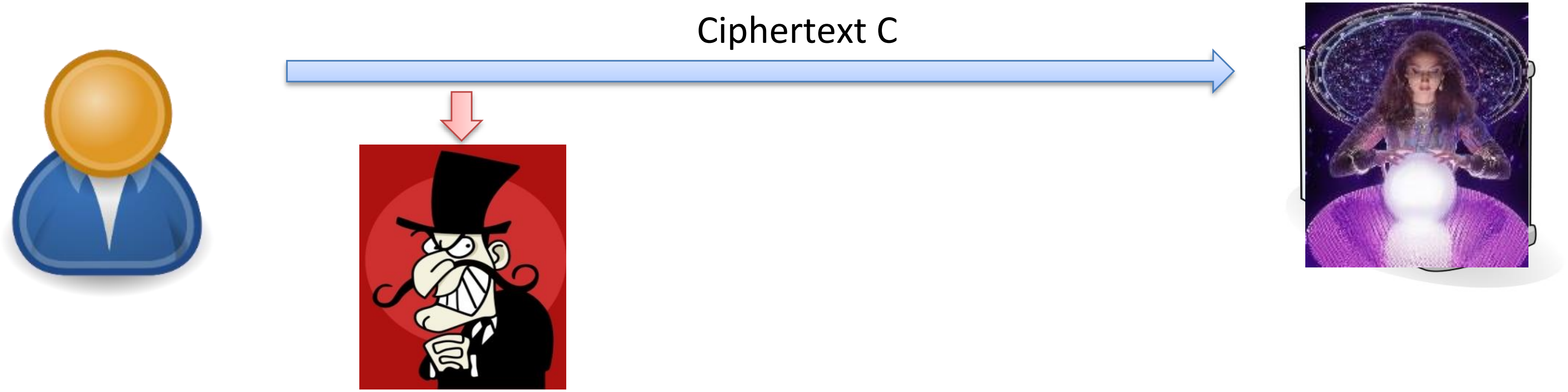

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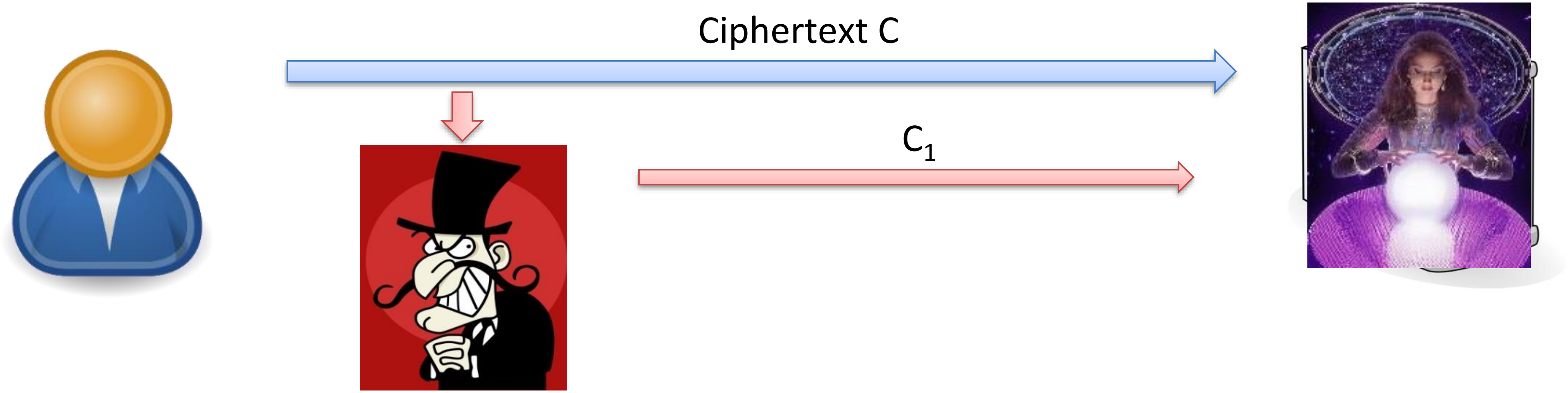

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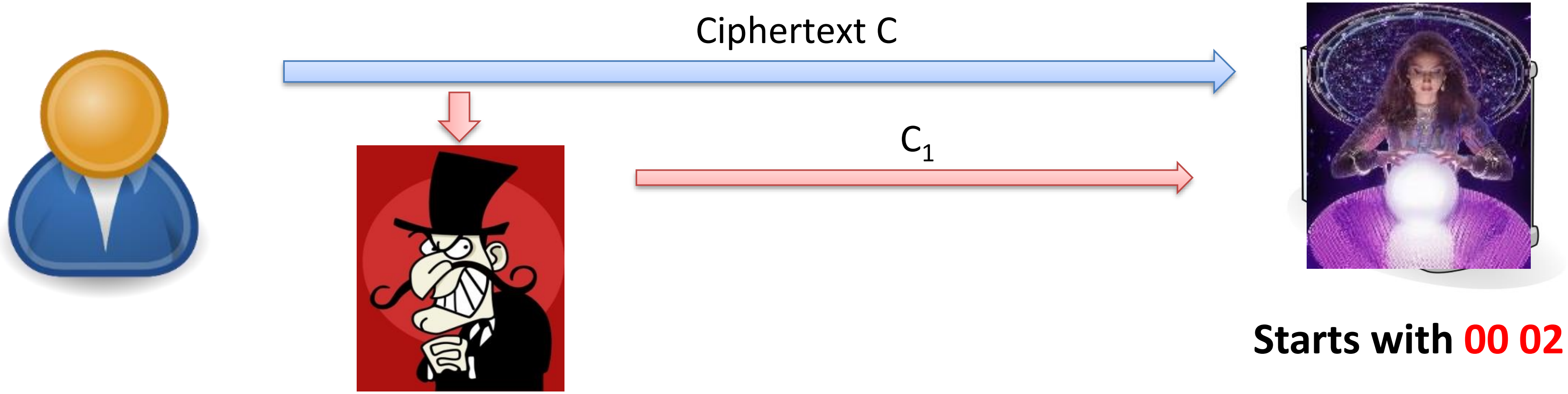

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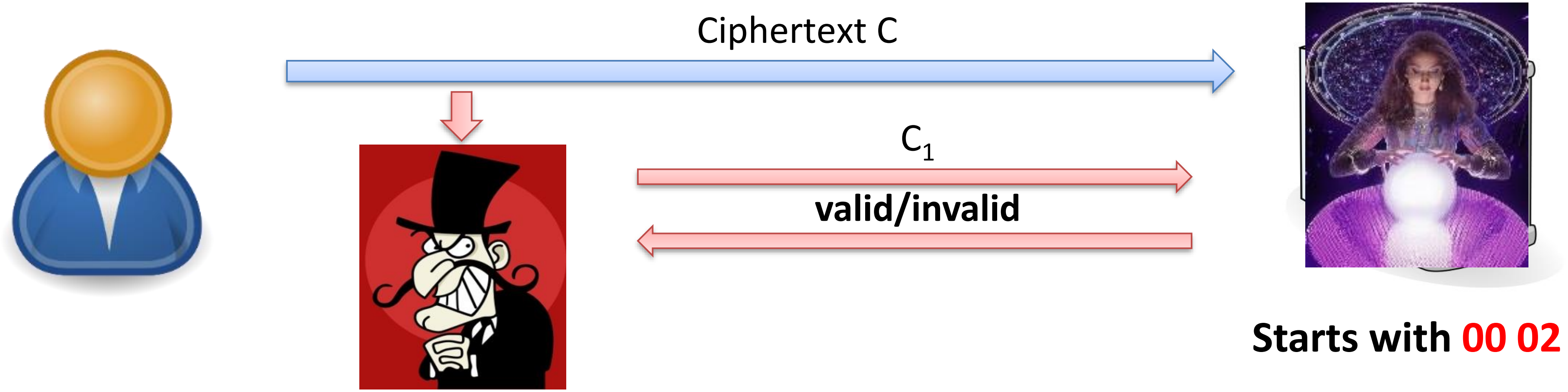

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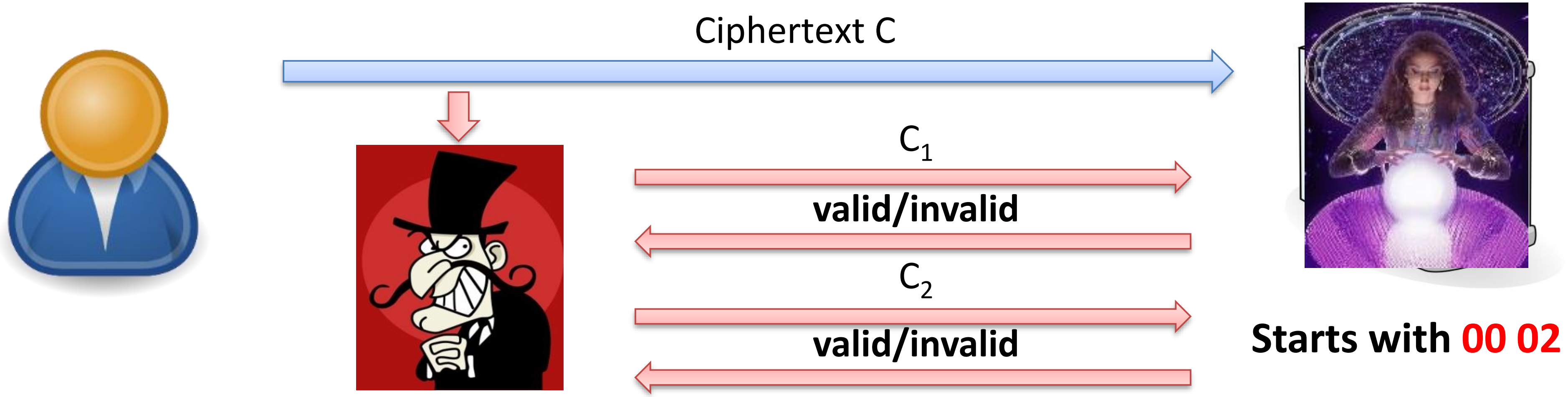

Ciphertext C

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C_2

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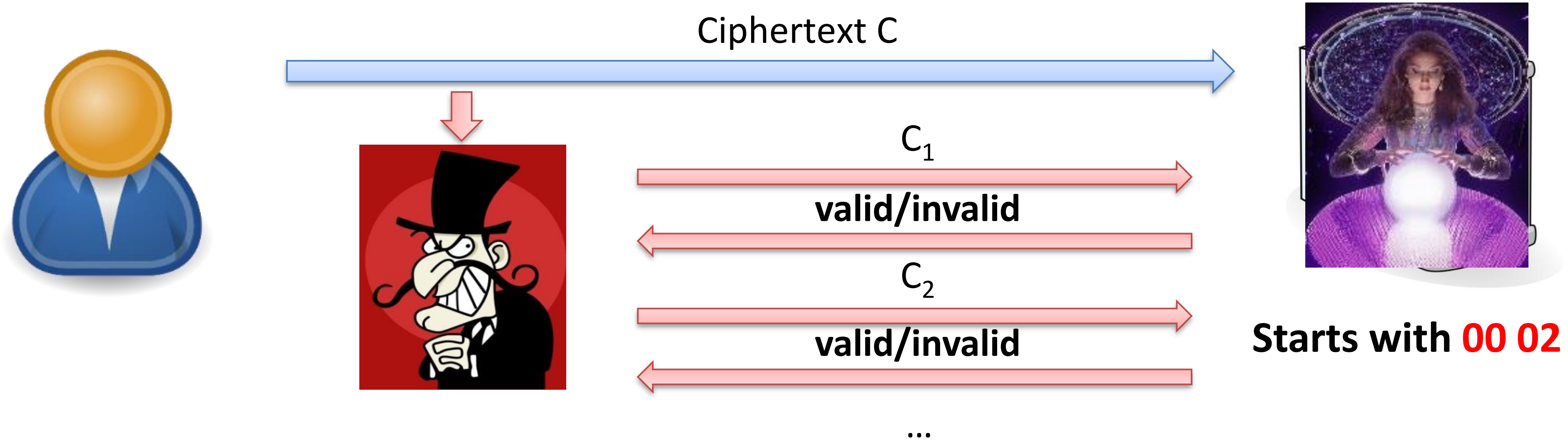

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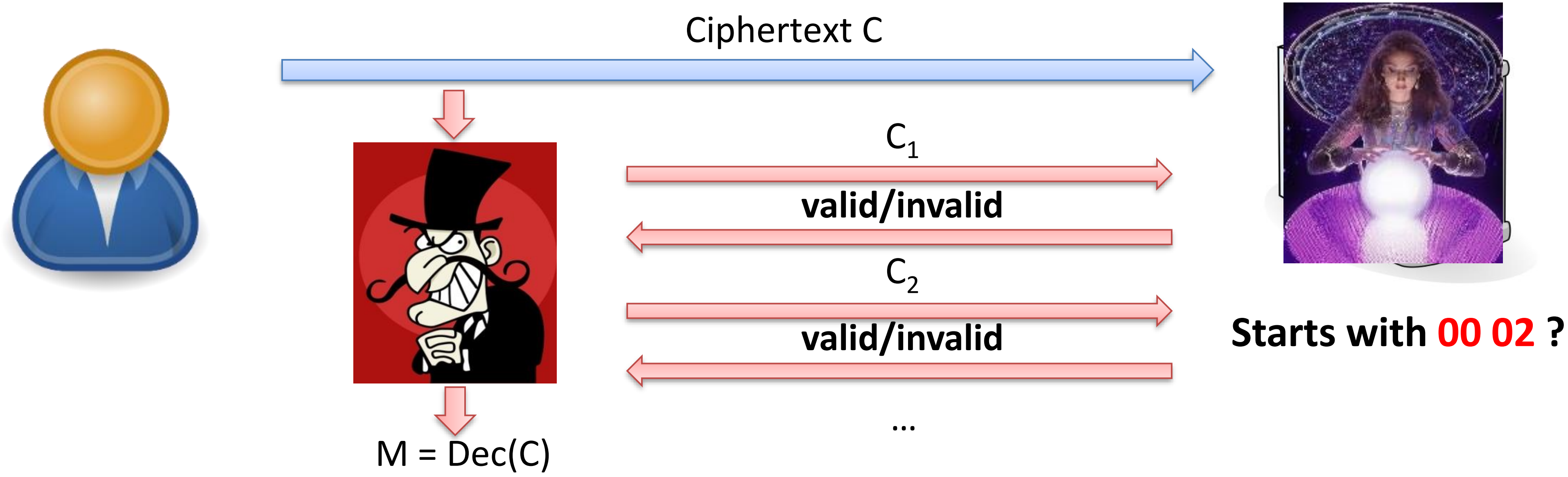

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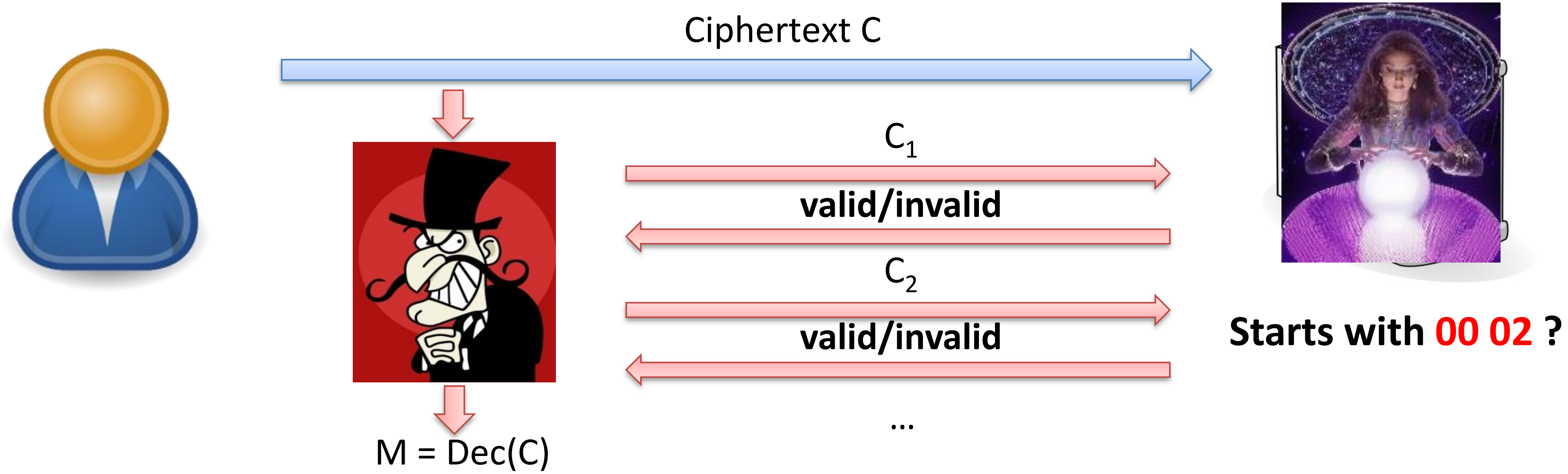

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- Similar attack on PKCS #1 v2 OEAP padding scheme [Manger 2001]

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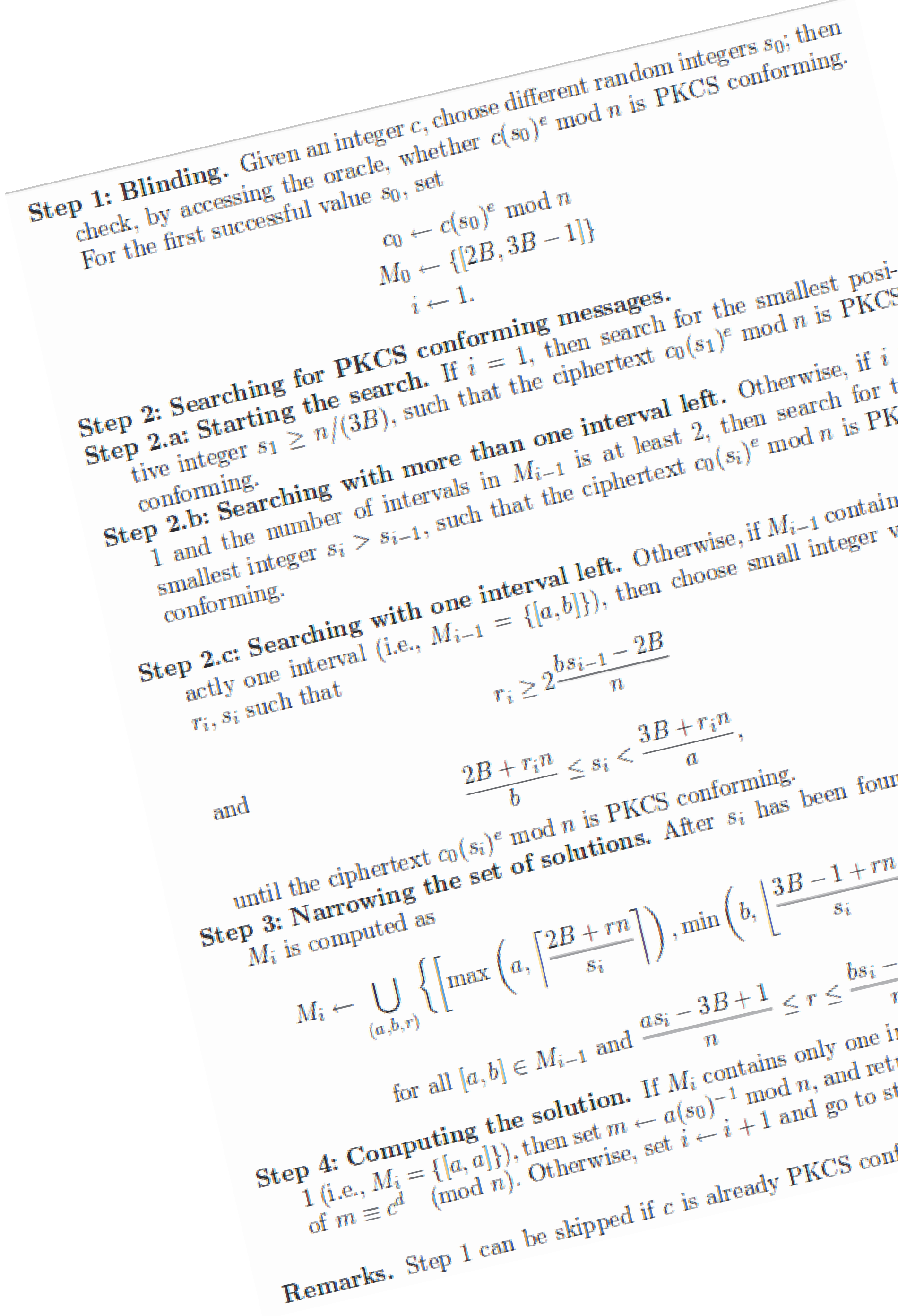

Step 1: Blinding. Given an integer c, choose different random integers s_0; then check, by accessing the oracle, whether $c(s_0)^e \bmod n$ is PKCS conforming. For the first successful value s_0, set

$$c_0 \leftarrow c(s_0)^e \bmod n$$
$$M_0 \leftarrow \{[2B, 3B-1]\}$$
$$i \leftarrow 1.$$

Step 2: Searching for PKCS conforming messages.

Step 2.a: Starting the search. If $i = 1$, then search for the smallest posi- tive integer $s_1 \geq n/(3B)$, such that the ciphertext $c_0(s_1)^e \bmod n$ is PKCS conforming.

Step 2.b: Searching with more than one interval left. Otherwise, if i 1 and the number of intervals in M_{i-1} is at least 2, then search for t smallest integer $s_i > s_{i-1}$, such that the ciphertext $c_0(s_i)^e \bmod n$ is PK conforming.

Step 2.c: Searching with one interval left. Otherwise, if M_{i-1} contain actly one interval (i.e., $M_{i-1} = \{[a, b]\}$), then choose small integer v r_i, s_i such that

$$r_i \geq 2\frac{bs_{i-1} - 2B}{n}$$

and

$$\frac{2B + r_i n}{b} \leq s_i < \frac{3B + r_i n}{a},$$

until the ciphertext $c_0(s_i)^e \bmod n$ is PKCS conforming.

Step 3: Narrowing the set of solutions. After s_i has been foun M_i is computed as

$$M_i \leftarrow \bigcup_{(a,b,r)} \left\{ \left[\max\left(a, \left\lceil \frac{2B + rn}{s_i} \right\rceil\right), \min\left(b, \left\lfloor \frac{3B - 1 + rn}{s_i} \right.\right.\right.\right.$$

$$\text{for all } [a, b] \in M_{i-1} \text{ and } \frac{as_i - 3B + 1}{n} \leq r \leq \frac{bs_i -}{n}$$

Step 4: Computing the solution. If M_i contains only one i 1 (i.e., $M_i = \{[a, a]\}$), then set $m \leftarrow a(s_0)^{-1} \bmod n$, and ret of $m \equiv c^d \pmod{n}$. Otherwise, set $i \leftarrow i + 1$ and go to st

Remarks. Step 1 can be skipped if c is already PKCS conf

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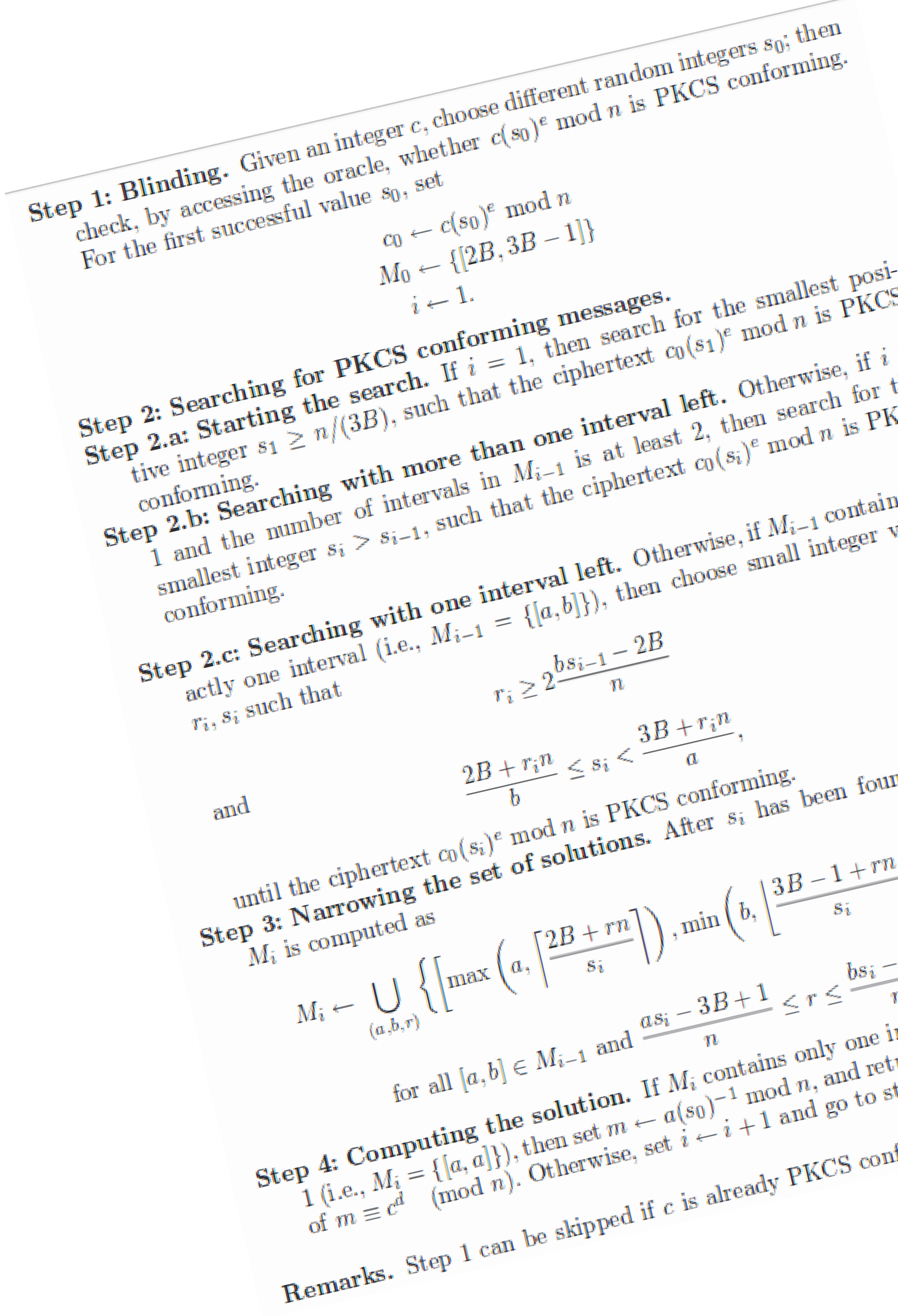
- "Million message attack"
  - In general performance depends on the oracle properties



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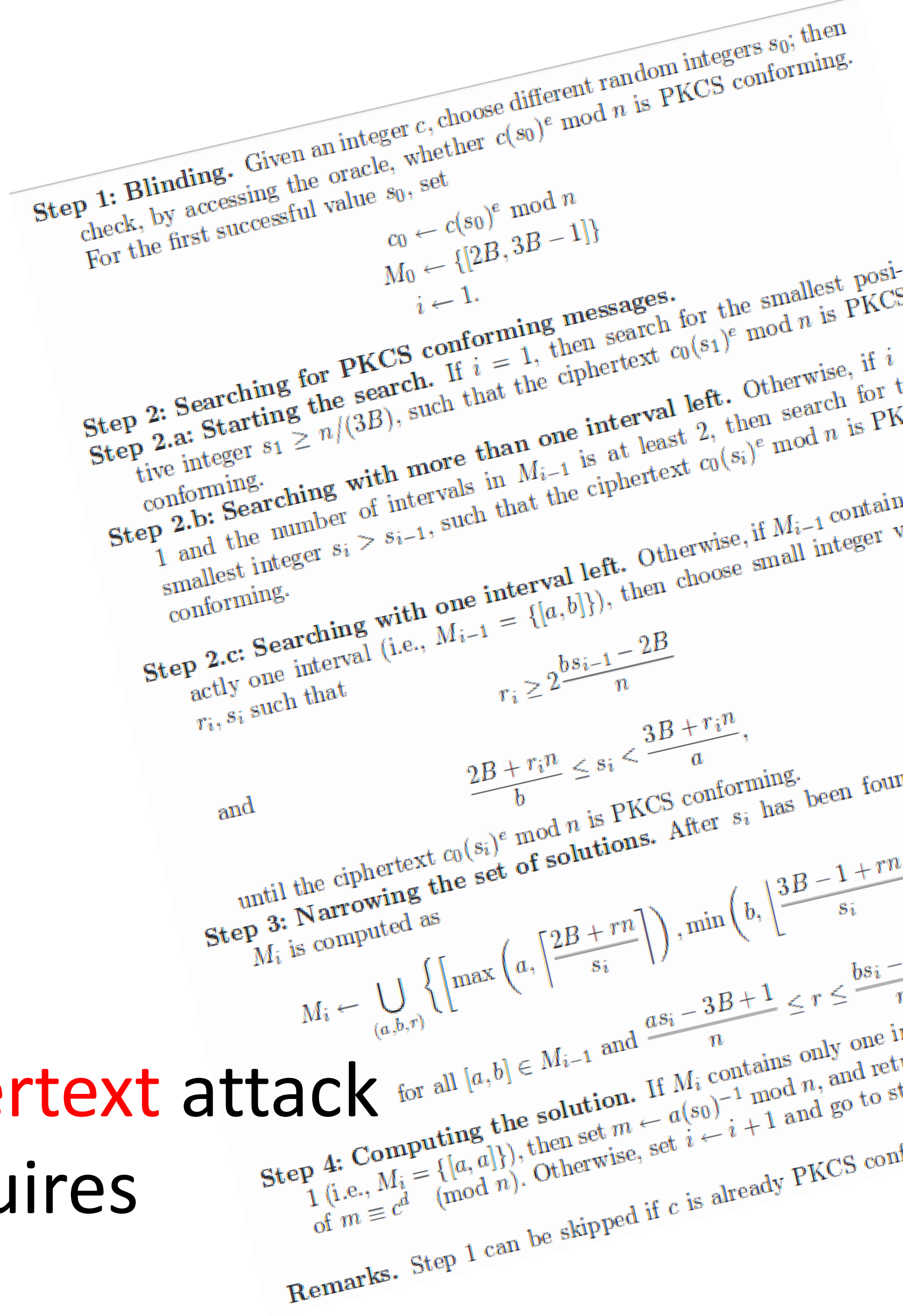
- For this talk we need to know
  - The attack is and adaptive chosen ciphertext attack
  - Decrypting 2048 bit RSA encryption requires at least 2048 sequential oracle queries



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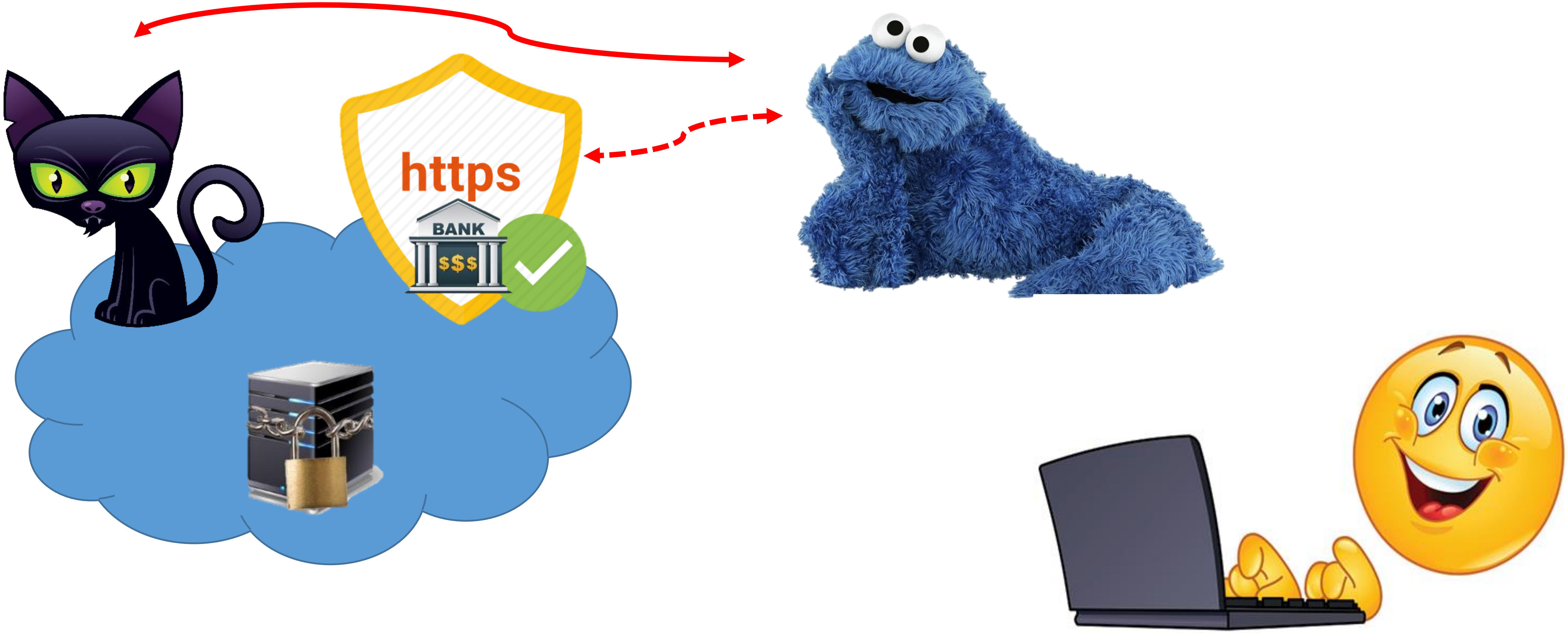

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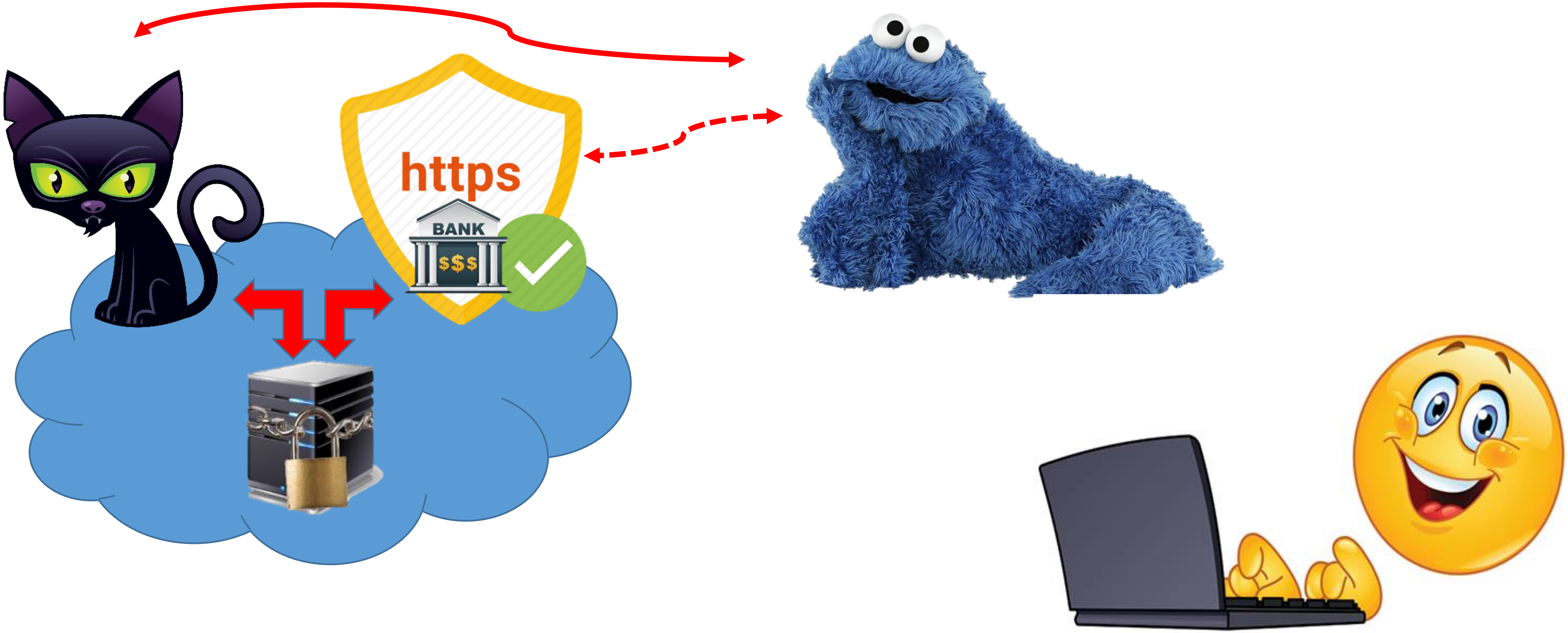

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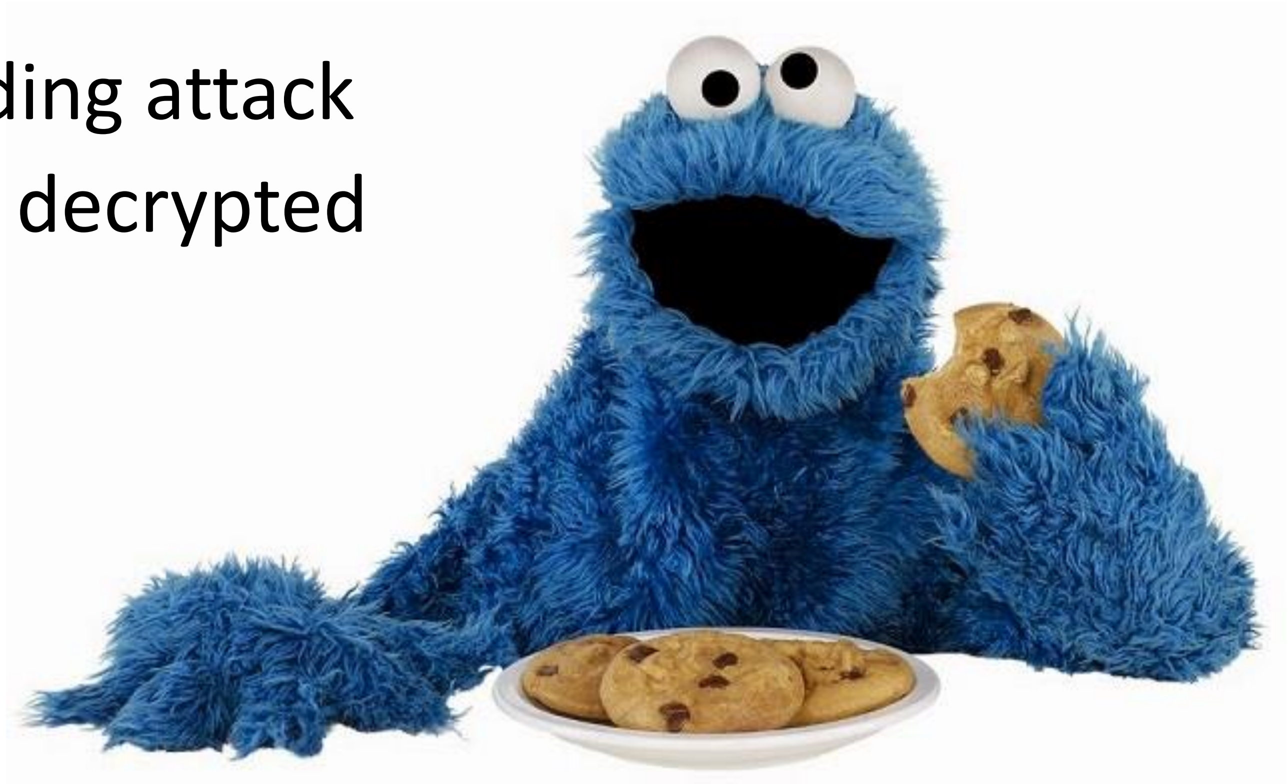

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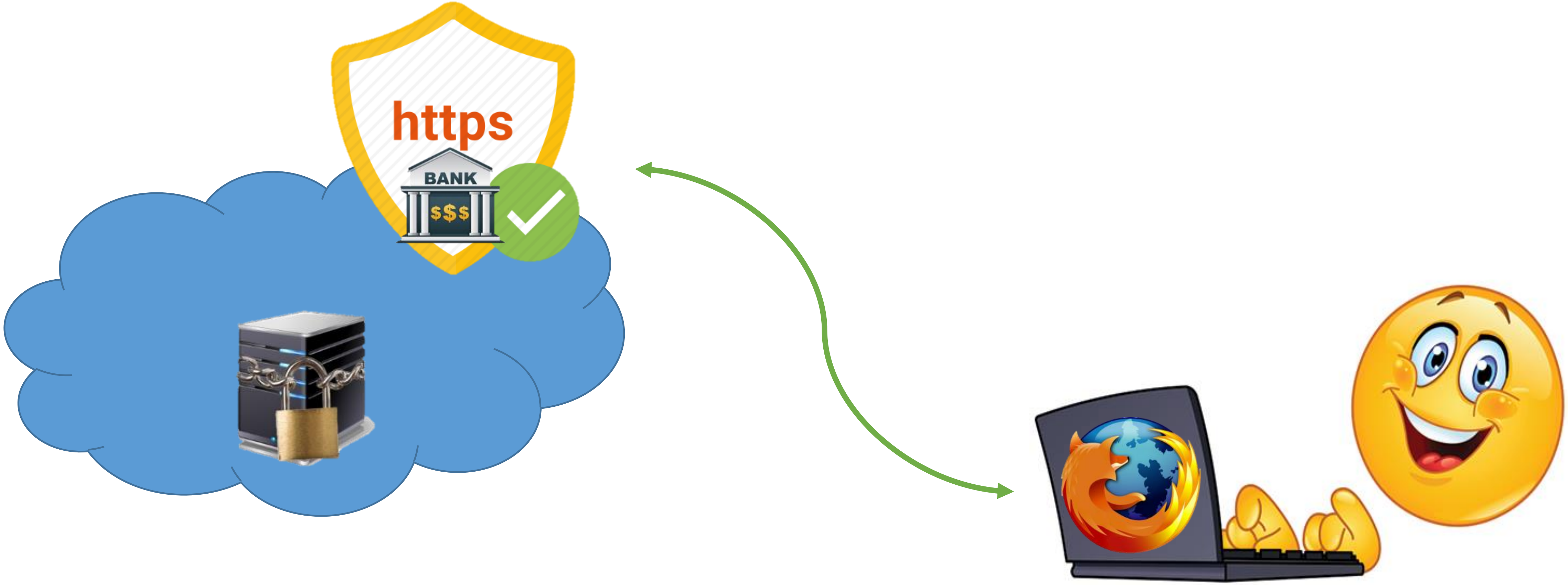

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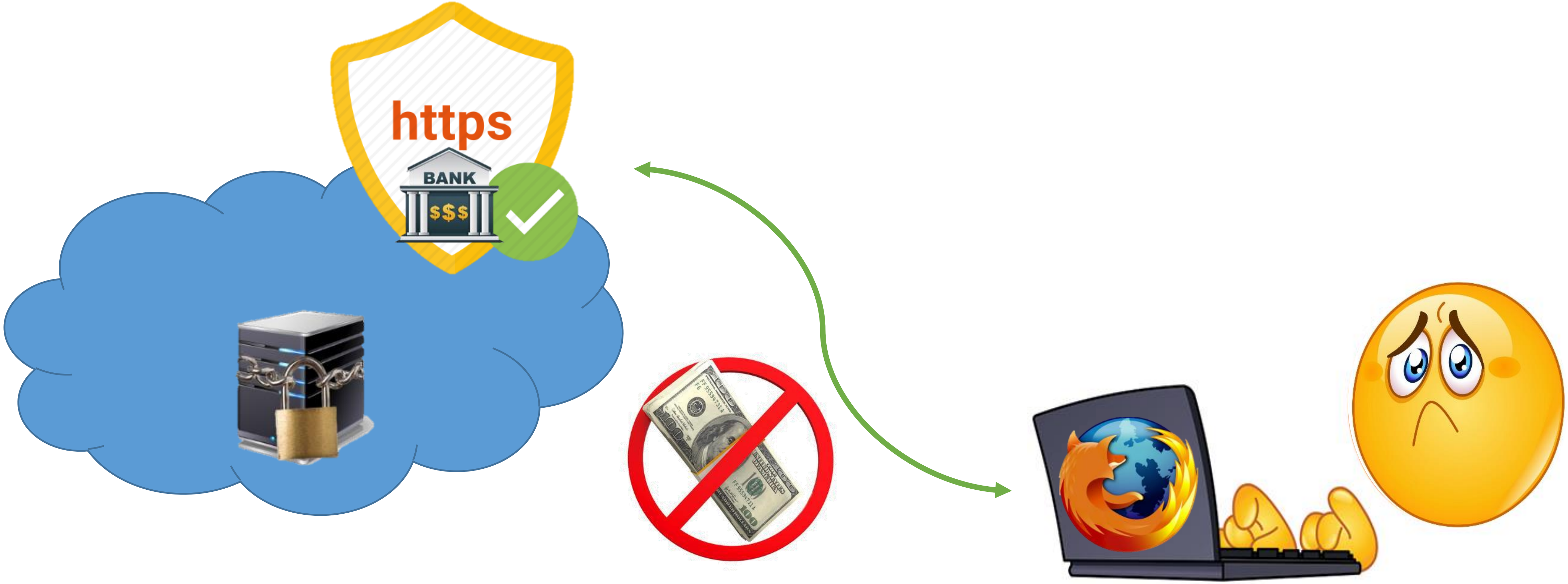

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https
BANK
$$$
Win Big Prizes .COM

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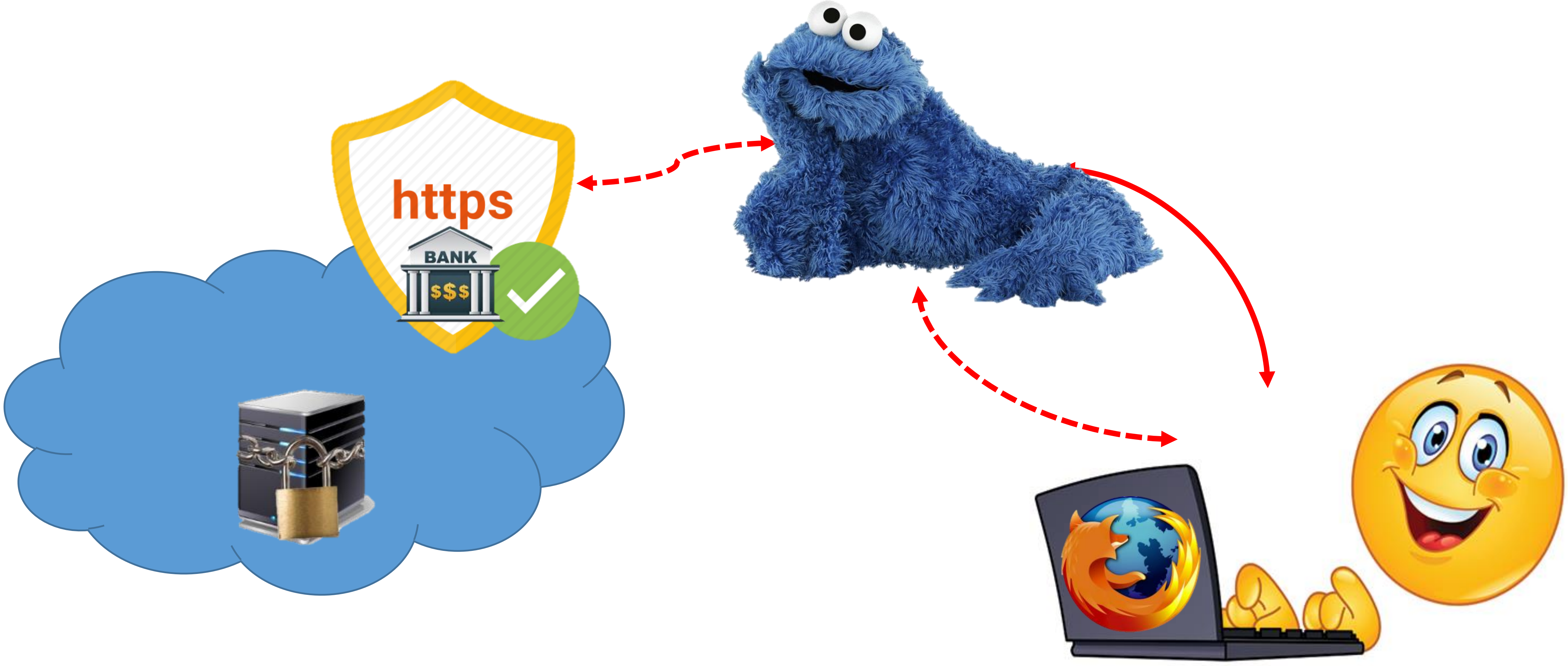

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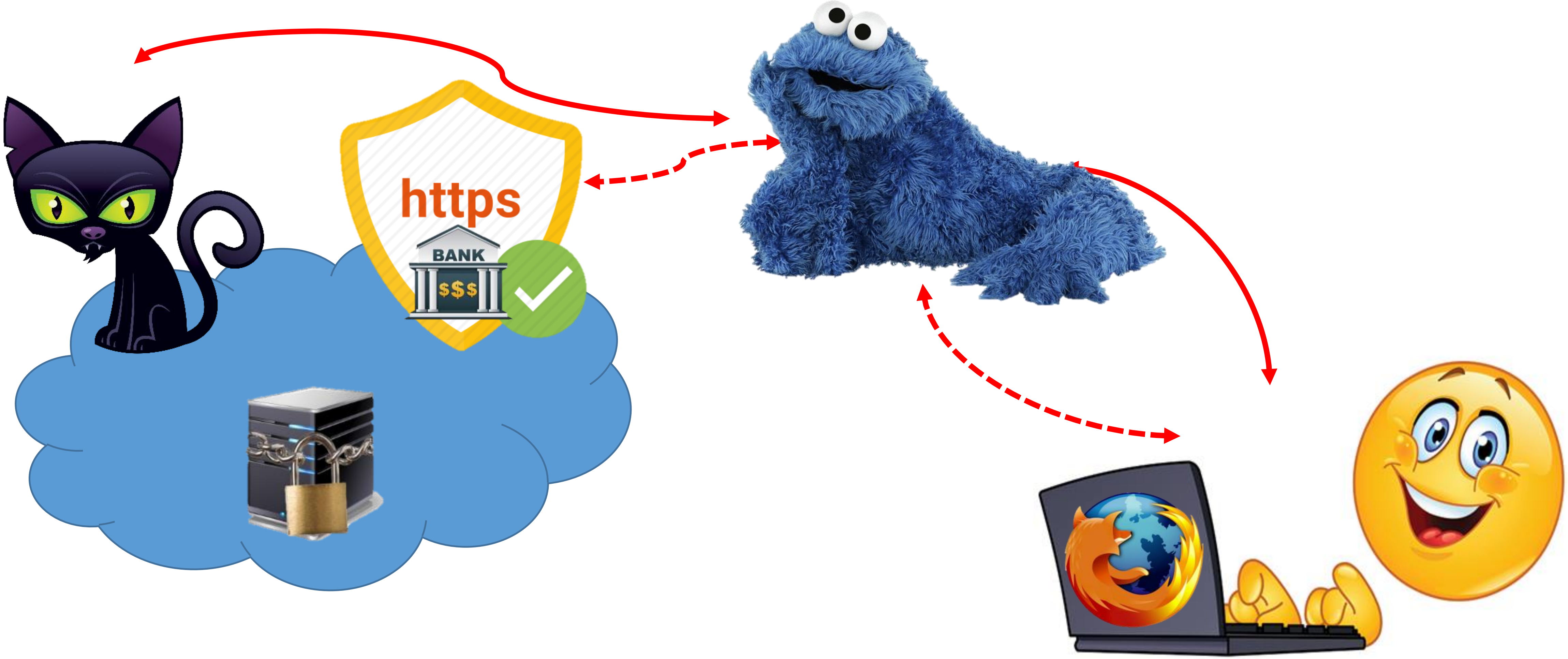

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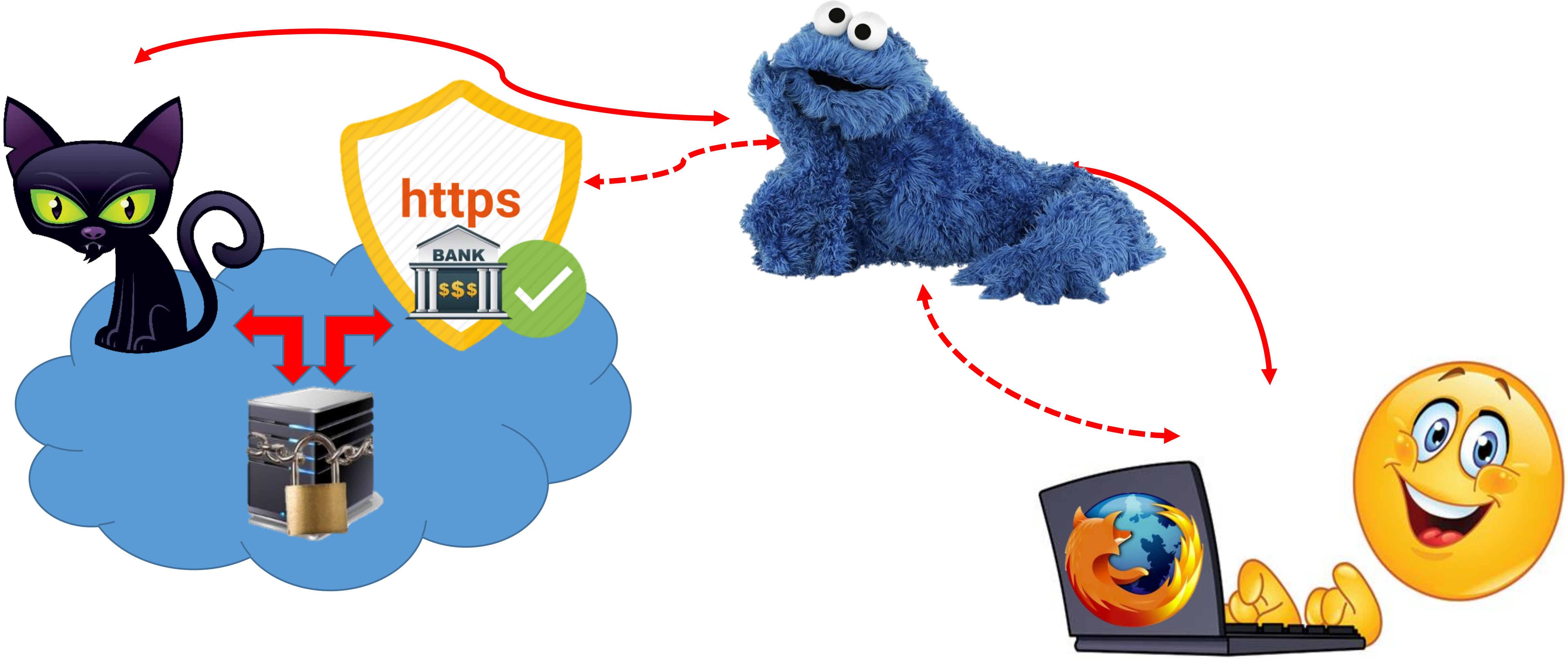

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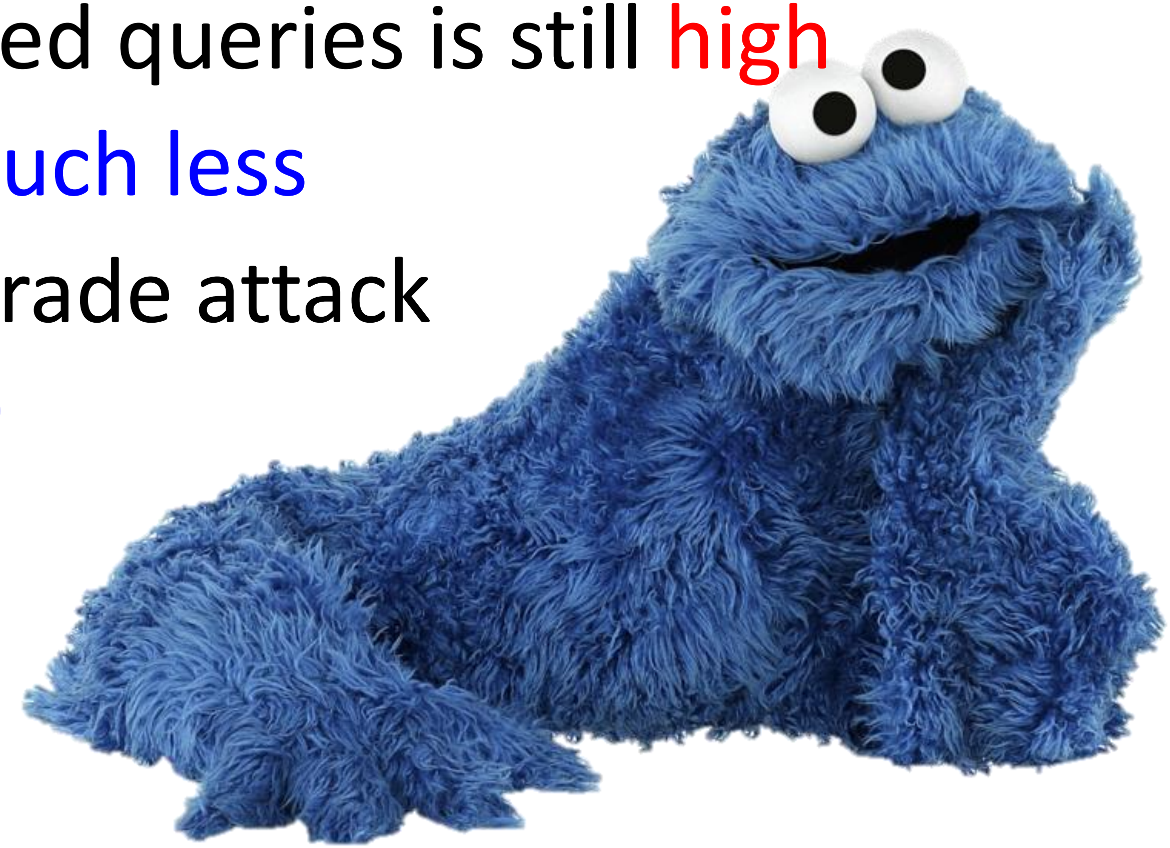

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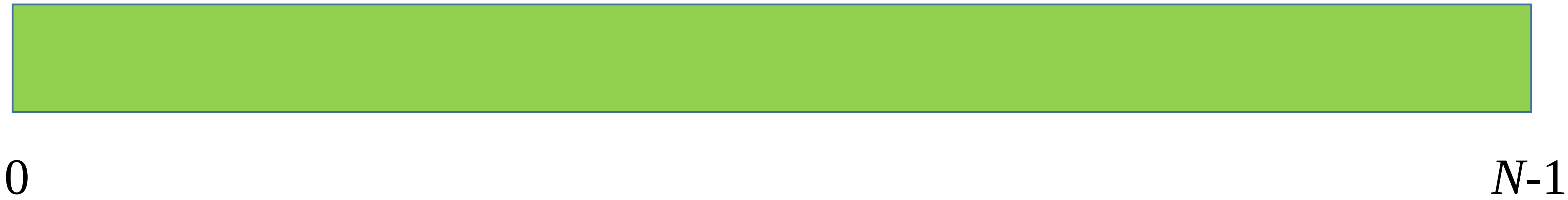

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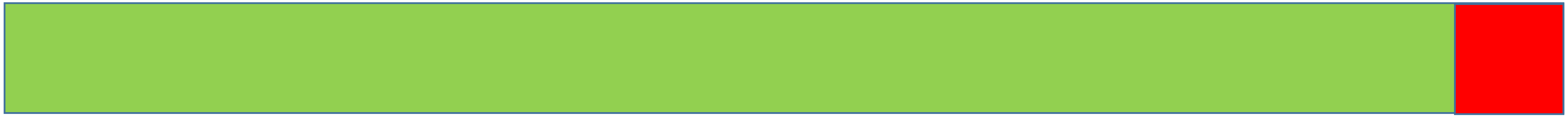

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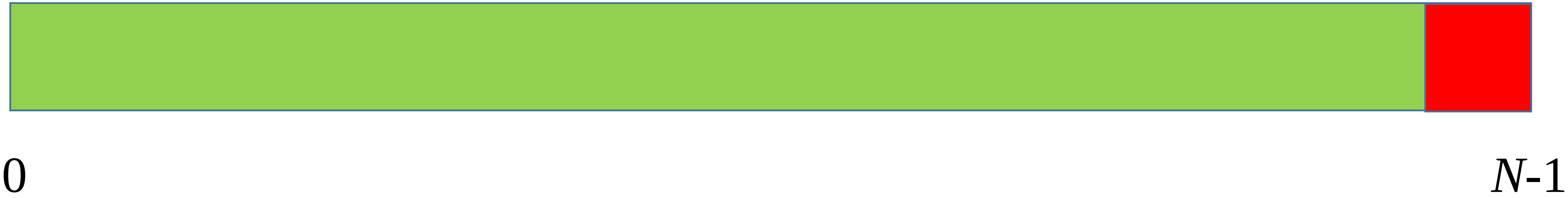

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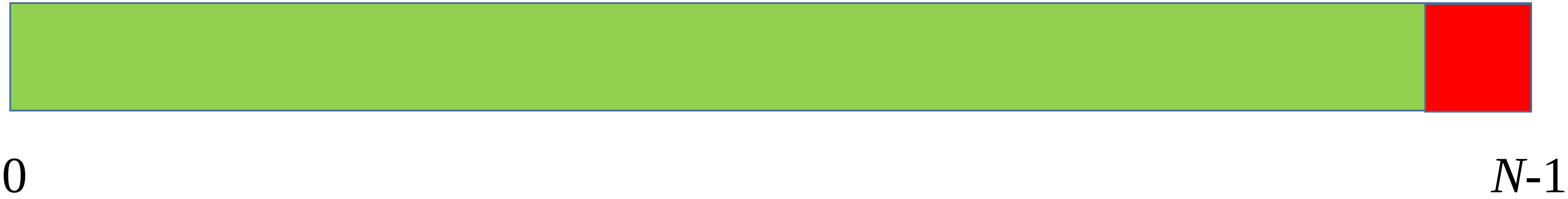

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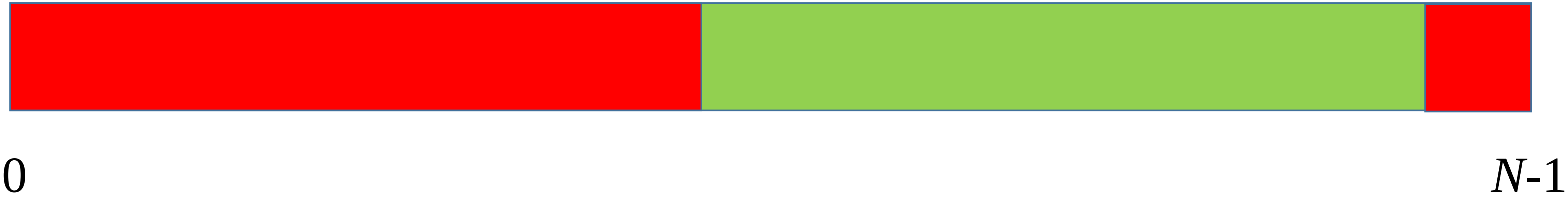

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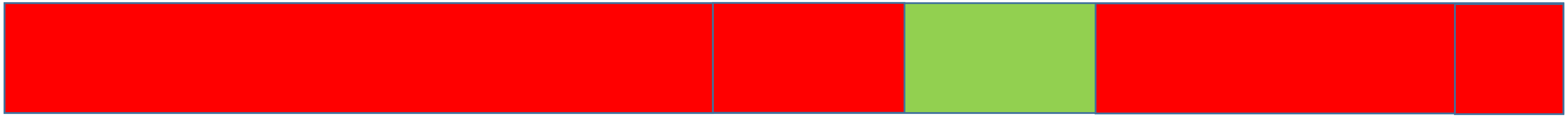

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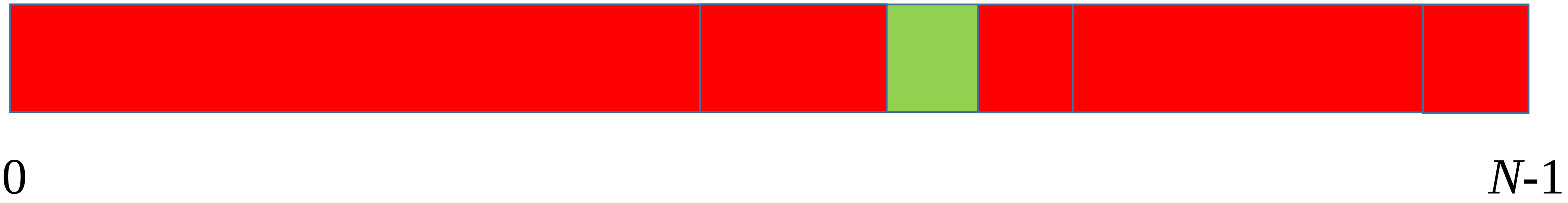

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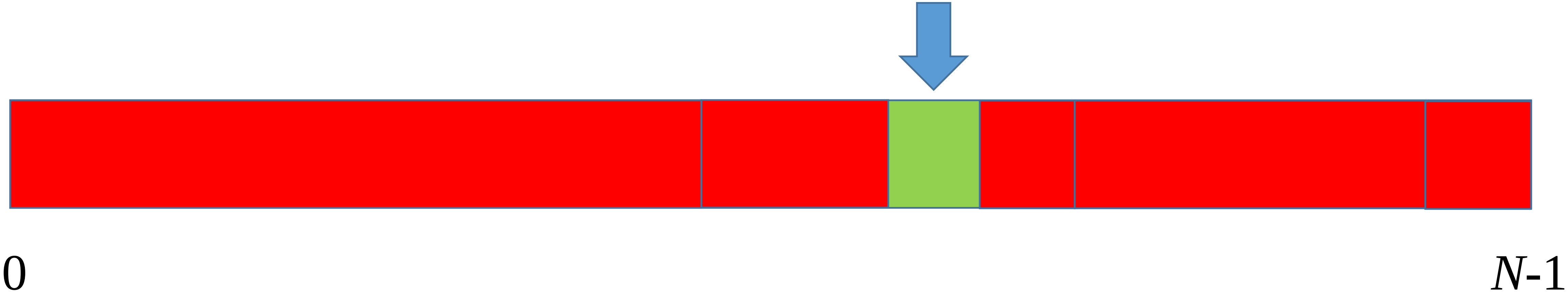

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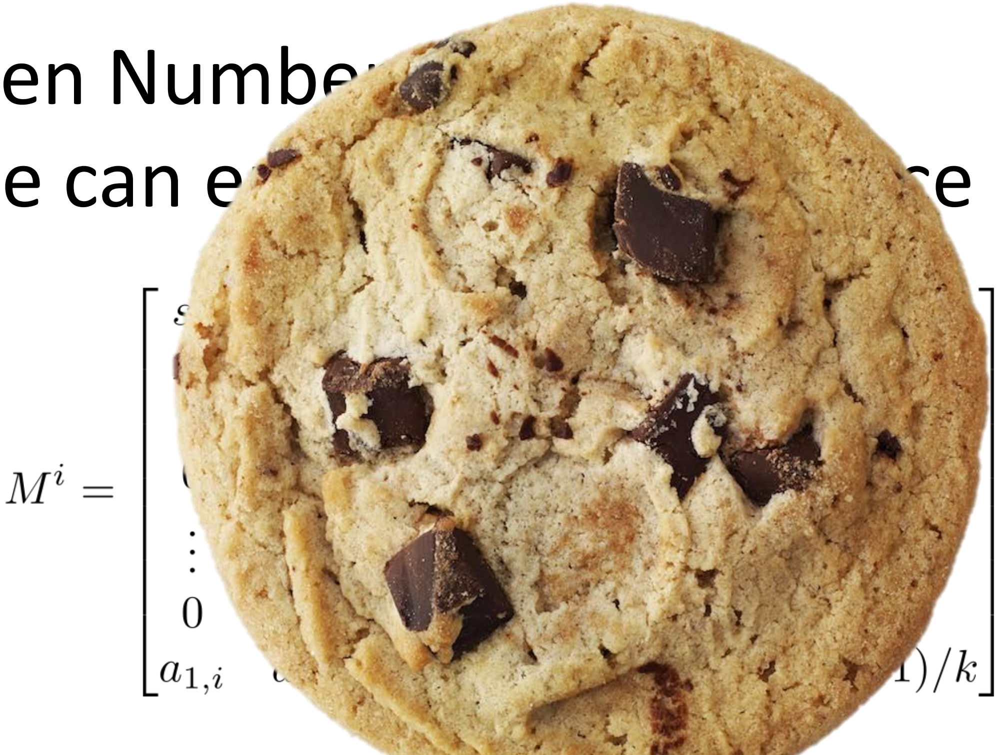

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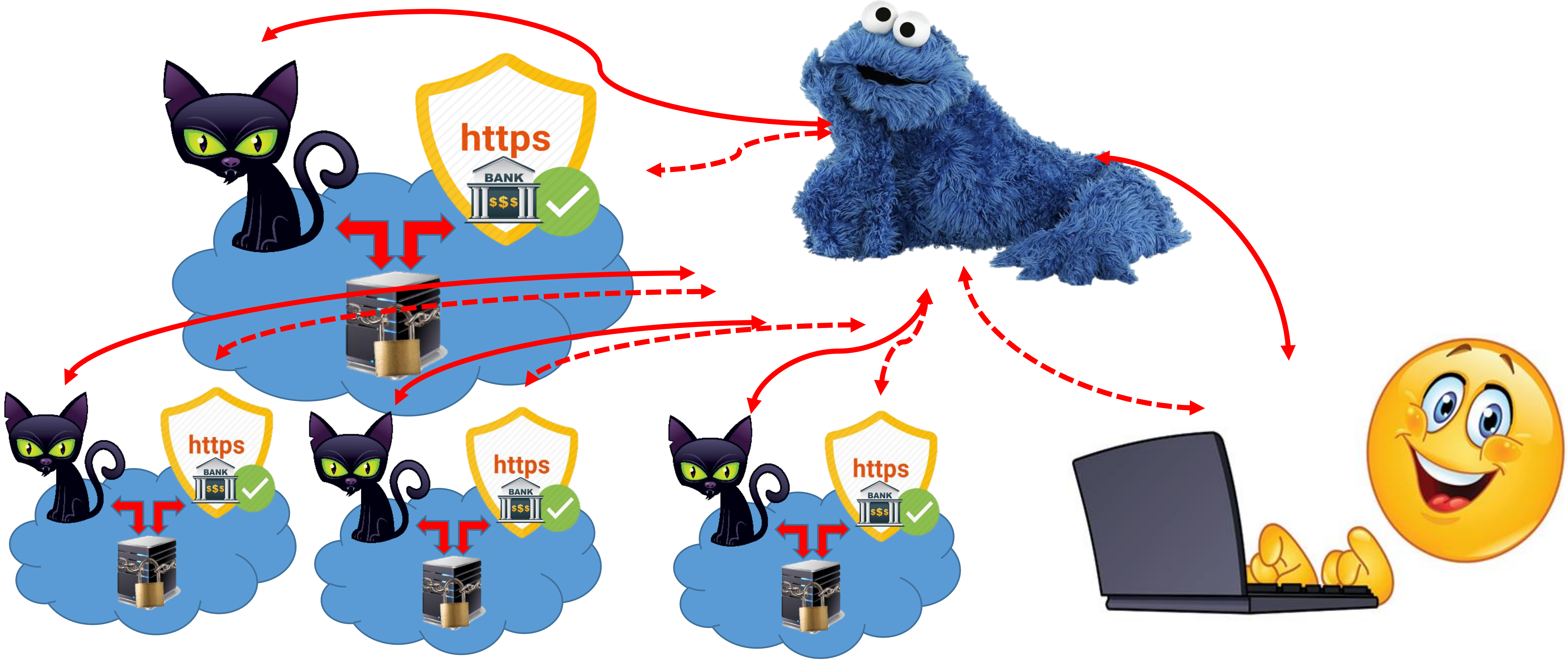

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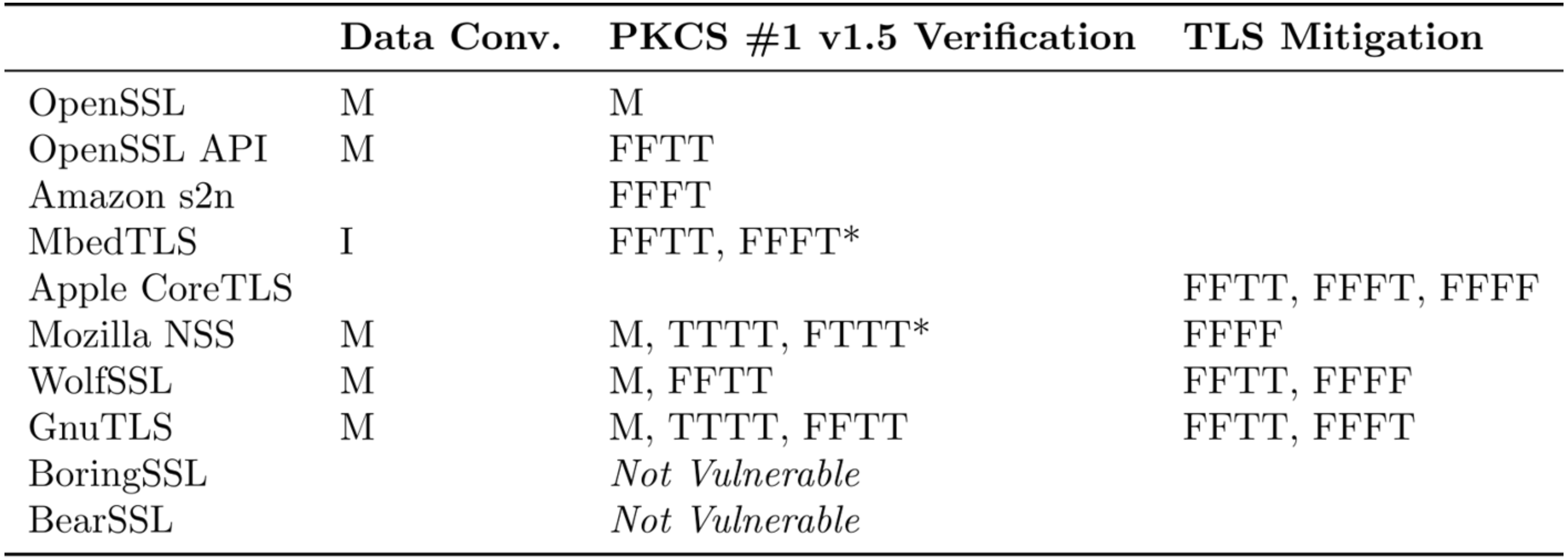

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OpenSSL	M	M	
OpenSSL API	M	FFTT	
Amazon s2n		FFFT	
MbedTLS	I	FFTT, FFFT*	
Apple CoreTLS			FFTT, FFFT, FFFF
Mozilla NSS	M	M, TTTT, FTTT*	FFFF
WolfSSL	M	M, FFTT	FFTT, FFFF
GnuTLS	M	M, TTTT, FFTT	FFTT, FFFT
BoringSSL		*Not Vulnerable*	
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99% OF THE WORLDS COOKIES ARE CONSUMED BY 1% OF THE MONSTERS
LIFE
# OCCUPY SESAME STREET

Disclosure

- We disclosed to:
  - OpenSSL, Mozzila’s NSS, Amazon’s s2n, Apple’s CoreTLS, mbed TLS, wolfSSL, GnuTLS
- All have patched their code, with various levels of success
- Lots of stories…

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