Network Security (NetSec)

IN2101 – WS 16/17

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Modes of Encryption

Electronic Code Book Mode – ECB

Cipher Block Chaining Mode – CBC

Output Feedback Mode – OFB

Counter Mode – CTR

Chapter 5: Symmetric Encryption

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  - Plaintext m
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Symmetric Encryption
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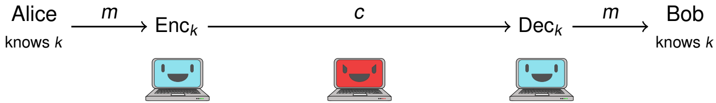

- m = “This is network security”
- k = 95 eb 50 0c 31 07 46 6f 88 8a f7 0b dd fb d7 64
- c = ad 5c 66 d3 55 be 00 88 8c 82 41 d2 75 3d 93 da fe d0 12 20 ac c1 2c e6 64 60 b4 82 2c 87 03 b2
- Enc = AES-128-ECB

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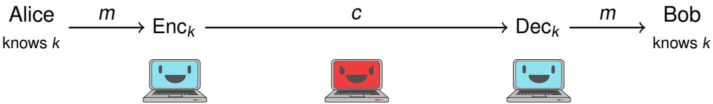

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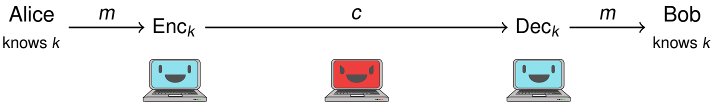

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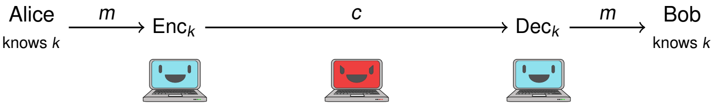

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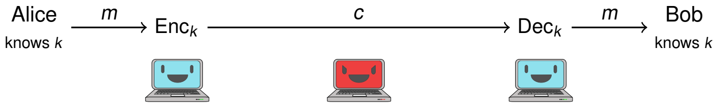

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- Authenticity?
  - No. Who are Alice and Bob anyway? Maybe Rogue-Alice is claiming to be Alice?

One-Time-Pad: A Perfect Cipher

- Example for Enc and Dec: One-Time-Pad
- Assumption: Alice and Bob share a perfectly random bitstream *otp*.
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- Requirements:
  - Key must have same size as message.
  - Key must only be used once.

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Kerckhoff's principle

The cipher method must not be required to be secret, and it must be able to fall into the hands of the enemy without inconvenience.

- In other words:
  - The cipher (encryption algorithm) is public.
  - Only the key is secret.

Examples of secure real-world ciphers

- AES
- 3DES
- ChaCha20
- One-Time-Pad

- Why can we trust them?
  - They have been publicly reviewed,
  - analyzed by cryptographers,
  - and standardized.
  - Well-tested implementations are available in your library

- Using them securely:
  1. RTFM
  2. keep the key secret (Kerckhoff's principle)

Repetition: Dos and Don’ts

- Do
  - Do use standardized ciphers from your library
  - Be aware of the dangers
    - Unlikely: A well-established cipher is broken or backdoored
    - Likely: Wrong usage of the cipher compromises security (RTFM)!
- Don’t
  - Don’t implement your own cipher. It will be broken, I guarantee!
  - Don’t claim “*it’s encrypted, it is secure*”. Forgetting integrity and authenticity may be worse than any information leakage!
  - Don’t forget about key management.

Attacking Symmetric Ciphers

- Goal: given c, learn something about m
- Note: if something about k can be learned, the attack is successful. Why?
- Attack Scenarios:
  - Ciphertext-only-attack
    - Attcker knows c
  - Known-plaintext attack
    - For a fixed k, the attacker got a pair (m, c) and tries to learn something about other ciphertexts
  - Chosen-plaintext and chosen-ciphertext attack.
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- Examples in networks
  - passively sniffing attacker: usually ciphertext-only
  - attacking a server: chosen-plaintext
  - replaying eavesdropped modified messages: chosen-ciphertext

Security of Ciphers

Disclaimer: hand-waving idea. This is not a cryptography course.

- A cipher is secure if the best known attack is brute-forcing all keys.
- Brute-Force: exhaustively testing all keys

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  - needs about 10^{22} years to brute-force the whole key space.
  - On average, only half of the possible keys must be tried, ...
  - only $5 \cdot 10^{21}$ years necessary

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- Only knowledge of *k* reveals the right *m*
- OTP is a perfect cipher
- Attack scenarios in details
  - Ciphertext-only: No attack possible; any possible plaintext can be generated with the ciphertext.
  - Pairs of *c* and *m* don't help:
    The *otp* can be calculated, but this *otp* won't be reused!
  - Any statistical attack: due to *otp*, the ciphertext is perfectly random!

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    - If m is not perfectly random, c cannot be perfectly random
  - Cipher is still secure

Example: iCry – insecure cryptographic cipher

- $k \in \mathbb{B}^4$ key of length 4 bit
- Split m into blocks of 4 bit each: $m = m_1\ m_2\ m_3 \ldots$
- Encrypt each block individually with $\oplus$
- $\mathrm{Enc}_k(m_i) = m \oplus k$
- Example: encrypting "L"
  - $m = \texttt{ord('L')} = \texttt{0x4c} = 0100_b\ 1100_b$
  - $k = 1010_b$
  - $c = \texttt{0xe6}$ (not an ASCII char)

	m_1:0100	m_2:1100
$\oplus$	k:1010	k:1010
	c_1:1110	c_2:0110

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  - Attacker can now read all future messages encrypted with this k

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0100	10100010	[not an ASCII char]
0101	10110011	[not an ASCII char]
0110	10000000	[not an ASCII char]
0111	10010001	[not an ASCII char]
1000	01101110	n
1001	01111111	[non-printable ASCII char]
1010	01001100	L
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- (because k is reused)

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- Stream cipher
  - Generates a random bitstream, called keystream
  - $c = keystream \oplus m$
  - Examples: ChaCha20, RC4 (broken!)

Example: Block Cipher AES-128

- AES-128
  - blocks size: 128 bit (16 bytes)
  - key size: 128 bit
- m = “This is network.”
- $\texttt{len}(m)$ = 16 bytes
- k = 128 truly random bits
- $\text{Enc}_k(m)$ = 2d 3c ab 1b a0 80 77 ec e8 1d 56 0d 09 2b f6 77

Example: Some Stream Cipher

- m = "HELLO" = `48 45 4c 4c 4f`
- k = `streamcipher.get_keystream_bytes(5)` = `12 a7 f9 07 55`
- $\mathrm{Enc}_k(m) = k \oplus m$ = `5a e2 b5 4b 1a`

	0100 1000	0100 0101	0100 1100	0100 1100	0100 1111
$\oplus$	0001 0010	1010 0111	1111 1001	0000 0111	0101 0101
	0101 1010	1110 0010	1011 0101	0100 1011	1000 1010

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- Reasons to use AES
  - Fast: 200 MBit/s in software and $>$ 2 GB/s with Intel AES-NI
  - Hardware implementations for embedded devices available
  - A well-tested implementation is available in your library
  - Secure (attacks exist, but AES is practically secure)
  - AES seems to be the best we have, and it is among the most researched algorithms

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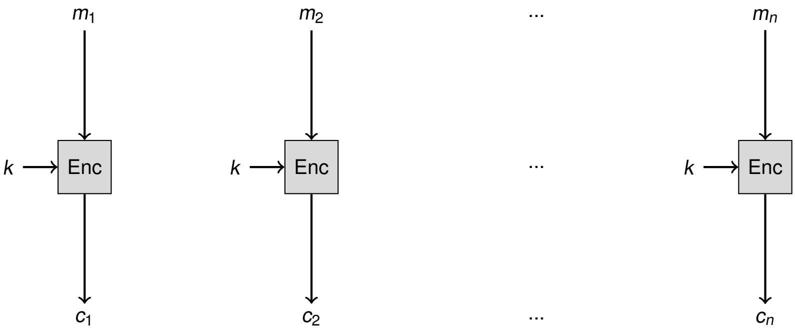
- We split m into blocks m_i where length(m_i) = x
- $m = m_1 \; m_2 \; \dots \; m_n$
- if length(m) is not a multiple of x, the last block is filled up
- Technical Term: padding

Electronic Code Book Mode – ECB

- $c_i = \text{Enc}_k(m_i)$



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- *m* = "This is network.This is network.Security"
- Enc = AES-128, mode = ECB
- *c* =

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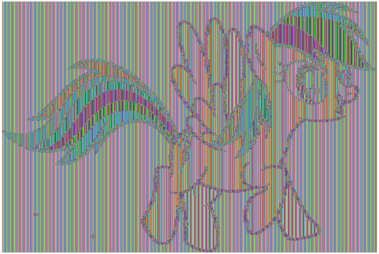
- Why are line 1 and line 2 identical?
- m_1 = “This is network.”
- m_2 = “This is network.”
- m_3 = “Security” + padding

Electronic Code Book Mode – ECB
Drawback

- Identical plaintext blocks are encrypted to identical ciphertext!



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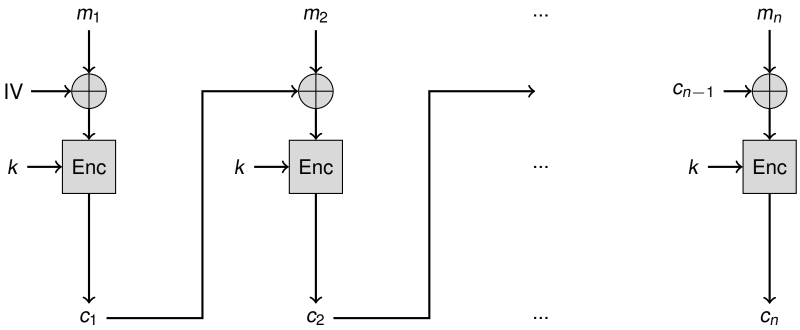

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  - Identical plaintext blocks are encrypted to non-identical ciphertext
- $c_0 = \mathrm{IV}$
- What is the use of the IV (initialization vector)?
  - Completely identical messages are encrypted to non-identical ciphertexts

Cipher Block Chaining Mode – CBC

- CBC Encrypt: $c_i = \text{Enc}_k(c_{i-1} \oplus m_i)$
- Why the $\oplus$ with the previous block?
  - Identical plaintext blocks are encrypted to non-identical ciphertext
- $c_0 = \text{IV}$
- What is the use of the IV (initialization vector)?
  - Completely identical messages are encrypted to non-identical ciphertexts
- IV may be public
- IV must be fresh

Cipher Block Chaining Mode – CBC

- Sending *m* encrypted over UDP, using CBC.
- *m* is split into blocks for the block cipher.
- $m = m_1\ m_2\ m_3\ m_4\ m_5\ m_6$
- *m* is split over two UDP packets.
- A new and random IV is put in clear at the beginning of the payload of every packet.

IP header
UDP header
IV_1
c_1 c_2 c_3

IP header
UDP header
IV_2
c_4 c_5 c_6

Cipher Block Chaining Mode – CBC
Decrypt

- CBC Encrypt: $c_i = \mathrm{Enc}_k(c_{i-1} \oplus m_i)$
- $c_0 = \mathrm{IV}$

Cipher Block Chaining Mode – CBC
Decrypt

- CBC Encrypt: $c_i = \text{Enc}_k(c_{i-1} \oplus m_i)$
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- Let's do the math:

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Cipher Block Chaining Mode – CBC
Decrypt

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- $c_0 = \text{IV}$
- Let's do the math:
- $c_i = \text{Enc}_k(c_{i-1} \oplus m_i)$
- $\text{Dec}_k(c_i) = \text{Dec}_k(\text{Enc}_k(c_{i-1} \oplus m_i))$

Cipher Block Chaining Mode – CBC
Decrypt

- CBC Encrypt: $c_i = \mathrm{Enc}_k(c_{i-1} \oplus m_i)$
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- $\mathrm{Dec}_k(c_i) = \mathrm{Dec}_k(\mathrm{Enc}_k(c_{i-1} \oplus m_i))$
- $\mathrm{Dec}_k(c_i) = c_{i-1} \oplus m_i$

Cipher Block Chaining Mode – CBC
Decrypt

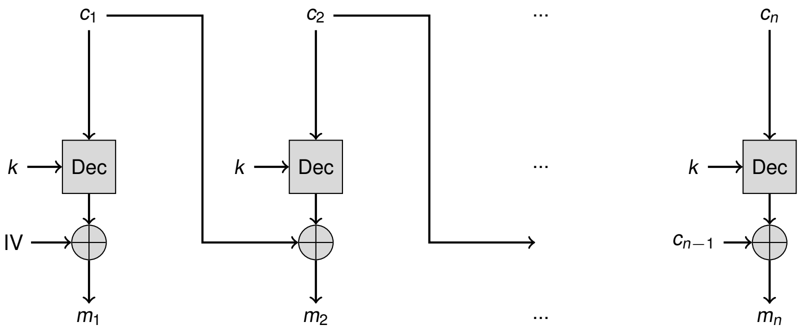
- CBC Encrypt: $c_i = \text{Enc}_k(c_{i-1} \oplus m_i)$
- $c_0 = \text{IV}$
- Let's do the math:
- $c_i = \text{Enc}_k(c_{i-1} \oplus m_i)$
- $\text{Dec}_k(c_i) = \text{Dec}_k(\text{Enc}_k(c_{i-1} \oplus m_i))$
- $\text{Dec}_k(c_i) = c_{i-1} \oplus m_i$
- $\text{Dec}_k(c_i) \oplus c_{i-1} = m_i$

Cipher Block Chaining Mode – CBC
Decrypt

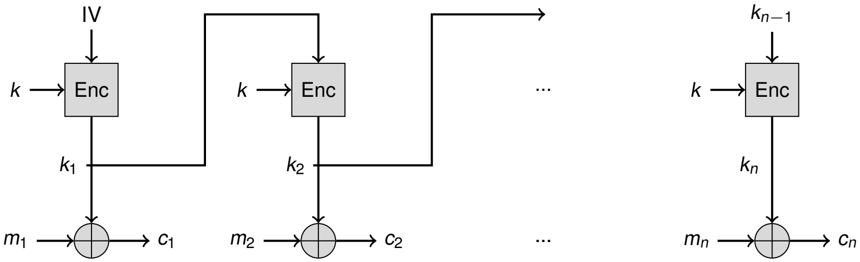
- CBC Encrypt: $c_i = \text{Enc}_k(c_{i-1} \oplus m_i)$
- $c_0 = \text{IV}$
- Let's do the math:
- $c_i = \text{Enc}_k(c_{i-1} \oplus m_i)$
- $\text{Dec}_k(c_i) = \text{Dec}_k(\text{Enc}_k(c_{i-1} \oplus m_i))$
- $\text{Dec}_k(c_i) = c_{i-1} \oplus m_i$
- $\text{Dec}_k(c_i) \oplus c_{i-1} = m_i$
- CBC-Decrypt: $m_i = c_{i-1} \oplus \text{Dec}_k(c_i)$

Cipher Block Chaining Mode – CBC

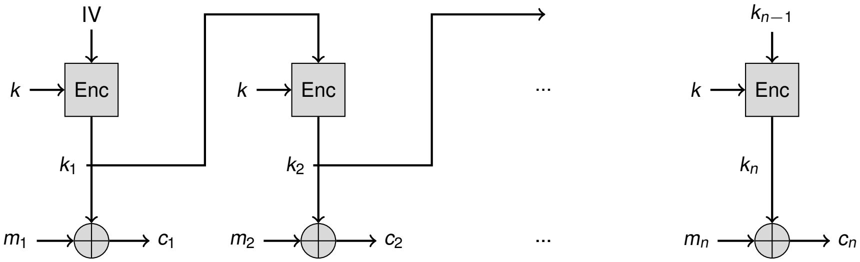
Decrypt



Output Feedback Mode – OFB
Encrypt

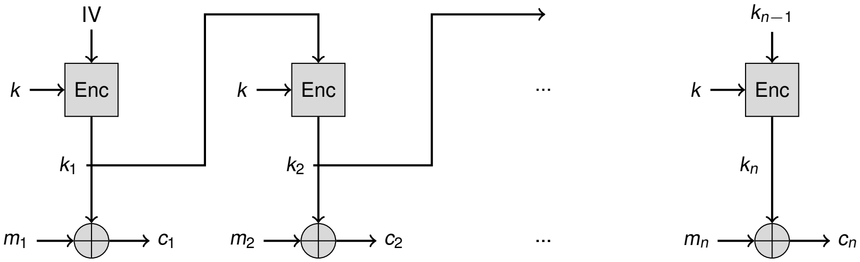


Output Feedback Mode – OFB
Encrypt



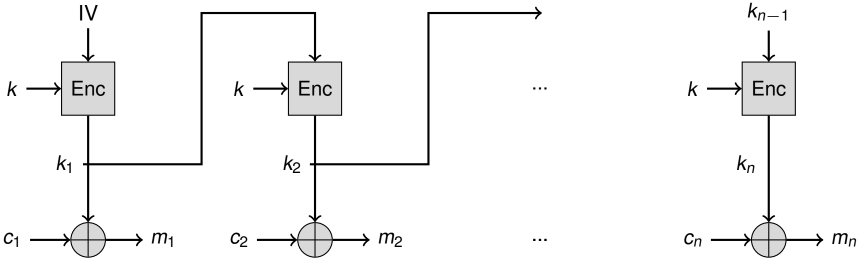
- Transforms a block cipher into a stream cipher.

Output Feedback Mode – OFB
Encrypt



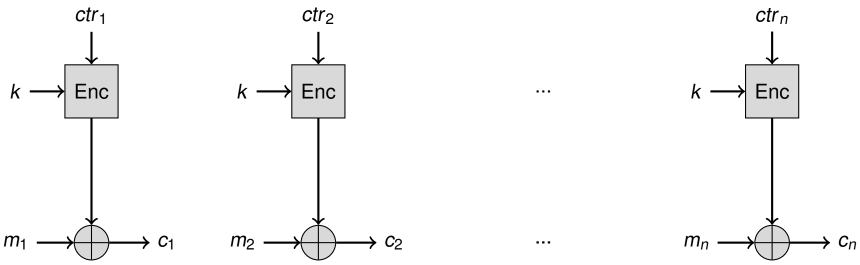
- Transforms a block cipher into a stream cipher.
- IV may be public but must be fresh.

Output Feedback Mode – OFB
Decrypt



Counter Mode – CTR

- ctr_i = IV || i



Counter Mode – CTR

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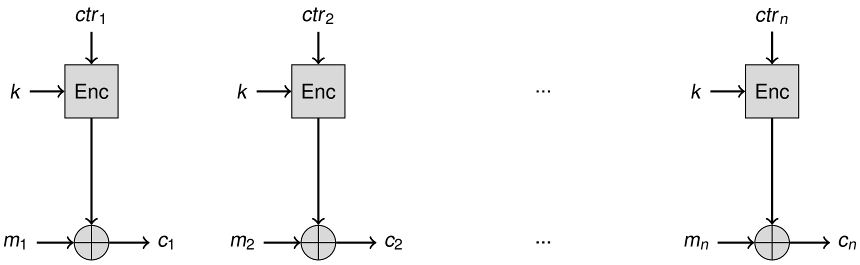

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Counter Mode – CTR

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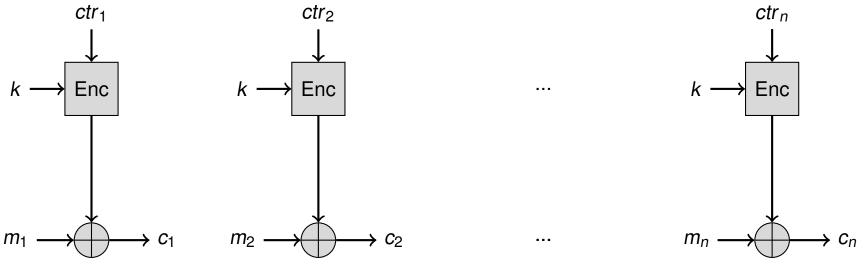

- Transforms a block cipher into a stream cipher.
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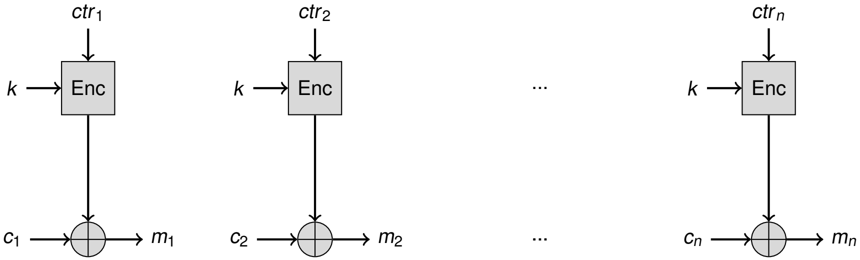
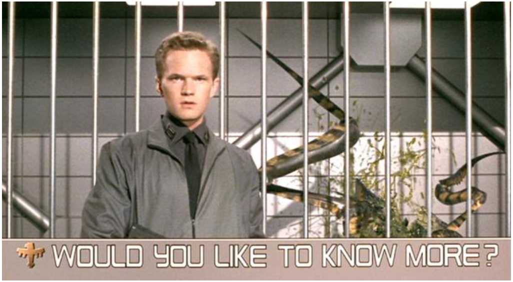
Counter Mode – CTR
Decrypt

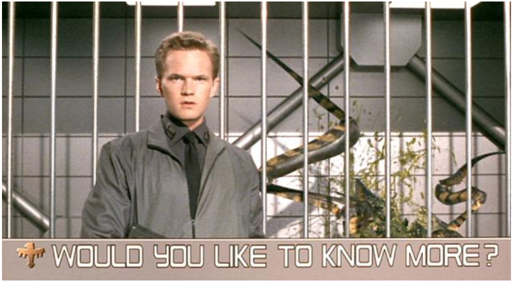


Counter Mode – CTR



- Jonathan Katz and Yehuda Lindell, *Introduction to Modern Cryptography*, 2nd edition, CRC Press, 2015
- Filippo Valsorda, *The ECB Penguin*, PyTux Blog, 2013, `https://filippo.io/the-ecb-penguin/`
- Günter Schäfer, *Security in Fixed and Wireless Networks: An Introduction to Securing Data Communications*, Wiley, 2004
- Günter Schäfer, *Netzsicherheit*, dpunkt, 2003

Counter Mode – CTR



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