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FC1 Algorithm Ushers In the Era of Post-Alien Cryptography

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Abstract

This document aims to introduce the concept of "post-alien cryptography", presenting a symmetric encryption algorithm which, in our opinion, can be considered the first ever designed to face the challenges posed by contact with an alien civilization. FC1 cipher offers an unprecedented grade of confidentiality. Based on the uniqueness of the modular multiplicative inverse of a positive integer a modulo n and on its computability in a polynomial time, this non-deterministic cipher can easily and quickly handle keys of millions or billions of bits that an attacker does not even know the length of. The algorithm's primary key is the modulo, while the ciphertext is given by the concatenation of the modular inverse of blocks of plaintext whose length is randomly chosen within a predetermined range. In addition to the full specification, we present a working implementation of it in Julia Programming Language, accompanied by real examples of encryption and decryption.

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I. INTRODUCTION

In a symmetric key encryption scheme, a single key is used for both encryption and decryption. An algorithm can be considered safe if the only way to guess the key is to explore all the possibilities given by the different combinations of zeros and ones. This is called a "brute-force attack" and under certain circumstances it can be very difficult, if not impossible, to implement. A 256-bit key (the length used by the current AES encryption standard) is at present considered "unbreakable" even by the next generation of quantum computers. So it appears that approved standards can ensure a good level of confidentiality for many decades to come. Neverthless, if we look at some structural aspects of them, we can find some relevant weaknesses that could jeopardize the security of encrypted data in light of some new challenges that we are likely to face in a near future. But before going into the technical details of the weaknesses, it is useful to dwell on the implicit hypothesis that underlies the alleged security of encryption standards. In fact, they are designed to instantly transfer encrypted data between two different points in space. But if we consider sending data to a different point in time, then the algorithms used would be perhaps inadequate to protect the confidentiality of the original text. For example, suppose Alice wants to transmit an AES-256 encrypted message to Bob who will use the symmetric key to decrypt it in 50 years. How can Alice be sure that the technological development of the coming years will not lead to the ability of testing 2^{256} different sequences of 0's and 1's in a reasonable time, so making the key in Bob's possession useless? Now let's see the structural aspects that may compromise the safety of the accepted standards. Current standards have four main aspects in common. The first two are related to the key: its length is known and does not exceed 256 bits. The last two relate to the algorithms: they are deterministic and convert a fixed block of plaintext into a ciphertext block of the same length. An algorithm is deterministic if a given plaintext always produces a given ciphertext. These four points are generally considered irrelevant and do not raise security concerns. In our opinion, there are however two specific scenarios that could change the rules of the game. The first one, which we call "internal" scenario, relates to the prospect of an upcoming world war, or at least of a long period of involution in the reciprocal relations among states. A tragic war is hitting Europe. Again. Diplomatic relations are cooling down and scientific discoveries become military secrets. In this context of separation and conflict how can one be sure that a certain technological level has not already been reached by the adversary? So, for example, how can we be sure that no one in the world is able to test 2^{256} different possibilities in a reasonable time? But if the internal context is worrying, perhaps the "external" one is even more so. By "external" scenario we refer to the possibility of an encounter with an alien civilization that could render current encryption schemes ineffective, thus posing serious security risks for the entire human species. FC1 was designed by imagining attackers possessing a computational capacity far superior to that of our present and future computers.

2 The Need Of A Post-Alien Cryptography

Imagine waking up tomorrow and discovering aliens exist, they're here and they're not good guys. Then you decide to join others to organize a resistance. The first thing you realize is that you need a secure communication channel to coordinate with others. The second bad news of the day is to understand that the AES-xxx is unable to protect your messages because the aliens use cryptanalytic techniques and computing power capable of breaking any deterministic algorithm. But without imagining alien invasion scenarios, let's think about how much the chances of a first contact with aliens will increase thanks to the synergy between the public and private sectors in space trips. Humanity is about to become a multiplanetary species and soon our spaceships will venture into deep space in search of planets to explore and on which to perpetuate the human race. It is logical to assume that aliens are technologically more advanced than us and have perhaps another math, but that they are able to understand ours. It also makes sense to assume that however advanced their computational abilities are, they are somehow "bounded". Since a brute-force attack implies in any case the use of computing power, it may be a good idea "to raise the bar", thus passing from keys of 256 bits to keys of hundreds of thousands or millions of bits. Likewise, it can be helpful not to publicly disclose the key length. But in the face of considerable computational capacity, the use of a larger key may not be sufficient. It is necessary to break the mold and move without delay from deterministic to non-deterministic algorithms, making the relationship between input and output more complex and unpredictable. These are the main lines

that have guided the construction of the FC1 algorithm, the first one we made public in a class of algorithms designed to face the exciting challenges of our future. We believe that FC1 ushers in the era of "post-alien cryptography" and we hope that the debate we have stimulated will lead to realize we need to have a vision oriented to the design of algorithms that can defend human life from any possible threat.

3 Specification

3.1 Modular Multiplicative Inverse

Definition

For a positive integer n, and $a \in \mathbb{Z}$ we say that $a' \in \mathbb{Z}$ is a multiplicative inverse modulo n if

$$aa' \equiv 1 \mod n$$

It can be proven [1] that:

1. a has a multiplicative inverse modulo n if and only if a and n are relatively prime
2. if a' exists, then it is unique

Computation

There are various methods to compute the inverse modulo n in a polynomial time [2] [3]which, if implemented in languages like Julia[1] having built-in support for Arbitrary Precision Arithmetic, make it possible to calculate a' in a few fractions of a second even for numbers with hundreds of thousands of digits (see Appendix B).

3.2 Description

Basic concept FC1 essentially relies on the uniqueness of the modular multiplicative inverse of a positive integer a modulo n and on the fact that it can be calculated in a polynomial time. Here the modulo is the main key which, due to the algorithm's design, can be any positive integer, while the ciphertext is the modular multiplicative inverse. The plaintext, once tagged with a hash, is divided into blocks, the length of which is chosen by a random number generator, converted into ciphertext and sent over an insecure channel.
Keys Keys to be kept secret and transferred over a secure channel are primary key (the modulo), and secondary key. The latter represents the length of a random string that is placed at the beginning of the ciphertext.

3.2.1 Encryption

Hash The very first operation that is performed is the computation of a hash of the plaintext using the SHA-256 function. This tag is then appended at the end of the text. The purpose is to ensure the integrity of the data transmitted. We denote the plaintext with the final tag by 'tplain':

$$tplain = plaintext \| hash$$

Ciphertext initialization With the value of the secondary key, a random string is created which we denote by 'startpad'. This is the initial ciphertext:

$$c = startpad$$

[1]With origins in the Computer Science and Artificial Intelligence Laboratory (CSAIL) and the Department of Mathematics, Julia is a programming language created in 2009 by Jeff Bezanson, former MIT Julia Lab researchers Stefan Karpinski, and Viral B. Shah, and professor of mathematics Alan Edelman. The Julia programming language is a flexible dynamic language, appropriate for scientific and numerical computing. Julia provides software support for Arbitrary Precision Arithmetic, which can handle operations on numeric values that cannot be represented effectively in native hardware representations, but at the cost of relatively slower performance. To allow computations with arbitrary-precision integers and floating point numbers, Julia wraps the GNU Multiple Precision Arithmetic Library (GMP) and the GNU MPFR Library, respectively. In an APA application the size of the integer is limited only by the available memory. Website: https://julialang.org/

Fencrypt A main function named 'fencrypt' has the task of controlling the flow, switching between different sections of the algorithm in relation to a certain threshold value of the length of the tagged plaintext that still remains to be encrypted. The threshold is fixed at 1.5 times the length of the modulo.

Frand In the first part of the algorithm fencrypt calls a random number generator in a given range, which we denote by 'frand'. The generated random integer represents the length of the i-block of tagged plaintext to be encrypted. We denote by $|modulo|$ the length of the modulo. The frand function generates a random value between 1 and $|modulo| - 3$. From the length of the modulo, 3 bits are subtracted to define the upper limit of the random function because 2 bits space is used to append the leading and trailing 1 (see next point 'Fintgen'). Moreover, since we want that the integer, whose modular inverse we are going to calculate, is less than the modulo, another bit is dropped:

$$1 \leq frandvalue \leq |modulo| - 3$$

Fintgen A leading and a trailing '1' are appended at each chunk of tagged plaintext whose length is randomly selected by frand function. The leading 1 is meant to make sure that the input of the function computing the modular inverse is a positive integer since the block could start with '0'. The trailing '1' serves to prevent the algorithm from blocking in the case of an even modulo and a tagged plaintext to be encrypted containing a long row of 0's. We denote by $tplain_i$ the i-block of tagged plaintext; then is:

$$input_i = 1 \| tplain_i \| 1$$

Finv Once the input has been prepared, it is possible to attempt to compute the modular inverse using the 'finv' function. If the input and the modulo are not coprime, finv cannot produce a result and it calls the main function fencrypt which calls frand again in order to try with a different random integer. Else, if they are coprime, the modular multiplicative inverse is computed in a polynomial time and passed to the next step.

Fblockgen If the modular inverse is computable, a function called 'fblockgen' comes into play comparing the modulo length with that of the modular inverse generated by finv. If the lengths are the same, fblockgen does not modify the string:

If $|modulo| = |finvvalue|_i$

$$output_i = finvvalue_i$$

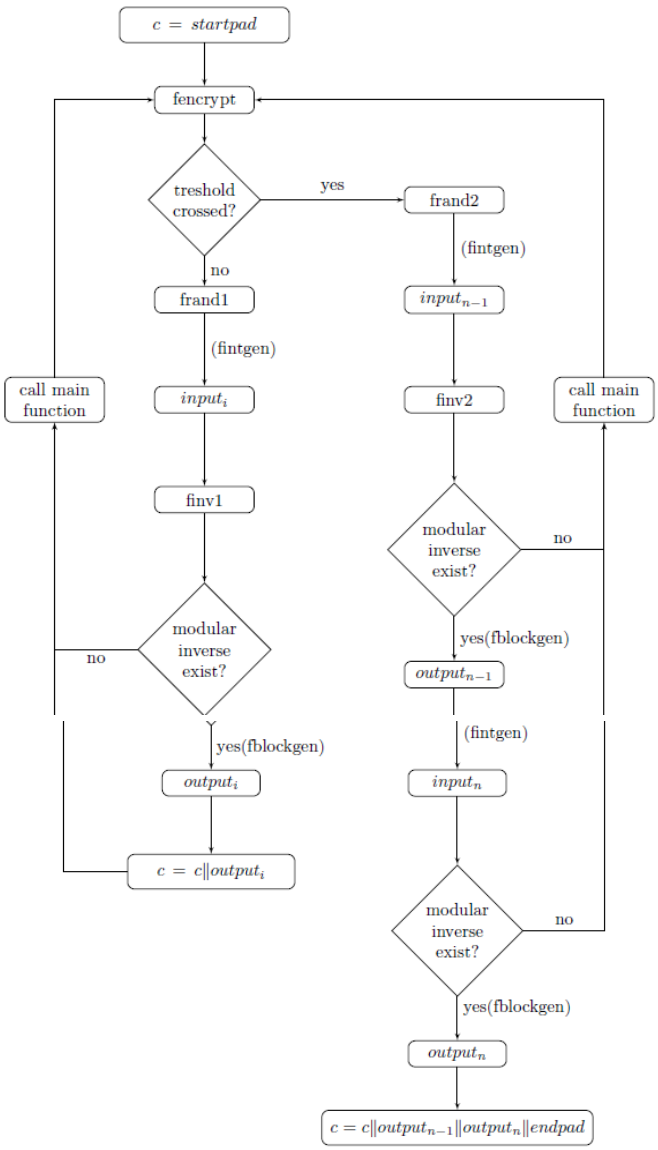
Otherwise, if the modular inverse length is less than modulo length, fblockgen adds one or more leading zeros so that the lengths match:

If $|modulo| > |finvvalue|_i$

$$output_i = 0..0 \| finvvalue_i$$

Final step of the first part The block created by fblockgen is concatenated to the existing ciphertext and the main function fencrypt is called.
Second part: ciphertext finalization When threshold is crossed, the finalization functions are called. They have the task of simultaneously calculating the last and the second-last block of ciphertext. This design solution is necessary to prevent the case the modular inverse does not exist for the last portion of tagged plaintext, with the consequence of blocking the whole encryption process. The last step involves adding a random final padding whose length must be less than modulo length. This final padding, that we call 'endpad', is actually a third key that we can consider inferred from the other two. It is automatically added by the encryption algorithm. In the subsequent decryption phase, the algorithm will recognize it as its length is less than that of the modulo and finally it will discard it without attempting to decrypt it.

Encryption flowchart



3.2.2 Decryption

We omit a complete description of the decryption algorithm since it is trivial, referring to Appendix A for a code example in Julia. Note that, once the whole tagged plaintext has been decrypted, it is checked, through the hash function, that the final tag is correct and that therefore the integrity of the data is not compromised.

3.3 Recommended Parameters Set

Primary key We recommend a minimum length of 501 bits. At the same time, we encourage the use of 50.000-100.000 bits keys to fully exploit the potential offered by the algorithm. To maximize the speed we suggest the use of a modulo having as factors non-trivial prime numbers. If, on the other hand, the aim is to create further problems for a potential attacker, we recommend the inclusion of some trivial factors such as 3, 5, 11 and so on. Remember that you can safely use an even modulo without absolutely slowing down the algorithm.
Secondary key It has no upper limit and can even be 0.

3.4 Security

The minimum recommended primary key length we have seen is 501 bits. The maximum length is instead not defined because it depends on the limits of the system on which the algorithm is run. In our tests we went as far as keys of over one Gigabit, which means a length of over a billion bits. Now, if by hypothesis the attacker knew the length of the key, the startpad was zero and he could have any information about the content of the first block of plaintext, for a brute-force attack he would have to try about $2^{1.000.000.000}$ different combinations. Since the attacker does not normally know the length of the key, assuming the startpad equals zero, the number of attempts would be:

$$\sum_{i=501-1}^{1.000.000.000-1} = 2^i$$

We denote by $|maxmodulo|$ the longest key that a system can handle in a "reasonably short time"[2] and by $|minmodulo|$ the minimum recommended length of the primary key. Generalizing and assuming that $|tplain| > |maxmodulo|$ we have:

$$\sum_{i=|minmodulo|-1}^{|maxmodulo|-1} = 2^i$$

FC1 therefore provides an incredible grade of confidentiality, compared to the standards currently in use, which makes it suitable for facing the difficult challenges of the next future. As far as integrity is concerned, it is ensured by adding a tag generated by a SHA-256 function. In a related work we discuss in detail other possible attacks (such as the 'replay attack') and we show how FC1 is immune to them.

References

[1] Victor Shoup (2009) *A Computational Introduction to Number Theory and Algebra*, Cambridge University Press; 2nd ed.

[2] Michele Bufalo, Daniele Bufalo, Giuseppe Orlando (2021) *A Note on the Computation of the Modular Inverse for Cryptography*, Axioms

[3] Niels Moeller (2007) *On Schoenhage's algorithm and subquadratic integer GCD computation*, MATHEMATICS OF COMPUTATION

[2]We should talk a lot about the meaning of "reasonably short time", but this is not the proper place because the subject deserves a separate work.