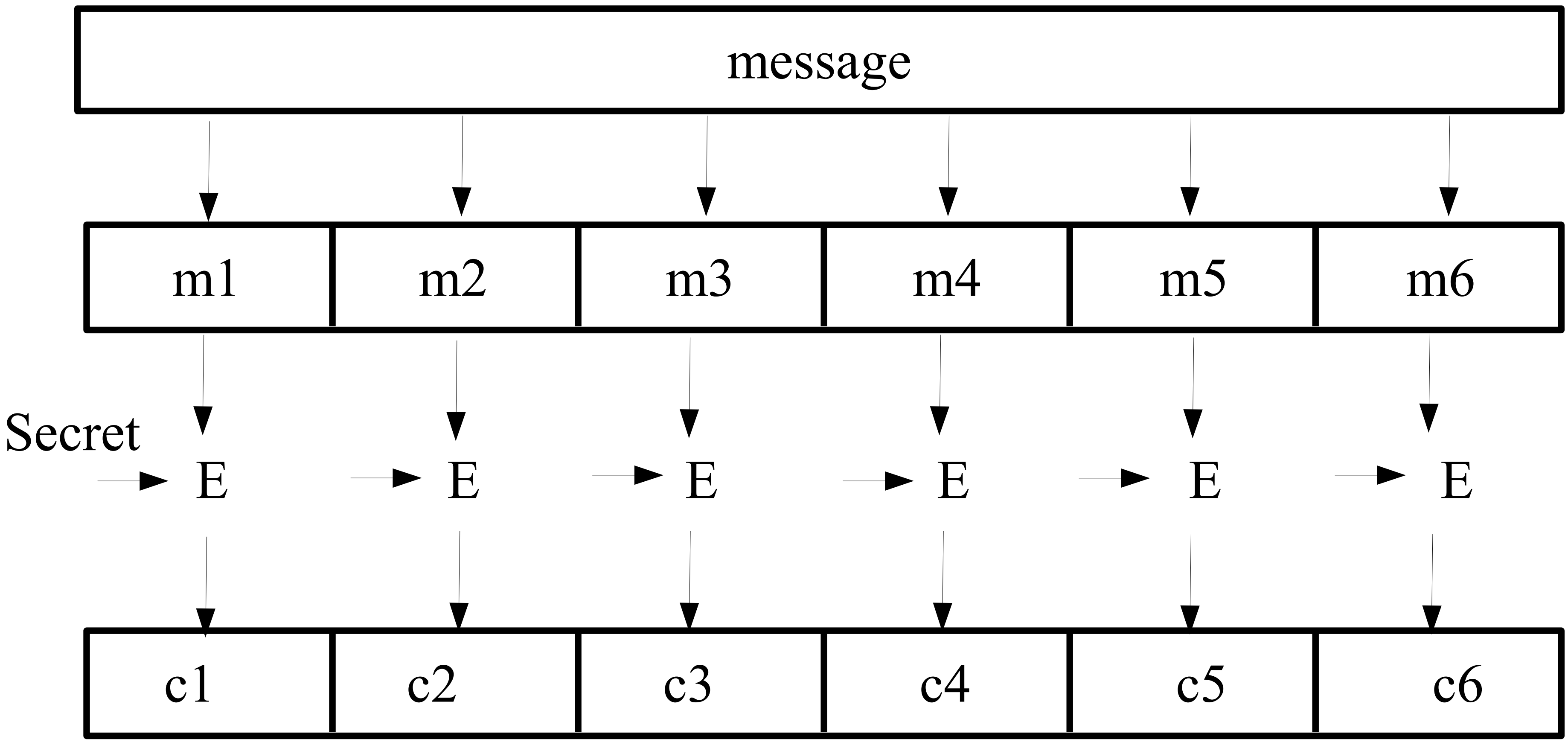
Block Cipher

Encrypting a large message

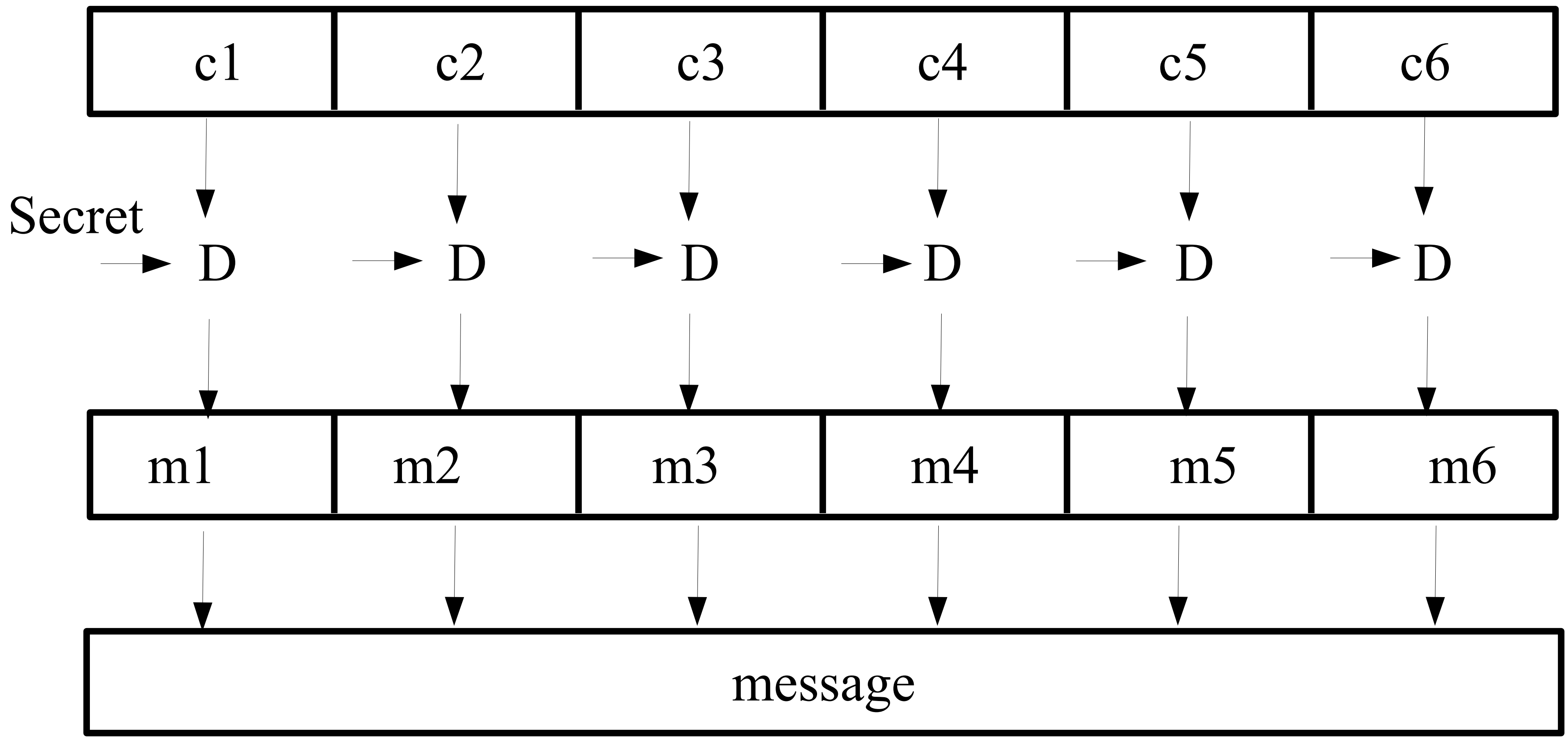
Electronic Code Book (ECB)



Block Cipher

Decrypting a large message

Electronic Code Book (ECB)



Block Cipher

En/Decrypting a large message

Electronic Code Book (ECB)

Problems:

Two same message blocks encrypt to the same cipher blocks

1. Two cipher blocks can be switched
2. One cipher block can be copied to another
   - ex: switch or copy salary block
3. No built-in integrity or authentication check

Possible fix: have many keys, one for each block

Recurring phrases cause repeated part-blocks of ciphertext

Plaintext patterns become obvious under codebook attack

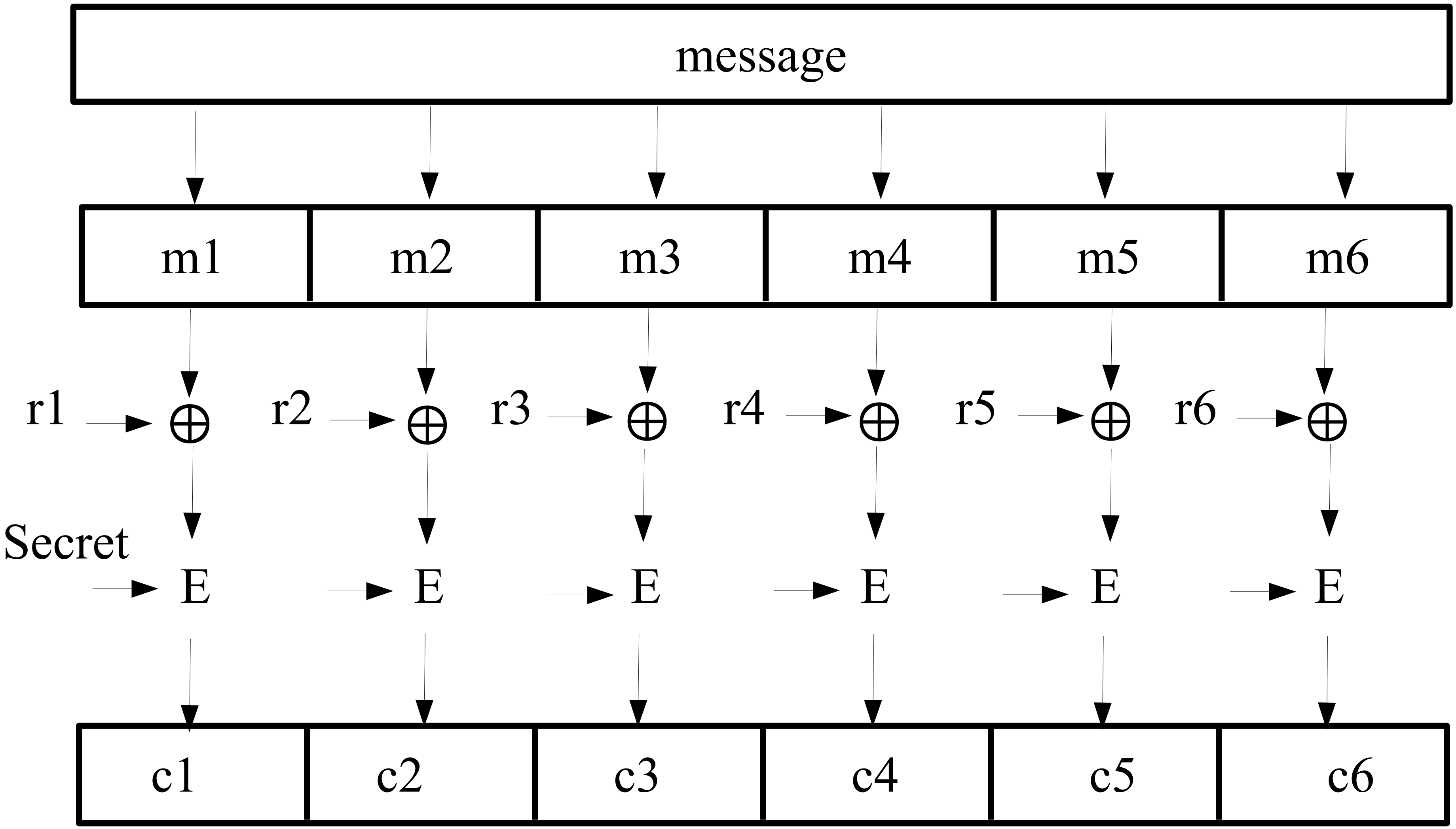
If attacker can dupe sender into sending known plaintext...

Possible fix: send large blocks and add random bits to each

Block Cipher

Encrypting a large message

Cipher Block Chaining (CBC) – 1st attempt   r1…r6 are random



Block Cipher

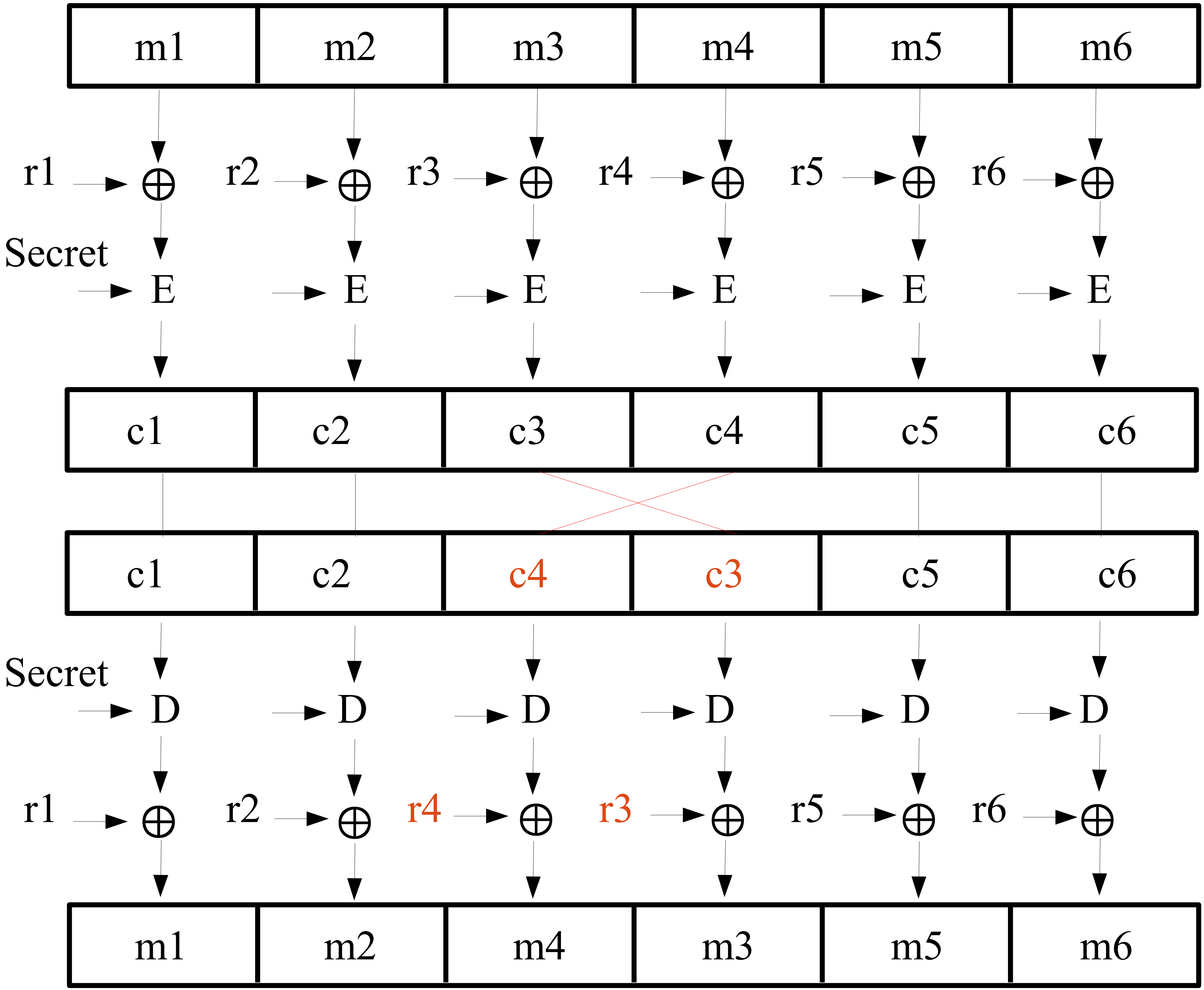
En/Decrypting a large message

Cipher Block Chaining (CBC) - 1st attempt

Problems:

1. Not efficient – one random number for every message block
2. Attacker can rearrange blocks with predictable effect on resulting plaintext. For example, just remove one block or swap two blocks - result can still be decrypted and receiver does not know the difference.
3. If an attacker knows the value of any message block mi, then can change it in a predictable way by modifying ri.

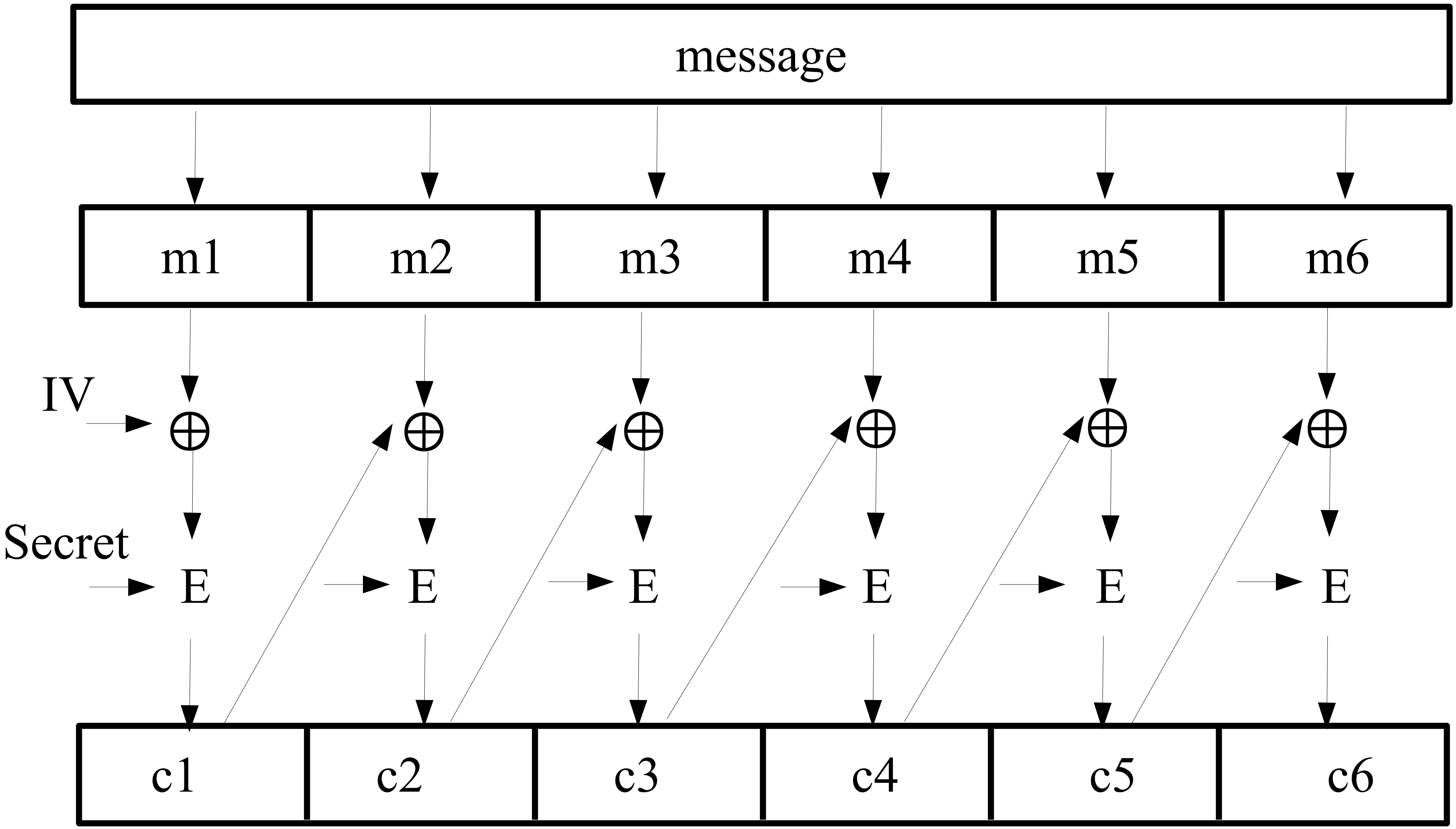
   Since random ri are sent with the message, attacker can modify them


m1
m2
m3
m4
m5
m6
r1
r2
r3
r4
r5
r6
Secret
E
E
E
E
E
E
c1
c2
c3
c4
c5
c6
c1
c2
c4
c3
c5
c6
Secret
D
D
D
D
D
D
r1
r2
r4
r3
r5
r6
m1
m2
m4
m3
m5
m6

Block Cipher

Encrypting a large message

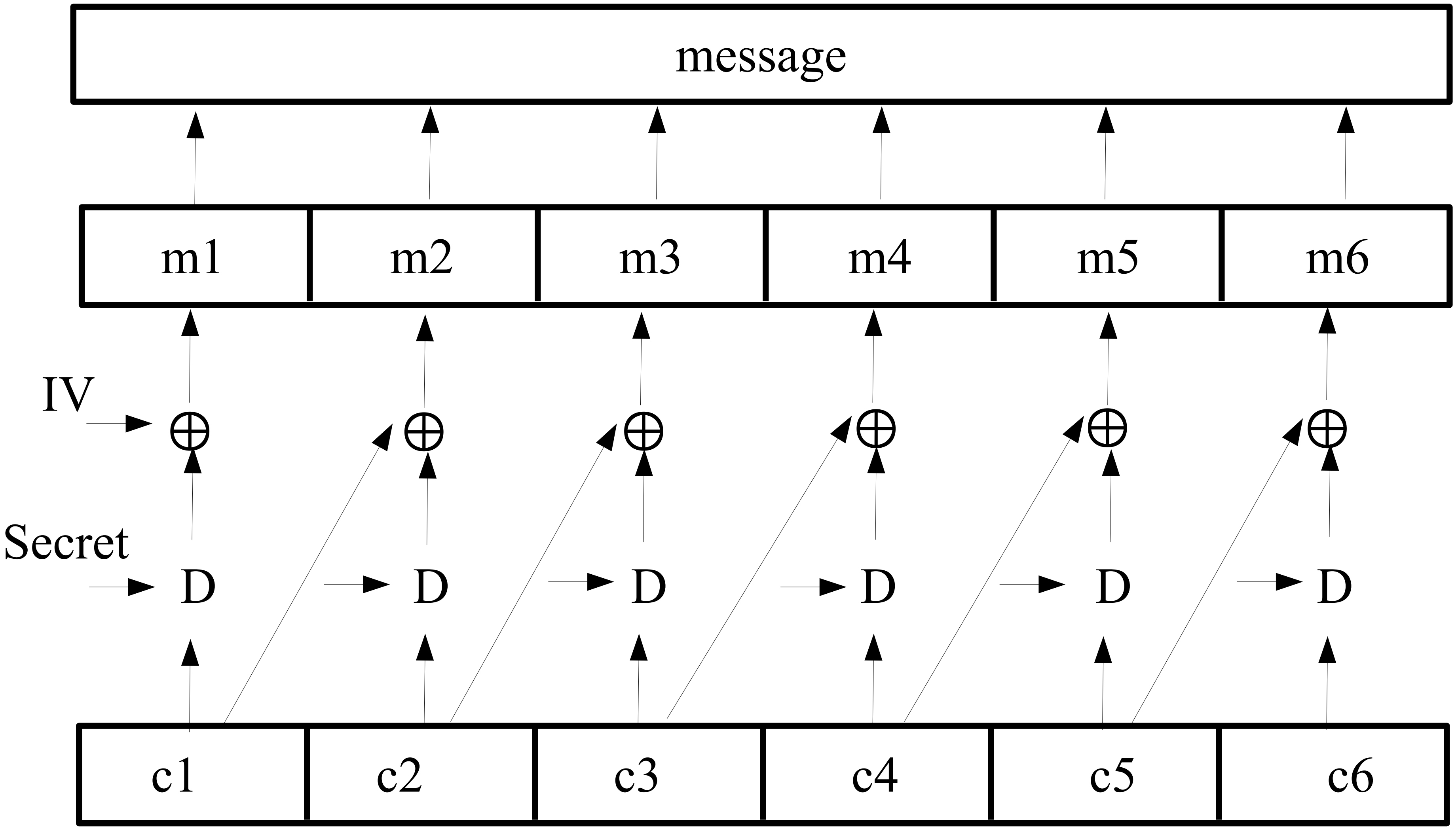
Cipher Block Chaining (CBC)   IV is a random number



Block Cipher

Decrypting a large message

Cipher Block Chaining (CBC)   IV is a random number



Block Cipher

En/Decrypting a large message

Cipher Block Chaining (CBC)

Discussion:

1. Must use random IV – guarantees that same plaintext causes different ciphertext
   If IV is not random, information is revealed even if message not decrypted
   Examples:
      commander orders troops to hold several times then attack
      If salary fields are known, can determine whose salary has changed
   Benefit:
      attackers cannot supply chosen plaintext to the encryption algorithm
      itself, even if chosen plaintext can be supplied to the CBC

Block Cipher

En/Decrypting a large message
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2. Attacker can rearrange blocks with predictable effect on resulting plaintext.
   Changing c_i has a predictable effect on m_{i+1}. Might decrypt to this:

Hello	7834	→	&8*#	7835

Block Cipher

En/Decrypting a large message

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3. If $m_1 \ldots m_n$ and $c_1 \ldots c_n$ and IV are known, all decryptions of c_i are known.
   If enough of these are obtained, a new ciphertext can be constructed and the decypt would be known.

Block Cipher

Entropy

Suppose the set of characters I transmit is {A} (i.e. one character)

What is the probability that the next character in a transmission stream is the character A?

Block Cipher

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Answer: 1 (we have complete predictability)

Block Cipher

Entropy

Suppose the set of characters I transmit is {A,B} (i.e. two characters)

What is the probability that the next character in a transmission stream is the character A if the stream characters are randomly selected for insertion?

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Pr(next one is A) = $1/n$

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Entropy expresses the minimum number of bits needed to encode a sequence of symbols.

Example: characters {A,B,C,D},
Pr(A) = ½, Pr(B)=¼ , Pr(C) = Pr(D) = ⅛
Let 1 be transmission of A, 01 be trans of B, 001 be C, 010 be D

Block Cipher

Entropy of a Symbol

Given alphabet $S=\{s_1, s_2, \ldots, s_n\}$ with probs $\{p_1, p_2, \ldots, p_n\}$ of occuring in message M of length m. Define entropy

$H(S) = -\sum_i p_i \log_2(p_i)$ for all non-zero p_i

Observe: if all p_i are equal, $H(S) = \log_2(n)$

if $p_1=1$, all other $p_i=0$, $H(S) = 0$.

if $p_1= ½$ and $p_2= ½$, other $p_i=0$, $H(S)=1$.

½ bit of entropy if p1 = 0.11002786.., p2 = 0.88997213...

If all probabilities are equal,

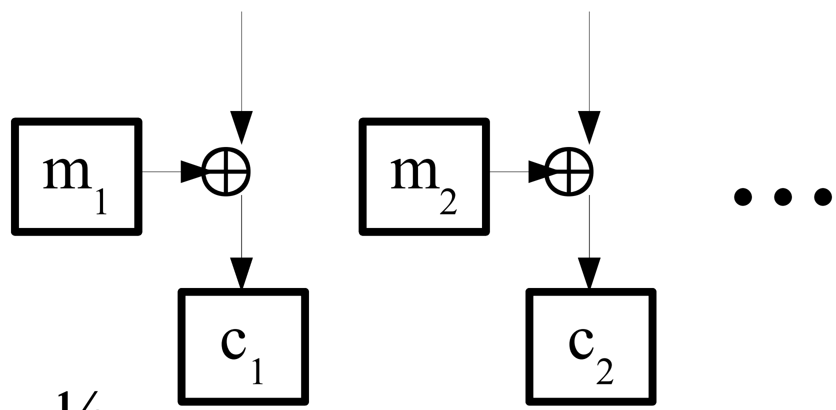
Pr(next character is A | prev char) = Pr(next character is A)

The higher the entropy the more secure the cryptosystem is

Block Cipher

Entropy and the xor operation

Let p_1 be the probability that 1 is the next message bit m_i and p_0 is the probability that 0 is the next m_i.



Then $\Pr(m_1 \oplus r_1 \text{ is } 0) = (½)p_1 + (½)p_0 = ½$

$\Pr(m_1 \oplus r_1 \text{ is } 1) = (½)p_0 + (½)p_1 = ½$

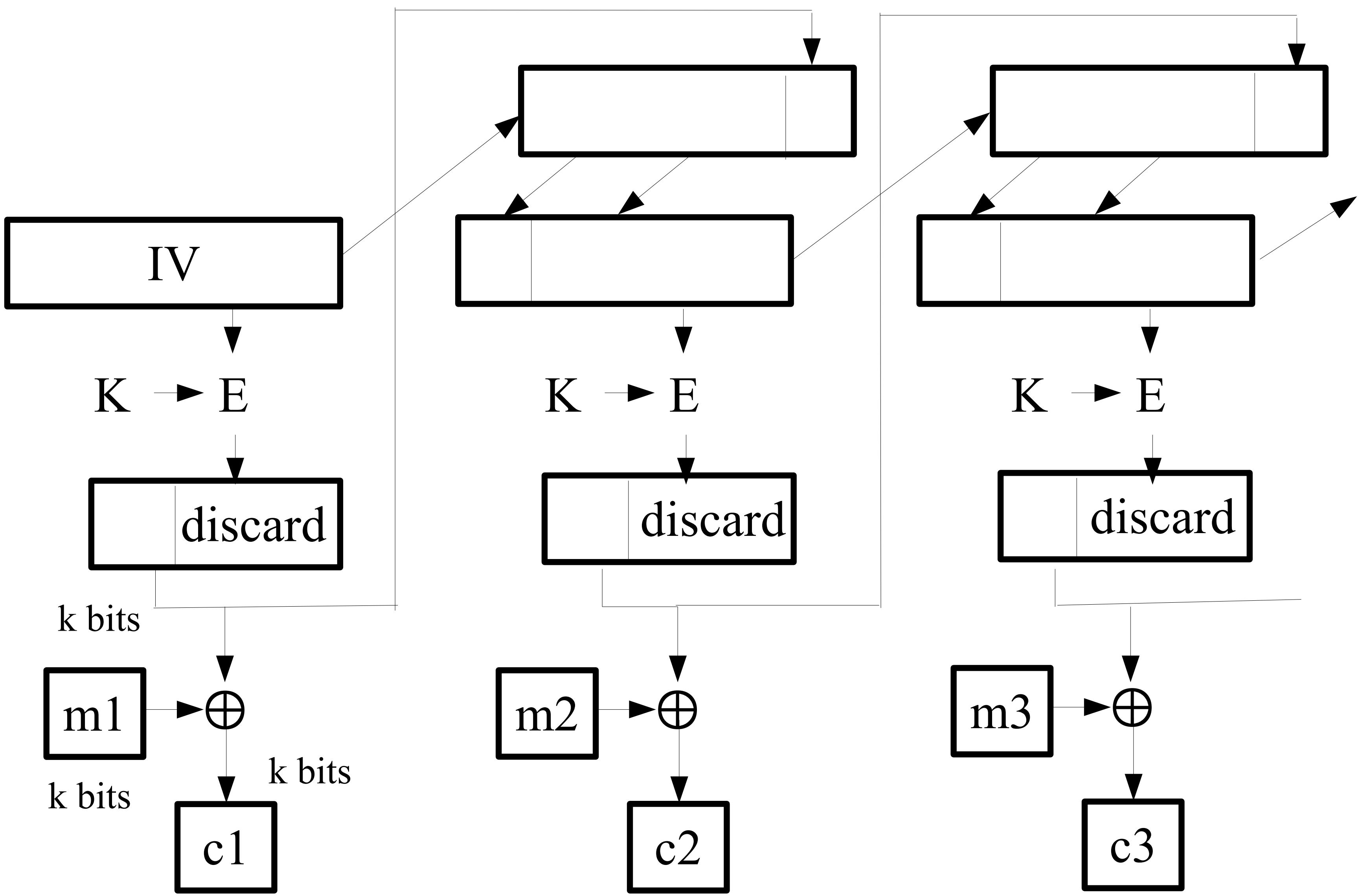
$H(c_i) = 1$ **Unconditionally secure**: $H(m_i \mid c_i) = H(m_i)$

Regardless of correlations in the message bits, the xor operation gives the highest entropy and greatest security!

Block Cipher

Encrypting a large message

Output Feedback Mode (OFB)   IV is a random number



Block Cipher

En/Decrypting a large message

Output Feedback Mode vs Cyber Block Chaining

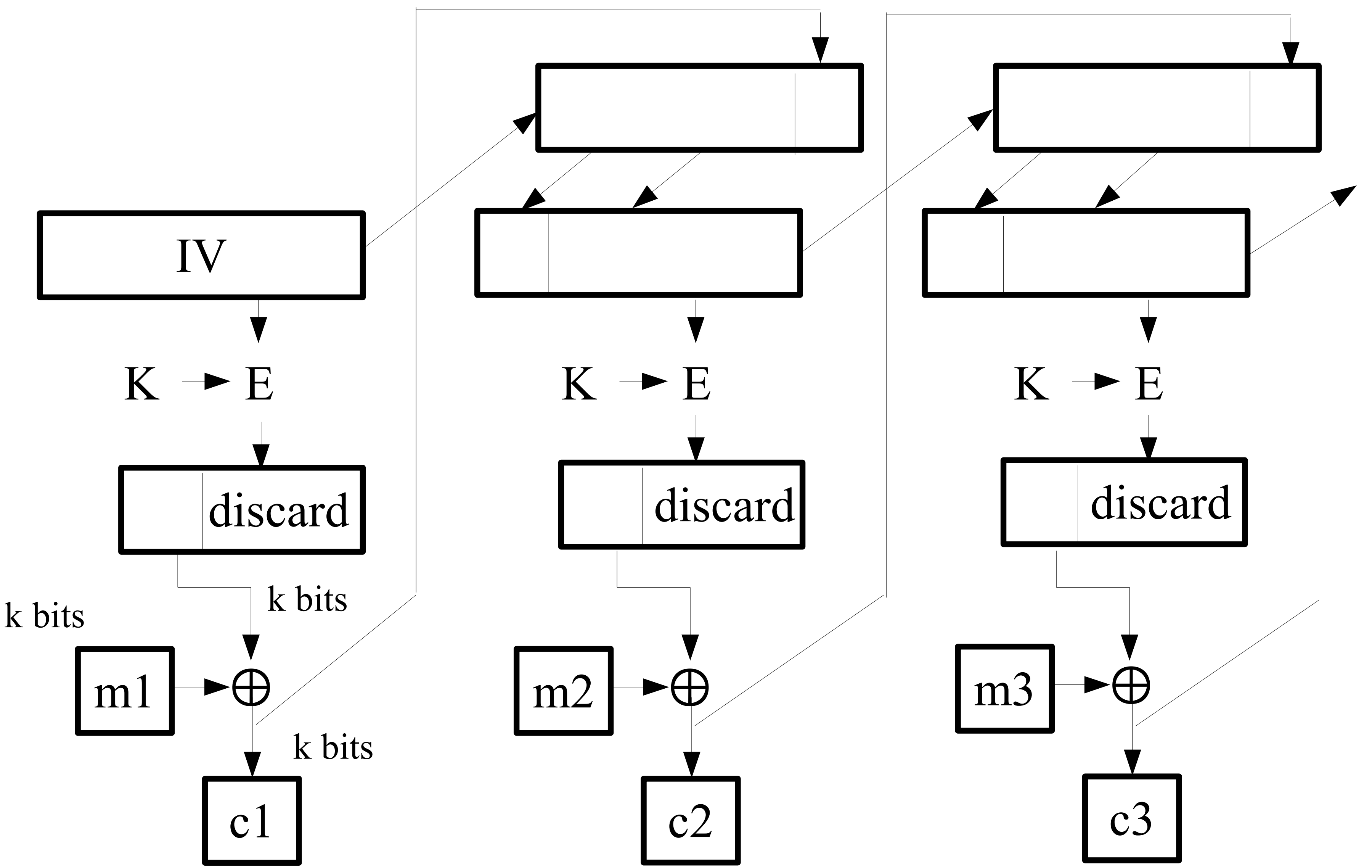
Discussion:

1. OFB: one-time pad can be generated in advance, encryption is based soley on (cheap) exclusion-or operation
2. OFB: garbled cipher block affects only its corresp. message block
   CBC: garbled cipher block affects two message blocks
3. OFB: portions of message can be encrypted and sent as bytes arrive
   CBC: must wait for a block to arrive before encrypting
4. OFB: if the plaintext and ciphertext are known by attacker, plaintext can be modified to anything by xoring ciphertext with the known plaintext
5. OFB and CBC: if any character is lost in transmission, rest of output may be garbled unless some sync markers are added

Block Cipher

Encrypting a large message

Cipher Feedback Mode (CFB)   IV is a random number



Block Cipher

En/Decrypting a large message

Output Feedback Mode vs Cipher Feedback Mode

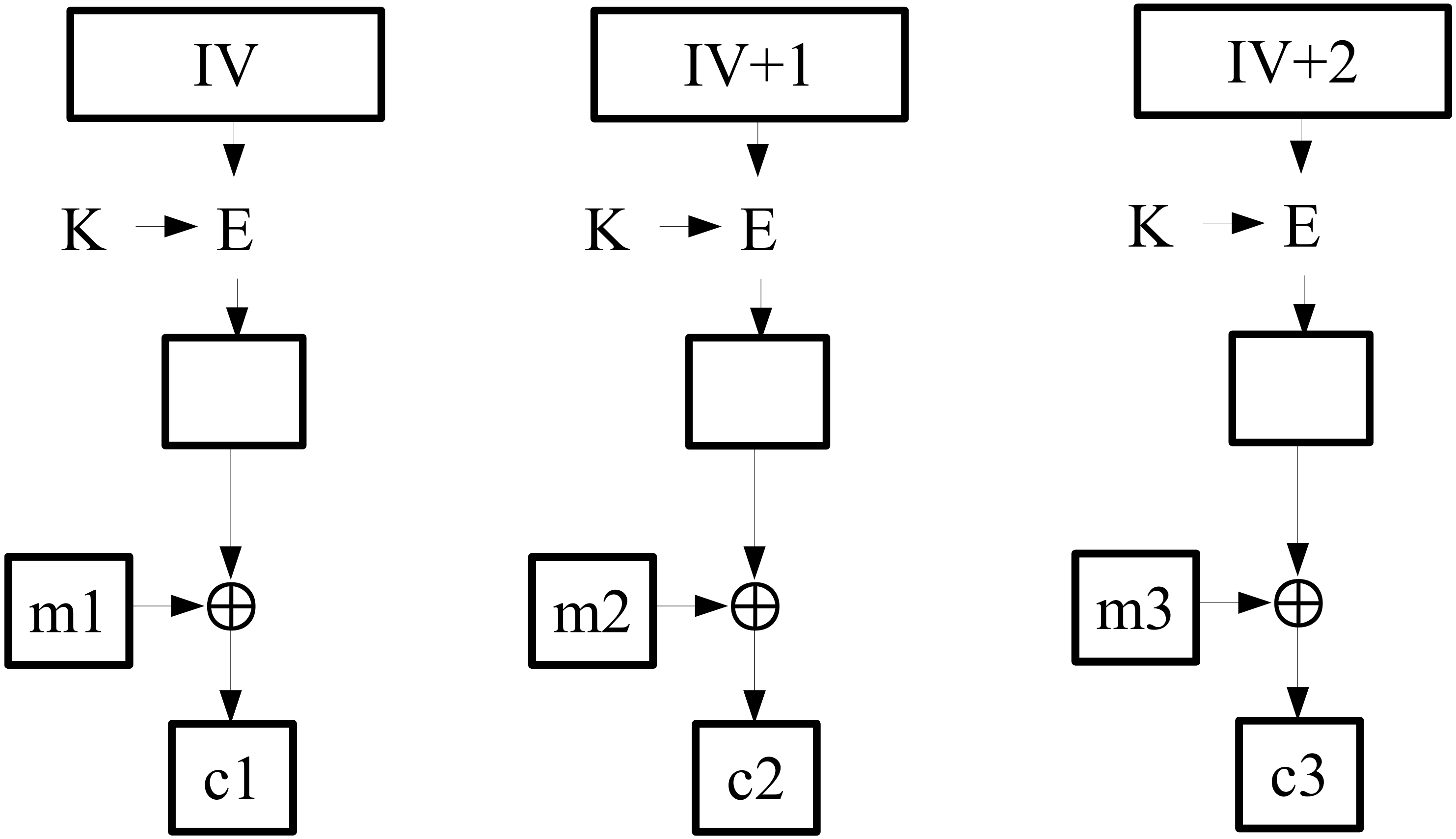
Discussion:

1. In OFB one-time pad can be generated before message is. Not so for CFB
2. In 8-bit CFB loss of bytes in transmission will synchronize after pad flushes through shift. Added bytes will also synchronize after and extra plaintext byte plus 8 garbage bytes. Not so for OFB or CBC where rest of transmission is garbled.
3. No block rearrangement attack on CFB although sections can be rearranged at the cost of garbling the splice points.
4. CFB: one DES operation for every byte of ciphertext (costly)

Block Cipher

Encrypting a large message

Counter Mode (CTR)



Block Cipher

En/Decrypting a large message

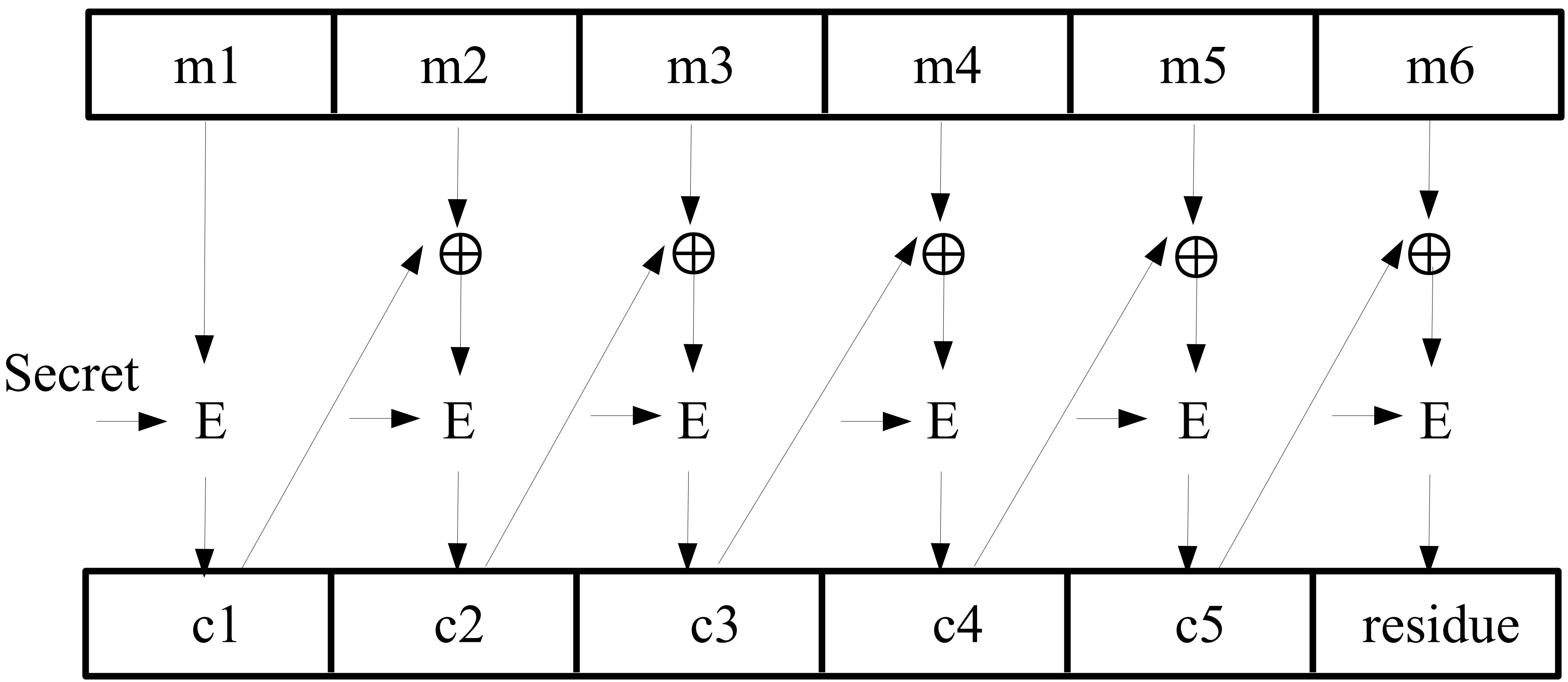
Counter Mode (CTR)

Discussion:

1. Like OFB, one-time pad is generated before the message is. Encryption is simple with exclusive-or
2. Like CBC, can decrypt beginning from any point in the ciphertext. Useful for encrypting random access files.
3. If different data is used with same key and IV, exclusive-oring the ciphertexts of the messages gives the exclusive-or of the plaintexts. This is also a problem with OFB.

Generating Message Integrity Check (MIC)

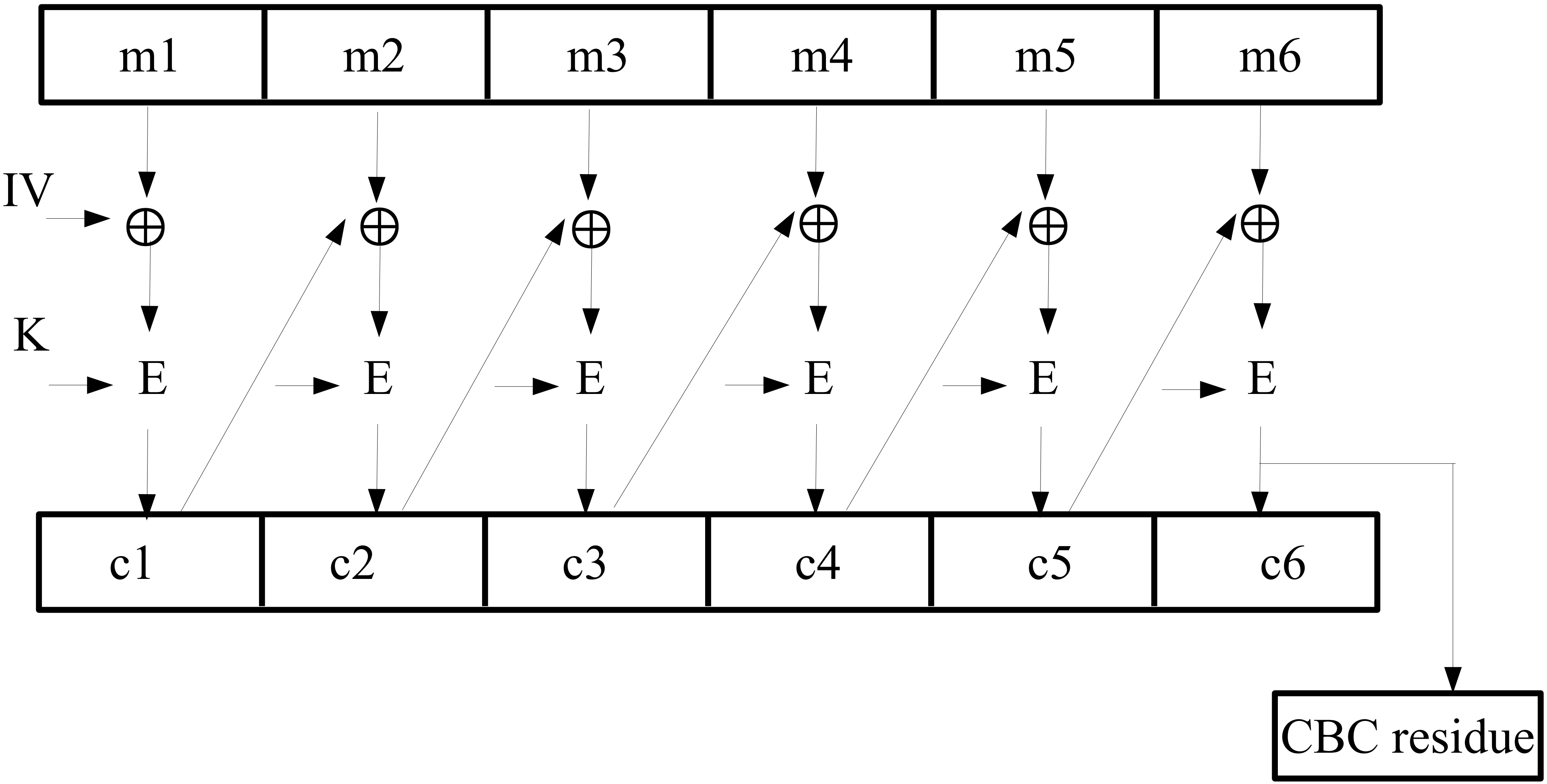
Suppose message is sent in the clear



Only send the residue as the check on the ciphertext and the plaintext message (no confidentiality)

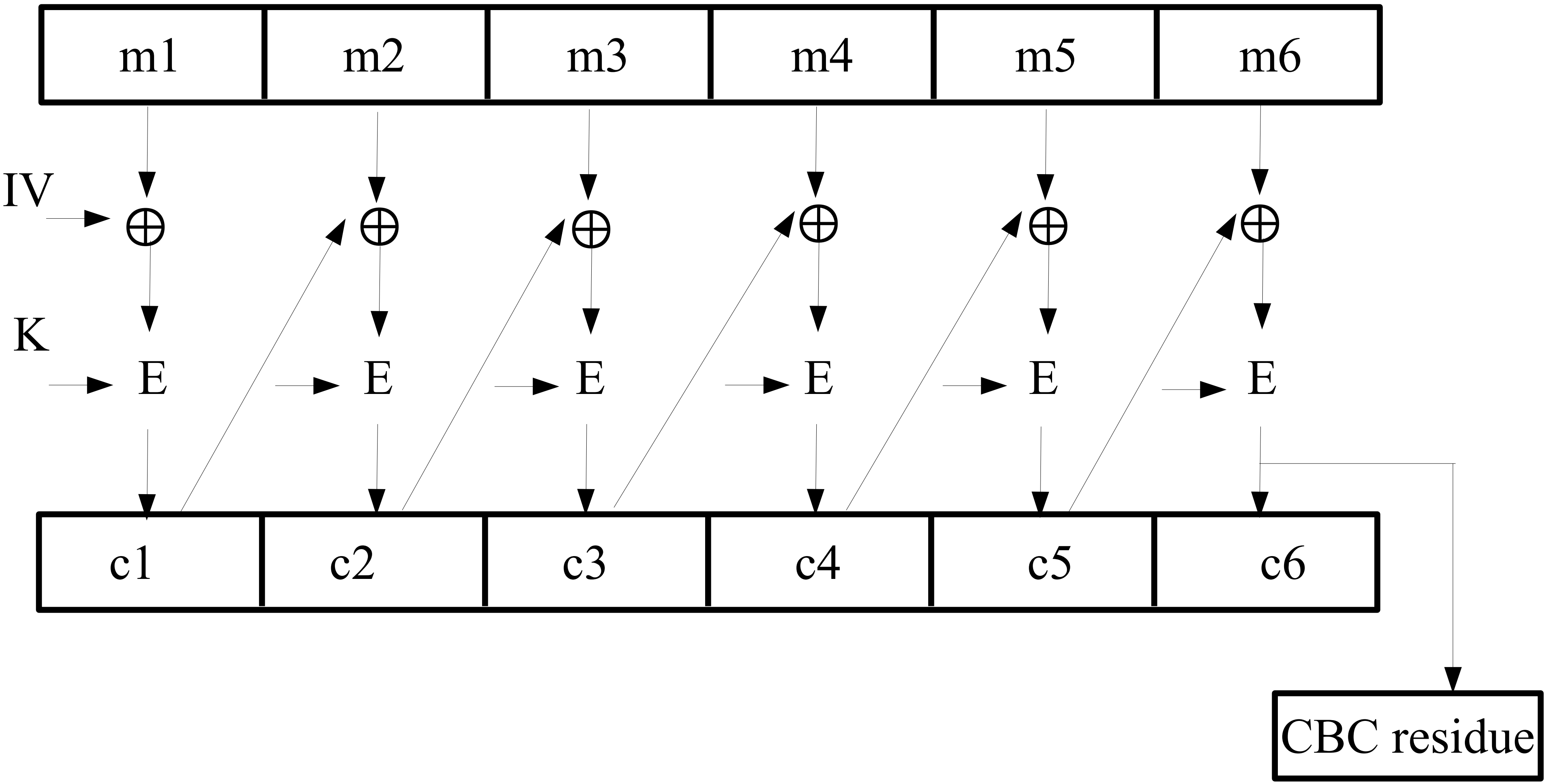
Generating Message Integrity Check (MIC)

Integrity plus confidentiality



Generating Message Integrity Check (MIC)

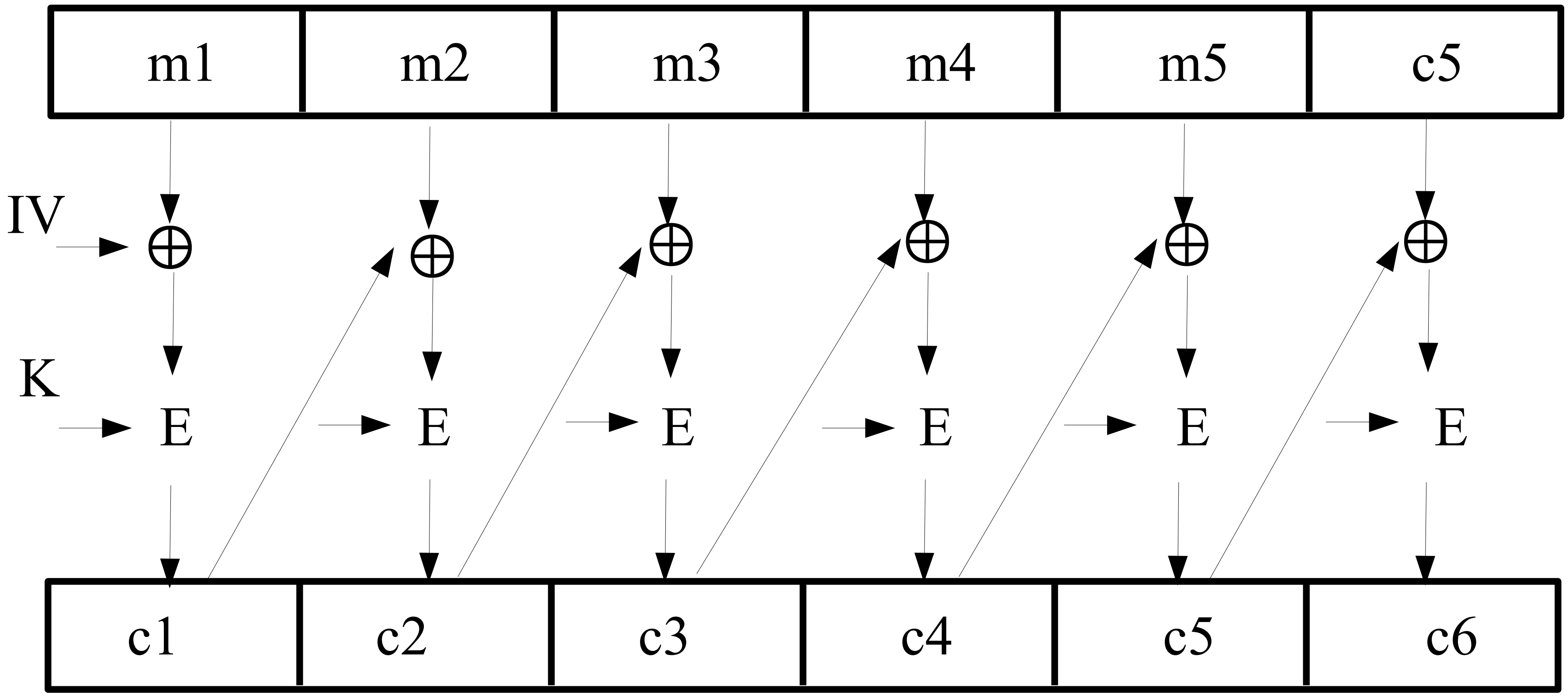
Integrity plus confidentiality



Huh? Send last block twice? Tamperer merely sends tampered message and just repeats its last block!!

Generating Message Integrity Check (MIC)

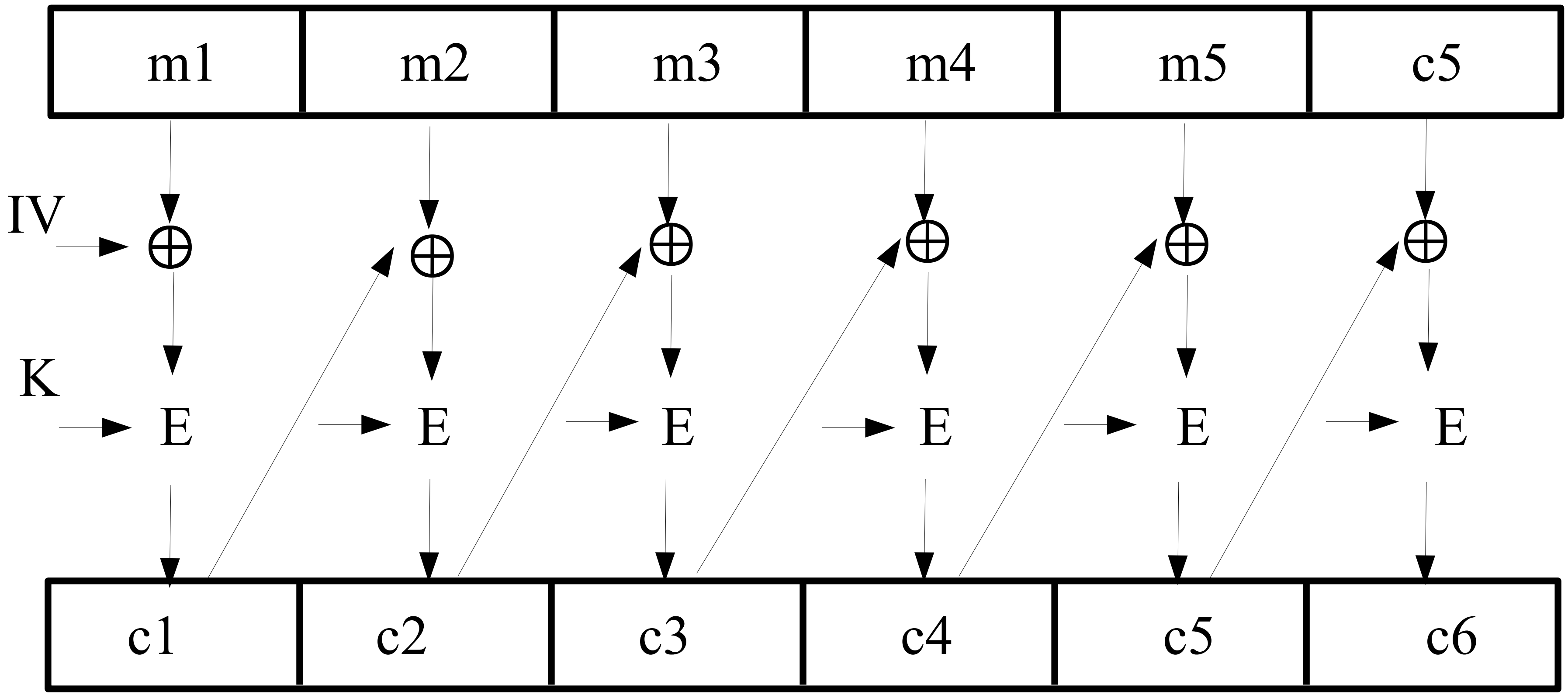
Integrity plus confidentiality



c6 is the residue.

Generating Message Integrity Check (MIC)

Integrity plus confidentiality



c6 is the residue. But actually c6 is 0!!

Generating Message Integrity Check (MIC)

Cyclic redundancy check

```
11010011101100 000        Data + padding
1011                      Divisor
-------------------
01100011101100 000        Result
```

Generating Message Integrity Check (MIC)

Cyclic redundancy check

```
11010011101100 000
1011
-------------------
01100011101100 000          Modified data
 1011                       Divisor
-------------------
00111011101100 000          Result
```

Generating Message Integrity Check (MIC)

Cyclic redundancy check

```
11010011101100 000
1011
-------------------
01100011101100 000
 1011
-------------------
00111011101100 000         Modified data
  1011                     Divisor
-------------------
00010111101100 000         Result
```

Generating Message Integrity Check (MIC)

Cyclic redundancy check

```
11010011101100 000
1011
-------------------
01100011101100 000
 1011
-------------------
00111011101100 000
  1011
-------------------
00010111101100 000          Modified data
   1011                     Divisor
-------------------
00000001101100 000          Result
```

Generating Message Integrity Check (MIC)

Cyclic redundancy check

```
11010011101100 000
1011
-------------------
01100011101100 000
 1011
-------------------
00111011101100 000
  1011
-------------------
00010111101100 000
   1011
-------------------
00000001101100 000          Modified data
       1011                 Divisor
-------------------
00000000110100 000          Result
```

Generating Message Integrity Check (MIC)

Cyclic redundancy check

```
-------------------
0000000110100 000          Modified data
        1011               Divisor
-------------------
0000000011000 000          Result
```

Generating Message Integrity Check (MIC)

Cyclic redundancy check

```
  -------------------
  0000000110100 000
          1011
  -------------------
  0000000011000 000          Modified data
           1011              Divisor
  -------------------
  0000000001110 000          Result
```

Generating Message Integrity Check (MIC)

Cyclic redundancy check

```
-------------------
0000000110100 000
        1011
-------------------
0000000011000 000
         1011
-------------------
0000000001110 000          Modified data
          1011             Divisor
-------------------
0000000000101 000          Result
```

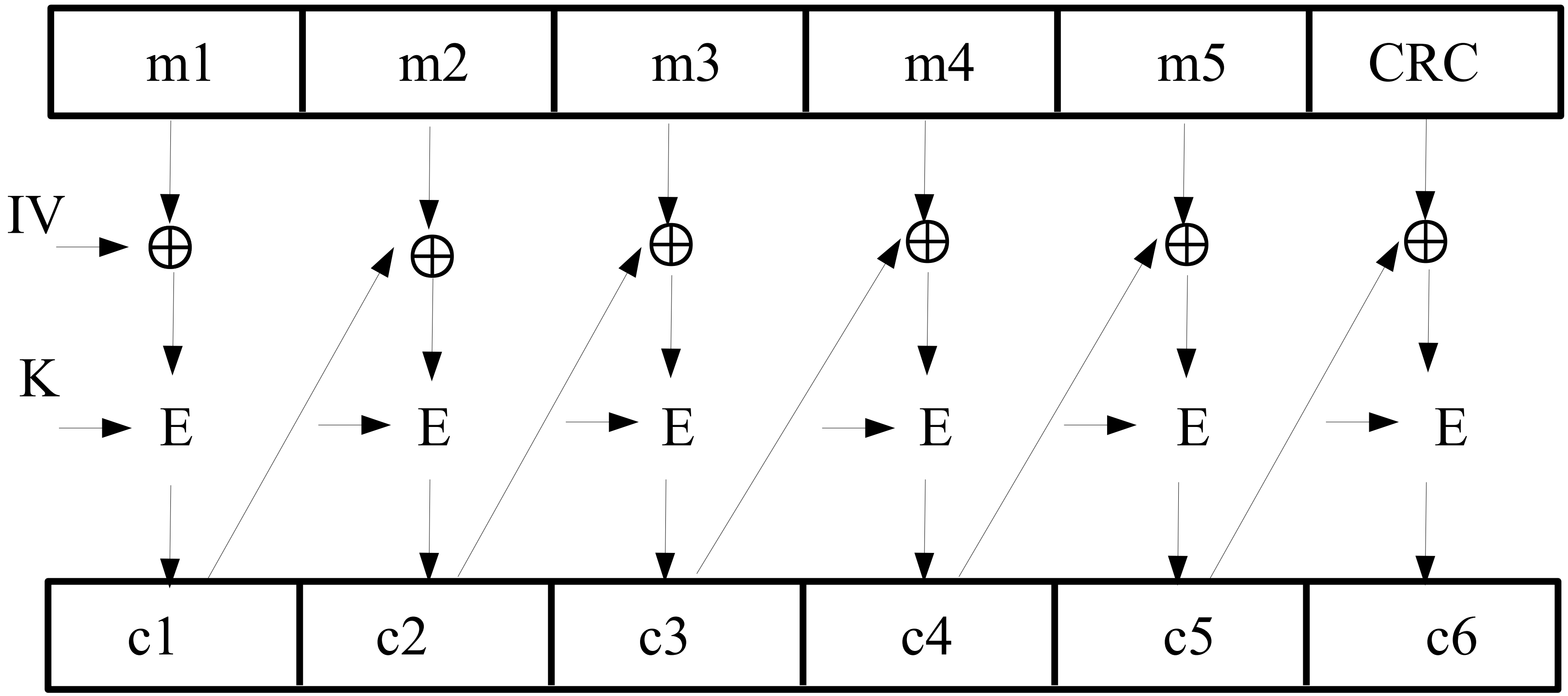
Generating Message Integrity Check (MIC)

Cyclic redundancy check

```
-------------------
0000000110100 000
        1011
-------------------
0000000011000 000
         1011
-------------------
0000000001110 000
          1011
-------------------
0000000000101 000        Result
           101 100       Divisor
-------------------
0000000000000 100        CRC
```

Generating Message Integrity Check (MIC)

Integrity plus confidentiality



c6 is the residue. CRC is used.

Generating Message Integrity Check (MIC)

To use CBC for both message integrity and encryption, use different keys for the residue and ciphertext!