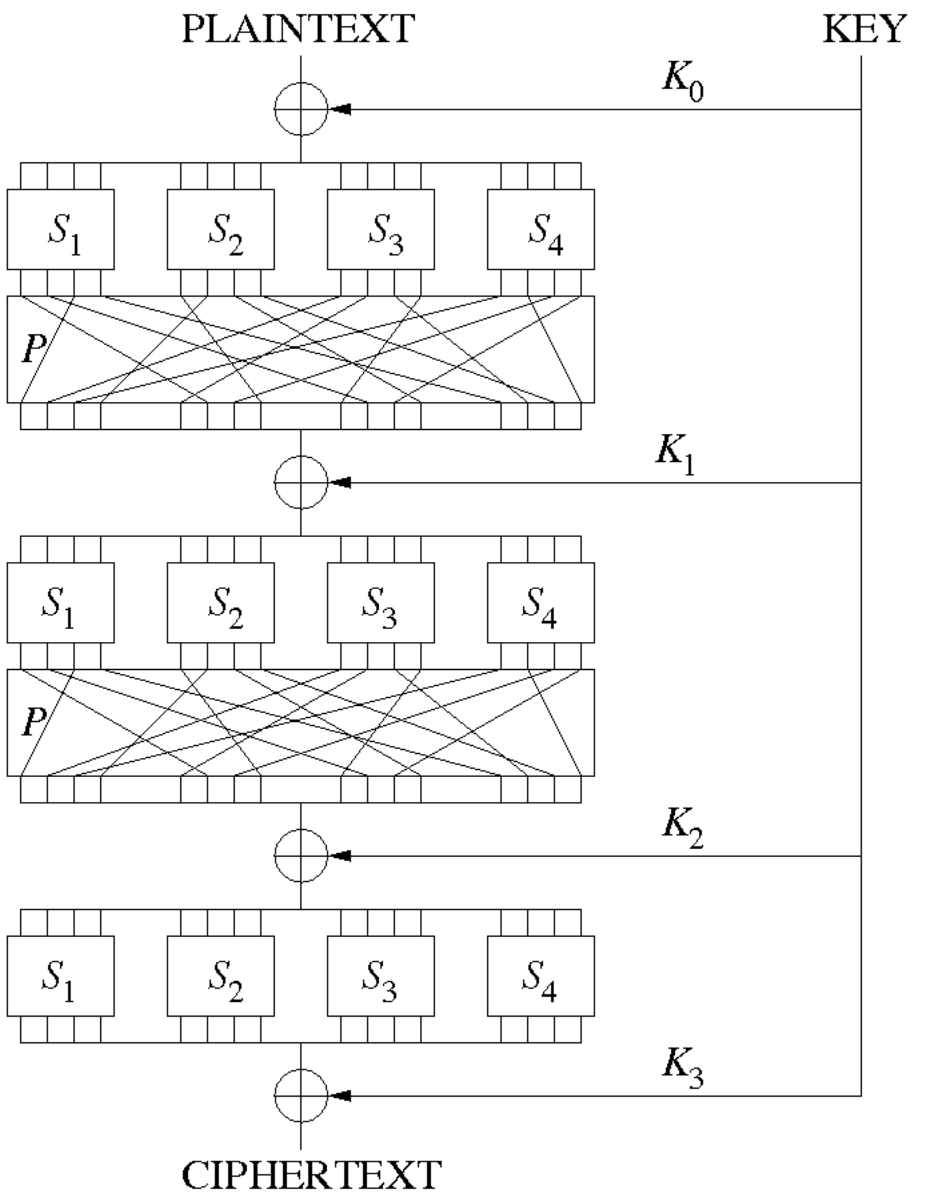
CBC padding oracle attacks

CBC padding oracle attack examples

- Serge Vaudenay published the original attack in 2002
  - Applied to web frameworks like Ruby on Rails, ASP.NET, and JavaServer Faces
  - https://www.iacr.org/cryptodb/archive/2002/EUROCRYPT/2850/2850.pdf
- POODLE (published by Google in 2014) exploited SSLv3 that is still widely used by web servers and browsers
  - https://security.googleblog.com/2014/10/this-poodle-bites-exploiting-ssl-30.html

Review: AES is a block cipher and is symmetric



Source: Wikipedia

Alice and Bob have a shared secret key

Eve makes a copy of the ciphertext as it is transmitted from Alice to Bob.

Alice and Bob have a shared secret key

Eve re-plays modified copies of the encrypted message and learns information about the plaintext from Bob's behavior (e.g., Bob throws an exception for padding error)

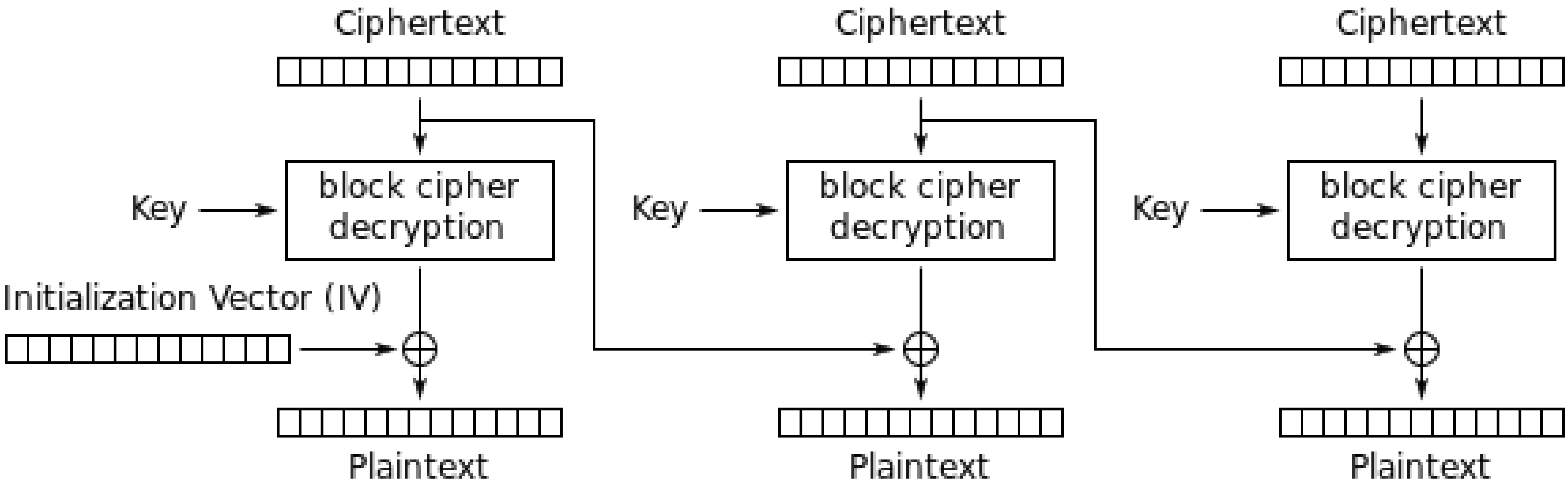
PKCS#7 padding

- AES always encrypts in 128-bit blocks
  - 128 bits == 16 bytes
- If you fill up blocks, that's great
  - The last block might not be full
- Need an “unambiguous” way to pad the last block so the decrypting party knows the padding to throw out
  - *E.g.*, PKCS#7 (PKCS == Public Key Cryptography Standards)

															01
														02	02
													03	03	03
												04	04	04	04
											05	05	05	05	05
										06	06	06	06	06	06
									07	07	07	07	07	07	07
								08	08	08	08	08	08	08	08
							09	09	09	09	09	09	09	09	09
						0A	0A	0A	0A	0A	0A	0A	0A	0A	0A
					0B	0B	0B	0B	0B	0B	0B	0B	0B	0B	0B
				0C	0C	0C	0C	0C	0C	0C	0C	0C	0C	0C	0C
			0D	0D	0D	0D	0D	0D	0D	0D	0D	0D	0D	0D	0D
		0E	0E	0E	0E	0E	0E	0E	0E	0E	0E	0E	0E	0E	0E
	0F	0F	0F	0F	0F	0F	0F	0F	0F	0F	0F	0F	0F	0F	0F
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

When last block is decrypted

- Check last byte of the last block, that's the number of bytes of padding
  - Call it N
- There should be N N's on the end
  - If not, throw a padding error
  - If so, remove them, they're padding
    - Might remove the whole last block if N = 16 (or 10 in hex)



Cipher Block Chaining (CBC) mode decryption

Requirements for attack

- Ability to modify ciphertexts and replay them
  - Chosen ciphertext attack
- A padding oracle
  - *I.e.*, something that tells you whether the corresponding plaintext (for any ciphertext you send) has valid padding or not

Example plaintext (we don't know the plaintext yet before the attack)

H	e	l	l	o	20	W	o	r	l	d	!	\n	03	03	03

Example protocol for a client to send an encrypted message to a server

N	u	m	b	l	k	s	:	1	K	e	y	I	D	:	A3
00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
98	CC	BE	01	FF	26	39	97	85	A1	02	1E	BC	A5	7E	98

Example protocol for a client to send an encrypted message to a server

Number of blocks

Which key?

N	u	m	b	l	k	s	:	1	K	e	y	I	D	:	A3
00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
98	CC	BE	01	FF	26	39	97	85	A1	02	1E	BC	A5	7E	98

Example protocol for a client to send an encrypted message to a server

N	u	m	B	l	k	s	:	1	K	e	y	I	D	:	A3
00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
98	CC	BE	01	FF	26	39	97	85	A1	02	1E	BC	A5	7E	98

IV is randomly chosen but visible on the wire and known to you, won't be 0 like in this illustration

Example protocol for a client to send an encrypted message to a server

N	u	m	B	l	k	s	:	1	K	e	y	I	D	:	A3
00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
98	CC	BE	01	FF	26	39	97	85	A1	02	1E	BC	A5	7E	98

Ciphertext is what you want to decrypt, you will recover the plaintext without needing to know the key!

Server response is visible to you

- “Message decrypted successfully”

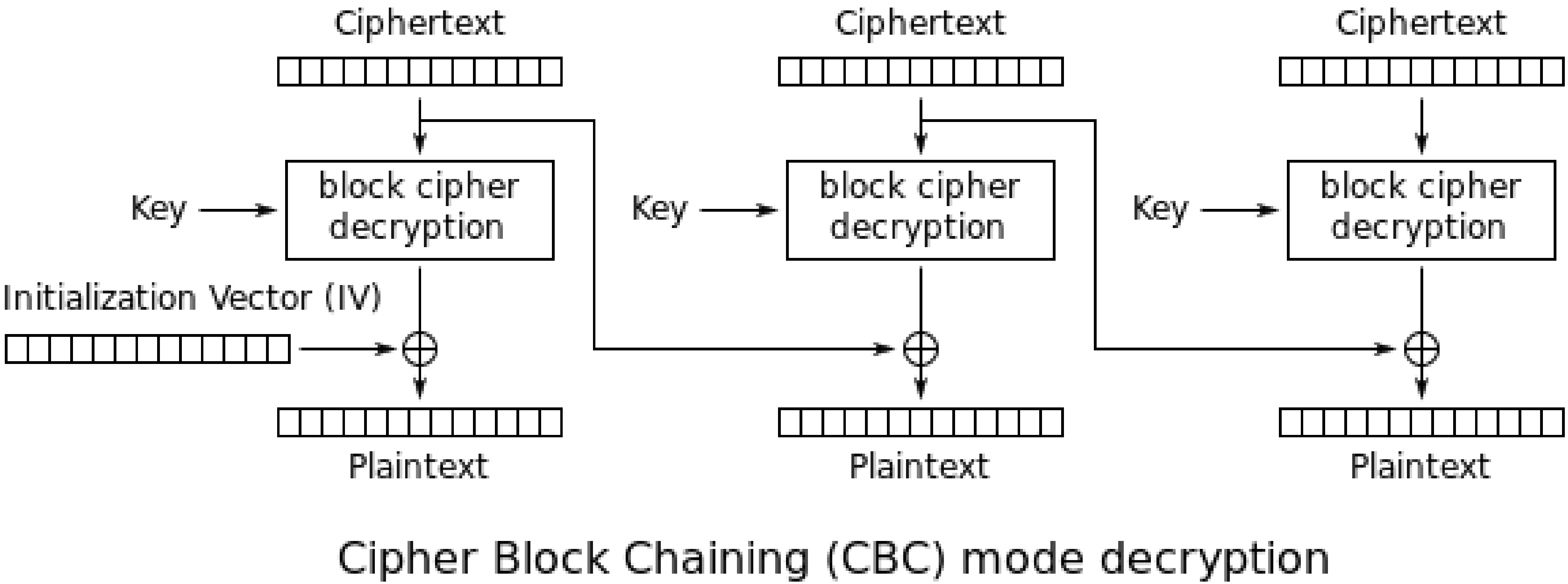
---or---

- “Padding error during decryption”

You can record a client message and replay it to the server

N	u	m	b	l	k	s	:	1	K	e	y	I	D	:	A3
00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
98	CC	BE	01	FF	26	39	97	85	A1	02	1E	BC	A5	7E	98

Try every value of this byte from 00 to FF


Ciphertext
Ciphertext
Ciphertext
Key
block cipher decryption
Key
block cipher decryption
Key
block cipher decryption
Initialization Vector (IV)
Plaintext
Plaintext
Plaintext
Cipher Block Chaining (CBC) mode decryption

Suppose two values give valid padding

- 00 gives valid padding, this is just confirmation that the original plaintext has valid padding
- 02 also gives valid padding
  - Can recover one byte of plaintext:

    Q XOR 02 == 01, so... Q == 01 XOR 02 == 03

    Q is the byte of plaintext we're trying to guess

WTF?

N	u	m	b	l	k	s	:	1	K	e	y	I	D	:	A3
00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	02
98	CC	BE	01	FF	26	39	97	85	A1	02	1E	BC	A5	7E	98

H	e	l	l	o	20	W	o	r	l	d	!	\n	03	03	01

“Information only has meaning in that it is subject to interpretation”

01 XOR 02 = 03

N	u	m	b	l	k	s	:	1	K	e	y	I	D	:	A3
00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	01
98	CC	BE	01	FF	26	39	97	85	A1	02	1E	BC	A5	7E	98

H	e	l	l	o	20	W	o	r	l	d	!	\n	03	03	02

Now attack here

Discussion

- You still don't know the key, and probably never will
- It doesn't matter how secure AES is or the size of the key
- CBC is probably the most commonly used mode
- What if a byte is already what it needs to be?
- What if there is more than one block?

References

- https://grymoire.wordpress.com/2014/12/05/cbc-padding-oracle-attacks-simplified-key-concepts-and-pitfalls/