

## Applied Crypto

### Exploring the Security of One-Time and Many-Time Pads

#### Overview

This team project investigates the cryptographic security of the one-time pad, known for its perfect security under certain conditions, and explores the implications of reusing a key, referred to as a many-time pad. We will examine the practical aspects of implementing these encryption methods, analyze their vulnerabilities, and develop strategies to exploit these vulnerabilities in a controlled environment. Here is some background story in signal intelligence. [https://en.wikipedia.org/wiki/Venona\\_project](https://en.wikipedia.org/wiki/Venona_project)

#### Objectives

1. Understand One-Time Pad  
Examine the concept of the one-time pad, its implementation, and why it is considered perfectly secure.
2. Implement One-Time Pad Encryption and Decryption  
Develop a Python program that simulates the encryption and decryption process between two parties.
3. Explore Many-Time Pad  
Extend the one-time pad implementation to simulate a many-time pad scenario, where a single key is used to encrypt multiple messages.
4. Cryptanalysis of Many-Time Pad  
Design and execute an attack strategy to decrypt messages encrypted with a many-time pad, focusing on exploiting the vulnerabilities introduced by key reuse.

**Note:** You may divide problems among team members, and each person may take primary responsibility for specific parts. However, teamwork does **not** mean working in isolation.

All team members are expected to:

- Review and **sign off on all problems**, not only the ones they primarily handle.
- Support other members when needed, especially since some problems are easier and others more challenging.
- Communicate and cross-check work to ensure overall quality and shared understanding.

All members receive the **same grade**, even though individuals may spend different amounts of time on different problems. Shared responsibility and mutual support are required. **You shall not claim full credit by stating that a problem was “not your responsibility.”**

#### Problem 1: Understanding One-Time Pad

Tasks:

1. Research the theoretical basis of the one-time pad, including its requirements and operational principles. Describe one-time pad conditions clearly.

#### Problem 2: One-Time Pad Implementation

Tasks: the encryption and decryption process between two parties, Alice and Bob.

1. Alice's Program  
Should prompt for a message input (plaintext), then display the ciphertext, and save both the ciphertext (in hex) and the key (in hex) in separate files.
2. Bob's Program:  
Should read the key and ciphertext from their respective files and display the decrypted plaintext.

### Problem 3: Implementing Many-Time Pad

Tasks: Modify the one-time pad implementation to encrypt multiple messages with the same key, simulating a many-time pad scenario. The purpose of this problem is to see if there are any recognizable patterns by observing the outputs. You can gain insights by changing the plaintexts or the key to verify your findings. These findings would be useful in the next problem.

1. The program should encrypt a list of 10 predefined plaintext messages with a single key, saving the plaintexts, key, and ciphertexts (all in hex) into a file. You can select 10 of your favorite messages. Assume the key is long enough to do encryption to all the 10 messages.

### Problem 4: Cryptanalysis of Many-Time Pad<sup>1</sup>

Tasks: Develop a strategy to decrypt messages encrypted with a many-time pad. More specifically, assume Eva has collected the 10 ciphertexts and she knew they are generated by the same key. In addition, all the plaintexts are in English. Space, comma, period, and question mark are being used in the plaintext, but no other special characters are allowed. Eva wants to decrypt the last message (target message).

Collected ciphertexts:

- 1) 71fe1ace4389087266117cd7c98c4182851b3acff3b086e3f83f94d6eb05c4ba85d8e1fa14f11d1c3b568ff6cff5c09c5d67ef5c9c71b7eeb3d45a5154ab17b83e071ce9d8988adb4afedf46a840
- 2) 71fe1ace559a1e7266117cd7ce8745d7be2e74c3f0f68eeef57e8884e607deb81dfa0f012f95819681ae7f29fe4839b5175ef5e8760bef0b9d44b504eba12b22f5404f89dd085d550a48865a14f9b15a94dabe609ca2df2cccf210cefdb1af5389719795e1f0179cb77c5c456954d88f3
- 3) 72fe069c51c81a20775928c7879d4fd2a93c3acff3f69fe5fe2e9493a303d9ea98c4e5b60ae40a146058e7c787fbd09a1474e25dc865b5e6af865d4a40a61bfd384e06e0cfc1ccd356ff8853ac438905fa5fe3fd41cb3bbc8ac9
- 4) 67e543885b9a5b2267177084cf8453ccb8633ad7fdb39de5b13f8a93a304d6bf8bc4f4ef5def110b6f56a3e186e2c68c1470ef5c9c2ffbd6a291571e40ba1afd3b4b1fe0c4cbccc15df5dc07b043da01fa6ae4fd158f37b3c0cd
- 5) 71fe029a148c1236320d7192878a59cfbc3a6ec5e7f68befb13196d6ea1ec4ea81d9e3fe50ea0f196d02a2f7cfe2c29c5577e35d8630baf6ea80465b01aa1abc394f57a1f4cccdca59ff8846e44b8805bb5cabe608c231f2dec8364ae7d90ab4358c5c3a421b06

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<sup>1</sup> [http://crypto.stanford.edu/~dabo/cs255/hw\\_and\\_proj/hw1.html](http://crypto.stanford.edu/~dabo/cs255/hw_and_proj/hw1.html)

- 6) 6ef914ce5989152b321a769ad79c42c7be6f6ad2fab19de1fc339d84f04ad3a589dfa0ff09ab0c196f13e7e780b4c097556ded57c871fbee393464a01aa0ab1381848cfd2d6898918efc046b00b8940bb08e3f313cb23b3dfd8645cfcd80ff82489
- 7) 71fe1ace4389087266117cd7c4865bd2b93b7fd2b5a58ce9f4308c9ff01e97ab82cbf2ef5dfc101d6a56b3fb8ab4d08b4167ef5c9c30b8f0ab97455b45e81efd364605e49ddb83df48eedc42b60c900fb14db4b229ca74b6c4d96442e1c34df8288f5c3a450a527ecc7c82865b8e
- 8) 71fe029a148c1437615978d7c58854dbec2c75cde5a39be5e37e9b97ef0697a285dfa0f01cff101d764983f29bf5
- 9) 71fe1ace50875b31730d6ad7cb8640c7ec3c73d4e1bf81e7b13796d6e518d8a4988ceff05dff101d2415a8fe9fe1d79a4623eb5e8430bfe3b3d442514faf40fd18420be0c8cb89924cf3cd5ee448950efd5cabe500c120f2d9d26440ebc34de029811977430b01748276d79012955cc6a65aebb9054becda5c9278
- 10) 71fe029a1483123c76597691878459cca9363ac4faf68ceffc2e8d82e61897b98fc5e5f809e20b0c7756b2e08aab83bc5560e257

Target Message:

71fe0680149d083b7c1e3996879a42d0a92e7780f6bf9fe8f42cd898e61cd2b8ccd9f3f35dff101d241da2eacff9cc8d5123fe5a897efbeda4974b

1. Design an attack strategy based on the vulnerabilities of key reuse in a many-time pad scenario. You can use some of the hints given below.
2. Implement the strategy in jupyter notebook. Remember, most of the time cryptoanalysis needs a human in the loop and a bit of luck.
3. Analyze and discuss the outcomes, including any partial decryption results and insights gained from the process.

**Hints:** Observe and reasoning.

Basic XOR Properties:

- **Hint A:** XORing 0 with any bit (0 or 1) leaves it unchanged, symbolized as  $0 \oplus x = x$ . This property is fundamental to understanding how XOR affects data.
- **Hint B:** XORing 1 with any bit flips it, which is to say  $1 \oplus x = 1 - x$ . This operation inverts the bit, playing a crucial role in encryption and decryption processes.
- **Hint C:** XORing any bit string with itself results in a string of zeros, expressed as  $k \oplus k = 0$ . This property is useful for key and data recovery techniques.

Encryption and Decryption with XOR:

- **Hint D:** The ciphertext  $c$  is produced by XORing the plaintext  $m$  with the key  $k$ , denoted as  $c = m \oplus k$ . This is the basic encryption formula.
- **Hint E:** Decrypting involves XORing the ciphertext  $c$  with the key  $k$  to retrieve the original message, represented as  $m = c \oplus k$ .

- **Hint F:** The key **k** can be derived by XORing the ciphertext **c** with its plaintext **m**, shown as  $k = c \oplus m$ . This equivalence highlights the symmetric nature of XOR-based encryption. It also reveals the key info if we know something about **m** and **c**. Here the phrase “we know something about **m**” means we know some of the characters of **m** in some positions, not necessarily the **m**.

#### Analyzing Multiple Encryptions (Many-Time Pad):

- **Hint G:** When two ciphertexts,  $c1 = m1 \oplus k$  and  $c2 = m2 \oplus k$ , are XORed together, the result is  $c1 \oplus c2 = m1 \oplus m2$ . This reveals the XORed plaintexts without the key, offering insights into patterns or repeating structures within the messages. Notice, we have ten of them. The combinations can reveal a lot more on the plaintexts.

#### ASCII Patterns and Cryptanalysis:

- **Hint H:** Observing ASCII representations, capital letters A-Z range from **0x41** to **0x5A**, showing a leading bit pattern of **010** ( $0x4 = 0100$ ,  $0x5 = 0101$ ), while lowercase letters a-z range from **0x61** to **0x7A**, with a leading bit pattern of **011**. Spaces are represented by **0x20**, with a pattern of **0010** ( $=0x2$ ). XOR operations between these (a letter and a space) can reveal shifts between uppercase and lowercase letters, aiding in pattern identification within encrypted texts.
- **Hint I:** Numeric characters in ASCII start with the bit pattern **0011**, assisting in distinguishing numbers from letters during analysis.

#### Advanced Cryptanalysis Techniques:

- **Hint J:** Beyond ASCII patterns, students shall employ crib dragging (exploiting known or guessed plaintexts) from above hints, particularly from Hint H and Hint K (Understanding the structure of the key, even partially, enables the decryption of the ciphertext including the target message. This often requires intuitive guesses and methodical verification to bridge gaps in the known data.
- **Hint K:** students may employ other cryptanalysis methods such as frequency analysis (identifying common letters or patterns), and dictionary attacks on short segments. These techniques leverage patterns and statistical properties of the plaintext to breach the encryption.

### Deliverables

1. **Written Report:** Includes a comprehensive explanation of each problem, the one-time pad, implementation details for both one-time and many-time pads, the attack strategy on the many-time pad, and an analysis of the results.
2. **Code:** Use Jupyter Notebook for the one-time pad encryption/decryption, many-time pad encryption, and the cryptanalysis of the many-time pad.

### Evaluation Criteria

- **Correctness:** The one-time and many-time pad implementations must function as specified, accurately encrypting and decrypting messages.

- Attack Strategy: The effectiveness of the cryptanalysis approach in exploiting the vulnerabilities of the many-time pad, including creativity and technical execution.
- Analysis: Depth of analysis in understanding the security implications of key reuse and the ability to communicate findings clearly.

### Submission

It is the same as Project 1 (both notebook and pdf).

### Grading rubrics (total 10)

	Max Point	Expectations
<b>Problem 1</b>	<b>1</b>	
Task 1	1	Describe one-time pad conditions clearly
<b>Problem 2</b>	<b>3</b>	
Task 1	1	Alice code is running correctly, and two files are generated. It meets the best coding practice such as comments, readability and maintainable.
Task 2	1	Bob code uses the key file to recover the plaintext correctly. It meets the best coding practice such as comments, readability and maintainable.
<b>Problem 3</b>	<b>2</b>	
Task 1	2	The code runs correctly. It meets the best coding practice such as comments, readability and maintainable.
<b>Problem 4</b>	<b>6</b>	
Task 1	1	Design a feasible attack strategy. If the strategy could not fully recover the target plaintext (task 3), some points will be deducted. The actual points deducted depend on the outcome of Task 3.
Task 2	2	The code runs correctly with or without human intervention. It meets the best coding practice such as comments, readability and maintainable.
Task 3	2	The target message is decrypted correctly.