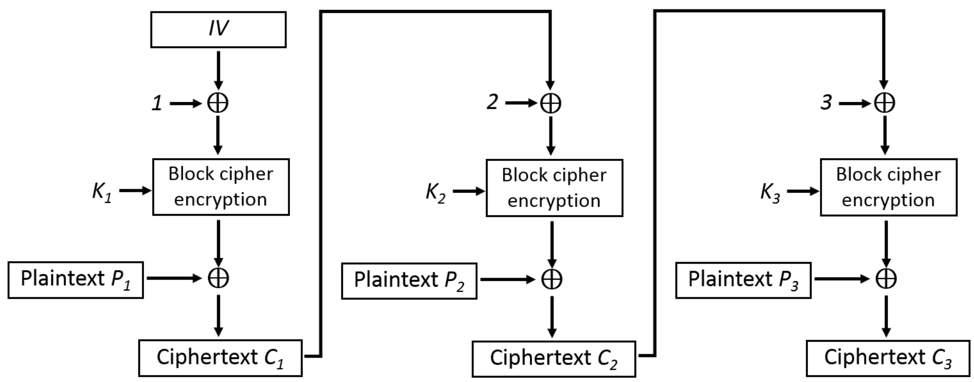
Midterm Review - Symmetric Cryptography

Question 1 ***Socially Distanced Cipher*** **(18 min)**

Bob and Alice want to plan a social distancing picnic, but don't want to invite Eve because she hasn't been wearing a mask in public. They decide to send messages using a new block cipher chaining mode, AES-SDC (Socially Distanced Cipher). Note that AES-SDC requires a different key for each block of the message.

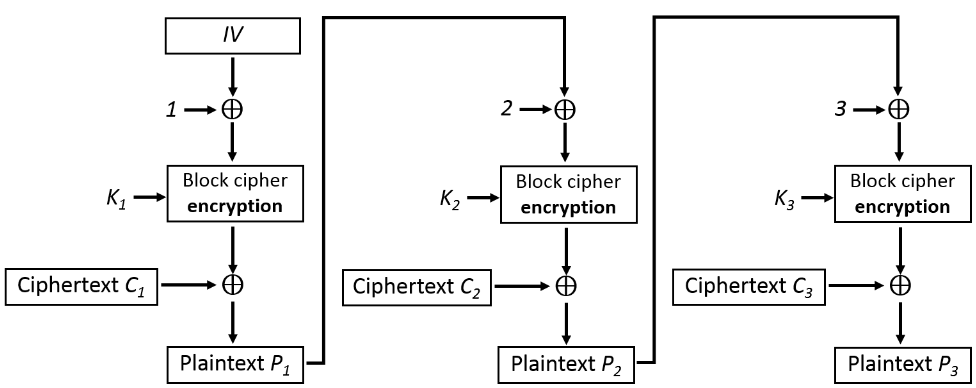
$$C_0 = IV$$

$$C_i = E_{k_i}(C_{i-1} \oplus i) \oplus P_i$$

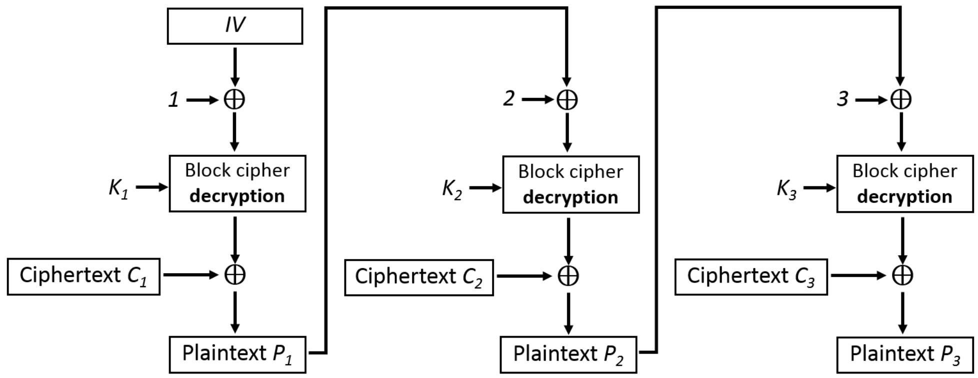


Q1.1 (3 points) Which of the following is the correct decryption expression/diagram for AES-SDC?

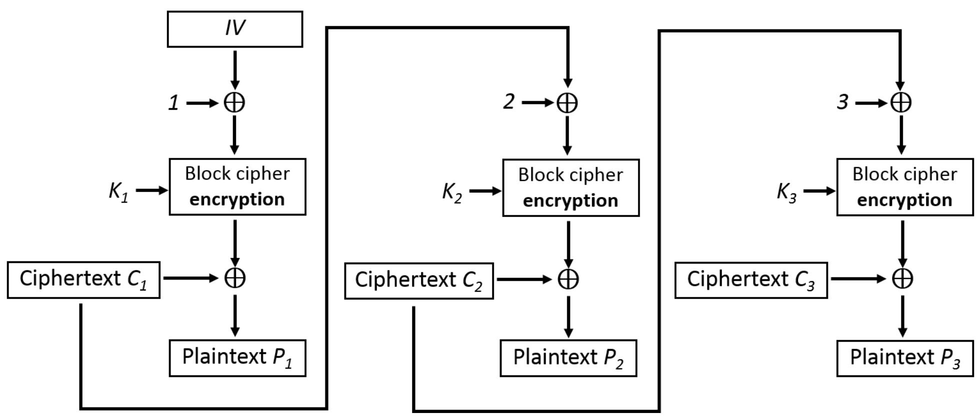
◯ (A) $P_i = E_{k_i}(P_{i-1} \oplus i) \oplus C_i$



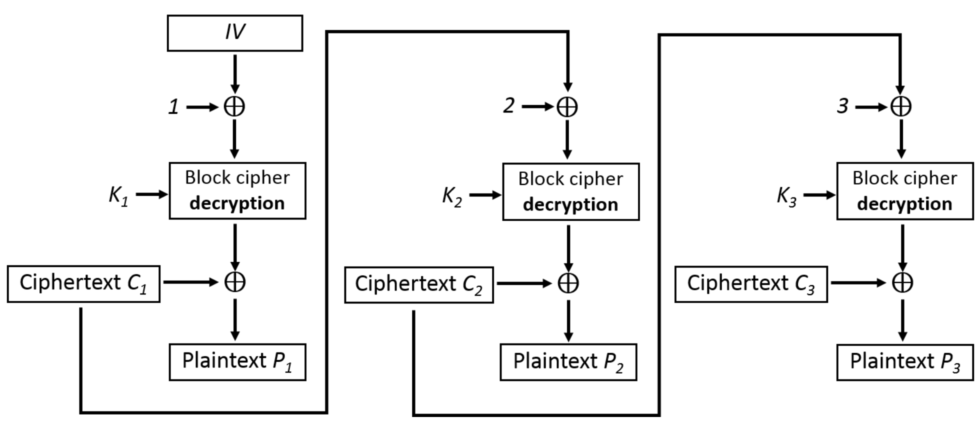
◯ (B) $P_i = D_{k_i}(P_{i-1} \oplus i) \oplus C_i$



● (C) $P_i = E_{k_i}(C_{i-1} \oplus i) \oplus C_i$



○ (D) $P_i = D_{k_i}(C_{i-1} \oplus i) \oplus C_i$



○ (E) ——

○ (F) ——

Solution: To solve for P_i, XOR both sides of the encryption expression: $C_i \oplus E_{k_i}(C_{i-1} \oplus i) = P_i$.

Q1.2 (3 points) Select all true statements about this encryption scheme.

Hint: The cipher mode you saw in Homework 2, $C_i = E_k(C_{i-1}) \oplus P_i$, is IND-CPA secure.

☐ (G) Encryption can be parallelized

■ (H) Decryption can be parallelized

■ (I) It is IND-CPA secure

☐ (J) None of the above

☐ (K) ——

☐ (L) ——

Solution: Encryption cannot be parallelized, because calculating a ciphertext block C_i requires the previous ciphertext block C_{i-1} to be calculated first.

Decryption can be parallelized, because calculating a plaintext block P_i only requires ciphertext blocks C_i and C_{i-1}, which are already known before decryption starts.

The scheme is IND-CPA secure. Intuitively, AES-SDC is the same as the cipher mode from Homework 2, with two differences. First, a different key is used for each block cipher. This doesn't affect IND-CPA security because the attacker still doesn't know any of the secret keys. Second, a counter is added before encryption. This also doesn't affect IND-CPA security, since the output of a block cipher looks random to an attacker without the key, regardless of whether the input is XOR'd with a counter.

Suppose Alice loses some of her shared keys with Bob. Alice wants to encrypt an n-block message using AES-SDC. For each scenario below, determine which blocks Alice can still encrypt.

Q1.3 (3 points) Alice has all the keys except k_4 and k_5.

○ (A) Alice can encrypt all parts of her message except P_4 and P_5

● (B) Alice can encrypt P_1, P_2 and P_3 only.

○ (C) Alice can encrypt the entire message

○ (D) Alice cannot encrypt any block of the message

○ (E) None of the above

○ (F) ——

Now, suppose Alice now has all the keys, and Alice sends a n-block message to Bob. Eve learns some keys and some blocks of ciphertext. For each scenario below, determine which blocks Eve can decrypt.

Q1.4 (3 points) Eve learns the IV, ciphertext blocks C_5 and C_6, and key k_5.

○ (G) Eve can decrypt C_5 only

○ (H) Eve can decrypt C_5 and C_6 only

○ (I) Eve can decrypt all messages intercepted

● (J) Eve cannot decrypt any intercepted messages

○ (K) None of the above

○ (L) —

Q1.5 (3 points) Eve learns the IV, ciphertext blocks C_2, C_3, and C_5, and keys k_2, k_3, and k_5.

○ (A) Eve can decrypt C_3 and C_5 only

○ (B) Eve can decrypt C_2, C_3, C_5 only

○ (C) Eve can decrypt C_2, C_3, C_4, C_5 only

● (D) Eve can decrypt C_3 only

○ (E) Eve cannot decrypt any intercepted messages

○ (F) None of the above

Solution: In order to decrypt a ciphertext C_i, Eve needs to gain access to both C_{i-1} as well as k_i. The same goes for if Alice wants to encrypt P_i. The counter can be inferred to begin at 0 for the first message and increment so on.

Q1.6 (3 points) Bob receives all the keys and ciphertext blocks C_1 through C_n, but C_3 is corrupted. Which plaintext blocks can Bob successfully decrypt?

○ (G) Bob can successfully decrypt all blocks except C_3

○ (H) Bob can successfully decrypt all blocks except C_4

○ (I) Bob can successfully decrypt all blocks except C_1, C_2, C_3

● (J) Bob can successfully decrypt all blocks except C_3 and C_4

○ (K) Bob cannot successfully decrypt any of the blocks

○ (L) None of the above

Question 2 *MAC Madness* **(18 min)**

Evan wants to store a list of every CS161 student's firstname and lastname, but he is afraid Mallory will tamper with his list.

Evan is considering adding a cryptographic value to each record to ensure its integrity. For each scheme, determine what Mallory can do without being detected.

Assume MAC is a secure MAC, H is a cryptographic hash, and Mallory does not know Evan's secret key k. Assume that firstname and lastname are all lowercase and alphabetic (no numbers or special characters), and concatenation does not add any delimiter (e.g. a space or tab), so nick‖weaver = nickweaver.

Q2.1 (3 points) H(firstname‖lastname)

● (A) Mallory can modify a record to be a value of her choosing

○ (B) Mallory can modify a record to be a specific value (not necessarily of her choosing)

○ (C) Mallory cannot modify a record without being detected

○ (D) —

○ (E) —

○ (F) —

> **Solution:** Anybody can hash a value, so Mallory could change a record to be whatever she wants and compute the hash of her new record.

Q2.2 (3 points) MAC(k, firstname‖lastname)

Hint: Can you think of two different records that would have the same MAC?

○ (G) Mallory can modify a record to be a value of her choosing

● (H) Mallory can modify a record to be a specific value (not necessarily of her choosing)

○ (I) Mallory cannot modify a record without being detected

○ (J) —

○ (K) —

○ (L) —

Solution: Because the concatenation doesn't have any indicator of where the first name ends and the last name begins, Mallory could shift some letters between the first name and last name. For example, she could change the name Nick Weaver to Ni Ckweaver, Nic Kweaver, Nickw Eaver, etc. Since the MAC would remain unchanged, this edit would be undetectable.

Q2.3 (3 points) $\mathsf{MAC}(k, \mathsf{firstname} \| \texttt{"-"} \| \mathsf{lastname})$, where "-" is a hyphen character.

○ (A) Mallory can modify a record to be a value of her choosing

○ (B) Mallory can modify a record to be a specific value (not necessarily of her choosing)

● (C) Mallory cannot modify a record without being detected

○ (D) ——

○ (E) ——

○ (F) ——

Solution: Now, the concatenation includes a separator between first name and last name, so the attack from the previous part is no longer possible. Note that names are alphabetical, so they would never include a dash in them.

Q2.4 (3 points) $\mathsf{MAC}(k, \mathsf{H}(\mathsf{firstname}) \| \mathsf{H}(\mathsf{lastname}))$

○ (G) Mallory can modify a record to be a value of her choosing

○ (H) Mallory can modify a record to be a specific value (not necessarily of her choosing)

● (I) Mallory cannot modify a record without being detected

○ (J) ——

○ (K) ——

○ (L) ——

Solution: Because the hashes produce a fixed-length value, concatenating them within the MAC without delimiters does not violate integrity.

Q2.5 (3 points) $\mathsf{MAC}(k, \mathsf{firstname}) \| \mathsf{MAC}(k, \mathsf{lastname})$

○ (A) Mallory can modify a record to be a value of her choosing

● (B) Mallory can modify a record to be a specific value (not necessarily of her choosing)

○ (C) Mallory cannot modify a record without being detected

○ (D) —

○ (E) —

○ (F) —

Solution: Because the first name and last name have separate MACs, Mallory could swap the first name and last name, and swap the two halves of the MAC.

In other words, Mallory could change the name Nick Weaver to Weaver Nick, and change the MAC from $\mathsf{MAC}(k, \mathsf{nick}) \| \mathsf{MAC}(k, \mathsf{weaver})$ to $\mathsf{MAC}(k, \mathsf{weaver}) \| \mathsf{MAC}(k, \mathsf{nick})$.

Q2.6 (3 points) Which of Evan's schemes guarantee confidentiality on his records?

○ (G) All 5 schemes

○ (H) Only the schemes with a MAC

○ (I) Only the schemes with a hash

● (J) None of the schemes

○ (K) —

○ (L) —

Solution: MACs and hashes do not have any confidentiality guarantees.