Pedagogy behind crypto CTF challenges and a way to improve them

Emanuel Nicolás Herrador
emanuel.nicolas.herrador@unc.edu.ar

FAMAF Facultad de Matemática, Astronomía, Física y Computación
UNC Universidad Nacional de Córdoba

What's CTF?

- Capture The Flag is a competition for cybersecurity field.
- Problems are solved obtaining *flags* (words with specific format) and they are given when we broke a weak protocol, corrupted file or system for it.
- Problem categories:

Web Exploitation	Cryptography	OSINT
Binary Exploitation	Forensics	Misc
Reverse Engineering	Hardware	PPC

Importance

- Practical experience and exposure to real-world vulnerabilities or attacks.
- Teamwork and community across social websites, jobs and universities. A way to combine all the worlds of learning (self learning, academy, industry).
- Worldwide competitions: *DEF CON*, *ICC*, *ECSC*, *Pwn20wn*, *Google CTF*.
- Gamification way to learn and teach:
  - To improve playing in cybersecurity.
  - Discovering new attacks or ways to think problems.
  - Mixing theory, practice and tricks.
- Used in a lot of universities for competitions, teach and generate more interest in cybersecurity field.

Complexity for a problemsetter

- Find interesting topics for problems.
- Problems related to protocol configurations or systems that are truly insecure in real life, and not just puzzle problems.
- Being creative and make it useful to learn.
- Make it neither too easy nor too difficult.
- Feasible to solve in the way we thought and, also, ensure it as unique to test specific objective skills for evaluation.
- Avoid being solved only with pre-existent automated tools or LLMs (as with *ico* problem of DEFCON finals 2025).

How would you create a chall in your study field?

- CTF challs are a useful way to learn and teach each area of study.
- Do you want to try creating one for teaching or share with partners?
- Do you have an idea for a CTF challenge? Tell me more!

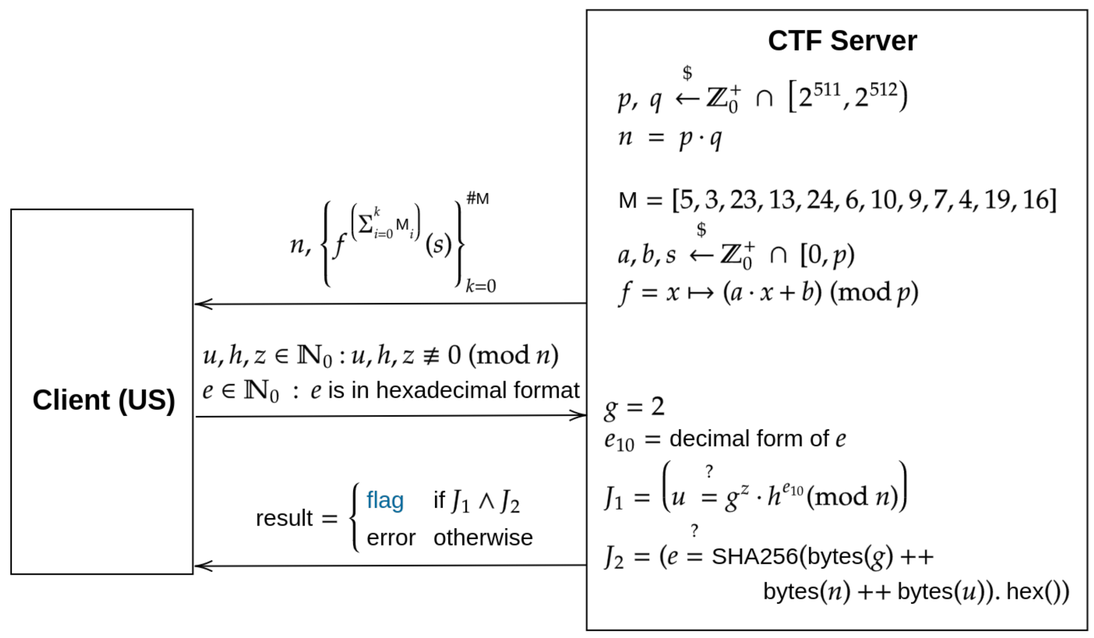
  I'll be giving feedback until 31/10 (form closes on 10).

Crypto CTF challenge example: Samsara

International Cybersecurity Challenge 2024
(Santiago, Chile)

Statement

Get the flag from the following system:



Solution: First, analyze the system. We've two main parts, an LCG that give us data and a ZKP scheme. The idea is to be able to use the last one to recover the flag from this server. Let see each one separately.

Last part (ZKP scheme)

- It's similar to a non-interactive *Girault's proof of knowledge* (with *Fiat-Shamir transformation*). The idea is to be like an honest prover and create values that holds conditions J_1 and J_2.
- h isn't used in hash and it's a weakness (*Frozen Heart Vulnerability*).
- Choosing random values u, z, we've $e = \mathrm{Hash}(g, n, u)$ and we aim for $h \equiv (u \cdot g^{-z})^{e_{\text{inv}}} \pmod n$ where $e_{\text{inv}} \equiv e^{-1} \pmod{\phi(n)}$ because:

$$g^z \cdot h^e \equiv g^z \cdot \left((u \cdot g^{-z})^{e_{\text{inv}}}\right)^e \equiv g^z \cdot u \cdot g^{-z} \equiv u \pmod n$$

- We can compute e_{inv} with *Extended Euclidean algorithm* if we know $\phi(n)$. If it doesn't exist, try another u, z random values.
- Sending these values to verifier, it should give us the flag message. So, from the first part we've to get $\phi(n)$ to solve this problem.

First part (Linear Congruential Generator)

- It's LCG with unknown parameters and are given non consecutive terms of this sequence (with its positions).
- Let be $s_k = f^{(k)}(s)$ the terms we have. An useful property to use is $s_A - s_B \equiv (a^A - a^B)\left(s + \frac{b}{a-1}\right) \pmod p$.
- Let $T = pX, S = pY$, then $\gcd(S, T) = p \iff \gcd(X, Y) = 1$. Since the probability that two random numbers are coprime is 61%, we've a good chance to get p with a little quantity of (T, S) tries.
- Aiming $R : R \neq 0 \wedge R \equiv 0 \pmod p$, we'll search for positions values $A, B, C, D, E, F, G, H \in \left\{\sum_{i=0}^{k} M_i\right\}_{k=0}^{\#M}$ such that:

$$0 \equiv (s_A - s_B)(s_C - s_D) - (s_E - s_F)(s_G - s_H) \equiv B^2 K \pmod p$$

  where $B = s + \frac{b}{a-1}$, $K = (a^A - a^B)(a^C - a^D) - (a^E - a^F)(a^G - a^H)$.
- Since $B \equiv 0 \pmod p$ is unlikely to happen, we aim for $p \mid K$. For that:

$$\{A+C, B+D\} = \{E+G, F+H\} \wedge \{A+D, B+C\} = \{E+H, F+G\}$$

- Let $m = \#M + 1$. The search can be done with bruteforce in $O(m^8)$, but searching intelligently in $O(m^6)$. The total number of useful combinations is 288 and we're able to get p and also $q = \frac{n}{p}$. So, we finally get $\phi(n) = (p-1)(q-1)$.

Complete solution and implementation

github.com/helcsnewsxd/latincrypt-2025