On the Practical (In-)Security of 64-bit Block Ciphers

Collision Attacks on HTTP over TLS and OpenVPN

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Choosing a cipher

What are the main factors determining the security of a cipher?

Cipher	Key-length	Cryptanalysis	Block size
DES	56 bits	2^{40}	64 bits
3DES	168 bits	2^{112}	64 bits
Blowfish	32—448 bits	None	64 bits
RC4	40—2048 bits	2^{8}	stream
AES	128—256 bits	Related-key	128 bits

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- Block size does matter
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Block ciphers and Modes of operation

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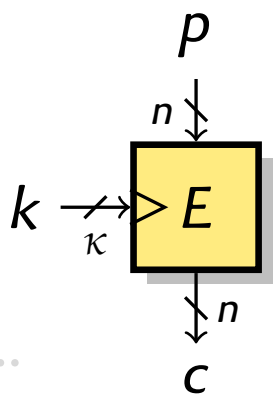
$$k \quad , \quad p \quad \mapsto c$$



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  - To deal with variable-length messages
  - To include randomness
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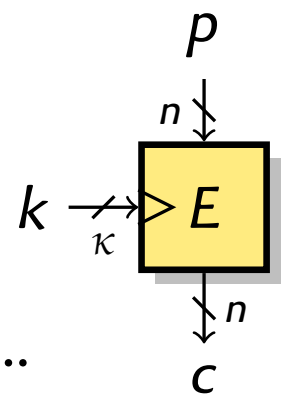

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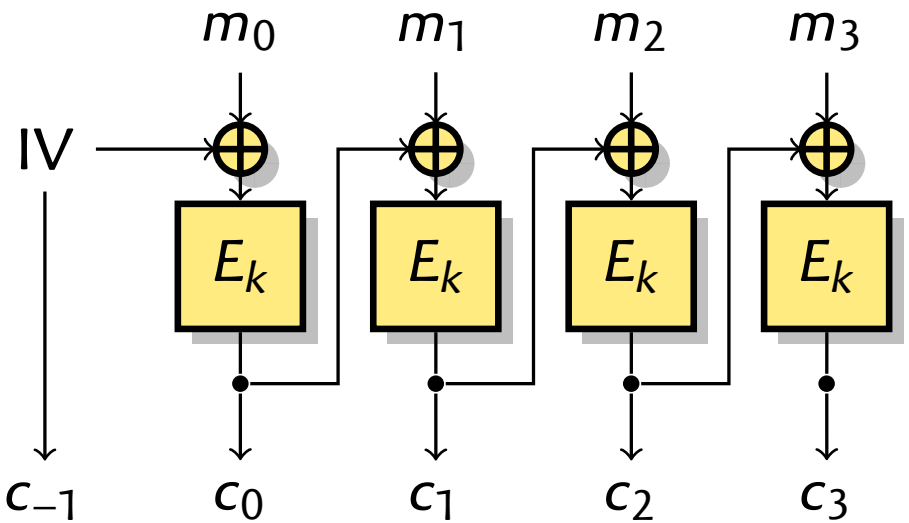
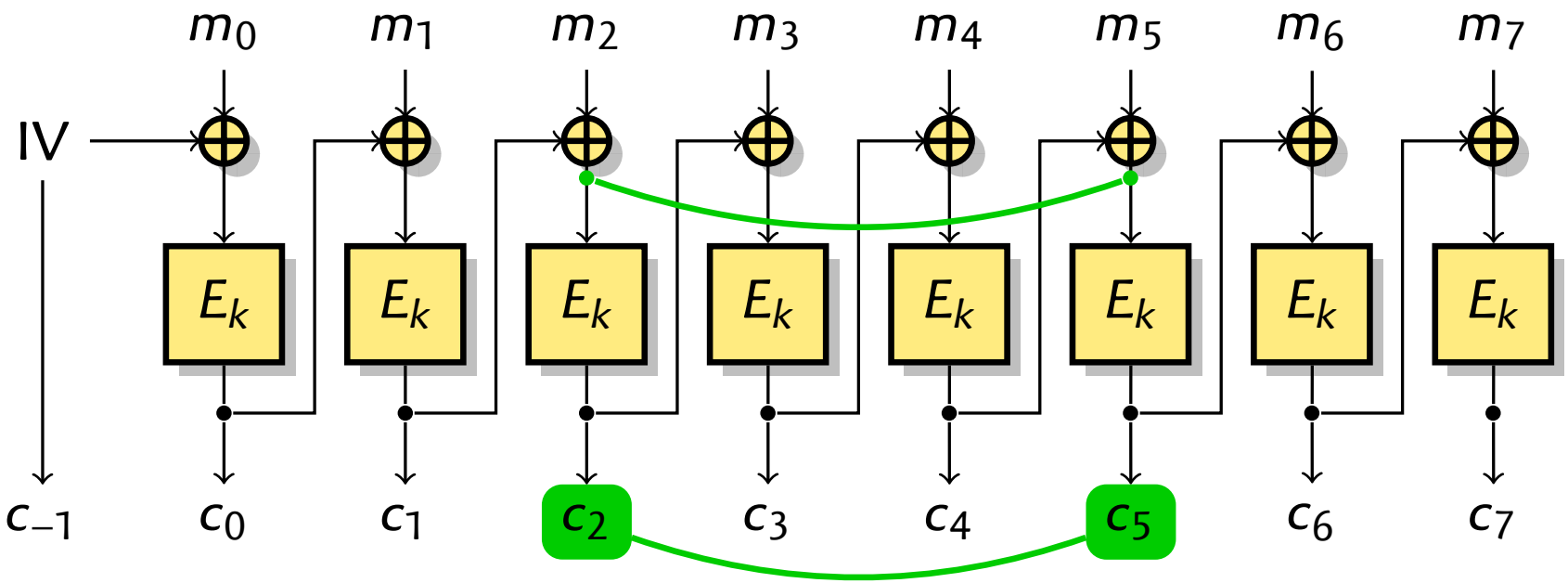


CBC collisions

- Security of modes can be lower than security of cipher
- Well known collision attack against CBC



- If $c_i = c_j$, then $c_{i-1} \oplus m_i = c_{j-1} \oplus m_j$
- Ciphertext collision reveals the xor of two plaintext blocks

Birthday paradox

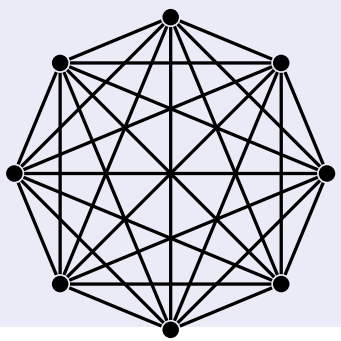
The birthday paradox

In a room with 23 people, there is a 50% chance that two of them share the same birthday.

Birthday attack

When drawing random n-bit strings,
a collision is expected after roughly $2^{n/2}$ draws.

More generally, 2^{2t-n} collisions with 2^t draws



- CBC leaks plaintext after $2^{n/2}$ blocks encrypted with the same key
  - In a single message or many different messages

Security of modes of operation

- Modes are proven secure assuming the block cipher is secure.
- Most modes (CBC, CTR, GCM, ...) have a security proof like:

$$\mathrm{Adv}^{\mathrm{CPA}}_{\text{CBC-}E}(q,t) \leq \mathrm{Adv}^{\mathrm{PRP}}_{E}(q',t') + \frac{\sigma^2}{2^n}$$

- The CPA security of CBC is essentially the PRP security of E (the block cipher)
- As long as the number of encrypted blocks $\sigma \lll 2^{n/2}$
  - Usually matching attack with birthday complexity ($2^{n/2}$)
  - With a 64-bit cipher, the bound is only 32 GB

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Communication issues

What cryptographers say [Rogaway 2011]

"[birthday] attacks can be a serious concern when employing a blockcipher of $n = 64$ bits, requiring relatively frequent rekeying to keep $\sigma \ll 2^{32}$"

What standards say [ISO SC27 SD12]

"the maximum amount of plaintext that can be encrypted before rekeying must take place is $2^{(n/2)}$ blocks, due to the birthday paradox.
As long as the implementation of a specific block cipher do not exceed these limits, using the block cipher will be safe."

What implementation do

TLS libraries, web browsers no rekeying

OpenVPN no rekeying (PSK mode) / rekey every hour (TLS mode)

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Outline

Impact

- How bad is it?
  - Is it bad to leak a few xors of blocks of plaintexts?
  - Do applications encrypt enough data under the same key?
- 64-bit block cipher are used in important protocols
  - With a 64-bit clock cipher, first collision around 32GB!
  - Blowfish-CBC in OpenVPN (default cipher)
  - 3DES-CBC in TLS (around 1-2%)
  - Kasumi in 3G (UMTS)
  - 64-bit ciphers with CBC were the norm before AES
- Collision attacks usually not considered a practical threat
  - `openssl ciphers HIGH` used to be sorted by key length
    - Before 2014: `AES256, CAMELLIA256, 3DES, AES128, CAMELLIA128`
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Protocol	RFC	Year	Block ciphers	Mandatory	Rekey
TLS 1.0	2246	1999	3DES, DES, IDEA	3DES	-
TLS 1.1	4346	2006	AES, 3DES, DES	3DES	2^{78}
TLS 1.2	5246	2008	AES, 3DES	AES	2^{78}
SSH 1	draft	1995	3DES, DES, IDEA	3DES	-
SSH 2	4253	2006	AES, 3DES, Blowfish	3DES	2^{30}
IKEv1	2409	1998	3DES, DES, Blowfish	DES	-
IKEv2	6996	2010	AES, 3DES, Blowfish	3DES	-
IPsec	7321	2014	AES, 3DES	AES	1GB

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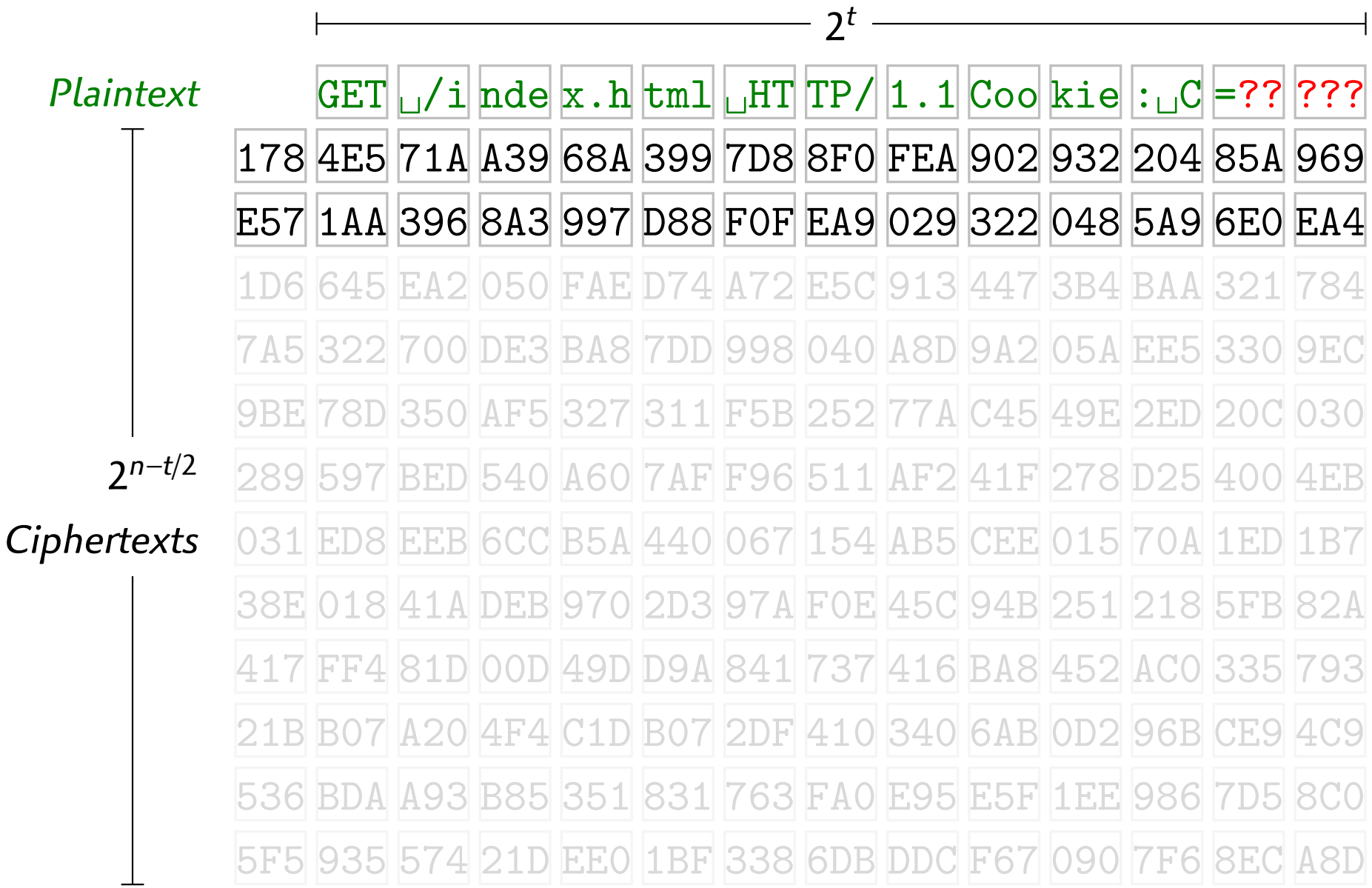

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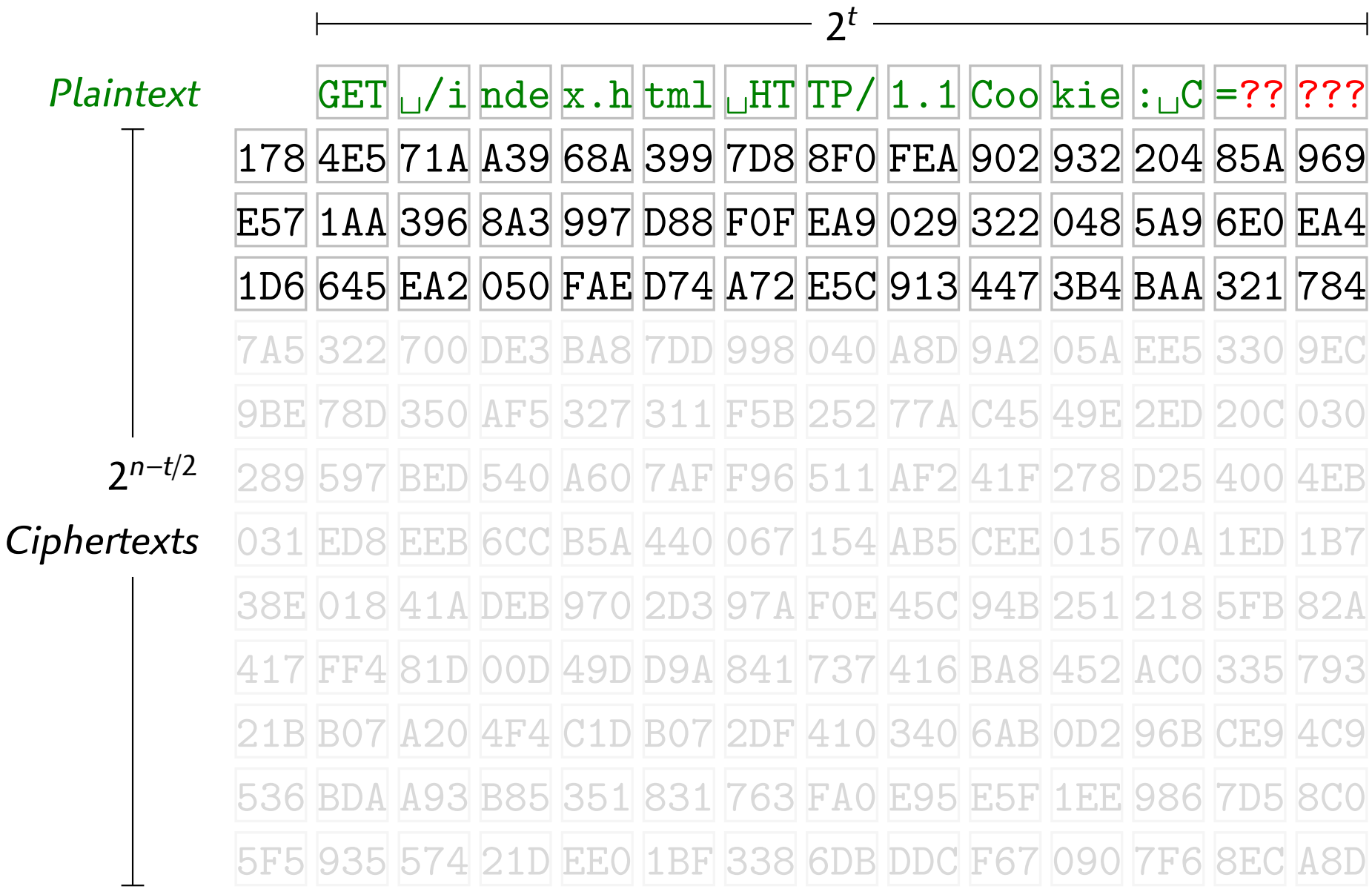

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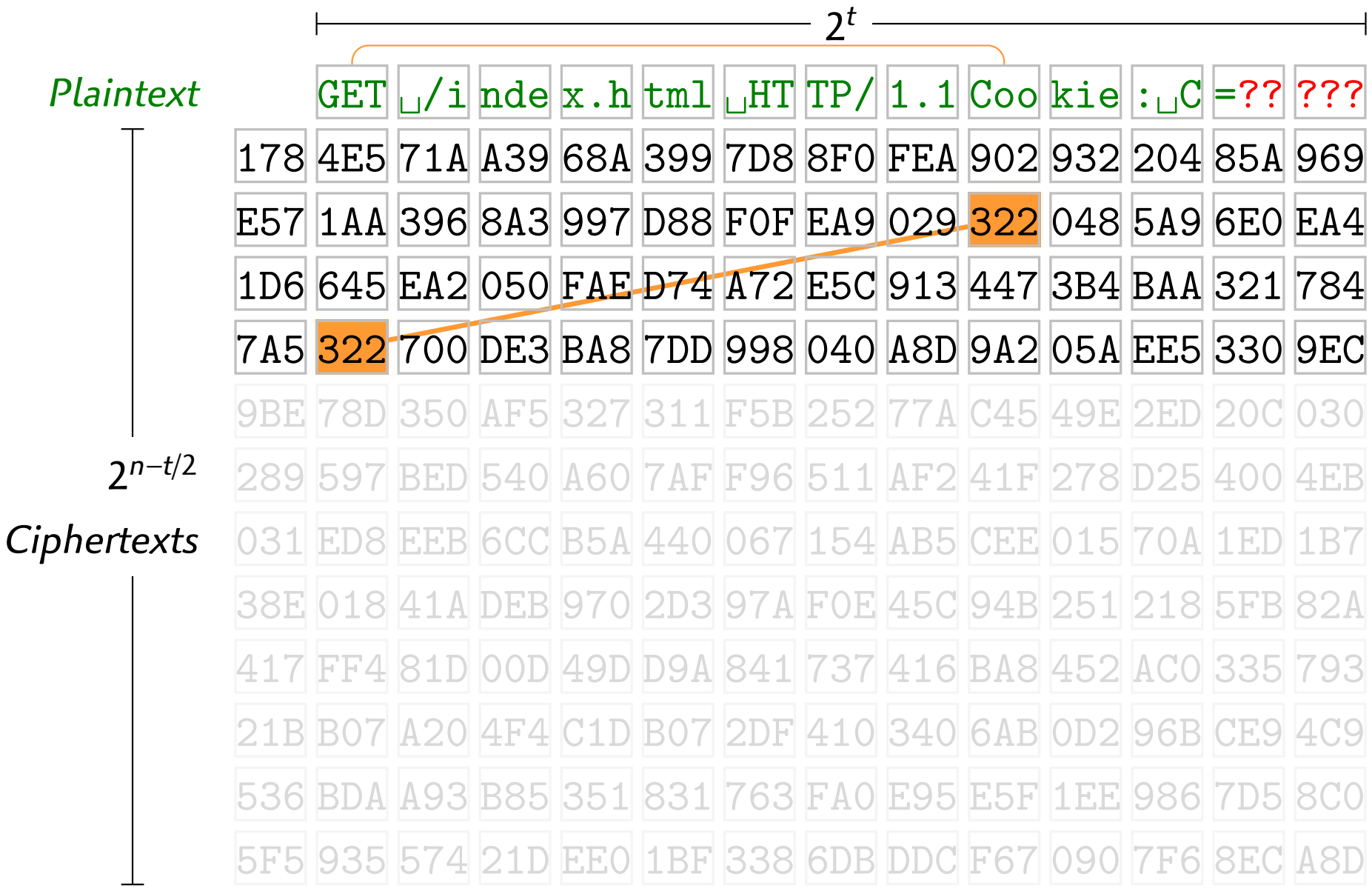

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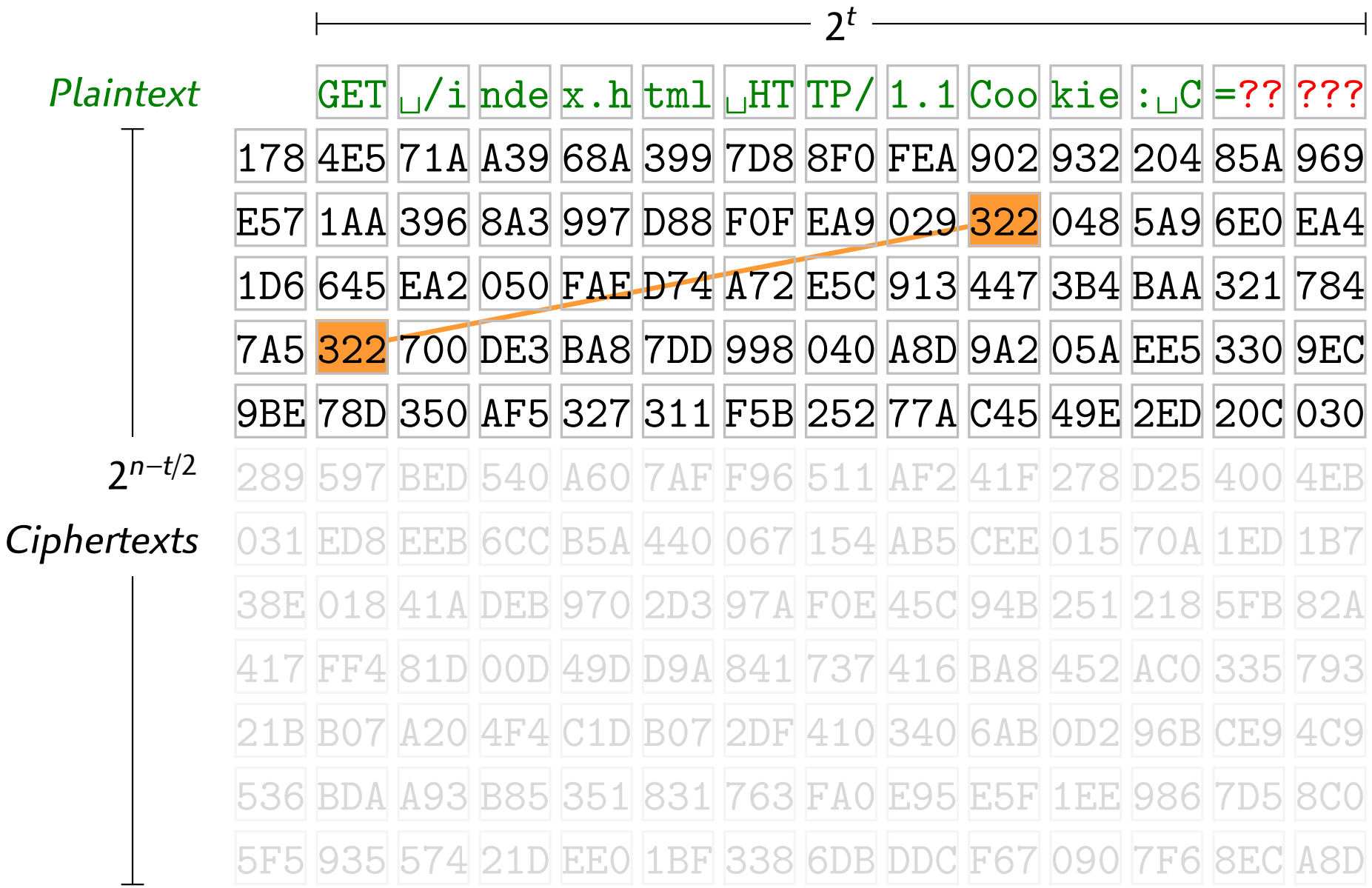

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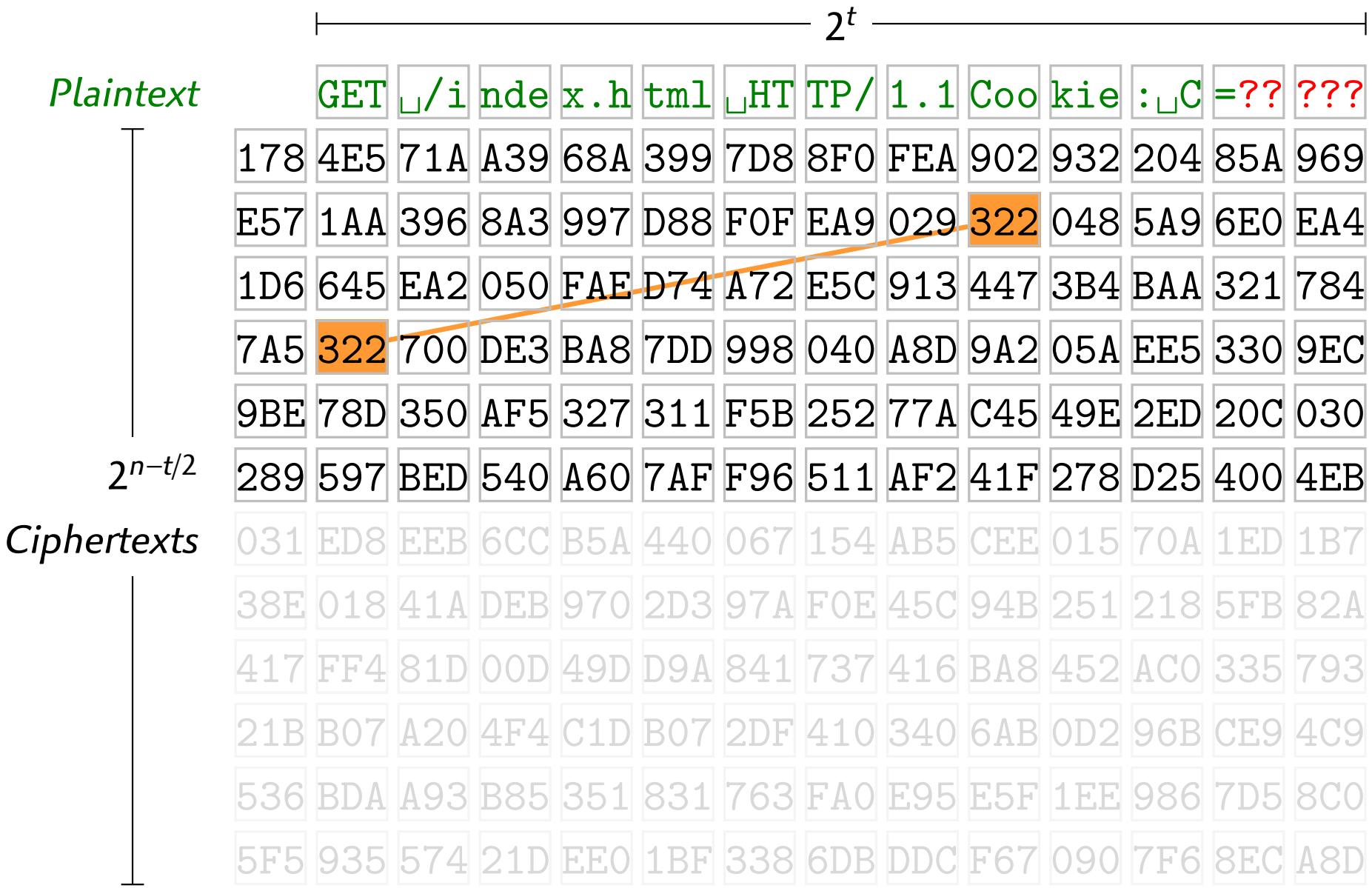

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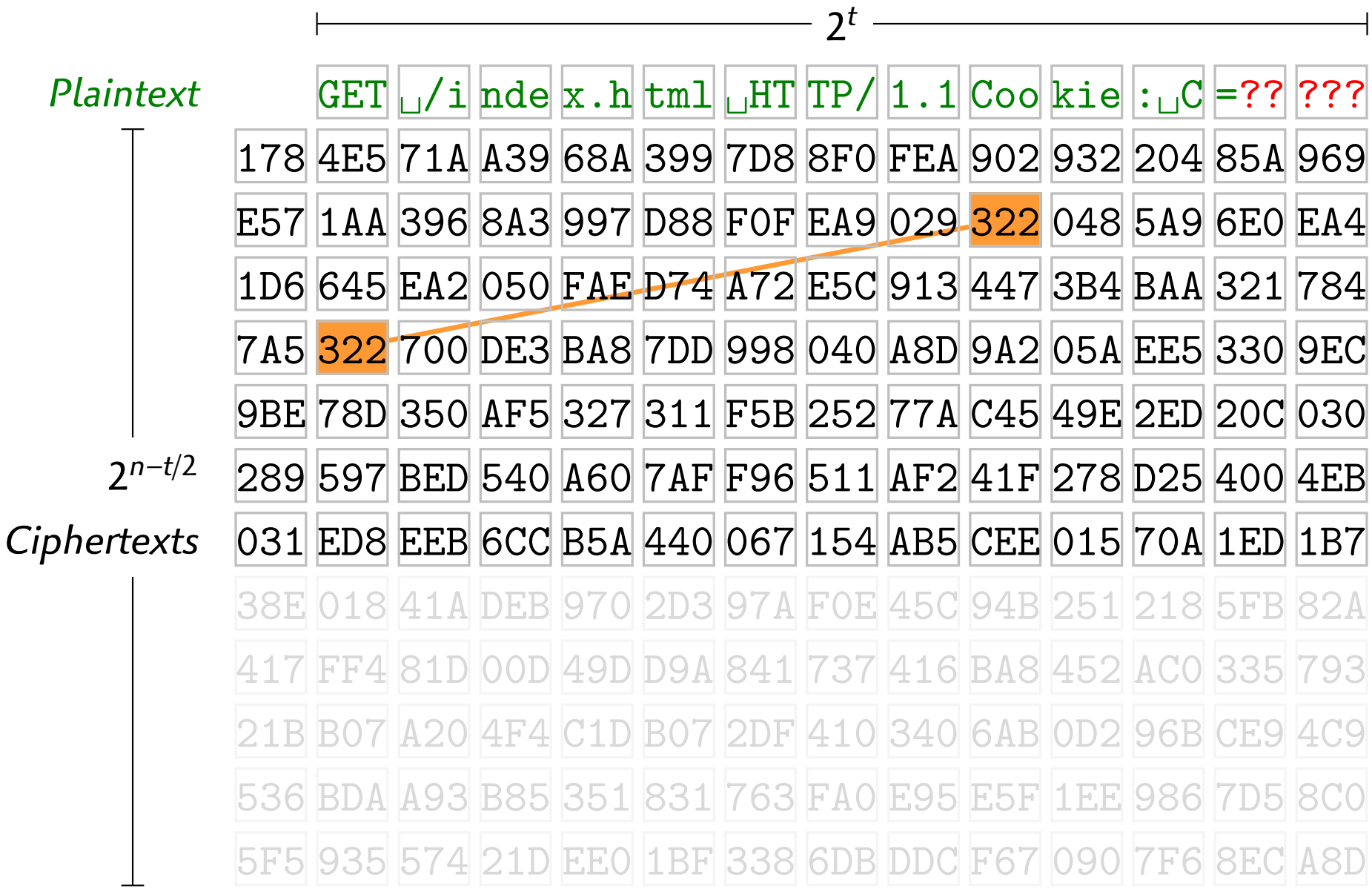

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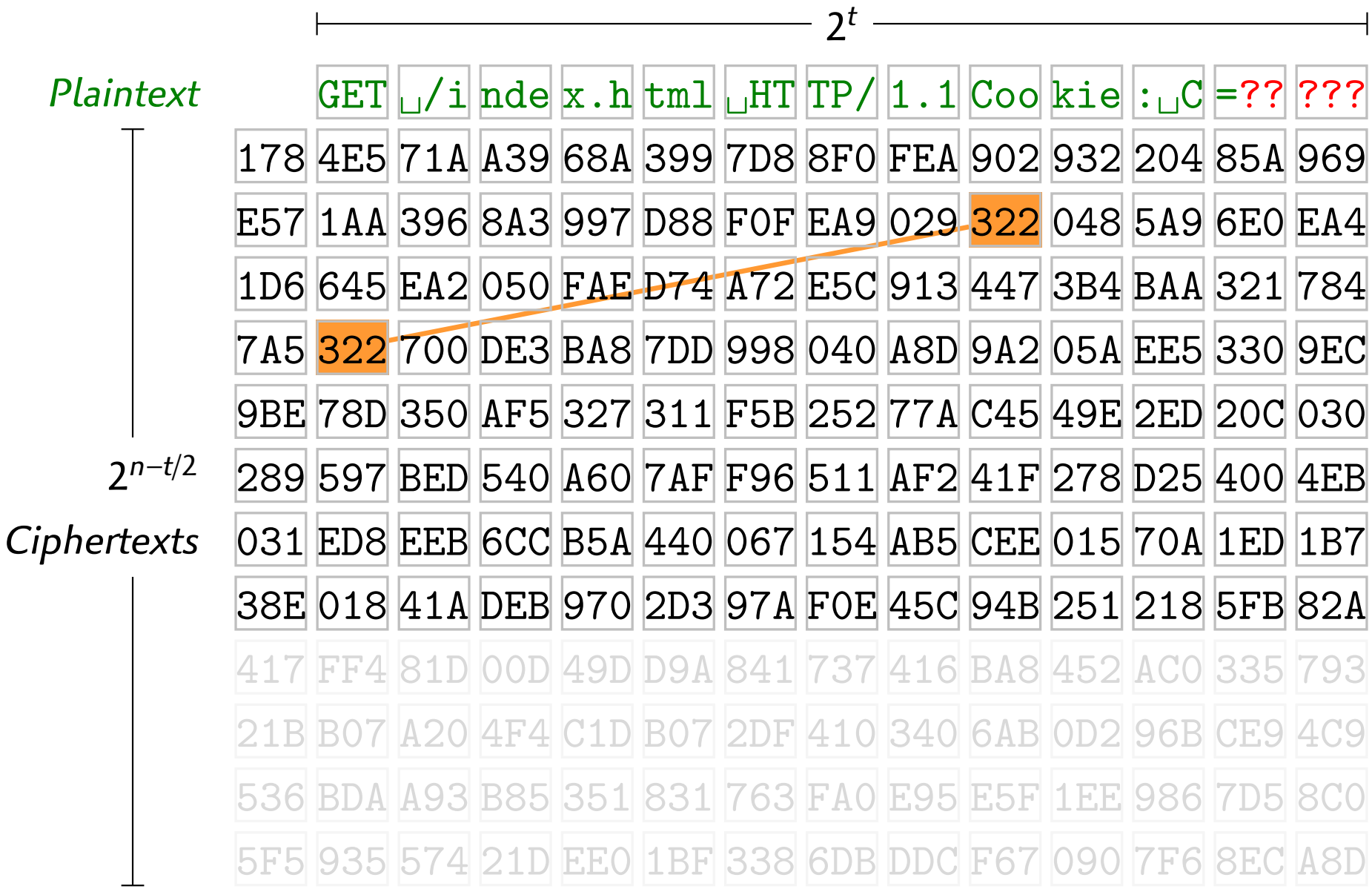

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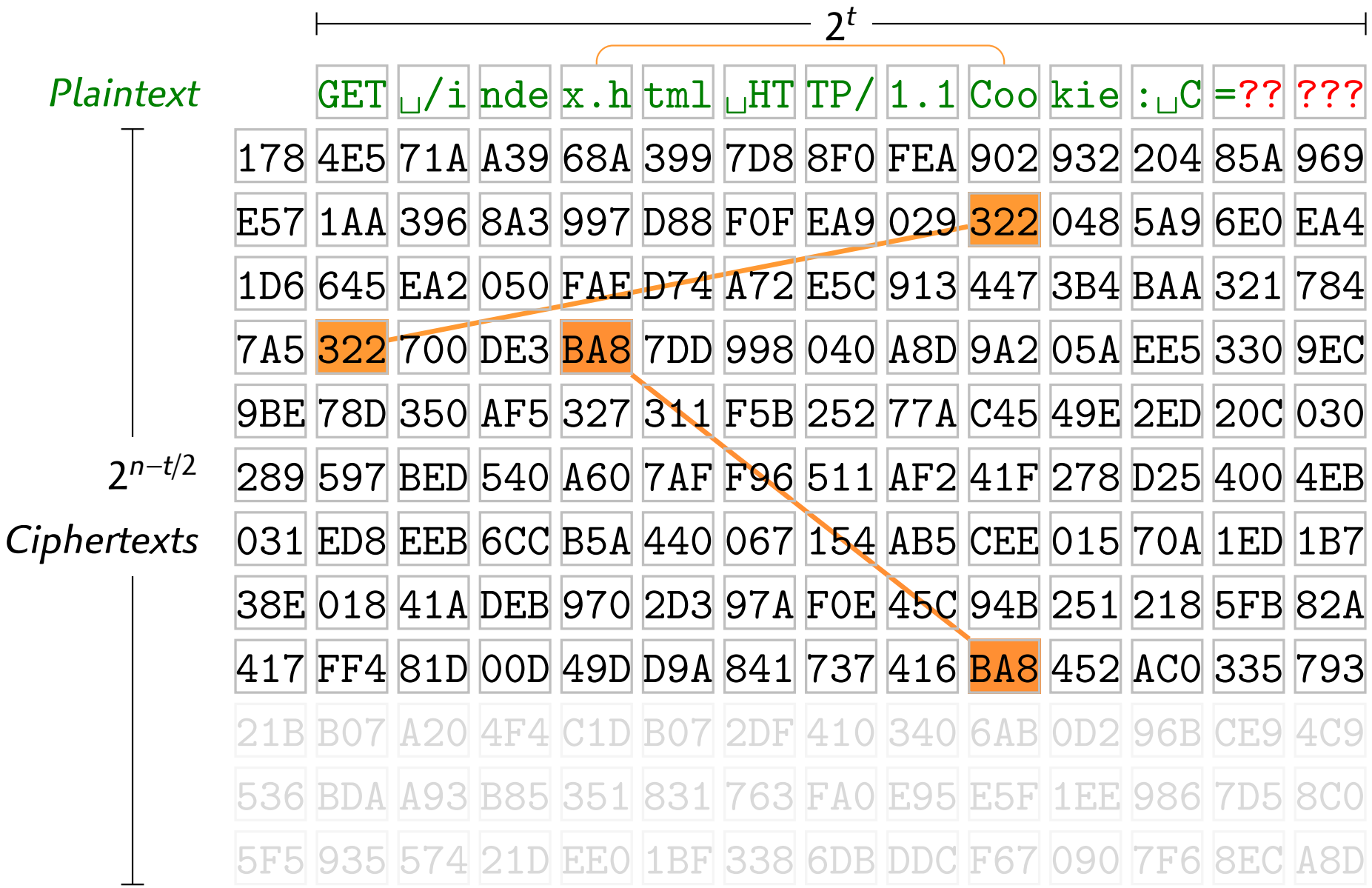

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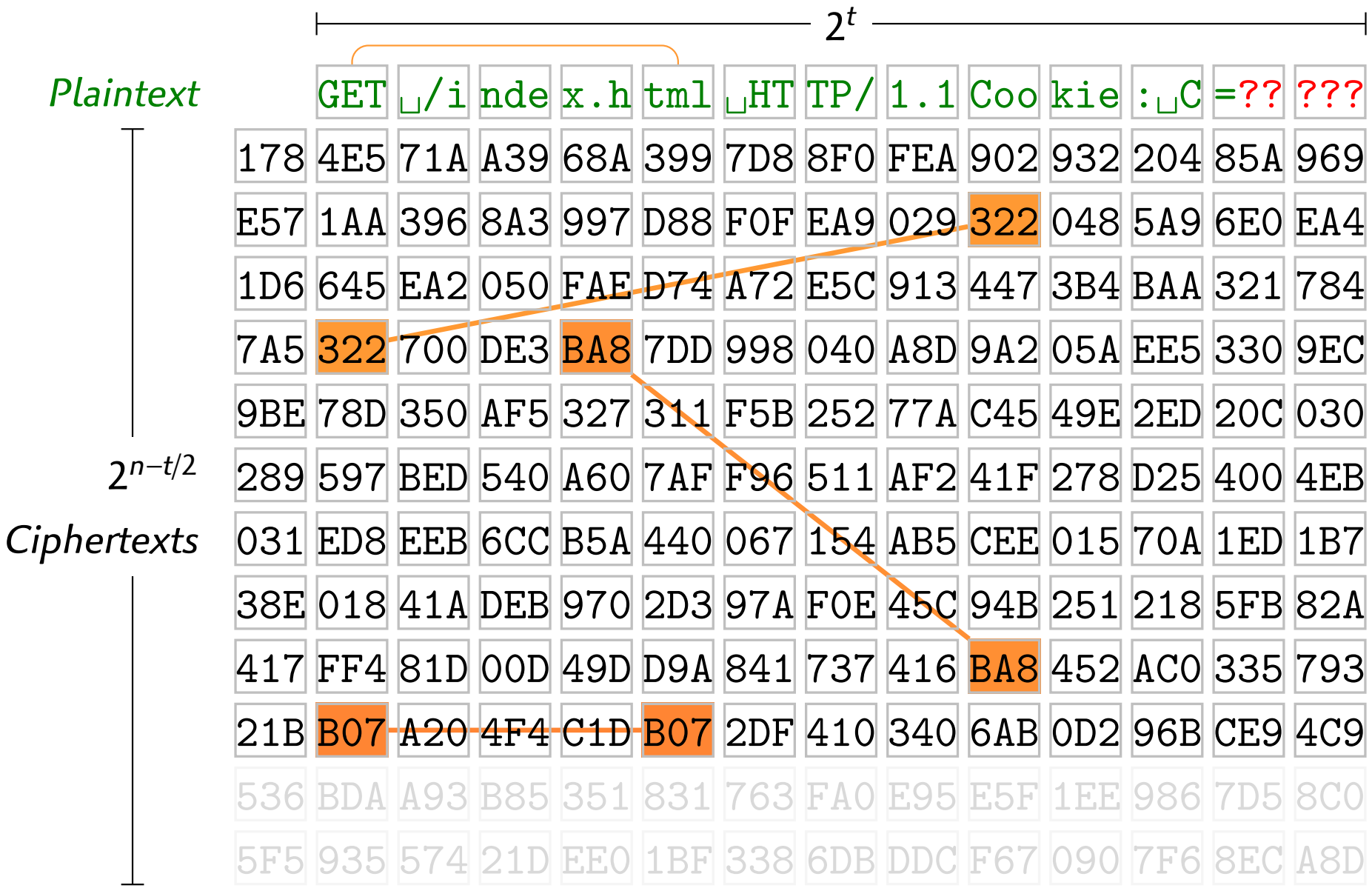

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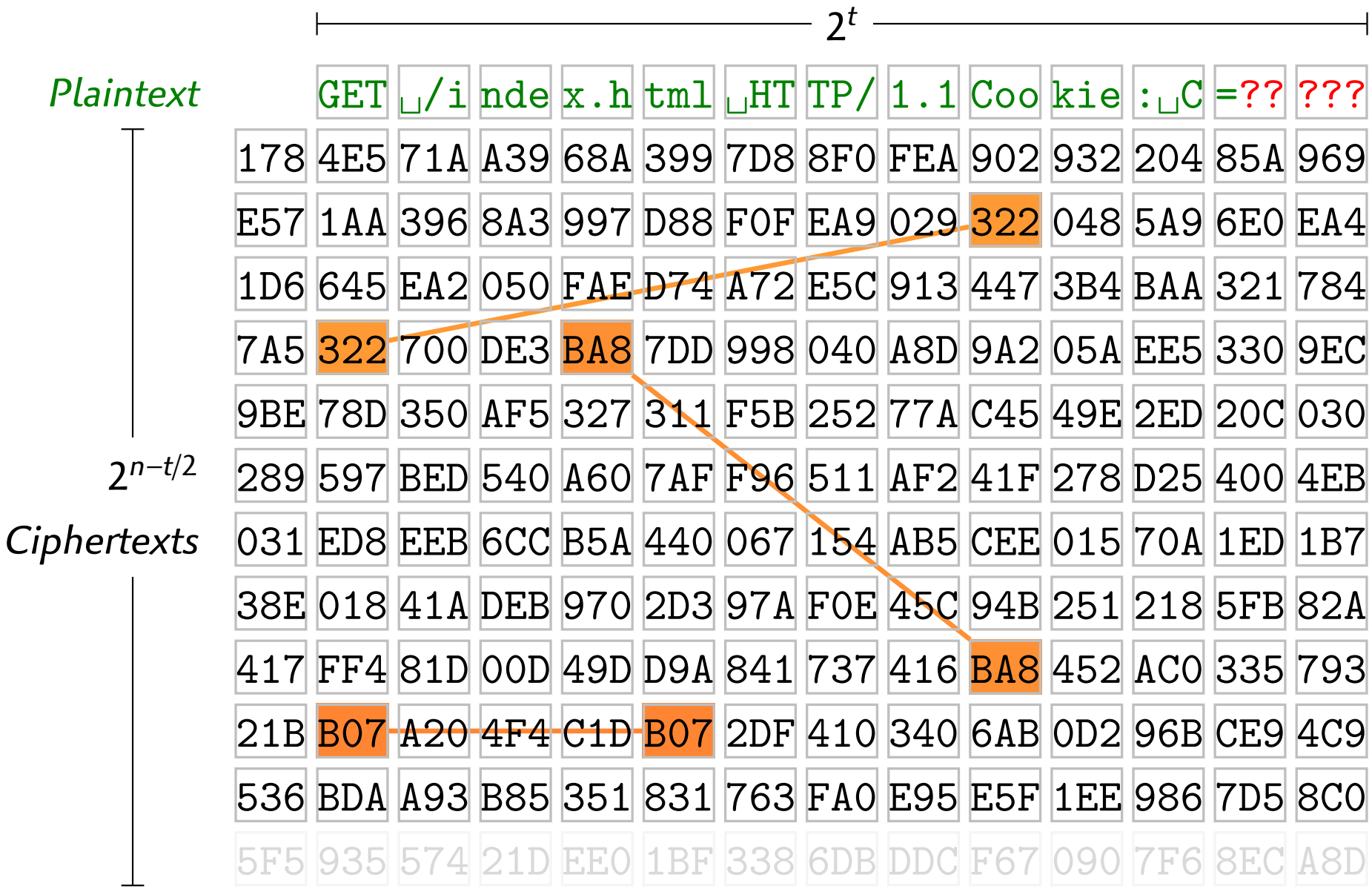

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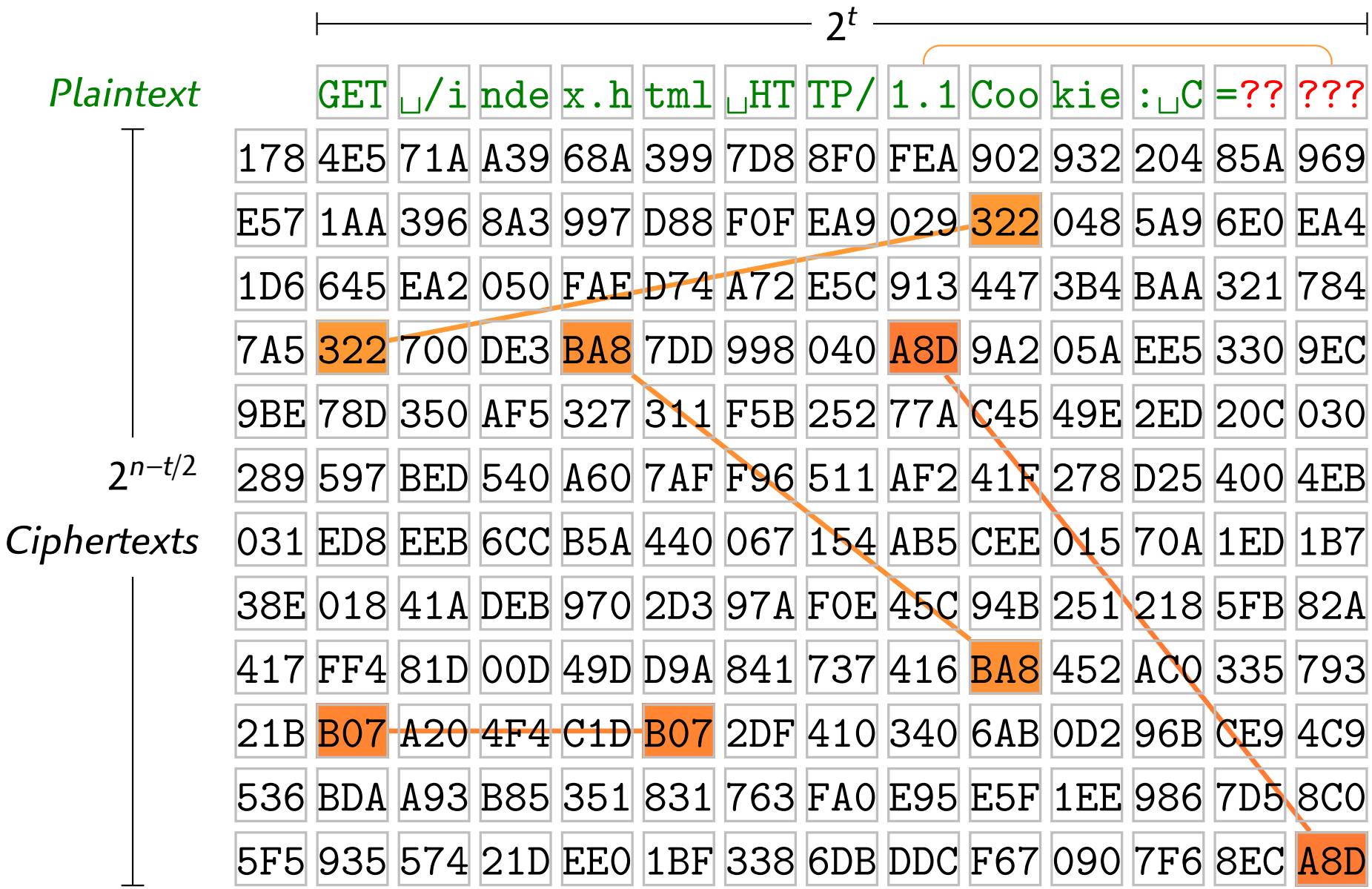

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HTTP authentication tokens

- HTTP is stateless: authentication tokens sent with every request
- Also sent with *cross-origin* requests to allow "Facebook button"

HTTP Basic Auth (RFC 7617)

- User/Password sent in a header (base64 encoded)

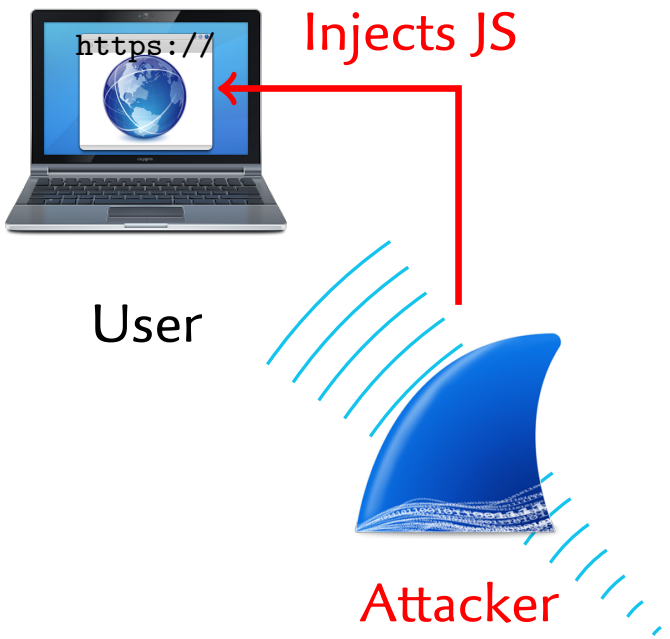
```
Authorization: Basic dGVzdDoxMjPCow=
```

HTTP Cookies (RFC 6265)

1. User sends password in a from
2. Server reply with a Cookie
3. Cookie is included in every subsequent request

```
Cookie: C=123456
```

Beastly Attack Scenario



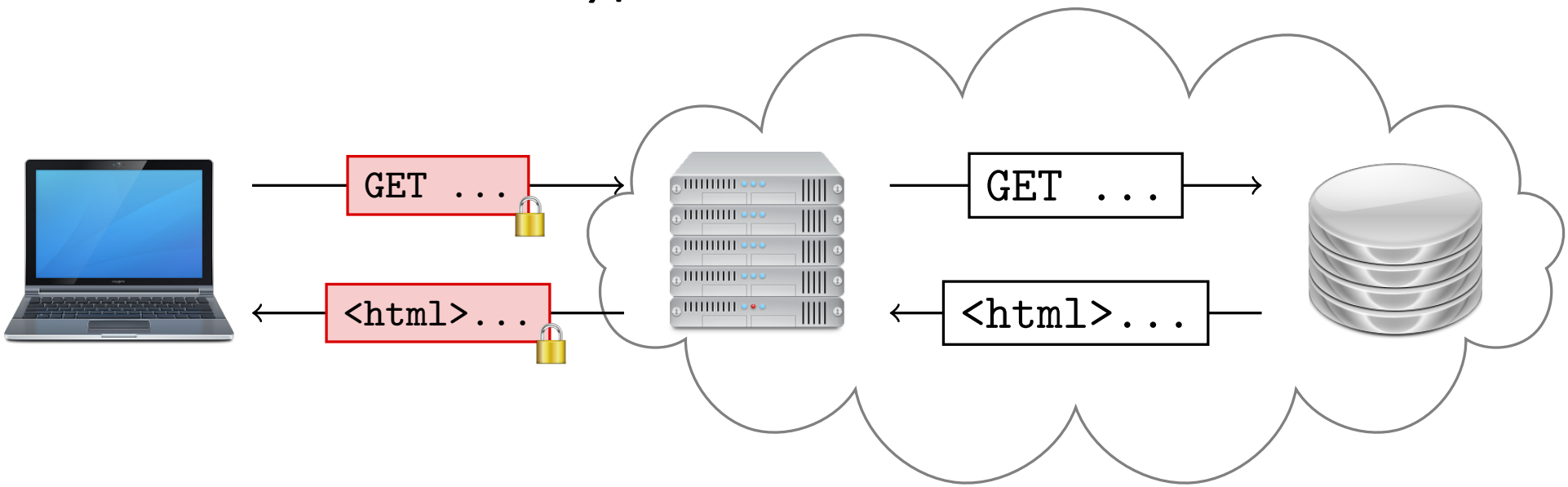
- Attacker has access to the network (*e.g.* public WiFi)
- User logged-in to secure website (w/ cookie or BasicAuth)

1. Attacker uses JS to generate traffic
   - Tricks victim to malicious site
   - JS makes *cross-origin* requests
2. Attacker captures encrypted data

[BEAST, Duong & Rizzo 2011]

OpenVPN

- A VPN creates an encrypted tunnel to between two machines



- OpenVPN is a popular free-software VPN solution
  - Default cipher: Blowfish in CBC mode (64-bit blocks)
  - *Pre-shared-key mode*: no rekeying
  - *TLS mode*: rekeying every hour (by default), 2^{32} packets limit

Proof-of-concept Attack Demo: HTTP over OpenVPN

- Demo with Firefox browser (Linux), and nginx server connected with OpenVPN in pre-shared-key mode
  - Default configuration
- Each HTTP request encrypted in OpenVPN packet, with fixed key

1. Generate traffic with malicious JavaScript
   - Use 4kB requests (pad URL or cookie)
   - About 2900 requests/second
2. Capture on the network with `tcpdump`
3. Remove header, extract ciphertext at fixed position
4. Sort ciphertext (`stdxxl`), look for collisions

- Expected time: 19 hours for 785 GB.
- In practice: 18.6 hours for 705 GB.

Outline

HTTPS: HTTP over TLS

- HTTPS: secure HTTP
  - HTTP over a TLS connection
  - One of the most widespread use of encryption
- TLS is agile: ciphersuite negotiation
  - Client sends ordered list of supported ciphersuites
  - Server chooses ciphersuite
  - Most servers force their ordering
  - Block cipher key derived from key exchange
- 3DES is one of the possible ciphers
  - Mandatory to implement up to TLS 1.1
  - How much is used?
  - How much data can be encrypted with the same key?

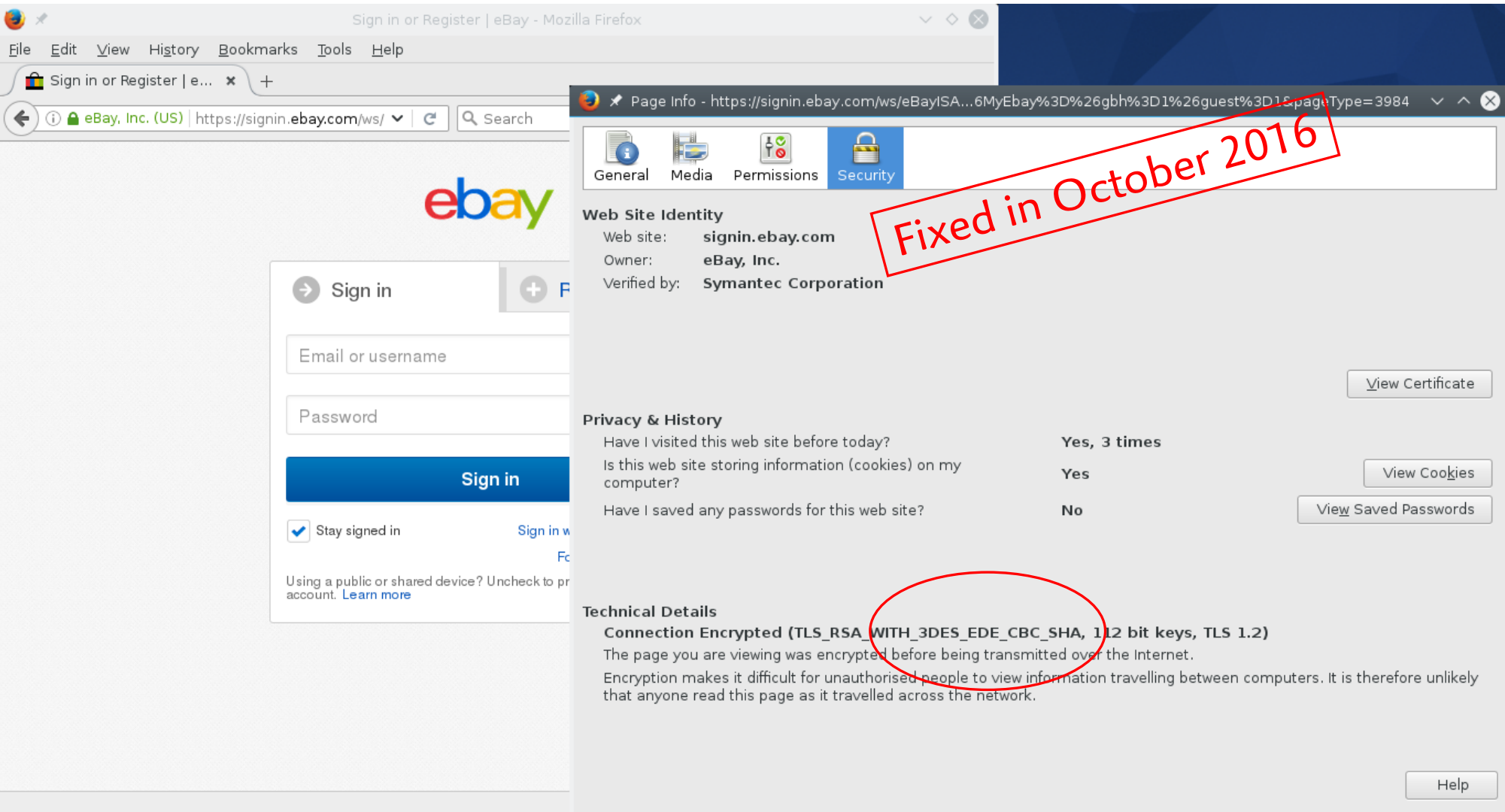
3DES use in TLS (HTTPS)

- It seems that 1—2% of HTTPS connections use 3DES
  - Outdated client/servers
    - Windows XP / Windows 2003 Server don't support AES out of the box
  - Many poorly configured servers support AES, but prefer 3DES
- Scan of Alexa's top 1 million websites
  - 3DES use assuming a modern browser (`AES > 3DES`, no `RC4`)

	February 2016		October 2016	
3DES	support	use	support	use
Top 1k	93%	1.6%	84%	1.5%
Top 10k	92%	2.1%	84%	1.0%
Top 100k	89%	1.9%	83.7%	0.9%
Top 1M	86%	1.3%	86%	1.0%

Poorly configured websites

ebay.com



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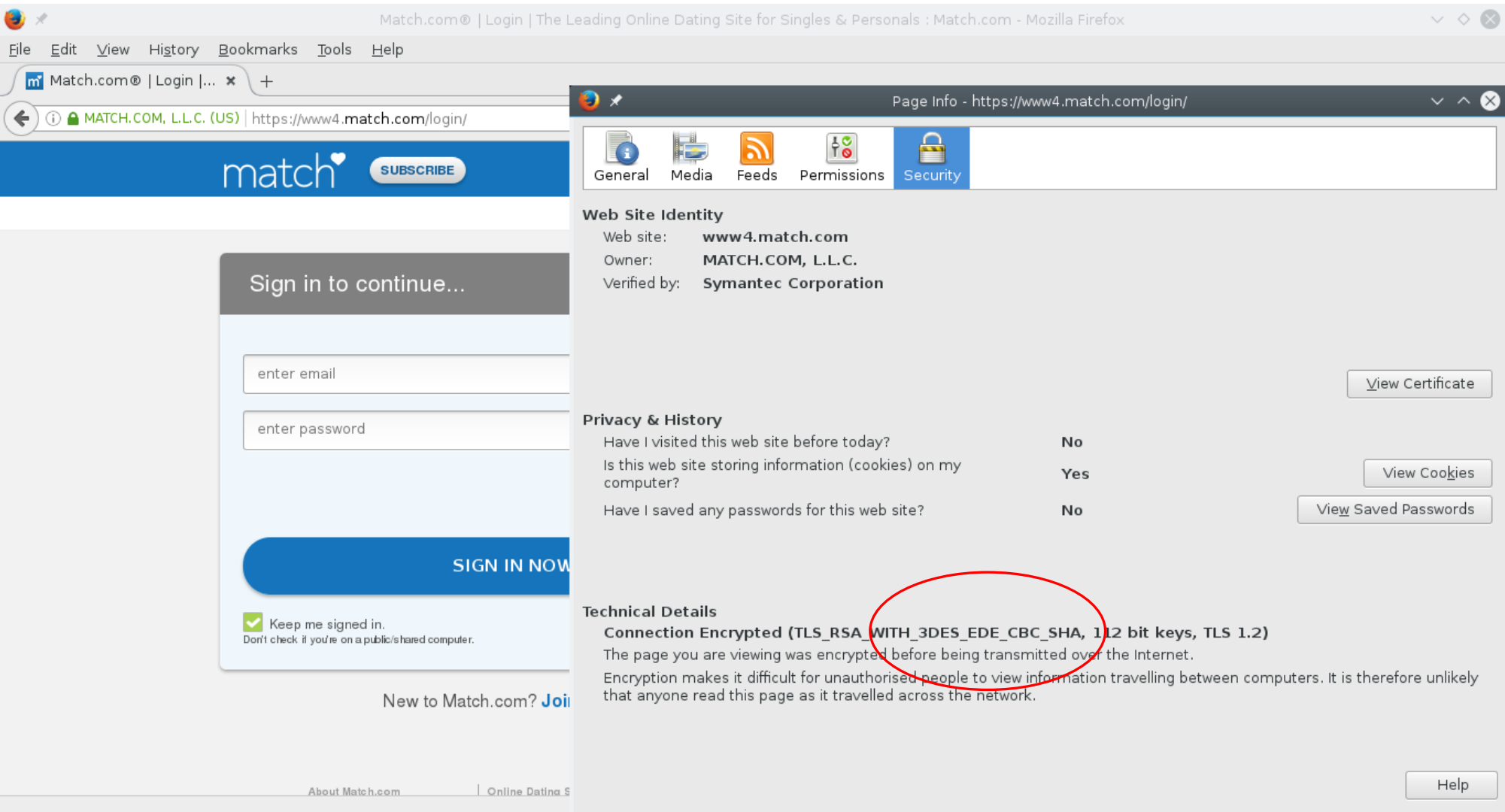

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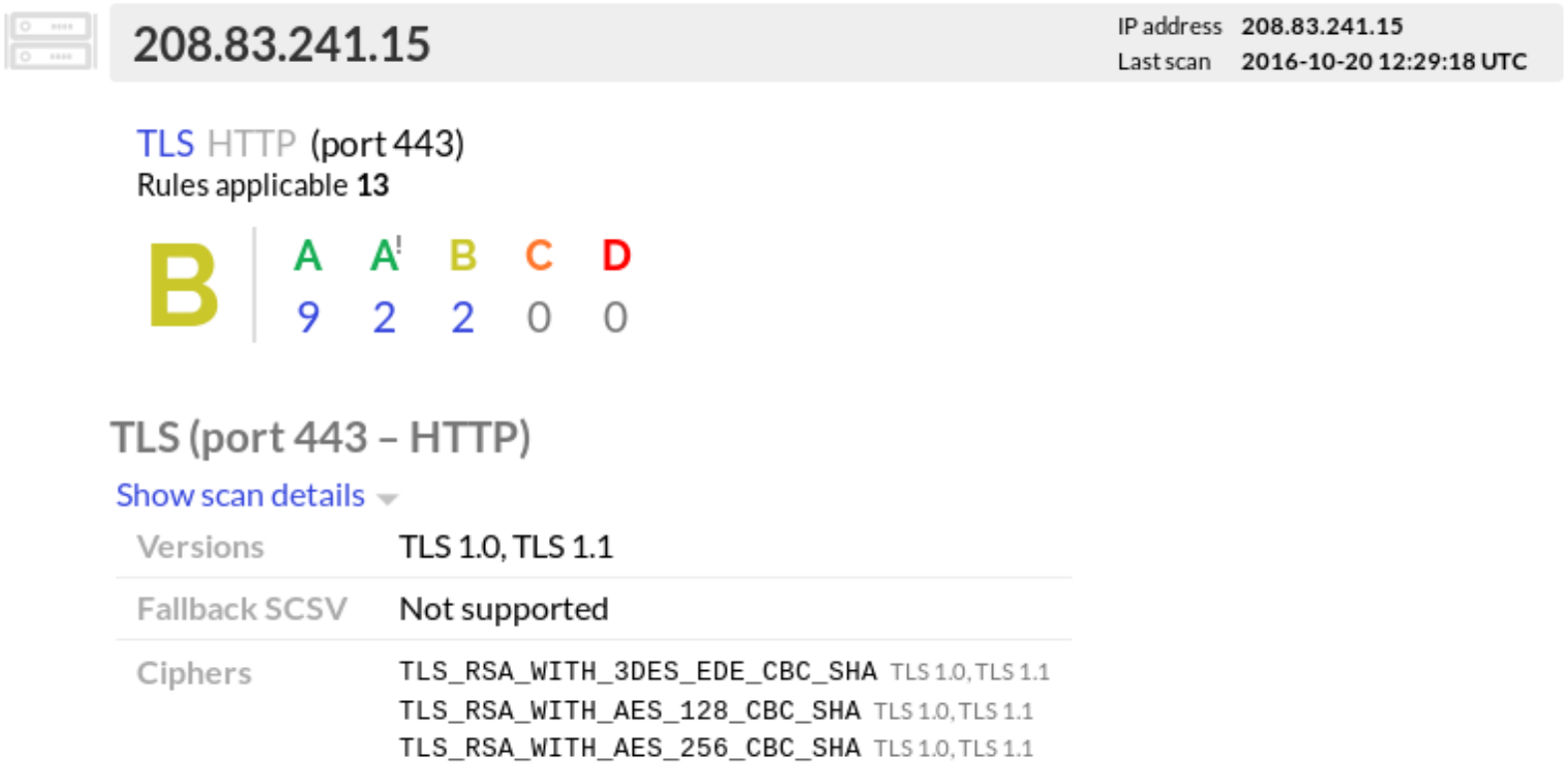
https://discovery.cryptosense.com/analyze/208.83.241.15



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webmail.trumporg.com

https://discovery.cryptosense.com/analyze/trumporg.com

TLS HTTP (port 443)
Rules applicable **12**

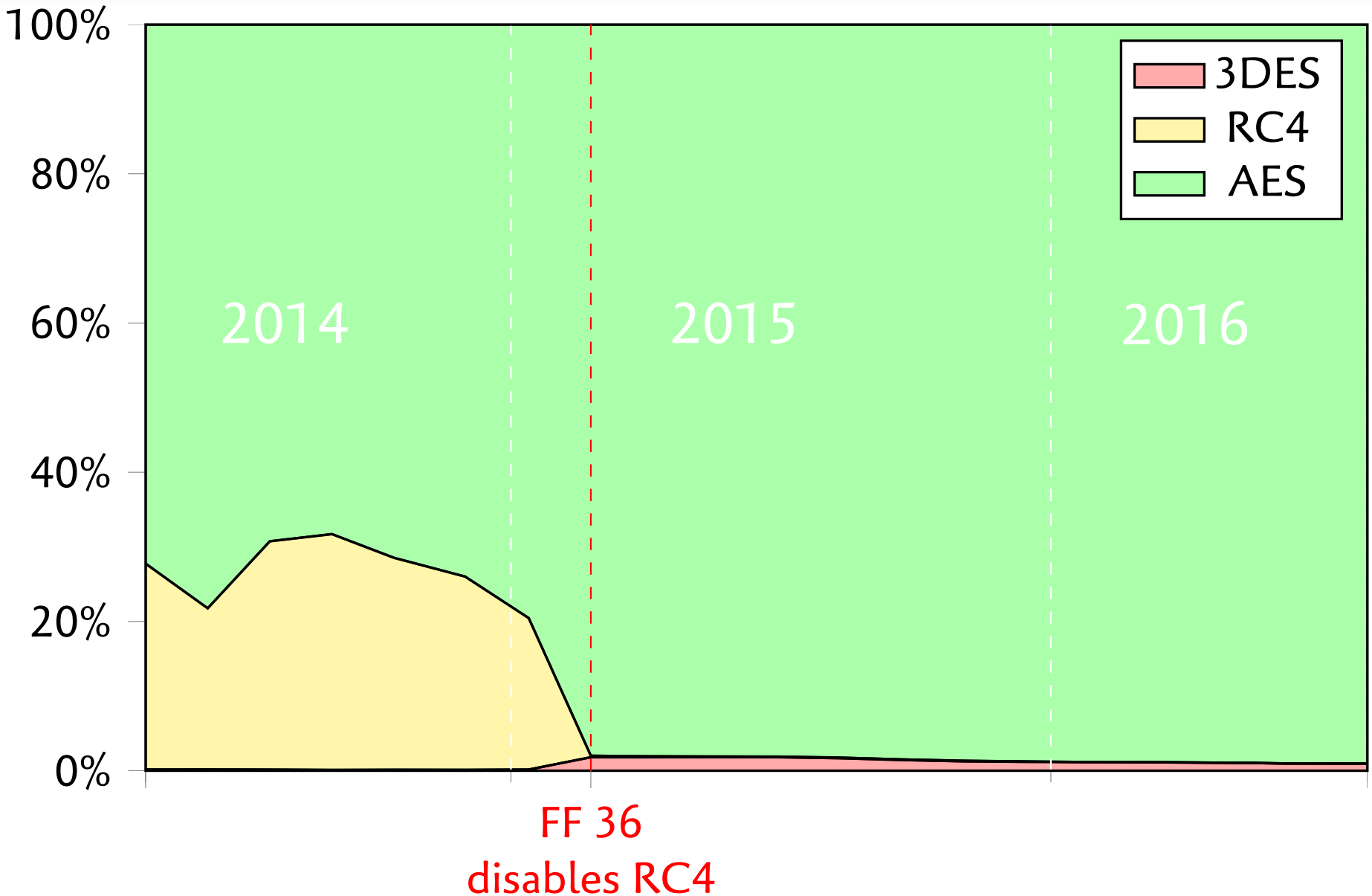
D	A	A!	B	C	D
	4	2	1	1	4

TLS (port 443 – HTTP)

Show scan details

Versions	SSL 2.0, TLS 1.0
Ciphers	TLS_RSA_WITH_RC4_128_MD5 TLS 1.0 TLS_RSA_WITH_RC4_128_SHA TLS 1.0 TLS_RSA_WITH_3DES_EDE_CBC_SHA TLS 1.0 TLS_RSA_WITH_DES_CBC_SHA TLS 1.0 TLS_RSA_EXPORT1024_WITH_RC4_56_SHA TLS 1.0 TLS_RSA_EXPORT1024_WITH_DES_CBC_SHA TLS 1.0 TLS_RSA_EXPORT_WITH_RC4_40_MD5 TLS 1.0 TLS_RSA_EXPORT_WITH_RC2_CBC_40_MD5 TLS 1.0 SSL2_RC4_128_WITH_MD5 SSL 2.0 SSL2_DES_192_EDE3_CBC_WITH_MD5 SSL 2.0 SSL2_RC2_128_CBC_WITH_MD5 SSL 2.0 SSL2_DES_64_CBC_WITH_MD5 SSL 2.0 SSL2_RC4_128_EXPORT40_WITH_MD5 SSL 2.0 SSL2_RC2_128_CBC_EXPORT40_WITH_MD5 SSL 2.0

TLS cipher use in Firefox (telemetry)



HTTPS session length

- HTTP 1.0 uses one connection per request
- HTTP 1.1 can reuse a connection (`Keep-alive`)

- *Web browsers* reuse a connection as long as possible
- *Web servers*

  Apache has a limit on connection reuse (default 200)
  Nginx has a limit on connection reuse (default 200)
  IIS doesn't have limit by default

  - In practice, many high-profile website support very long sessions

- We found many vulnerable websites that
  - Use 3DES with a modern browser
  - Support very long sessions (> 1M)

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- We found many vulnerable websites that
  - Use 3DES with a modern browser
  - Support very long sessions (> 1M)

Proof-of-concept Attack Demo: HTTPS

- Demo with Firefox (Linux), and IIS 6.0 (Windows Server 2003)
  - Default configuration of IIS 6.0 does not support AES
- Each HTTP request encrypted in TLS record, with fixed key

1. Generate traffic with malicious JavaScript
   - Use 4kB requests (pad URL or cookie)
   - About 1500 requests/second
2. Capture on the network with `tcpdump`
   - Tamper with traffic to have a single active connection
3. Remove header, extract ciphertext at fixed position
4. Sort ciphertext (`stdxxl`), look for collisions

- Expected time: 38 hours for 785 GB.
- In practice: 30.5 hours for 610 GB.

Outline

Countermeasures

- Switch to 128-bit block ciphers (*e.g.* AES)
  - Fix server TLS config
- Limit connection length
  - Can be done on client or server independently
- Use a beyond-birthday-secure mode (*e.g.* CENC)
  - Could be an option for lightweight crypto

Should we get rid of 3DES in TLS?

- Make sure it's only used as a last resort, and use rekeying
- Even then, having it available is a potential weakness
  - There might be downgrade attacks
  - Example: 3DES can be forced if TLS false start

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Disclosure

Sweet32 attack disclosed on August 24

- https://sweet32.info
- CVE-2016-2183, CVE-2016-6329

- OpenVPN 2.3.12 issues a warning when using 64-bit block cipher
  - Future versions will implement connection limit, and cipher negotiation defaulting to AES
- Mozilla has implemented data limits in NSS 3.27 (1M records)
- OpenSSL moved 3DES to `LOW` category
- Microsoft removed 3DES from False Start white-list
- Some websites fixed their TLS configuration

Comparison with RC4 attacks

Practical attacks against TLS with RC4 [AFBPPS, Usenix '13]

- With a different key each session
  - Using biases in the RC4 keystream
  - Plaintext recovery (220 first bytes) with 2^{28} — 2^{32} sessions
- With longer sessions
  - Using Fluhrer-McGrew biases (single or multiple sessions)
  - Cookie recovery with 2^{33} — 2^{34} requests
  - Latest improvement: $2^{30.2}$ requests [Vanhoef & Piessens, Usenix '15]

Practical attack against TLS with 3DES

- Using a single long-lived session
- $2^{29.1}$ short query (512 bytes) 280 GB total
- Or $2^{27.6}$ longer queries (4 kB) 785 GB total

Conclusion

Block size does matter

- Birthday attack against CBC with $2^{n/2}$ data
- Attacks with 2^{32} data are practical
- Independent of key size, block cipher strength
  - 64-bit block ciphers (3DES, Blowfish) not much more secure than RC4

- Protocols designed in the 90's still use 64-bit ciphers
- Demo of two practical attacks
  - Blowfish default cipher in OpenVPN
  - Badly configured HTTPS servers use 3DES

https://sweet32.info