Problem 1: Malleability of ElGamal

Remember the auction example from the lecture: Bidder 1 produces a ciphertext $c = E(pk, bid_1)$ where $E$ is the ElGamal encryption algorithm (using integers mod $p$ as the underlying group). Given $c$, Bidder 2 can then compute $c'$ such that $c'$ decrypts to $2 \cdot bid_1 \mod p$. This allows Bidder 2 to consistently bid twice as much as Bidder 1.

Now refine the attack. You may assume that $bid_1$ is the amount of Cents Bidder 1 is willing to pay. And you can assume that Bidder 1 will always bid a whole number of Euros. (I.e., $bid_1$ is a multiple of 100.)

Show how Bidder 2 can consistently overbid Bidder 1 by only 1 %. What happens to your attack if Bidder 1 suddenly does not bid a whole number of Euros?

Hint: Remember that modulo $p$, one can efficiently find inverses. For example, one can find a number $a$ such that $a \cdot 100 \equiv 1 \mod p$.

Problem 2: Hybrid encryption – implementations

Implement a hybrid encryption using ElGamal and AES. You are allowed to use ready-made ElGamal and AES.

In the contributed file `hybrid.py` (lecture webpage), you find a prepared template in Python that already provides function for ElGamal and AES encryption as well as some utility functions and testing code that you might need. I recommend to use that code. If you wish to use another language, you will have to find your own ElGamal and AES routines.

You should check that $\text{hybrid_decrypt(sk, hybrid_encrypt(pk, msg))}$ returns $msg$.

It is OK if you only allow encrypting messages whose length is a multiple of 16 bytes (blocklength of AES).

Problem 3: Hash functions

Let $E$ be a block cipher with key and block length $n$. Let $F(x||y) := E(x, y)$ (a hash function with fixed input length $2n$, called a compression function).

Show how to find a collision for $F$. (I.e., break collision-resistance of $F$.)

---

1 As long as $bid_1 < p/2$, that is. Otherwise $2 \cdot bid_1 \mod p$ will not be twice as much as $bid_1$. However, for large $p$, $bid_1 \geq p/2$ is an unrealistically high bid.