Hashes, MACs & Authenticated Encryption

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Today's Lecture

- Hashes and Message Authentication Codes
  - Properties of Hashes and MACs
  - CBC-MAC, MAC -> HASH (slow),
  - SHA1, SHA2, SHA3
  - HASH -> MAC, HMAC

- Authenticated Encryption
  - CCM

Hashes

- A hash of any message is a short string generated from that message.
- The hash of a message is always the same.
- Any small change makes the hash totally different.
- It is very hard to go from the hash to the message.
- It is very unlikely that any two different messages have the same hash.

Signatures

- Using RSA $E_{pub}(D_{priv}(M)) = M$
- This can be used to sign messages.
- Sign a message with the private key and this can be verified with the public key.
- Any real crypto suite will not use the same key for encryption and signing.
  - as this can be used to trick people into decrypting.

Signatures

Alice has a signing key Ks

and wants to sign message M

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Detached Signature: $D_{ks}(\#(M))$

- Firstly hash message
- Secondly, decrypt with private key ks

Uses of Hashing

- Download/Message verification
- Tying parts of a message together (hash the whole message)
- Hash message, then sign the hash.
- Protect Passwords
  - Store the hash, not the password

- Hash of VM

- md5 VM
- shasum VM
- shasum -a 512 VM

Attacks on hashes

- Preimage Attack: Find a message for a given hash: very hard.
- Prefix Collision Attack: a collision attack where the attacker can pick a prefix for the message.
- Collision Attack: Find two “random” messages with the same hash.

Birthday Paradox

- How many people do you need to ask before you find 2 that have the same birthday?
- 23 people, gives (23*22)/2 = 253 pairs.
- Prob. that two people have a different birthday is: 364/365
- $(364/365)^{(23*22/2)} = 0.4995$

Message Authentication Codes

- MACs are hashes with a key.
  - Written $MAC_{Key}(M)$
- You can only make or check the hash, if you know the key.
- Stops guessing attacks.

Message Authentication Codes

- MACs are sometimes used for authentication:
  - E.g. in Alice and Bank share keyA, Alice sends to the bank:
    "Pay Bob £10",MAC_{keyA}("Pay Bob £10")

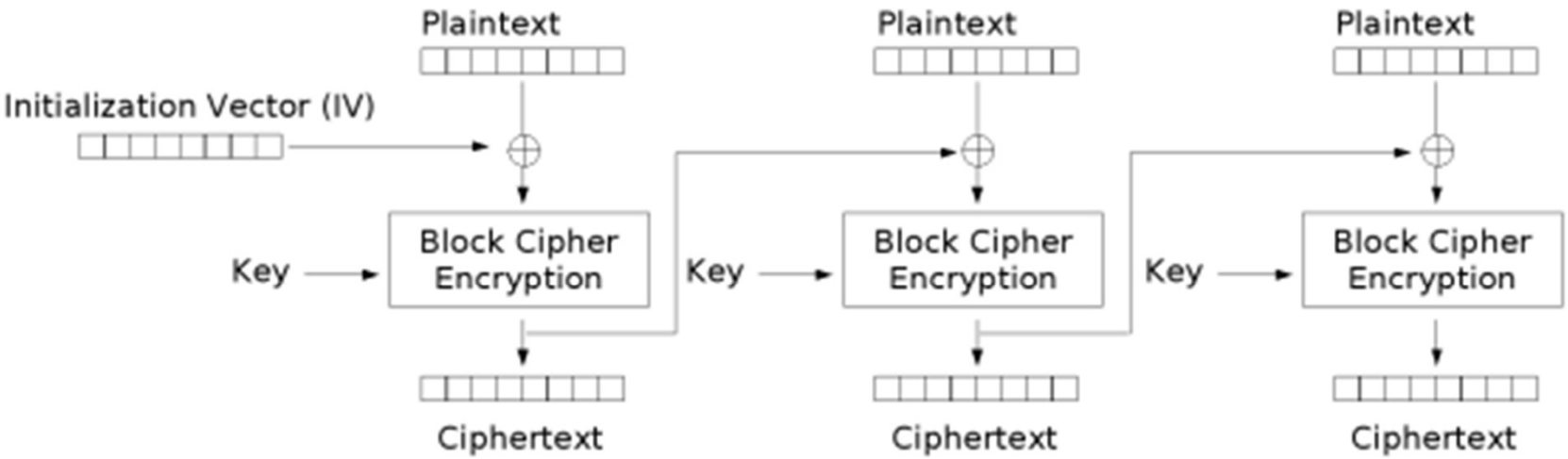
Possible attack on MAC: "Length extension attack" add data to a MAC without knowing the key

How can we make a MAC?

Must have:

- A Key
- Short string from long message.
- Single bit change in message = totally different hash.
- Hard to go from the hash to the message.
- Unlikely that any two different messages have the same hash.

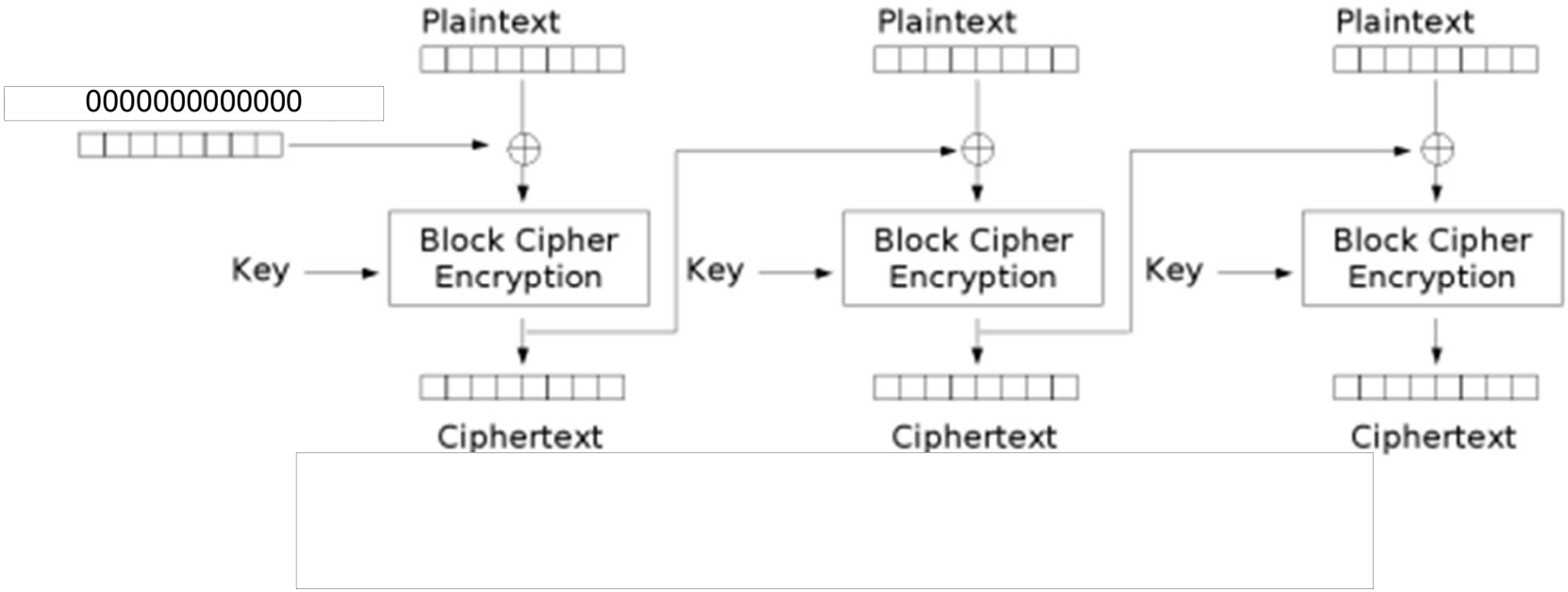
CBC Encryption



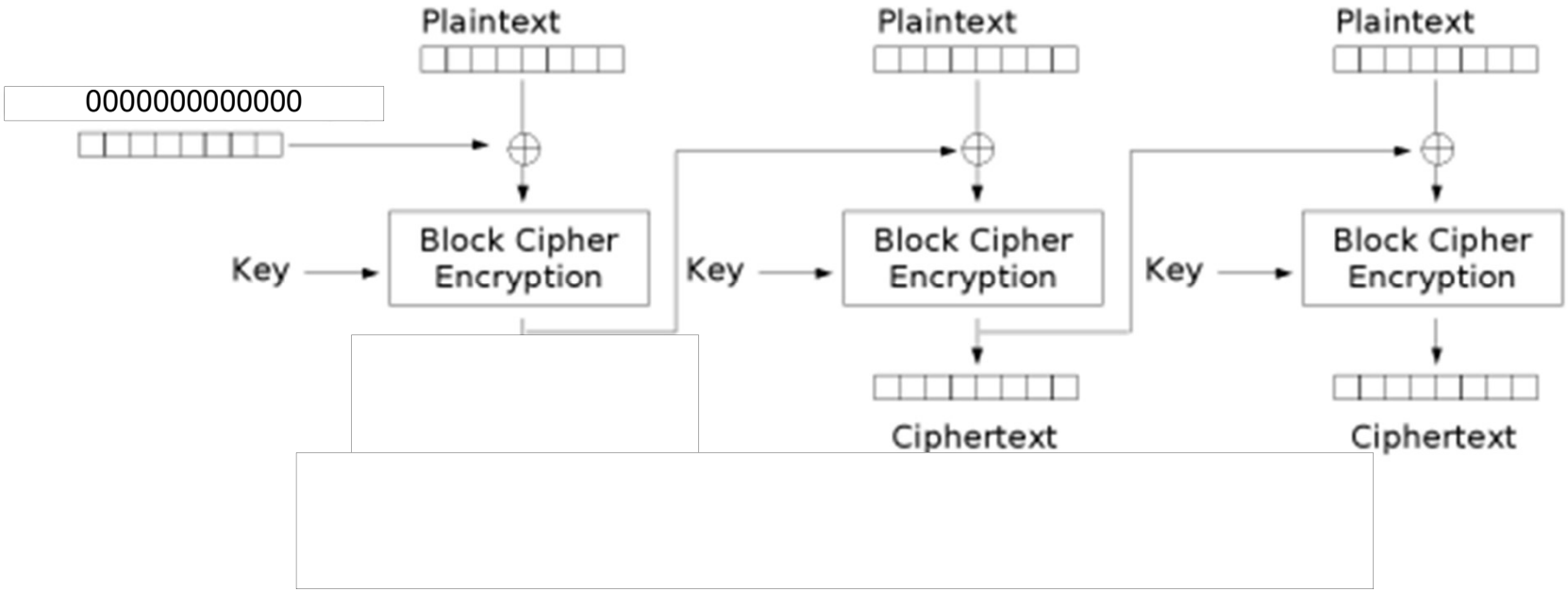
Cipher Block Chaining (CBC) mode encryption

http://en.wikipedia.org/wiki/Block_cipher_modes_of_operation

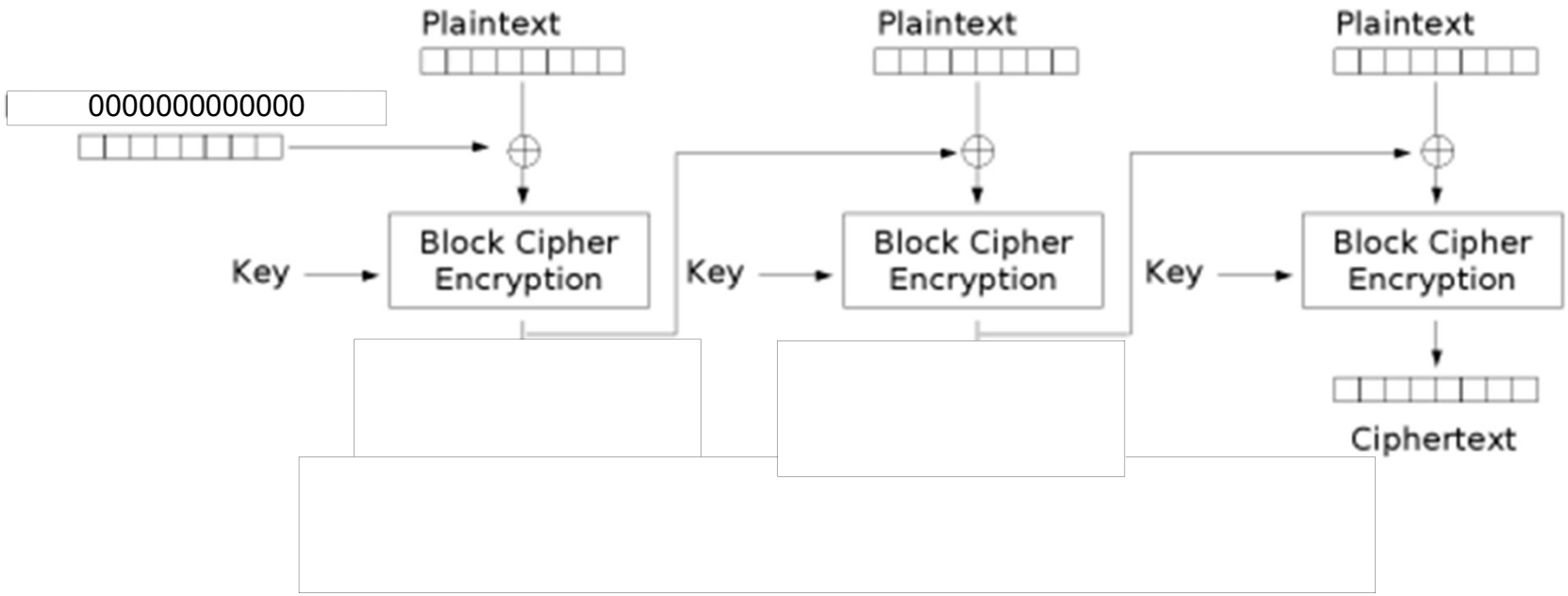
Making a CBC MAC



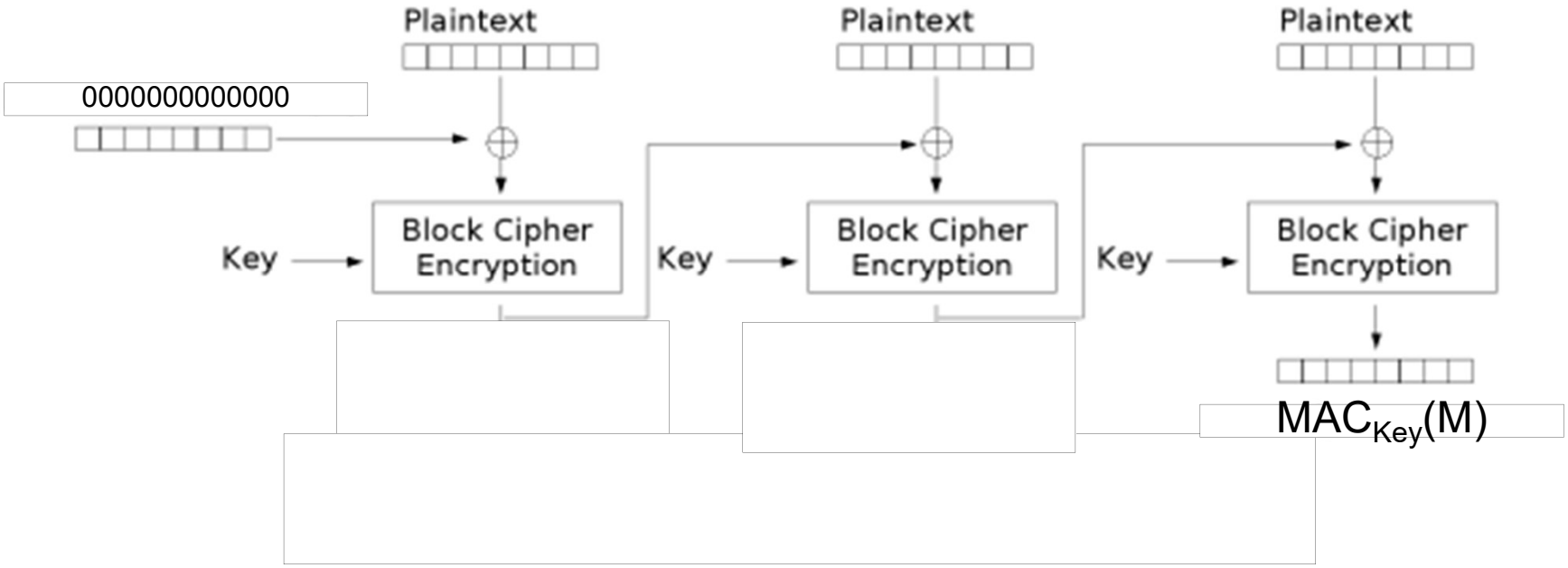
Making a CBC MAC



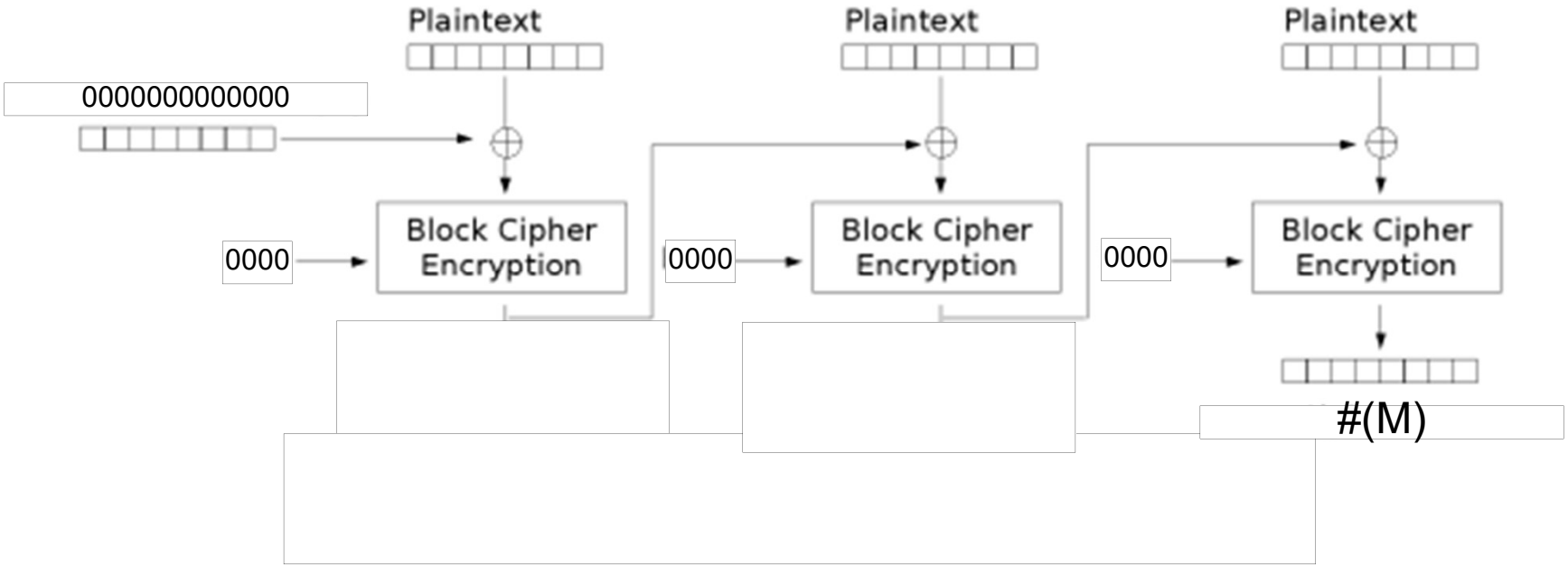
Making a CBC MAC



CBC MAC


Plaintext
Plaintext
Plaintext
0000000000000
Key
Block Cipher Encryption
Key
Block Cipher Encryption
Key
Block Cipher Encryption
MAC$_{Key}$(M)

An Inefficient Hash Function



The SHA Family of Hash

- The most common (and best) hashes are the SHA hashes.
- 1993, The US National Institute of Standards and Technology (NIST), developed a new hash SHA-0
- 1995, the NSA stepped in and “fixed” it: SHA-1 (160-bit hash).

SHA1

- A birthday attack on SHA-1 should need 2^80 hash tests
- In 2005 a 2^63 attack was found.
- Not really practical, but no-one trusts SHA-1 any more.
- So … SHA-2

SHA2

- SHA2 is an improved version of SHA1 with a longer hash.
- 256 or 512 bits: also called SHA256, SHA512.
- Based on SHA-1 it has some of the same weaknesses. So, even though it seems secure the cryptographers aren't happy.

The SHA-3 Competition

- Submissions opened on October 31, 2008,

- Round 1
  - 13 submissions rejected without comment.
  - 10 withdrawn by authors.
  - 16 rejected for design or performance.
    - Inc. Sony's
- Conference in Feb 2009. 14 scheme picked to go through to round 2.
  - Dropped schemes include
    - Ron Rivest's,
    - Lockheed Martin

The SHA-3 Competition

- Winner announced on October 2, 2012 as Keccak, (Daemen et al. the AES guy)
- Adopted as NIST-standard in 2015

Merkle–Damgård (MD) Hashes

- The MD family of hashes is also popular.
- MD4 & MD5 used, but weak.
  - Only useful when we only care about preimage attacks or Integrity.
- MD6: Ron Rivest's candidate for SHA3.
  - Seems good & fast.

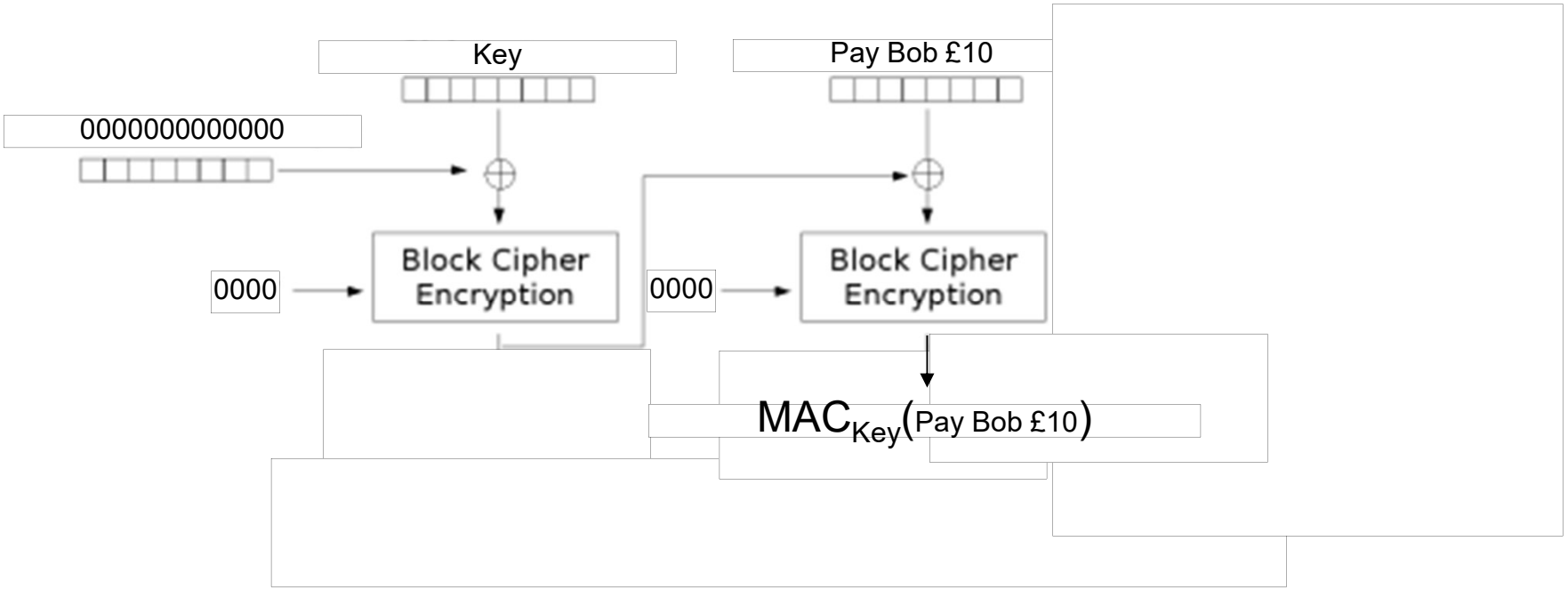
Broken Hash to MAC

- If we had a Hash we could try to make a MAC by:

$$MAC_{Key}(M) = H(Key,M)$$

- But this might allow a length extension attack.

Broken Hash to MAC

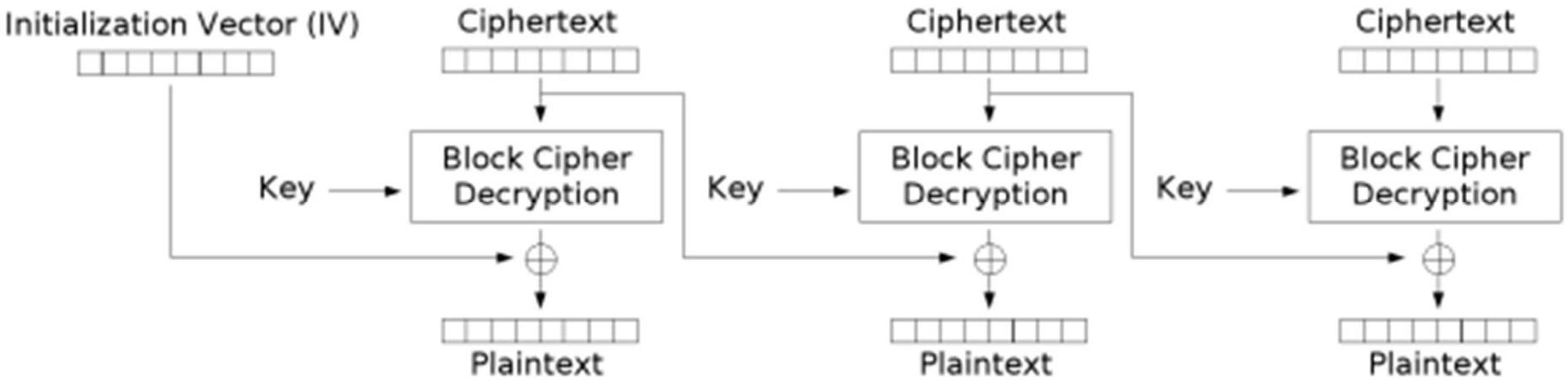


Only Alice and the Bank know “Key”
Alice sends “Pay Bob £10,MAC_{Key}(Pay Bob £10)” to Bank

Cipher Texts Can Be Altered

- AES encryption with a particular key maps any 128-bit block to a 128-bit block (or 256)
- AES decrypt also maps any 128-bit block to a 128-bit block.
- Decrypt can be run on any block (not just encryptions).

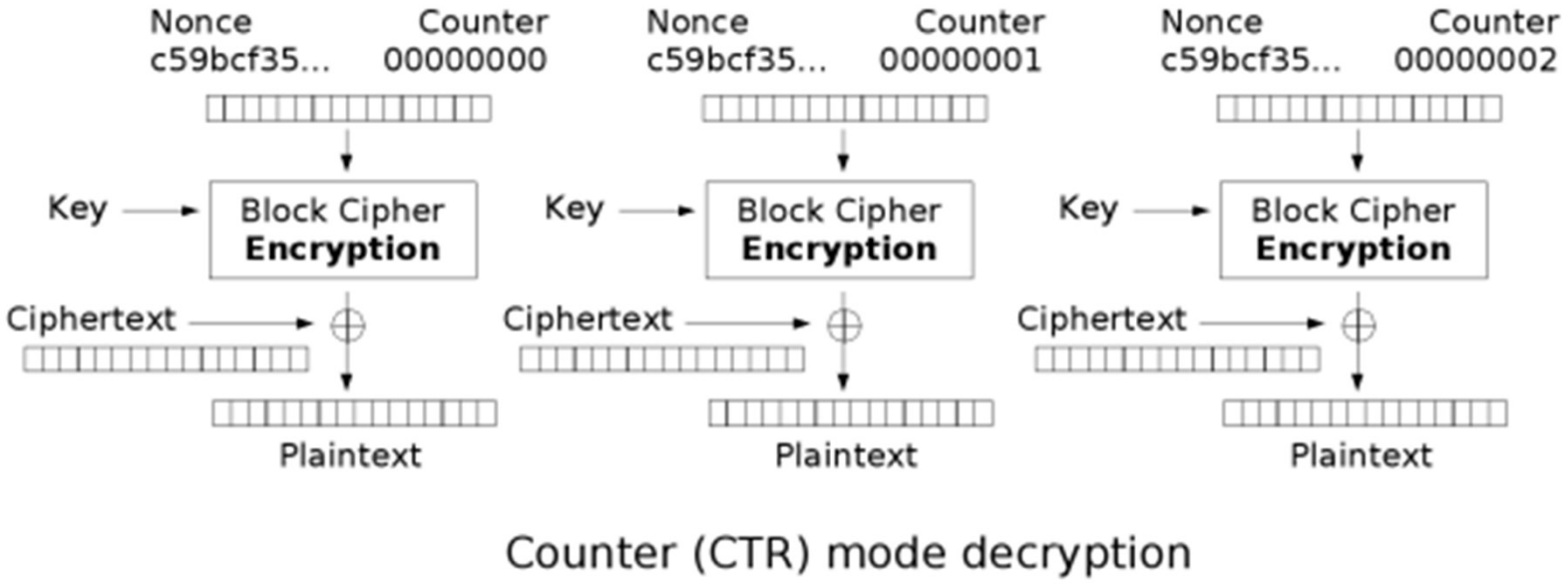
CBC decrypt



Cipher Block Chaining (CBC) mode decryption

http://en.wikipedia.org/wiki/Block_cipher_modes_of_operation

CTRdecrypt



Counter (CTR) mode decryption

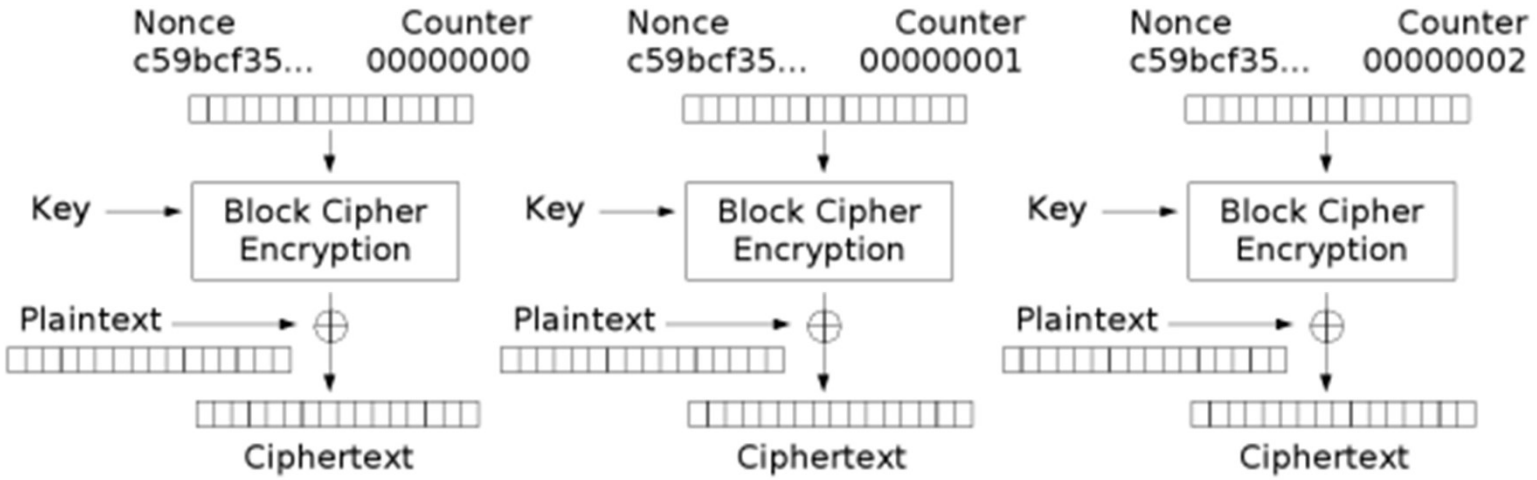
http://en.wikipedia.org/wiki/Block_cipher_modes_of_operation

Block mode

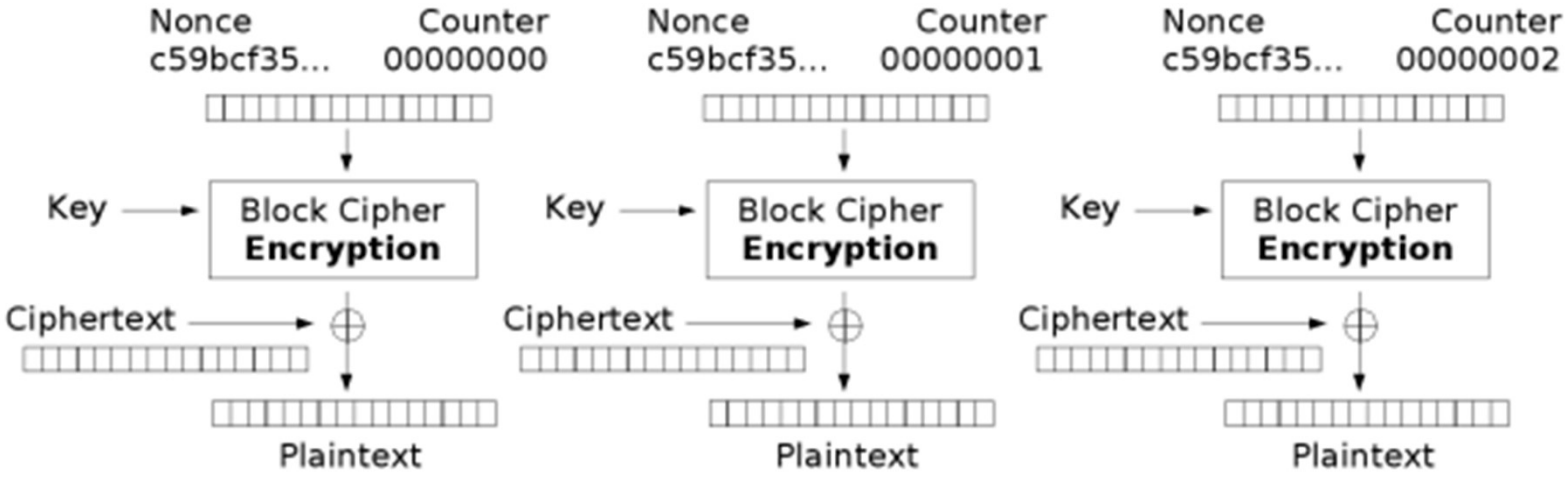
- CBC mode: any change affects all of the rest of the message.
- ECB mode: any change affects only the block.
- CTR mode: any change affects only the bits altered.

Known Plain Text Attacks

- If I know the plaintext I can change CTR encrypted messages. (see previous lecture)



Counter (CTR) mode encryption



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Authenticated Encryption Modes

- Authenticated encryption modes stop this.
- With Authenticated Encryption you can only form a valid ciphertext if you know the key.
- Most common way to do this is to add a MAC to the ciphertext.

CCM mode encryption

- First calculate an AES CBC-MAC on the data.
- Then encrypt the message followed by the MAC using the same key and CTR mode.
- Not rocket science, but proven secure
  - Fully defined as RFC 3610

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