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Content-Type: multipart/oracle

Tapping into Format Oracles in Email End-to-End Encryption

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What's an email?

MIME

```
From:          Alice
To:            Bob
Subject:       Example
Content-Type: text/plain

Hello Bob, how was your weekend?
```

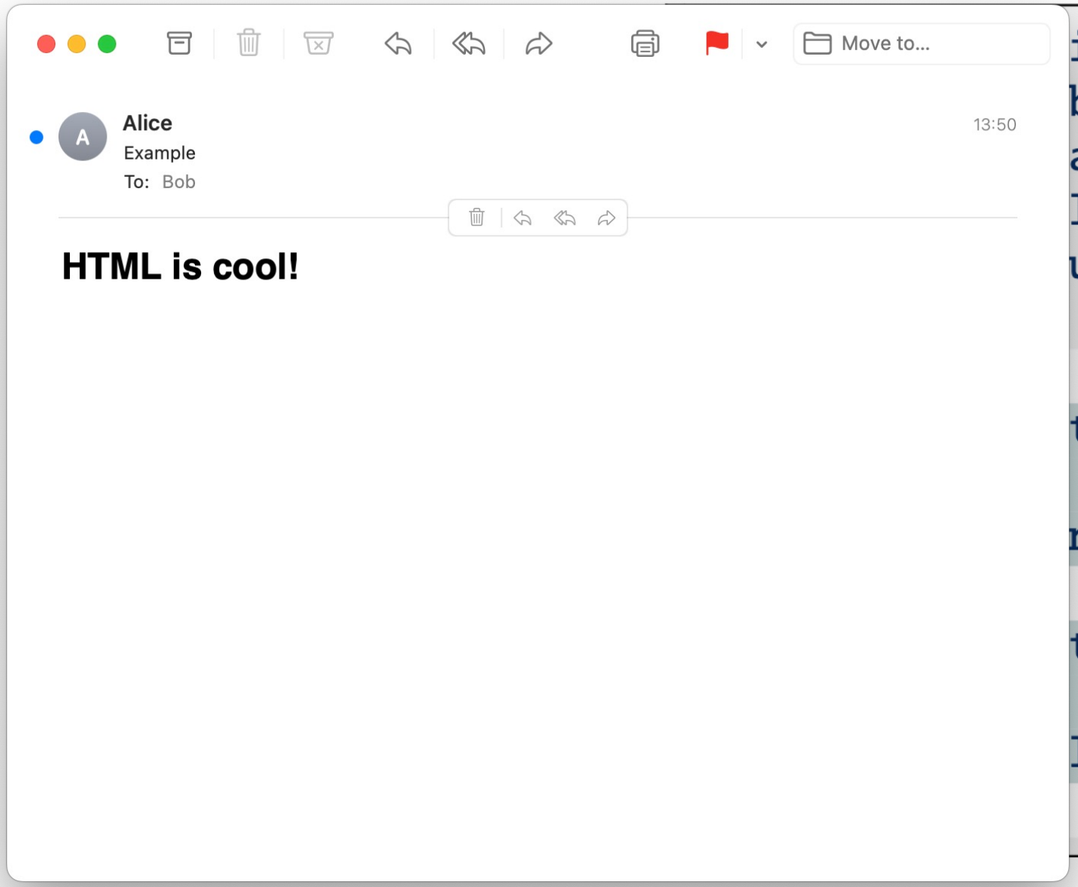
What's an email?

MIME

```
From:          Alice
To:            Bob
Subject:       Example
Content-Type: multipart/alternative;
              boundary=alternative

--alternative // --------------------
  Content-Type: text/plain

  Plain old boring plaintext.
--alternative // --------------------
  Content-Type: text/html

  <b>HTML is cool!</b>
--alternative--
```

What’s an email?

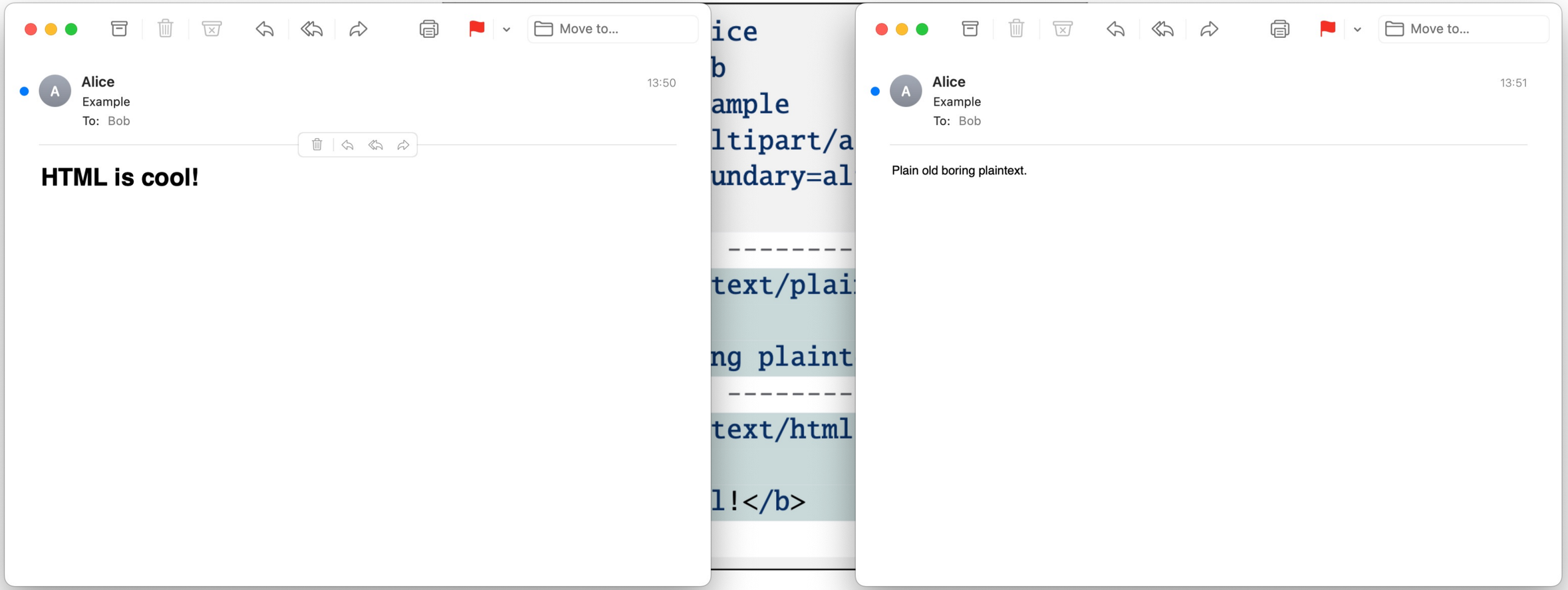
MIME



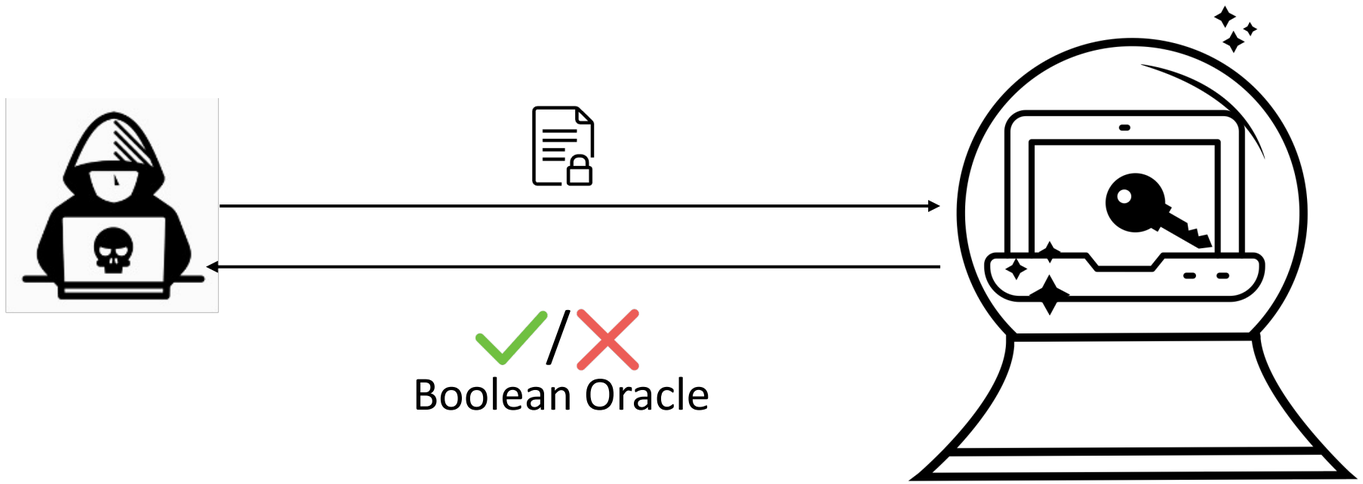

```
ice
b
ample
ltipart/alternative;
undary=alternative

 --------------------
text/plain

ng plaintext.
 --------------------
text/html

l!</b>
```

What’s an email?

MIME



Decryption Oracle Attacks



Decryption Oracle Attacks

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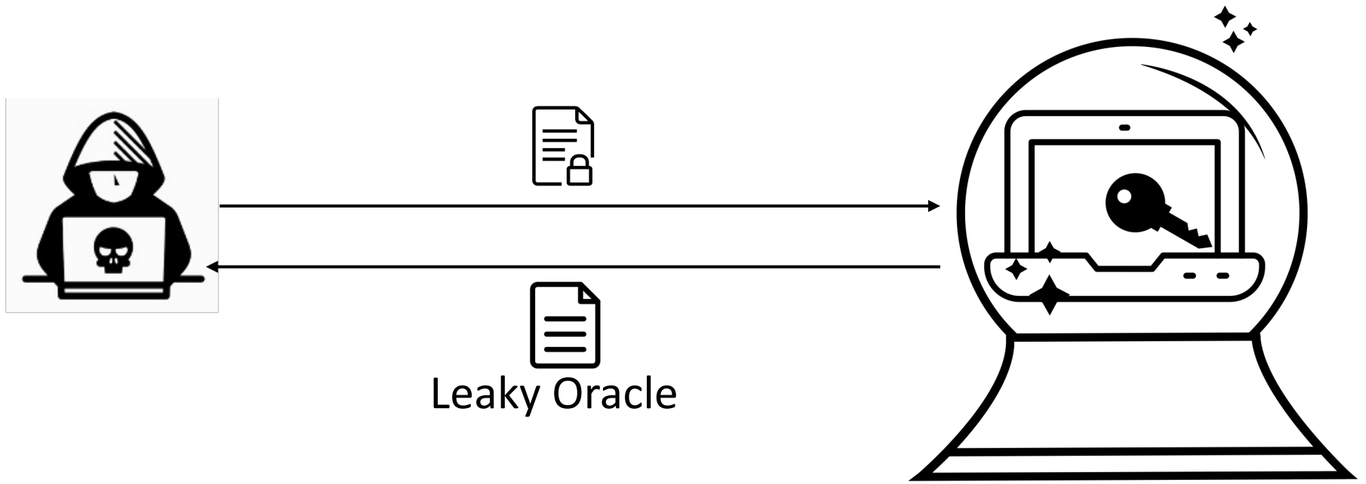
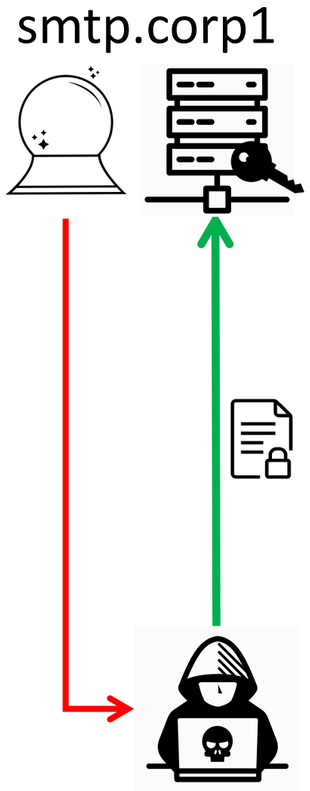
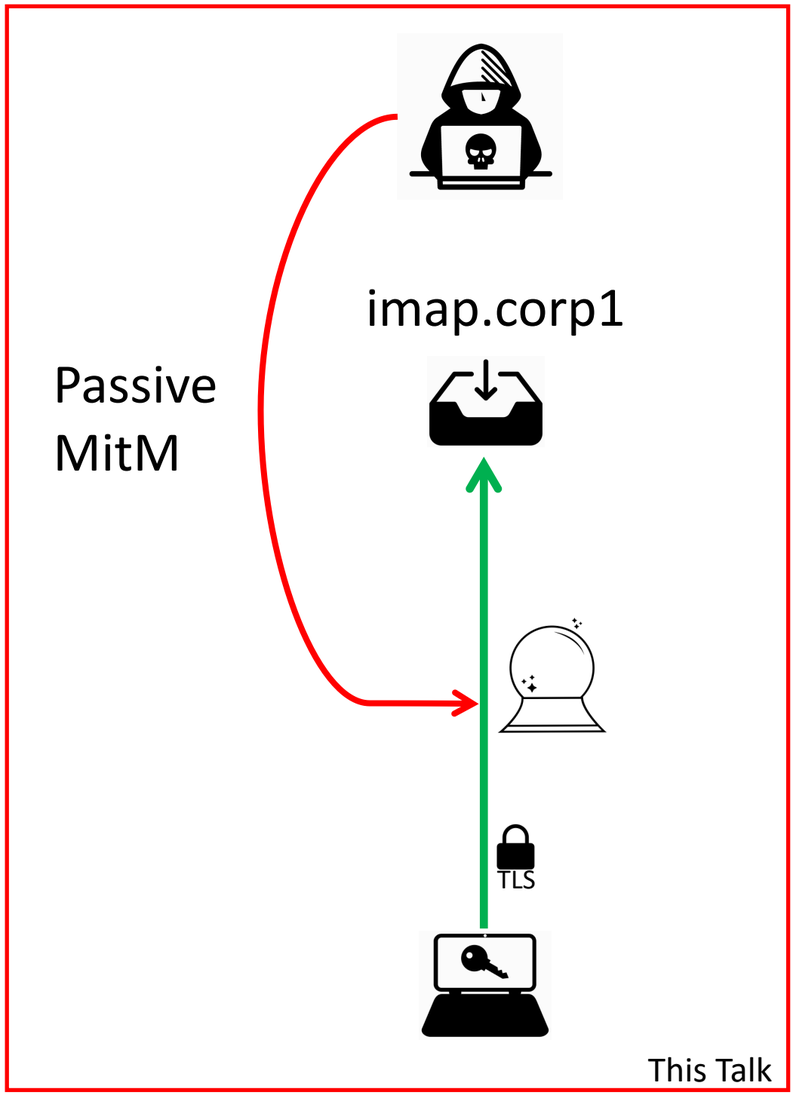


Attacker Model



Paper Appendix



IMAP – Fetching

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Message ID Data Items

```
C: A FETCH 1 (BODYSTRUCTURE)
S: * 1 FETCH (BODYSTRUCTURE (
        ("text" "plain" NIL NIL NIL "7BIT" 29 NIL)
        ("text" "html" NIL NIL NIL "7BIT" 22 NIL)
        "alternative" ("boundary" "alternative") NIL NIL NIL))
S: A OK fetch done.
C: B FETCH 1 (BODY[1])
S: * 1 FETCH (BODY[1] {29}
         Plain old boring plaintext.
     )
S: B OK fetch done.
```

```
From:          Alice
To:            Bob
Subject:       Example
Content-Type:  multipart/alternative;
               boundary=alternative

--alternative // --------------------
  Content-Type: text/plain

  Plain old boring plaintext.
--alternative // --------------------
  Content-Type: text/html

  <b>HTML is cool!</b>
--alternative--
```

In Search of Side-Channels

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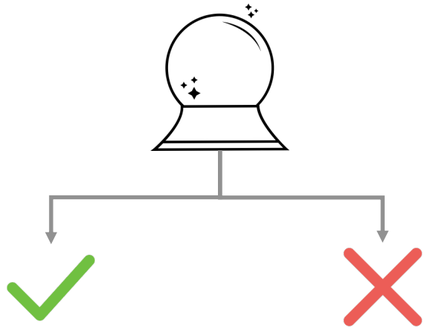
```
From:          Alice
To:            Bob
Subject:       Example
Content-Type:  multipart/alternative;
               boundary=alternative

--alternative // ------------------------------------
  Content-Type: application/encrypted

  [Base64-encoded ciphertext]
--alternative // ------------------------------------
  Content-Type: application/encrypted

  [Base64-encoded ciphertext]
--alternative--
```

```
C: A FETCH 1 (BODYSTRUCTURE)
S: * 1 FETCH (BODYSTRUCTURE (…))
C: B FETCH 1 (BODY[2])
S: * 1 FETCH (BODY[2] {…}
```



C: C LOGOUT C: C FETCH 1 (BODY[1])

Oracle in E-Mail E2EE

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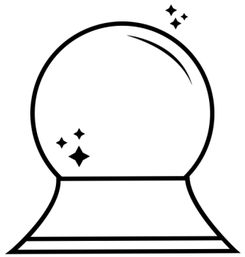
Criterion	S/MIME v3.2	OpenPGP
 Ciphertext Malleability	 No Integrity Protection	 MDC
 Potential Oracles	 PKCS#7 Padding, PKCS#1v1.5	 CFB Mode, Weak Bleichenbacher Oracles

	Multiple Encrypted Parts	Fetching Behavior		Decryption	Practical Exploit
		Body (Parts)	Lazy		
Required for practical exploit	✓	●	✓	●	

Legend					
✓	Yes	●	Automatic in background.	■	Found
–	No	○	Needs explicit user interaction.	□	Not found
~	Situation dependent	◑	Upon opening email.		
		?	Not detectable.		

Client	Multiple Encrypted Parts	Fetching Behavior		Decryption	Practical Exploit
		Body (Parts)	Lazy		
Required for practical exploit	✓	●	✓	●	
Clients not supporting multiple encrypted parts					
Airmail	–	●	–	◑	□
eM Client	–	◑	✓	?	□
Mail (macOS)	–	●	~	●	□
MailDroid	–	●	✓	○	□
Nine	–	●	–	◑	□
Outlook 2016	–	●	–	?	□
Outlook 2019	–	●	–	?	□
Postbox	–	●	–	?	□
R2Mail2	–	◑	✓	◑	□
Thunderbird	–	●	–	?	□

Client	Multiple Encrypted Parts	Fetching Behavior		Decryption	Practical Exploit
		Body (Parts)	Lazy		
Required for practical exploit	✓	●	✓	●	
Clients not automatically fetching single body parts					
Claws	✓	◑	–	◑	□
Horde IMP	✓	◑	✓	◑	□
Evolution	✓	◑	–	◑	□
KMail	✓	◑	–	○	□
Mutt	✓	◑	–	○	□
The Bat!	✓	◑	–	○	□
Trojitá	✓	◑	✓	◑	□

Client	Multiple Encrypted Parts	Fetching Behavior		Decryption	Practical Exploit
		Body (Parts)	Lazy		
Required for practical exploit	✓	●	✓	●	
Clients not using lazy fetching					
MailMate	✓	●	–	◑	□
Clients fulfilling all criteria					
Mail (iOS)	✓	●	✓	●	■

Empty Line Oracle

A NEW FORMAT ORACLE

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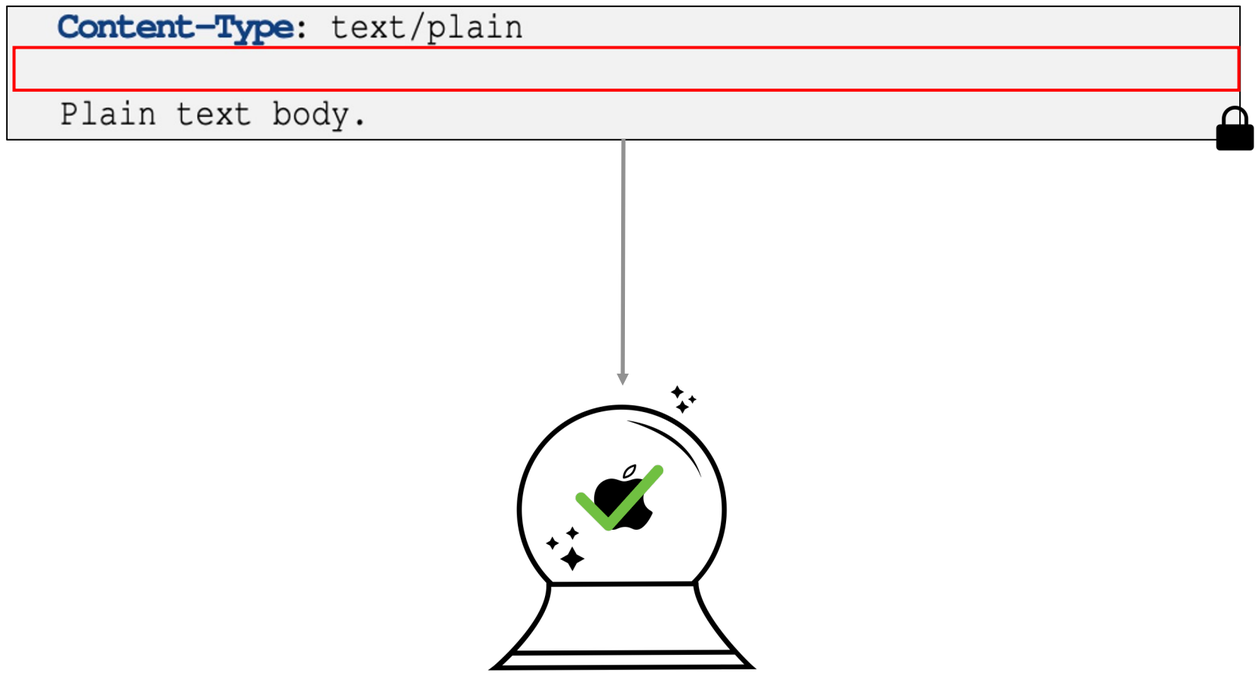

Empty Line Oracle

A NEW FORMAT ORACLE

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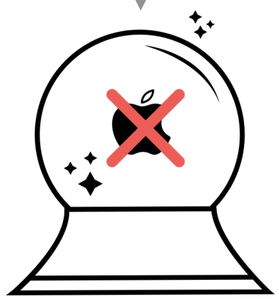
```
Content-Type: text/plain
No Empty Line
Plain text body.
```



The Empty Line Oracle Exploit

DECRYPTING A BLOCK

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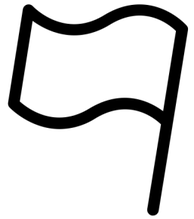


Setup:

Guess two bytes in a block.

```
\x00    \x00  ✗
\x00    \x01  ✗
  ⋮
\n      \n    ✓
```

Per Byte:

Fixate one known byte to `\n`

```
\n      \x00  ✗
\n      \x01  ✗
  ⋮
\n      \n    ✓
```

Result:

Decrypted Ciphertext Block

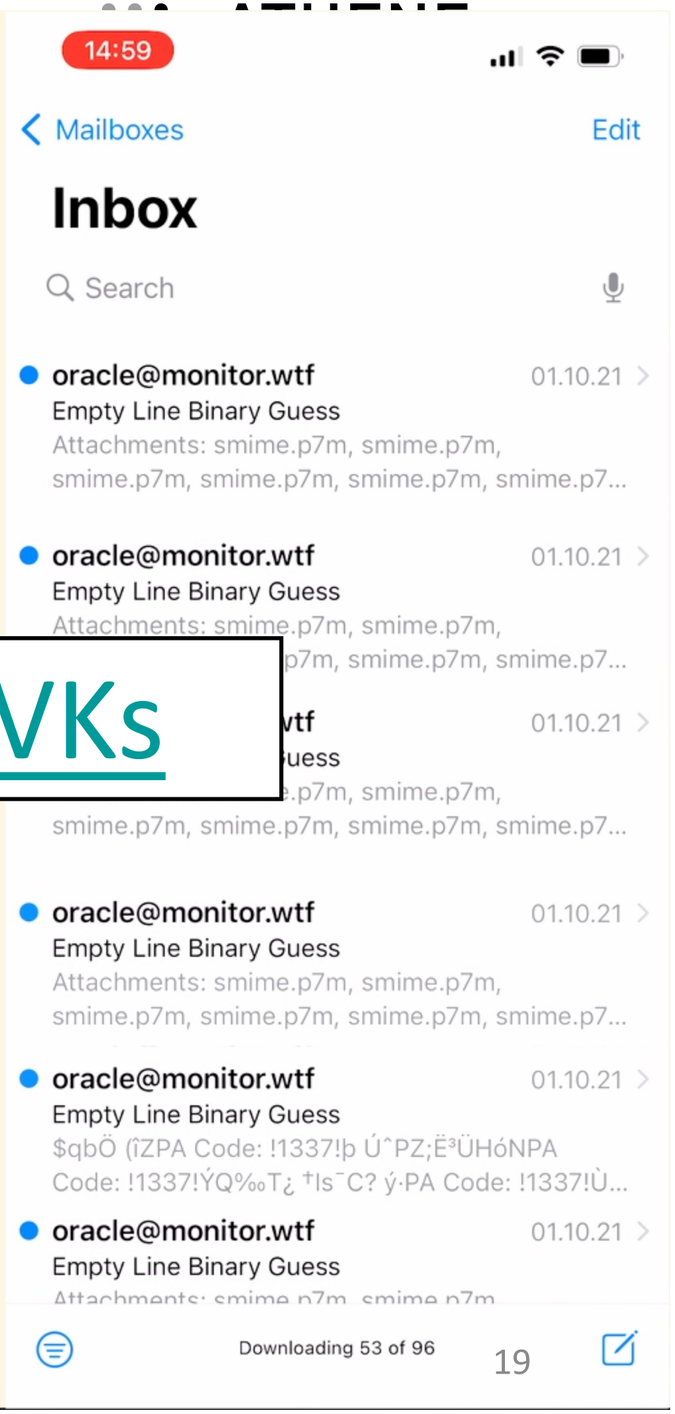
Optimizations:

900 Queries/Ciphertext Block
< 7 Minutes

```
2022-12-07 14:59:22,462 - INFO - UID 200104 Using Alphabet b'1\x00'..b'1\x0f'
2022-12-07 14:59:22,463 - INFO - UID 200105 Using Alphabet b'1\x10'..b'1\x1f'
2022-12-07 14:59:22,465 - INFO - UID 200106 Using Alphabet b'1 '..b'1/'
2022-12-07 14:59:22,468 - INFO - UID 200107 Using Alphabet b'10'..b'1?'
2022-12-07 14:59:22,472 - INFO - UID 200108 Using Alphabet b'1@'..b'1O'
2022-12-07 14:59:22,476 - INFO - UID 200109 Using Alphabet b'1P'..b'1_'
2022-12-07 14:59:22,477 - INFO - UID 200110 Using Alphabet b'1`'..b'1o'
2022-12-07 14:59:22,479 - INFO - UID 200111 Using Alphabet b'1p'..b'1\x7f'
2022-12-07 14:59:22,484 - INFO - UID 200112 Using Alphabet b'2\x00'..b'2\x0f'
2022-12-07 14:59:22,488 - INFO - UID 200113 Using Alphabet b'2\x10'..b'2\x1f'
2022-12-07 14:59:22,493 - INFO - UID 200114 Using Alphabet b'2 '..b'2/'
2022-12-07 14:59:22,497 - INFO - UID 200115 Using Alphabet b'20'..b'2?'
2022-12-07 14:59:22,499 - INFO - UID 200116 Using Alphabet b'2@'..b'2O'
2022-12-07 14:59:22,501 - INFO - UID 200117 Using Alphabet b'2P'..b'2_'
2022-12-07 14:59:22,503 - INFO - UID 200118 Using Alphabet b'2`'..b'2o'
2022-12-07 14:59:22,506 - INFO - UID 200119 Using Alphabet b'2p'..b'2\x7f'
2022-12-07 14:59:22,509 - INFO - UID 200120 Using Alphabet b'3\x00'..b'3\x0f'
2022-12-07 14:59:22,512 - INFO - UID 200121 Using Alphabet b'3\x10'..b'3\x1f'
2022-12-07 14:59:22,513 - INFO - UID 200122 Using Alphabet b'3 '..b'3/'
2022-12-07 14:59:22,516 - INFO - UID 200123 Using Alphabet b'30'..b'3?'
2022-12-07 14:59:22,520 - INFO - UID 200124 Using Alphabet b'3@'..b'30'
2022-12-07 14:59:22,523 - IN
2022-12-07 14:59:22,527 - IN
2022-12-07 14:59:22,531 - IN
```

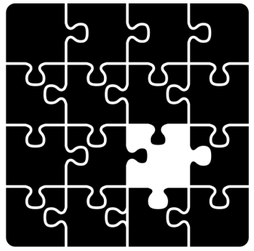
https://youtu.be/1_nvhFfWVKs

```
59D12Jwp | .. Kh/FIKPKLomw6O
59D12Jwp | .. I0ItLehv7CofxSCjyi6JsOjufkfOcdwD5h28zBx1dsUjQy0t6G/sKh/FIKPKLomw6O5+R85x3APm\n
59D12Jwp | .. HbzMHHV2xSNALS3ob+wqH8Ugo8ouibDo7n5HznHcA+YdvMwcdXbFI0EtLehv7CofxSCjyi6JsOju\n
59D12Jwp | .. fkfOcdwD5h28zBx1dsUjRi0t6G/sKh/FIKPKLomw6O5+R85x3APmHbzMHHV2xSNHLS3ob+wqH8Ug\n
59D12Jwp | .. o8ouibDo7n5HznHcA+YdvMwcdXbFI0QtLehv7CofxSCjyi6JsOjufkfOcdwD5h28zBx1dsUjRS0t\n
59D12Jwp | .. 6G/sKh/FIKPKLomw6O5+R85x3APmHbzMHHV2xSNaLS3ob+wqH8Ugo8ouibDo7n5HznHcA+YdvMwc\n
59D12Jwp | .. dXbFI1stLehv7CofxSCjyi6JsOjufkfOcdwD5h28zBx1dsUjWC0t6G/sKh/FIKPKLomw6O5+R85x\n
59D12Jwp | .. 3APmHbzMHHV2xSNZLS3ob+wqH8Ugo8ouibDo7n5HznHcA+YdvMwcdXbFI14tLehv7CofxSCjyi6J\n
59D12Jwp | .. sOjufkfOcdwD5h28zBx1dsUjXy0t6G/sKh/FIKPKLomw6O5+R85x3APmHbzMHHV2xSNcLS3ob+wq\n
59D12Jwp | .. H8Ugo8ouibDo7n5HznHcA+YdvMwcdXbFI10tLehv7CofxSCjyi6JsOjufkfOcdwD5h28zBx1dsUj\n
59D12Jwp | .. Ui0t6G/sKh/FIKPKLomw6O5+R85x3APmHbzMHHV2xSNTLS3ob+wqH8Ugo8ouibDo7n5HznHcA+Yd\n
59D12Jwp | .. vMwcdXbFI1AtLehv7CofxSCjyi6JsOjufkfOcdwD5h28zBx1dsUjUS0t6G/sKh/FIKPKLomw6O5+\n
59D12Jwp | .. R85x3APmHbzMHHV2xSNWLS3ob+wqH8Ugo8ouibDo7n5HznHcA+YdvMwcdXbFI1ctLehv7CofxSCj\n
59D12Jwp | .. yi6JsOjufkfOcdwD5h28zBx1dsUjVC0t6G/sKh/FIKPKLomw6O5+R85x3APmHbzMHHV2xSNVLS3o\n
59D12Jwp | .. b+wqH8Ugo8ouibDo7n5HznHcA+YdvMwcdXbF\n
59D12Jwp | .. )\r\n
59D12Jwp | S: 4 OK fetch done.\r\n
59D12Jwp | C: 5 LOGOUT\r\n
59D12Jwp | S: * BYE bye done.\r\n
59D12Jwp | S: 5 OK logout done.\r\n
59D12Jwp | {"message": "Connection was closed."}
```

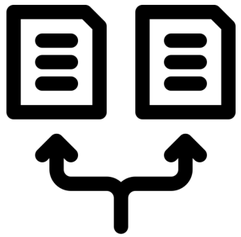


Resistance

WHY ARE THE CLIENTS NOT VULNERABLE?



Incomplete Implementations



Selective Fetching

Parallel Decryption & Fetching

Implementation Quirks

Resistance

USABILITY VS SECURITY

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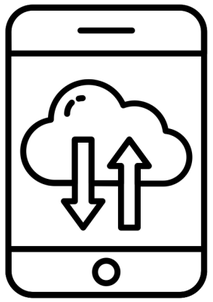
Separate encryption of attachments

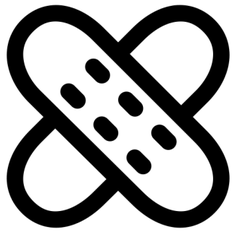
Notifications and Searching



Low Data Contingents & Flaky Connections

Countermeasures

SHORT- AND MID-TERM

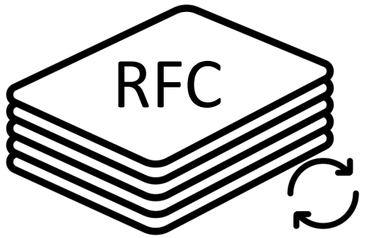


Stopgap

Prevent Oracles

Constant Time Operations

Restrict Features



Update Standards

AEAD

[1]

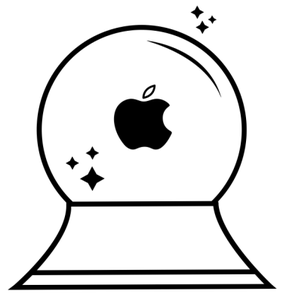
[1] Schwenk et al. - Mitigation of Attacks on Email End-to-End Encryption

Conclusion

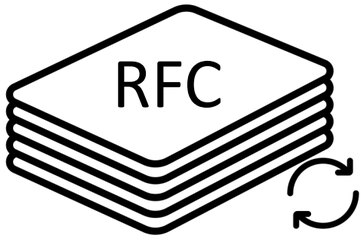
ORACLE ATTACK ON EMAIL E2EE

Many Clients
are safe

'Defenses' are
involuntary



Some Attacks
still possible



Explicit Countermeasures
are necessary

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Thanks for Listening!

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