PV181 Laboratory of security and applied cryptography

Seminar 9:

Crypto-libraries protected against hardware attacks

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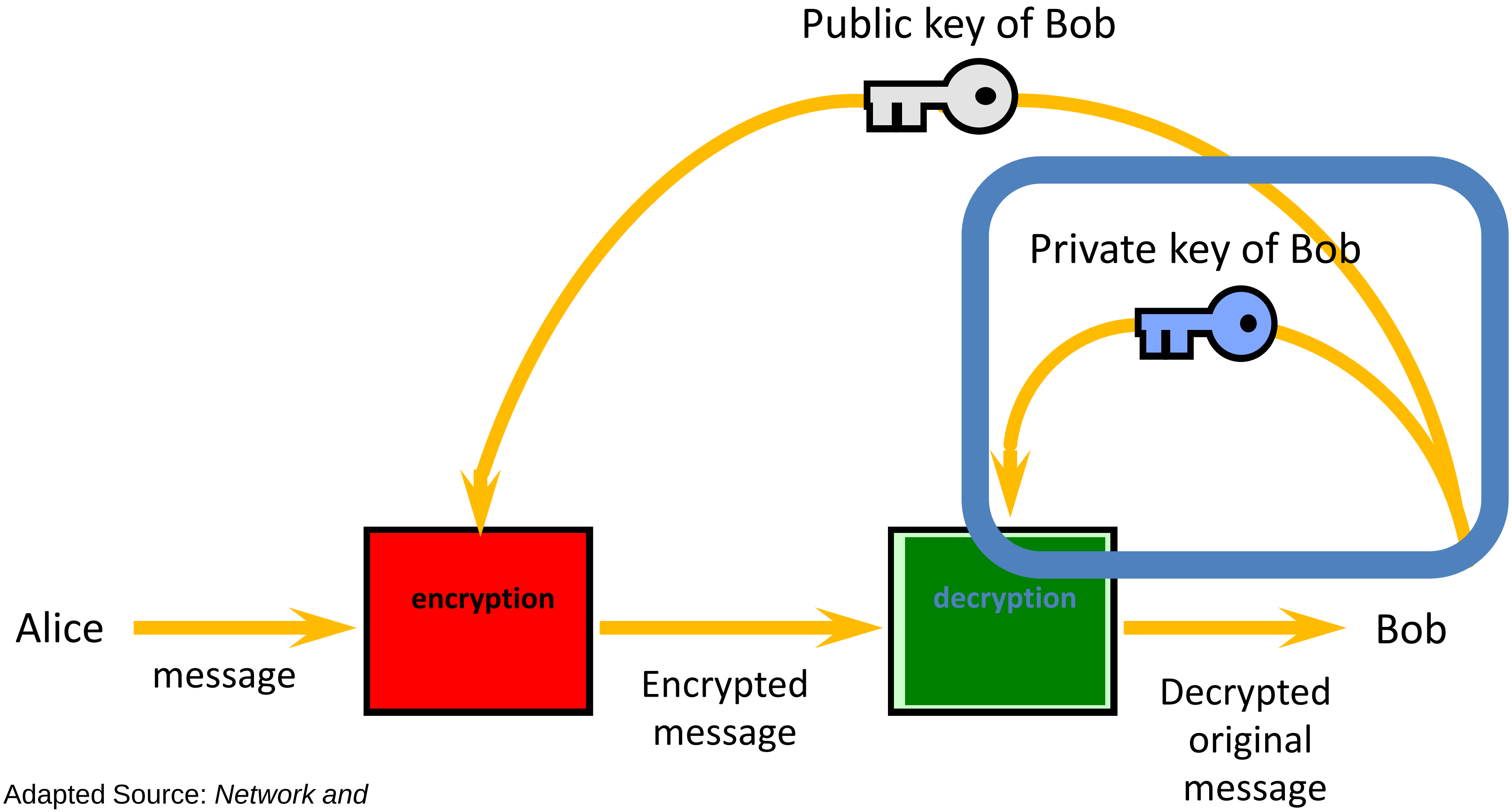
CROCS
Centre for Research on
Cryptography and Security

Outline

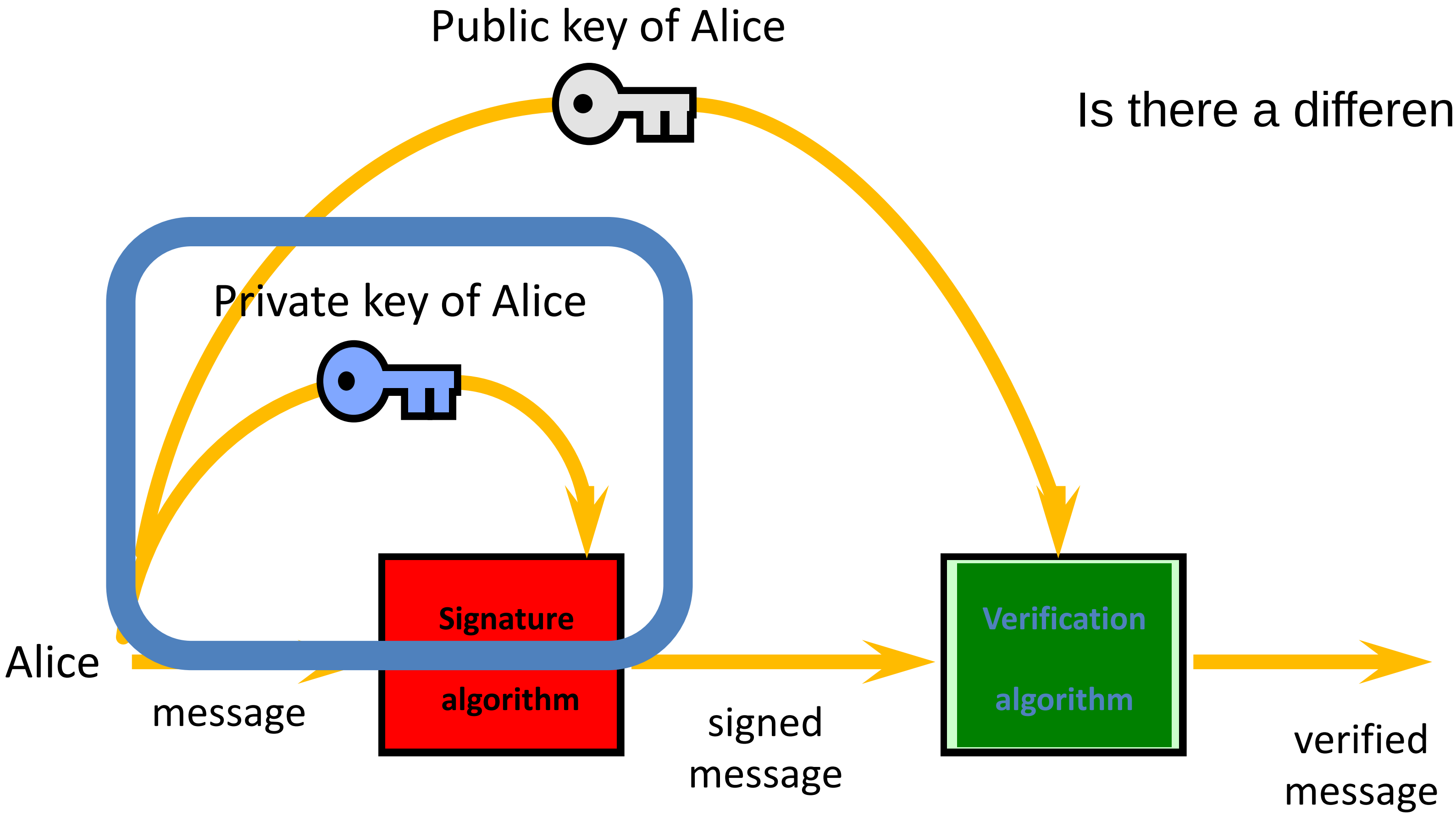
- Recall + goal of this seminar
  - Digital signatures
  - RSA and a bit about ECC
- Side Channel + Fault Injection speed run
- Secured X25519 library: sca25519
  - Optionally (but unlikely): Demo
- Assignment this week:
  - Securing RSA execution

Recall: Asymmetric cryptosystem



Adapted Source: *Network and Internetwork Security* (Stallings)

Recall: Digital signature scheme



Is there a difference?

Source: *Network and Internetwork Security* (Stallings)

RSA (recall)

RSA: reminder

1. Secret primes p, q: $n = p \cdot q$
2. Public exponent e:
$$\gcd(e,(p-1)) = \gcd(e,(q-1)) = 1$$
3. Private exponent d: $d \cdot e \equiv 1 \; mod \; \varphi(n)$

Encryption (public n, e): $E(m) = m^e \; mod \; n = c$

Decryption (private n, d): $D(c) = c^d \; mod \; n = m$

RSA-CRT + demo

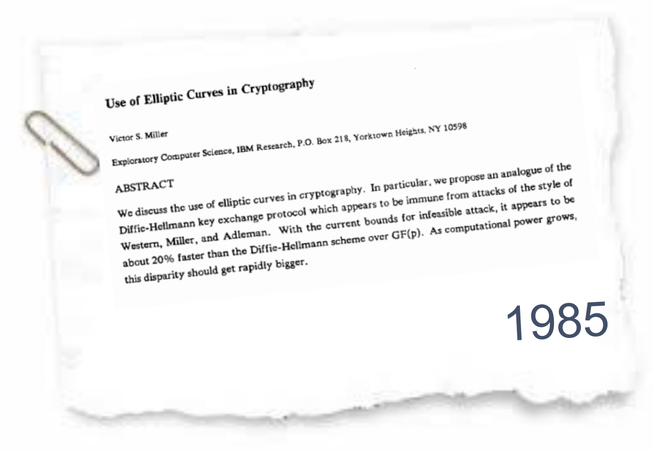
- Optimization of computing a signature giving about 3 or 4-fold speed-up
- Precompute the following values:
  - Find d_p = d (mod p-1), computed as $d_p = e^{-1}$ (mod p-1)
  - Find d_q = d (mod q-1)
  - Compute $i_q = q^{-1}$ (mod p)
- Computations using m_p = m (mod p) and m_q = m (mod q)
- Signature or encryption (forgetting about hashing):
  - $s_p = m^{d_p}$ (mod p)
  - $s_q = m^{d_q}$ (mod q)
  - Garner's method (1965) to recombine s_p and s_q:
    - $s = s_q + q \cdot (i_q(s_p - s_q) \pmod{p})$
- Computations using m_p = m (mod p) and m_q = m (mod q)
- Open RSA.py and run it. Analyze it, what are your conclusions?
  - What is the speed improvement?

ECC (recall)

Recall: RSA vs. ECC

- exponentiation ≈ scalar multiplication
- multiplication ≈ points addition
- squaring ≈ point doubling

- The next few slides be ECC recall



Use of Elliptic Curves in Cryptography

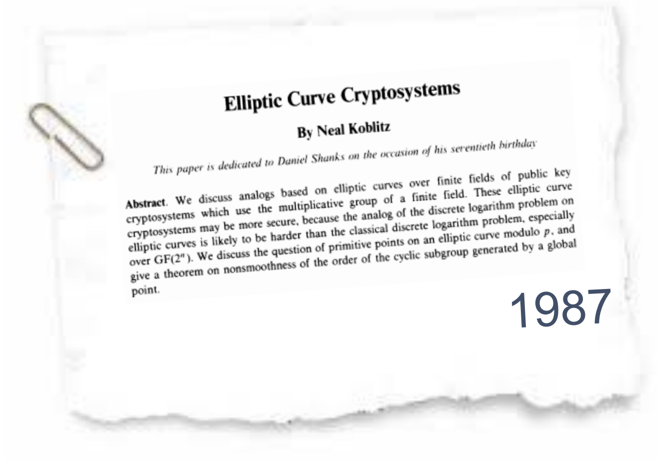
Victor S. Miller

Exploratory Computer Science, IBM Research, P.O. Box 218, Yorktown Heights, NY 10598

ABSTRACT

We discuss the use of elliptic curves in cryptography. In particular, we propose an analogue of the Diffie-Hellmann key exchange protocol which appears to be immune from attacks of the style of Western, Miller, and Adleman. With the current bounds for infeasible attack, it appears to be about 20% faster than the Diffie-Hellmann scheme over GF(p). As computational power grows, this disparity should get rapidly bigger.

1985



Elliptic Curve Cryptosystems

By Neal Koblitz

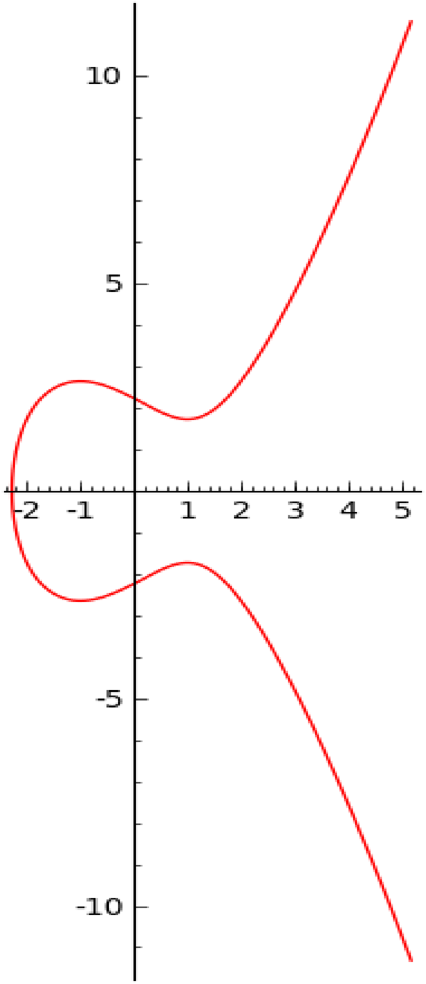
This paper is dedicated to Daniel Shanks on the occasion of his seventieth birthday

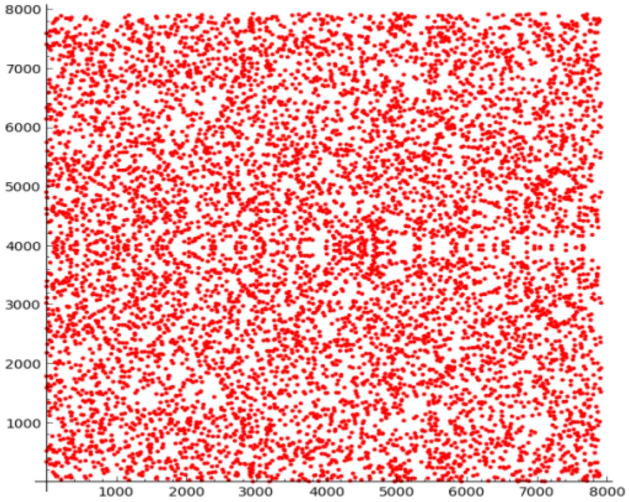
Abstract. We discuss analogs based on elliptic curves over finite fields of public key cryptosystems which use the multiplicative group of a finite field. These elliptic curve cryptosystems may be more secure, because the analog of the discrete logarithm problem on elliptic curves is likely to be harder than the classical discrete logarithm problem, especially over $GF(2^n)$. We discuss the question of primitive points on an elliptic curve modulo p, and give a theorem on nonsmoothness of the order of the cyclic subgroup generated by a global point.

1987

Elliptic curve example

- Example
  - $y^2 = x^3 - 3x^2 + 5$ over $\mathbb{Q}$, and ∞
- How would it look over a finite field,
  - for example: F_p? for $p = 7919$

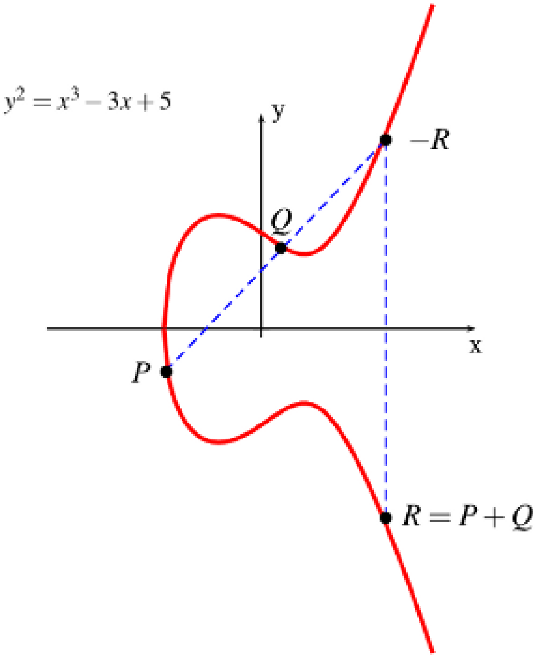


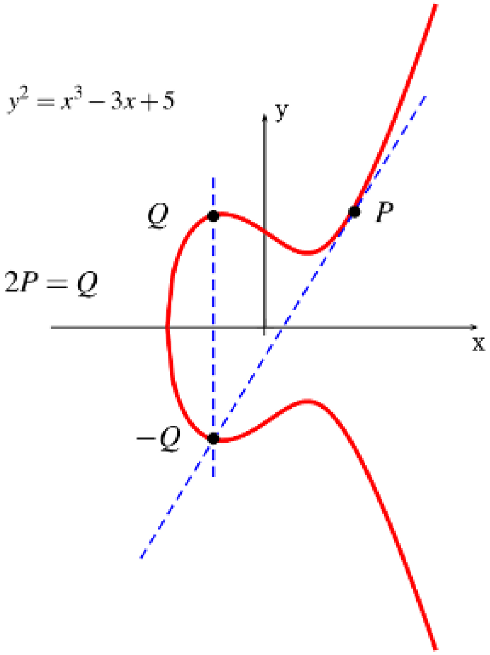


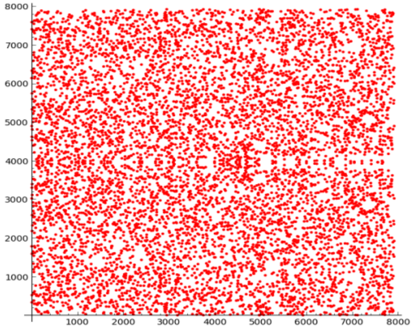
Can you see a pattern?

Elliptic curve implementations

- Group operation over the curve: addition and doubling

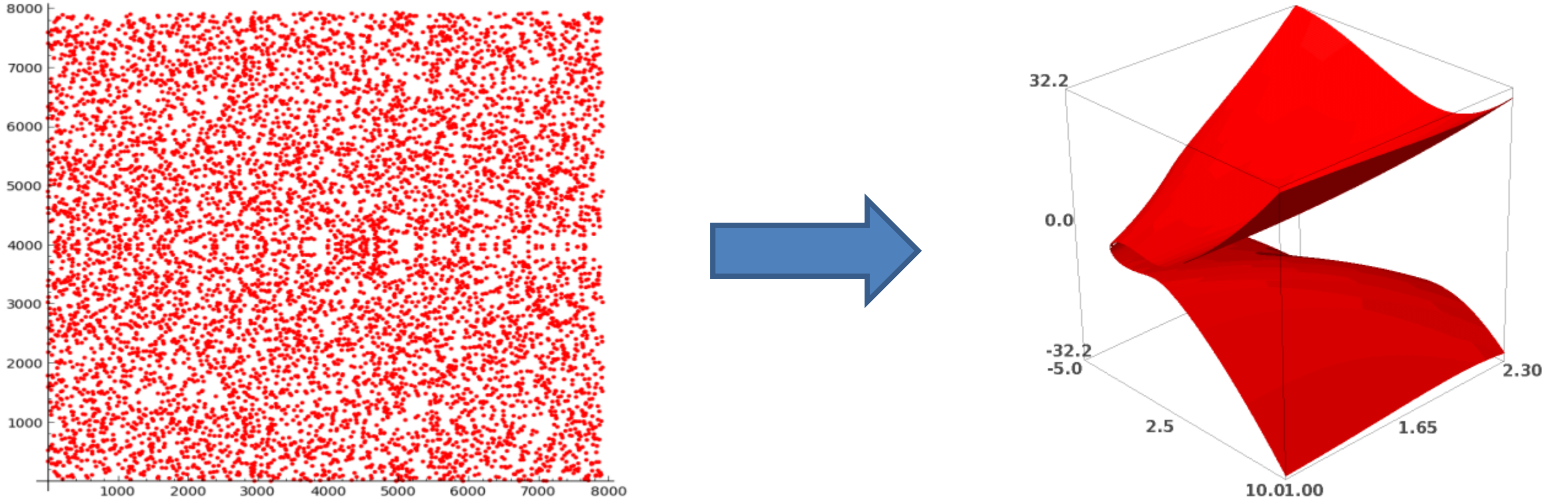






Elliptic curve implementations' details

- Above operations on the finite field:



- …

ECC keys

- Generating key pair
  - Select a random integer **d** from [1,n − 1]
  - Compute **P** = [d]G = d*G;
  - Hard to get d from P and G!
- Private key: **d**
- Public key: **P**,
  - also: **G**, and curve details are also public

- For 256-bit curve
  - the private key **d** will be approx. 256-bit long
  - the public key **P** is a point on the curve – will be approx 512-bit long, unless compressed

SCA & FI

Why is hardware security important?

Card / Money Theft

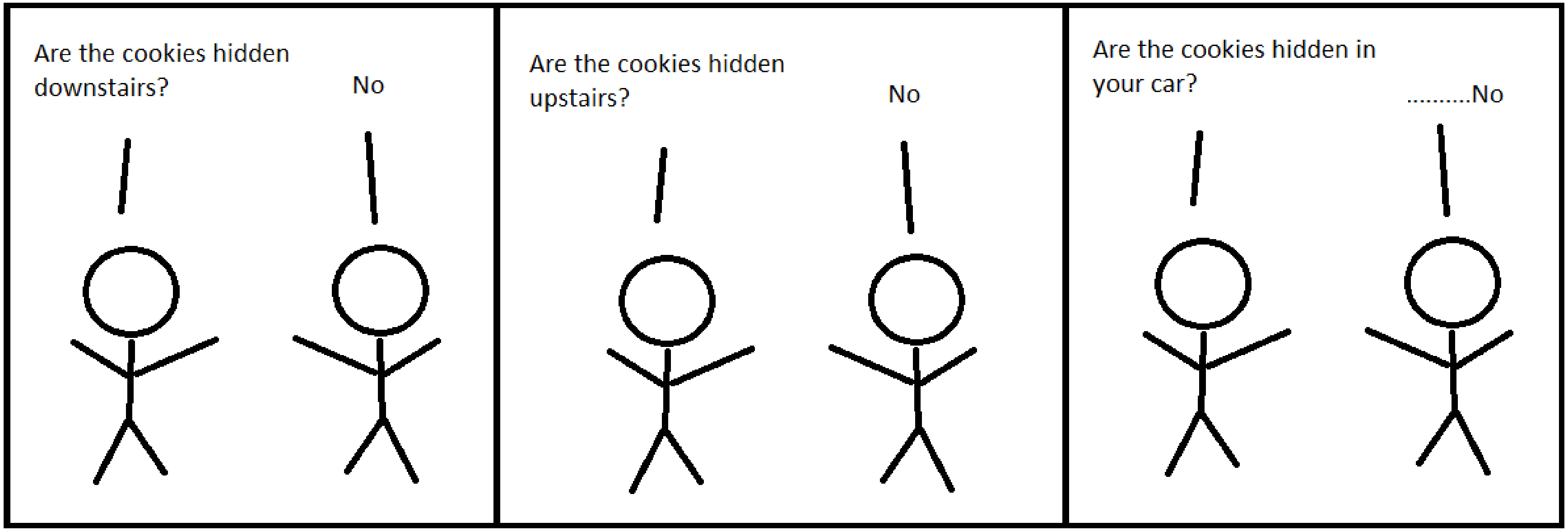
Identity Theft

- **Premium**

Phone / Money Theft

Impersonation

Cookies Example



https://www.simplethread.com/great-scott-timing-attack-demo/

Passive vs Active Side Channels

Passive: analyze device behavior

Active: change device behavior

Recent Practical Attacks

TPM-FAIL, November 13, 2019

LadderLeak, May 28, 2020

LadderLeak: Side-channel security flaws exploited to break ECDSA cryptography

Existing attacks refined to attack elliptic curve algorithm

SCA Titan: January 7, 2021

Minerva, October 3, 2019

Researchers Discover ECDSA Key Recovery Method

TPMScan, March 12, 2024

TPMScan: A wide-scale study of security-relevant properties of TPM 2.0 chips

Petr Svenda
Masaryk University, Brno, Czech Republic
Antonin Dufka
Masaryk University, Brno, Czech Republic
Milan Broz
Masaryk University, Brno, Czech Republic
Roman Lacko
Masaryk University, Brno, Czech Republic
Tomas Jaros
Masaryk University, Brno, Czech Republic
Daniel Zatovic
Red Hat, Brno-Medlánky, Czech Republic
Josef Pospisil
National Cyber and Information Security Agency, Brno, Czech Republic

Keywords: TPM, RSA, ECDSA, ECSCHNORR, ECDAA, ECC key recovery

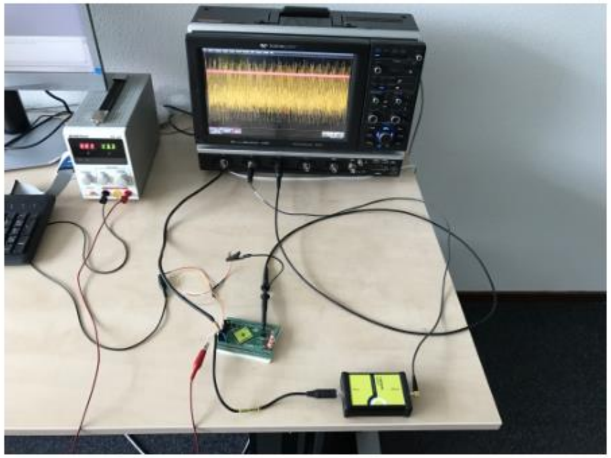
EUCLEAK, Recently

What can be attacked & why?

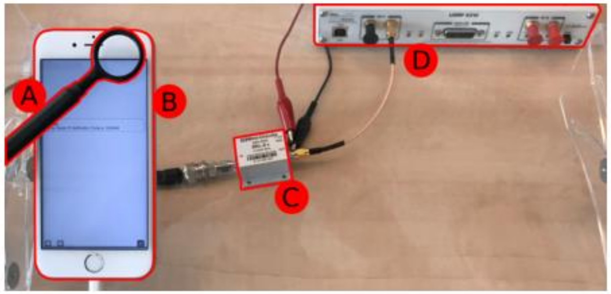
- Type of device?
- What kind of primitive?
- How much control do you have?
- What can you access?
- What would be the attacker’s goal?
- What is your goal?
- Where is the money?
- …

Some Practical Setups

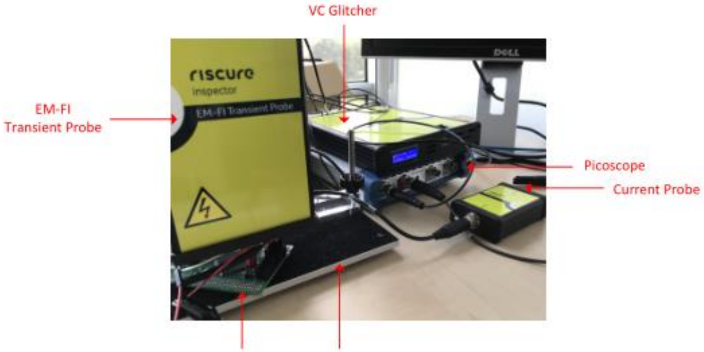
DPA setup with ARM CortexM4



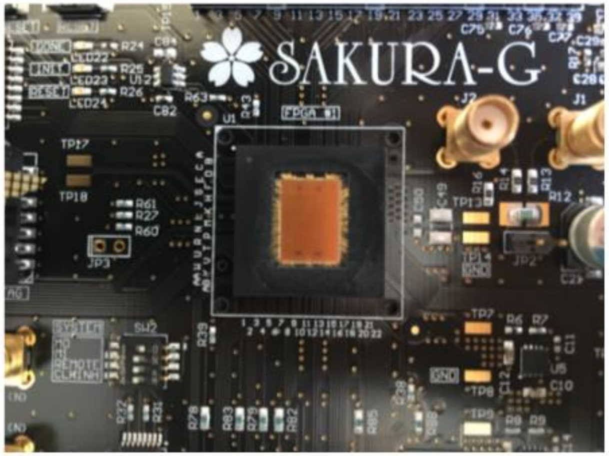
Tempest



FA setup

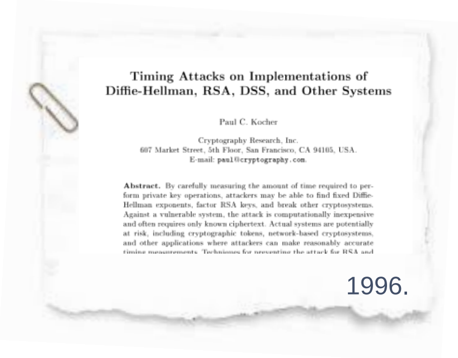


FPGA board for SCA



Simple Power Analysis (SPA) on RSA

```
ModExp(c) {
    $A = 1$
    for ( $i = n-1$; $i \geq 0$; $i--$ )
        $A = A^2 \bmod N$            S
        if ($d_i == 1$)
            $A = A*c \bmod N$        M
        end if
    end for
    Return $A = c^d \bmod N$
}
```



Timing Attacks on Implementations of
Diffie-Hellman, RSA, DSS, and Other Systems

Paul C. Kocher

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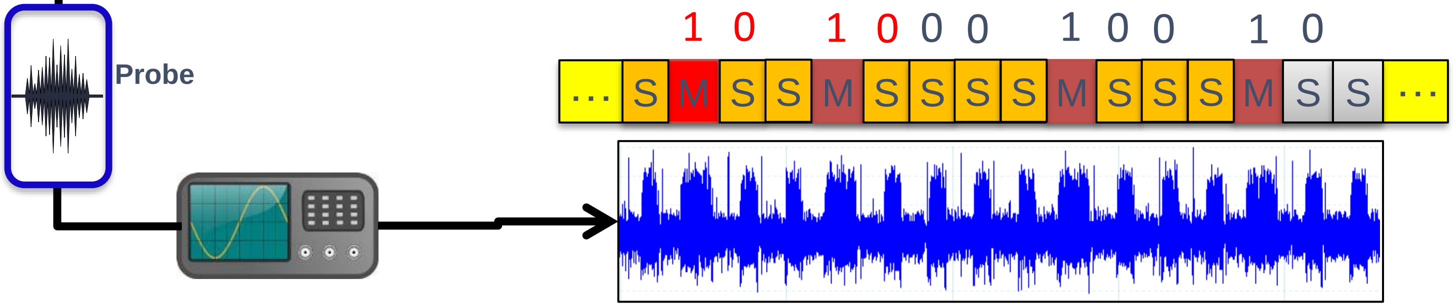
607 Market Street, 5th Floor, San Francisco, CA 94105, USA.
E-mail: paul@cryptography.com.

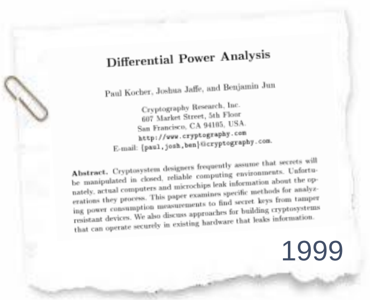
Abstract. By carefully measuring the amount of time required to perform private key operations, attackers may be able to find fixed Diffie-Hellman exponents, factor RSA keys, and break other cryptosystems. Against a vulnerable system, the attack is computationally inexpensive and often requires only known ciphertext. Actual systems are potentially at risk, including cryptographic tokens, network-based cryptosystems, and other applications where attackers can make reasonably accurate timing measurements. Techniques for preventing the attack for RSA and

1996.

"By carefully measuring the ***amount of time*** required to perform private key operations, attackers may be able to find […] RSA keys."



Differential (Correlation) Power Analysis



Differential Power Analysis

Paul Kocher, Joshua Jaffe, and Benjamin Jun

Cryptography Research, Inc.
607 Market Street, 5th Floor
San Francisco, CA 94105, USA.
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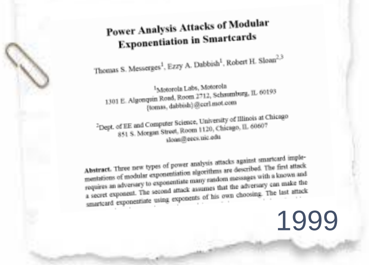
E-mail: `{paul,josh,ben}@cryptography.com`.

Abstract. Cryptosystem designers frequently assume that secrets will
be manipulated in closed, reliable computing environments. Unfortu-
nately, actual computers and microchips leak information about the op-
erations they process. This paper examines specific methods for analyz-
ing power consumption measurements to find secret keys from tamper
resistant devices. We also discuss approaches for building cryptosystems
that can operate securely in existing hardware that leaks information.

1999



Power Analysis Attacks of Modular Exponentiation in Smartcards

Thomas S. Messerges[1], Ezzy A. Dabbish[1], Robert H. Sloan[2,3]

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[2]Dept. of EE and Computer Science, University of Illinois at Chicago
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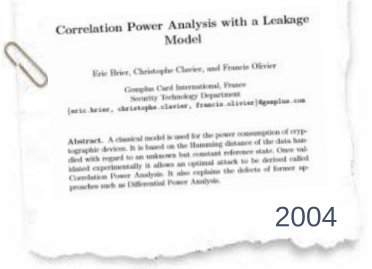
Abstract. Three new types of power analysis attacks against smartcard imple-
mentations of modular exponentiation algorithms are described. The first attack
requires an adversary to exponentiate many random messages with a known and
a secret exponent. The second attack assumes that the adversary can make the
smartcard exponentiate using exponents of his own choosing. The last attack

1999



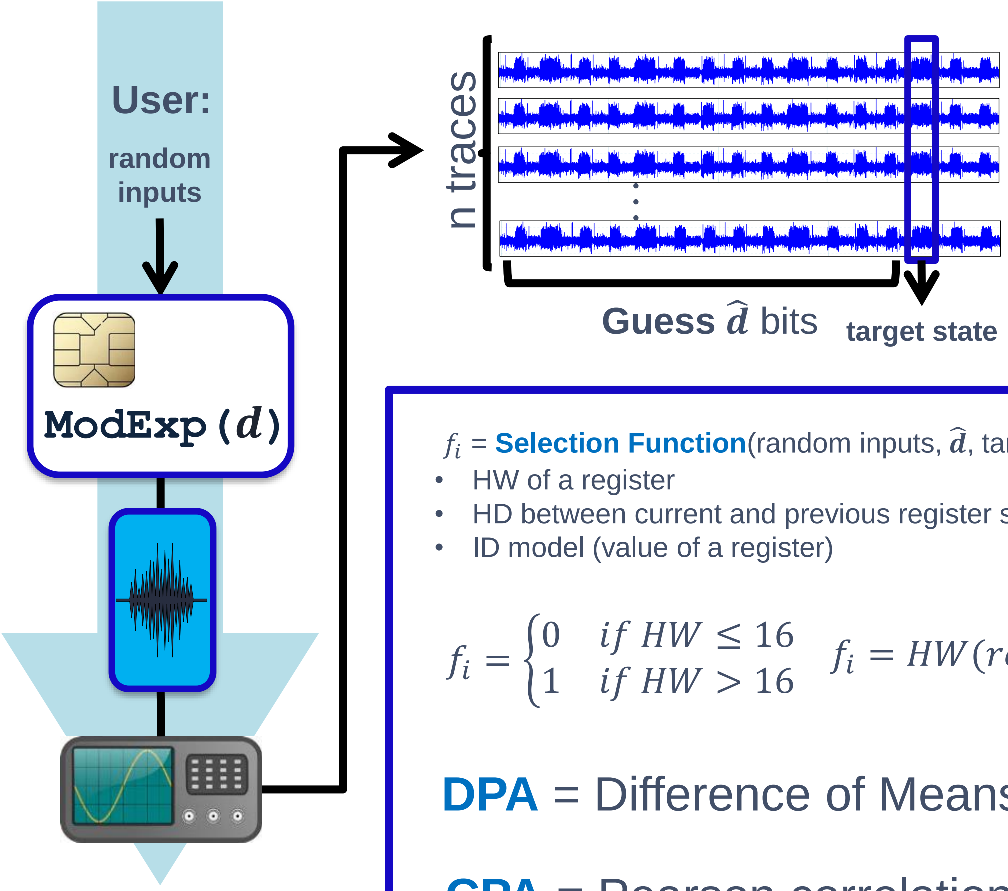
Correlation Power Analysis with a Leakage Model

Eric Brier, Christophe Clavier, and Francis Olivier

Gemplus Card International, France
Security Technology Department
`{eric.brier, christophe.clavier, francis.olivier}@gemplus.com`

Abstract. A classical model is used for the power consumption of cryp-
tographic devices. It is based on the Hamming distance of the data han-
dled with regard to an unknown but constant reference state. Once val-
idated experimentally it allows an optimal attack to be derived called
Correlation Power Analysis. It also explains the defects of former ap-
proaches such as Differential Power Analysis.

2004



User:

random inputs

ModExp(d)

n traces

Guess $\hat{d}$ bits

target state

f_i = **Selection Function**(random inputs, $\hat{d}$, target state)

- HW of a register
- HD between current and previous register state
- ID model (value of a register)

$$f_i = \begin{cases} 0 & if\ HW \leq 16 \\ 1 & if\ HW > 16 \end{cases} \qquad f_i = HW(reg\_state)$$

DPA = Difference of Means

CPA = Pearson correlation

Goals of Fault Injection

- The goal is to change a critical value or to change the flow of a program.
- Faults can be injected in several ways:
  - Power glitches
  - Optical glitches with laser
  - Clock manipulation by introducing a few very short clock cycles
  - Cutting the power to the processor while performing important computations
- Differential Fault Analysis (DFA)

RSA-CRT: Differential Fault Analysis

- Optimization of computing a signature giving about 3 or 4-fold speed-up
- Precompute the following values:
  - Find $d_p = d \pmod{p-1}$, computed as $d_p = e^{-1} \pmod{p-1}$
  - Find $d_q = d \pmod{q-1}$
  - Compute $i_q = q^{-1} \pmod{p}$
- Computations using $m_p = m \pmod{p}$ and $m_q = m \pmod{q}$
- Signature or encryption (forgetting about hashing):
  - $s_p = m^{d_p} \pmod{p}$
  - $s_q = m^{d_q} \pmod{q}$
  - Garner's method (1965) to recombine s_p and s_q:
    - $s = s_q + q \cdot (i_q(s_p - s_q) \pmod{p})$
- Due to a limited time, we need to skip the math details on how to recover p and q, but it is possible with one fault!
  - If you are interested, ask me after the seminar; it is a so-called Bellcore attack, see for example: https://eprint.iacr.org/2012/553.pdf

How to protect against FI?

- You have to check that the operations was correctly executed, for example:
  - Duplication of operations;
  - For signature generation you can verify the result
  - Some SCA countermeasures will work even for FI
    - But not all

Warm-up Question (1-2):

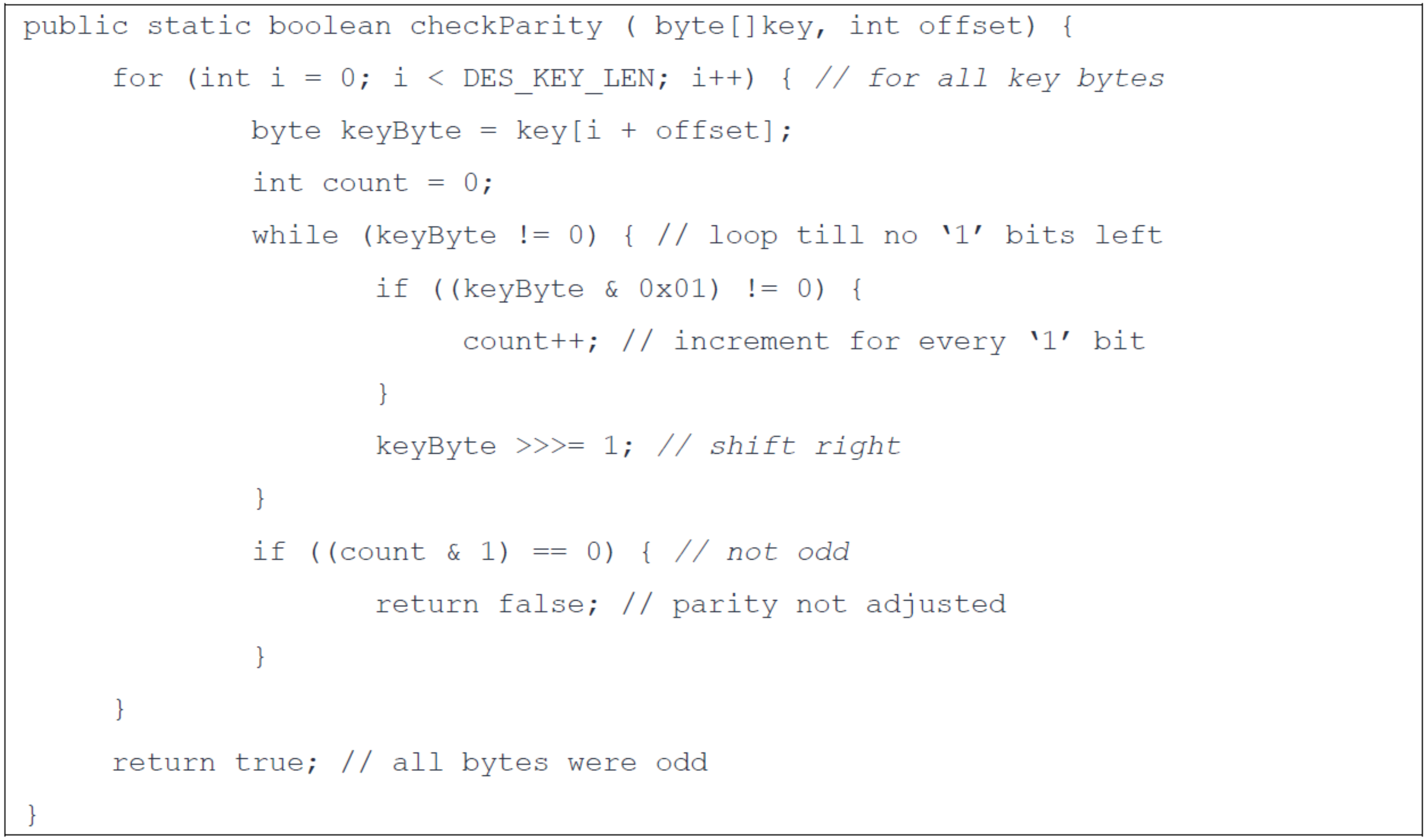
Software for PIN code verification

```
Input: 4-digit PIN code
Output: PIN verified or rejected
Process CheckPIN (pin[4])
int pin_ok=0;
if (pin[0]==5)
    if (pin[1]==9)
        if (pin[2]==0)
            if (pin[3]==2)
                pin_ok=1;
            end
        end
    end
end
return pin_ok;
EndProcess
```

- What is the problem here?
- What are the execution times of the process for PIN inputs?
  - [0,1,2,3], [5,3,0,2], [5,9,0,0]
- The execution time increases as we get closer to
  - [5,9,0,2]

- How would you perform a fault injection attack here?

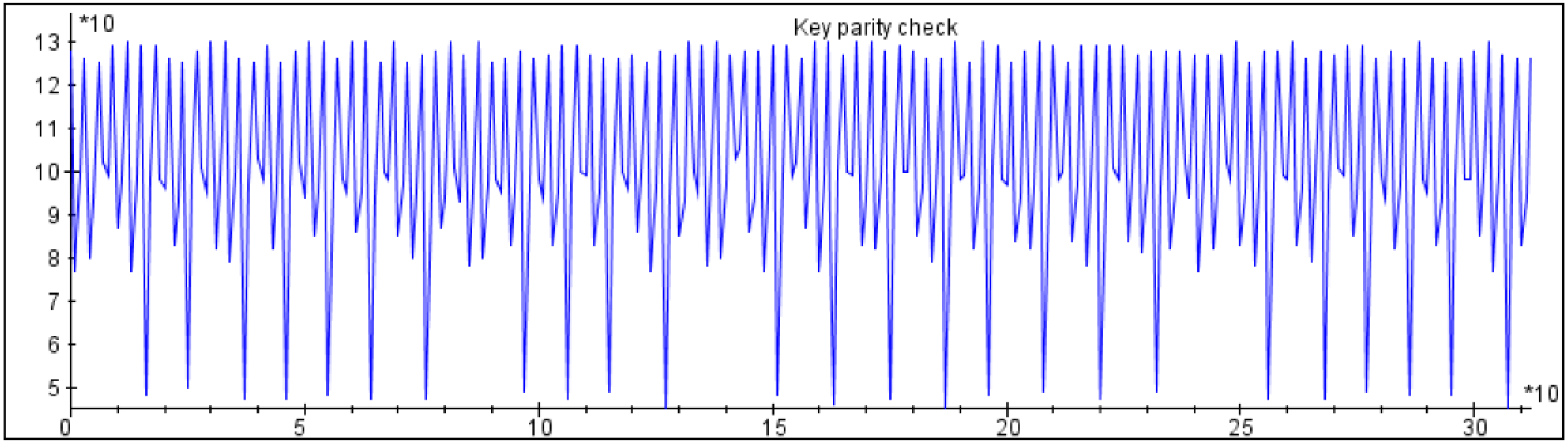
Warm-up Task – parity check for DES key



```
public static boolean checkParity ( byte[]key, int offset) {
     for (int i = 0; i < DES_KEY_LEN; i++) { // for all key bytes
             byte keyByte = key[i + offset];
             int count = 0;
             while (keyByte != 0) { // loop till no ‘1’ bits left
                    if ((keyByte & 0x01) != 0) {
                         count++; // increment for every ‘1’ bit
                    }
                    keyByte >>>= 1; // shift right
             }
             if ((count & 1) == 0) { // not odd
                    return false; // parity not adjusted
             }
     }
     return true; // all bytes were odd
}
```

Warm-up Task – parity check for DES key

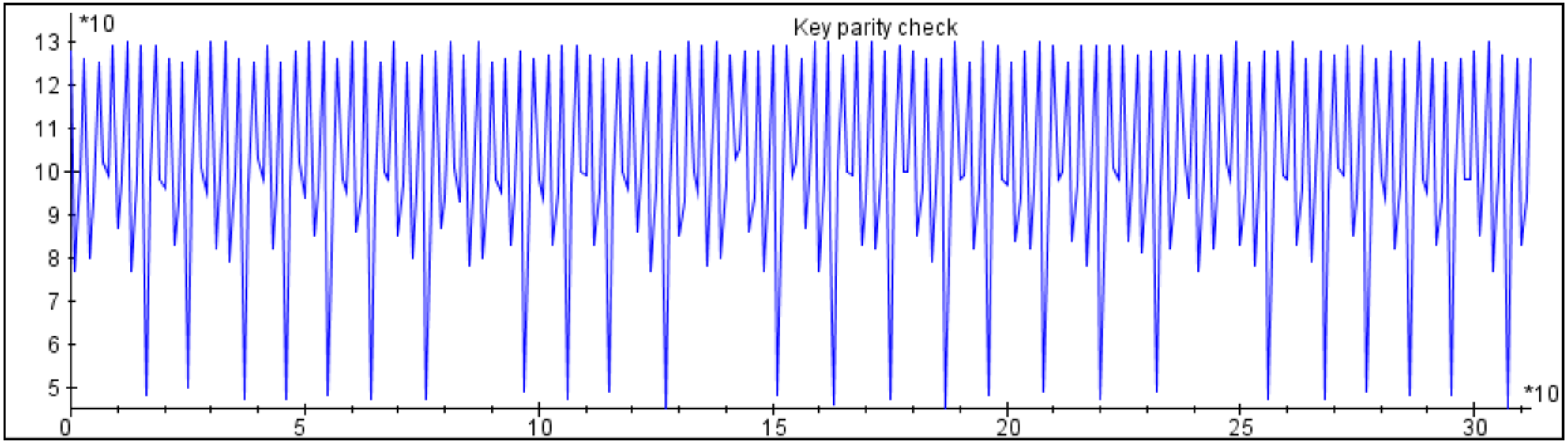
cont’d



Tell me what is the key ☺

Warm-up Task – parity check for DES key

cont'd



1 0 1 0 0 0 1 0 0 0 1 1 1 1 1 0 1 1 1 1 1 0 0 0 1

0x45 0x08 0xEF 0x23

Question 1:

faster and more secure modexp - Montgomery ladder

```
$x_0=x$; $x_1=x^2$
for j=k-2 to 0 {
  if $d_j=0$
    $x_1=x_0*x_1$; $x_0=x_0^2$
  else
    $x_0=x_0*x_1$; $x_1=x_1^2$
  $x_1=x_1$ mod N
  $x_0=x_0$ mod N
}
return $x_0$
```

Both branches with the same number and type of operations (unlike square and multiply on previous slide)

Is it constant-time & secure? Why?

Question 2:

even more secure modexp

```
$x_0=x$; $x_1=x^2$
for j=k-2 to 0 {
  $b=d_j$
  $x_{(1-b)}=x_0*x_1$; $x_b=x_b^2$
  $x_1=x_1$ mod N
  $x_0=x_0$ mod N
}
return $x_0$
```

Memory access often is not constant time!
Especially in the presence of caches.

Is it constant-time & secure? Why?

Question 3:

even more secure modexp

```
$x_0=x$; $x_1=x^2$
for j=k-2 to 0 {
  $b=d_j$
  $x_{(1-b)}=x_0*x_1$; $x_b=x_b^2$
  $x_1=x_1$ mod N
  $x_0=x_0$ mod N
}
return $x_0$
```

Memory access often is not constant time!
Especially in the presence of caches.

Is it constant-time & secure? Why?

Question 4:

even more more secure modexp

```
$x_0$=x; $x_1$=$x^2$; sw = 0
for j=k-2 to 0 {
  b=$d_j$
  cswap($x_0$,$x_1$,b$\oplus$sw)
  sw = sw$\oplus$di
  $x_1$=$x_0$*$x_1$; $x_0$=$x_0^2$
  $x_1$=$x_1$ mod N
  $x_0$=$x_0$ mod N
}
return $x_0$
```

Constant-time? Depends on the cswap… but it can be ☺
Other-side channels? Depends 😐

Is it constant-time & secure? Why?

Message and exponent blinding

$c = m^d mod\ N$

1. $m_r = m.r^{-e} mod\ N$	message blinding
2. $d_r = d + r * \varphi(n)$	exponent blinding
3. $c_r = {m_r}^{d_r}\ mod\ n$	blinded exponentiation
4. $c = c_r * r\ mod\ n$	message “unblinding”

The sequence of operations (S, M) is related to the exponent bits.

However:

- If ***d*** is random: the sequence of exponent bits changes for every RSA execution
- If ***m*** is random: Intermediate data is random (masked) → hardly predicted!

Message and exponent blinding

$c = m^d mod\ N$

1. $m_r = m.r^{-e} mod\ N$ message blinding
2. $d_r = d + r * \varphi(n)$ exponent blinding
3. $c_r = {m_r}^{d_r}\ mod\ n$ blinded exponentiation
4. $c = c_r * r\ mod\ n$ message “unblinding”

- Message blinding is the same!
- Exponent blinding needs to be done twice:

  $s_p = m^{d_p}$ (mod p) = $m^{d_p+r*(p-1)}$ (mod p)
  $s_q = m^{d_q}$ (mod q) = $m^{d_q+r*(q-1)}$ (mod q)

- That does not stop FI attacks!

Why do coordinate and scalar blinding protect ECC against SCA?

$$M = [s]P = [s](X, Y) = [s](x, y, 1)$$

1. $M = [s](x.z, y.z, z)$ → coordinate blinding
2. $s_r = s + r.|E|$ → scalar blinding
3. $M_r = [s_r](x.z, y.z, z)$ → blinded scalar mult.
4. → no unblinding

The same situation as for RSA. Point blinding is also possible but not presented above.

Note: there are of course differences in some detailed countermeasures.

CODE INSPECTION

PROTECTED CRYPTO LIBRARY

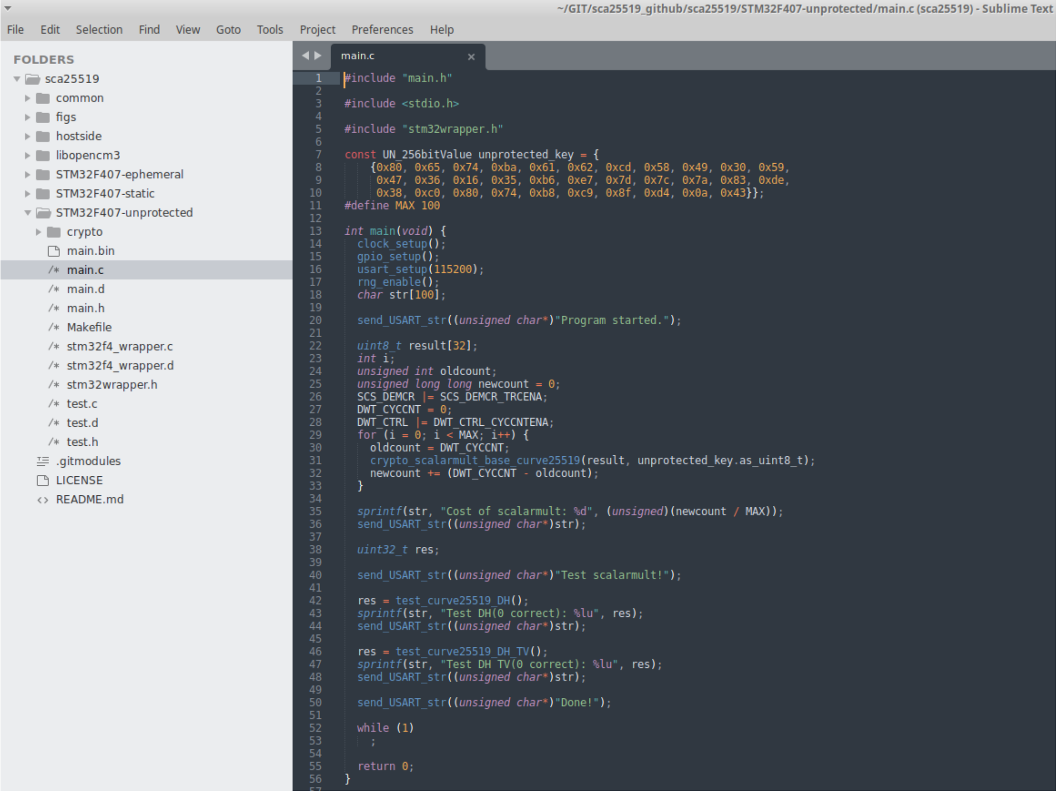
SCA&FI-protected Elliptic Curve library

- A protected library for ECDH
  - key exchange & session key establishment
  - It will be published in TCHES2023 volume 1 and
    - presented at Ches 2023 in Prague
- Code library available from GitHub
- Useful links:
  - https://eprint.iacr.org/2021/1003
  - https://github.com/sca-secure-library-sca25519/sca25519
- Taking care of ECDSA:
  - https://eprint.iacr.org/2022/1254
  - I will add it to the repository later on.

What to do first

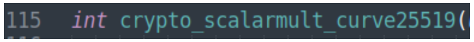
- Download (or clone) the code from:
  - https://github.com/sca-secure-library-sca25519/sca25519
- If you do not know C then it will be tricky but in this case try to be intuitive.
- Task 1: have a look at the STM32F407-unprotected:
  - Please find the starting point.
  - Please find the scalar multiplication function.
    - And the scalar multiplication loop.
  - What the code is doing?

Task 1: Unprotected Crypto Library

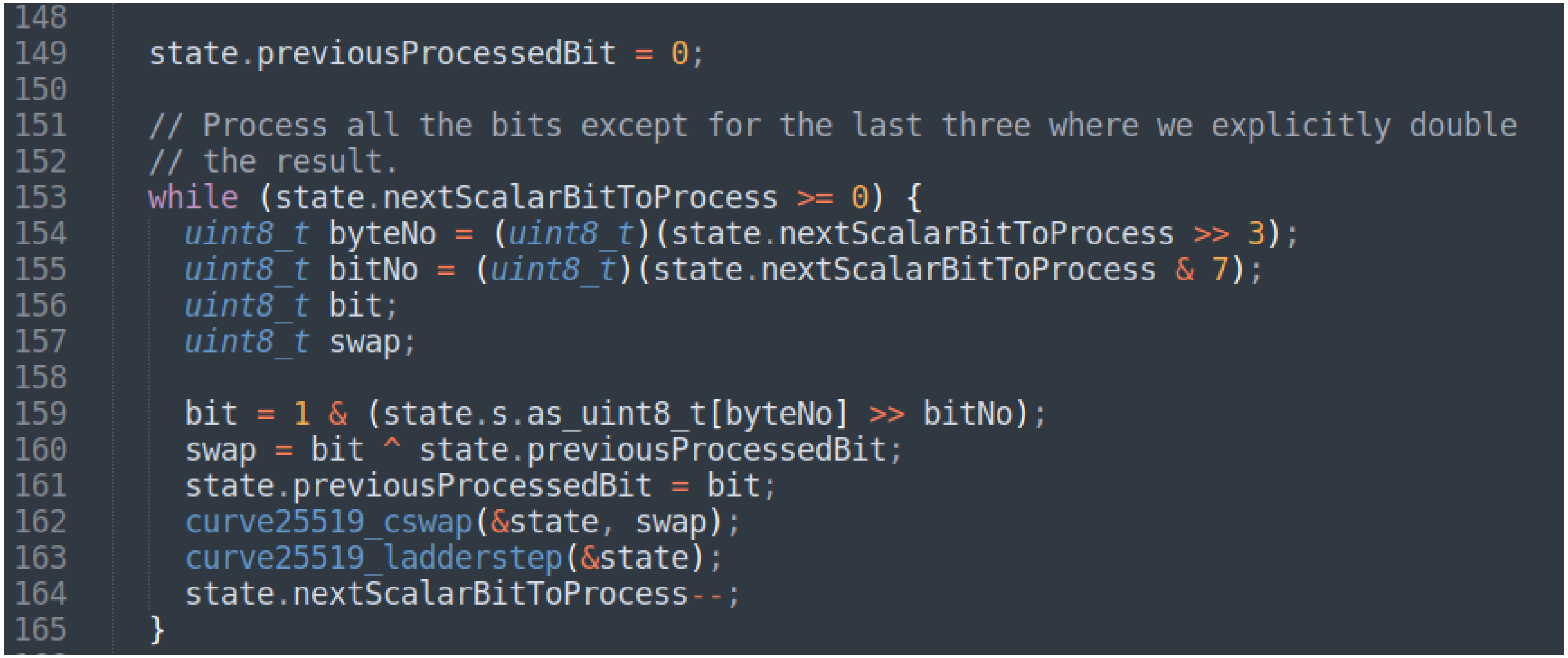


```c
#include "main.h"

#include <stdio.h>

#include "stm32wrapper.h"

const UN_256bitValue unprotected_key = {
    {0x80, 0x65, 0x74, 0xba, 0x61, 0x62, 0xcd, 0x58, 0x49, 0x30, 0x59,
     0x47, 0x36, 0x16, 0x35, 0xb6, 0xe7, 0x7d, 0x7c, 0x7a, 0x83, 0xde,
     0x38, 0xc0, 0x80, 0x74, 0xb8, 0xc9, 0x8f, 0xd4, 0x0a, 0x43}};
#define MAX 100

int main(void) {
  clock_setup();
  gpio_setup();
  usart_setup(115200);
  rng_enable();
  char str[100];

  send_USART_str((unsigned char*)"Program started.");

  uint8_t result[32];
  int i;
  unsigned int oldcount;
  unsigned long long newcount = 0;
  SCS_DEMCR |= SCS_DEMCR_TRCENA;
  DWT_CYCCNT = 0;
  DWT_CTRL |= DWT_CTRL_CYCCNTENA;
  for (i = 0; i < MAX; i++) {
    oldcount = DWT_CYCCNT;
    crypto_scalarmult_base_curve25519(result, unprotected_key.as_uint8_t);
    newcount += (DWT_CYCCNT - oldcount);
  }

  sprintf(str, "Cost of scalarmult: %d", (unsigned)(newcount / MAX));
  send_USART_str((unsigned char*)str);

  uint32_t res;

  send_USART_str((unsigned char*)"Test scalarmult!");

  res = test_curve25519_DH();
  sprintf(str, "Test DH(0 correct): %lu", res);
  send_USART_str((unsigned char*)str);

  res = test_curve25519_DH_TV();
  sprintf(str, "Test DH TV(0 correct): %lu", res);
  send_USART_str((unsigned char*)str);

  send_USART_str((unsigned char*)"Done!");

  while (1)
    ;

  return 0;
}
```

Task 1: Unprotected Crypto Library cont’d



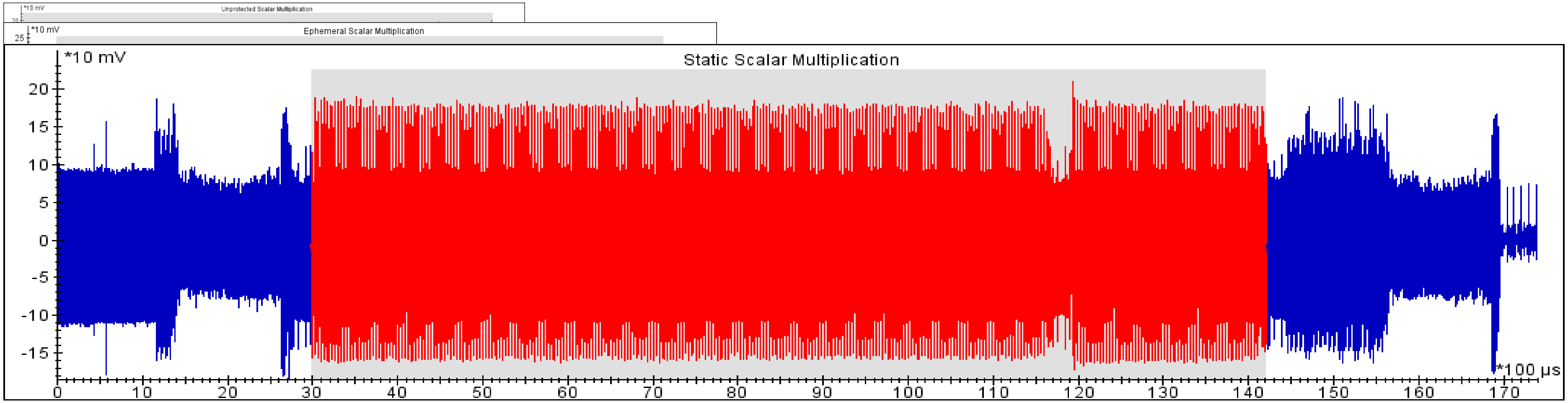
```
int crypto_scalarmult_curve25519(
```



```

    state.previousProcessedBit = 0;

    // Process all the bits except for the last three where we explicitly double
    // the result.
    while (state.nextScalarBitToProcess >= 0) {
        uint8_t byteNo = (uint8_t)(state.nextScalarBitToProcess >> 3);
        uint8_t bitNo = (uint8_t)(state.nextScalarBitToProcess & 7);
        uint8_t bit;
        uint8_t swap;

        bit = 1 & (state.s.as_uint8_t[byteNo] >> bitNo);
        swap = bit ^ state.previousProcessedBit;
        state.previousProcessedBit = bit;
        curve25519_cswap(&state, swap);
        curve25519_ladderstep(&state);
        state.nextScalarBitToProcess--;
    }
```

Protected Crypto Library – other implementations

Ephemeral & Static increase complexity

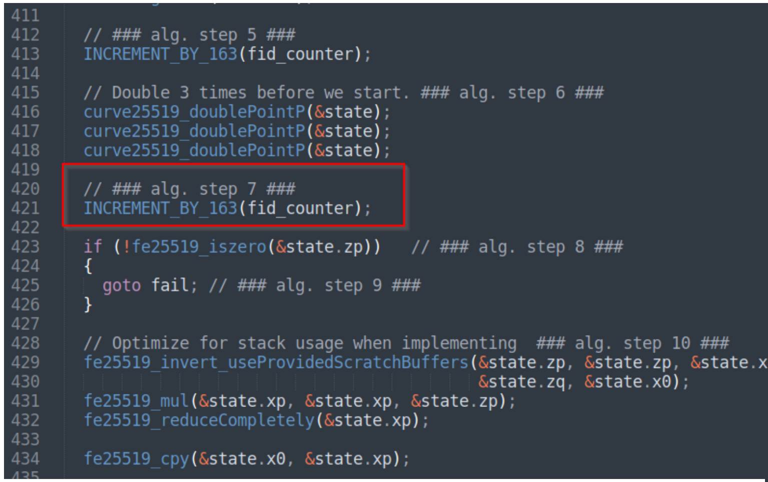


Task 2: Ephemeral Crypto Library

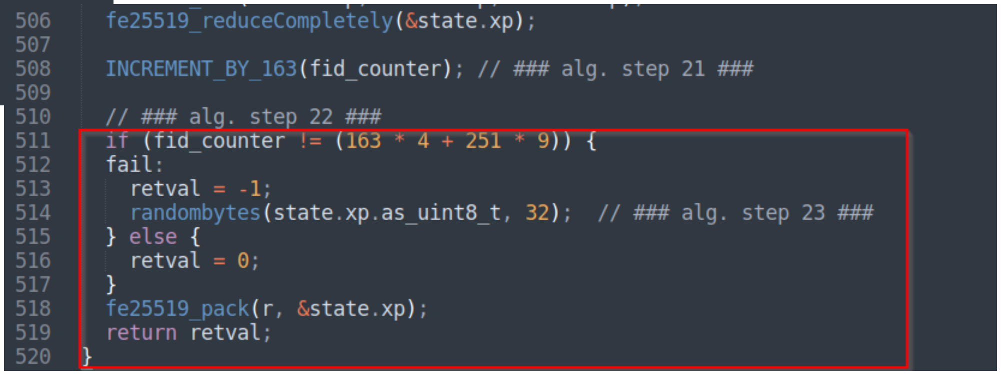
- Have a look at the STM32F407-ephermeral (and STM32F407-static):
  - Find scalar multiplication functions and the scalar multiplication loops
- Try to find one side-channel countermeasure and one fault injection countermeasure. Have also a look at the list of implemented countermeasures in:
  - https://tches.iacr.org/index.php/TCHES/issue/view/312
- Can you explain the countermeasures?
- If you have time, then try to find one or two more countermeasures

Remark: do not worry – this is a hard exercise.

Task 2: Ephemeral Crypto Library - FI



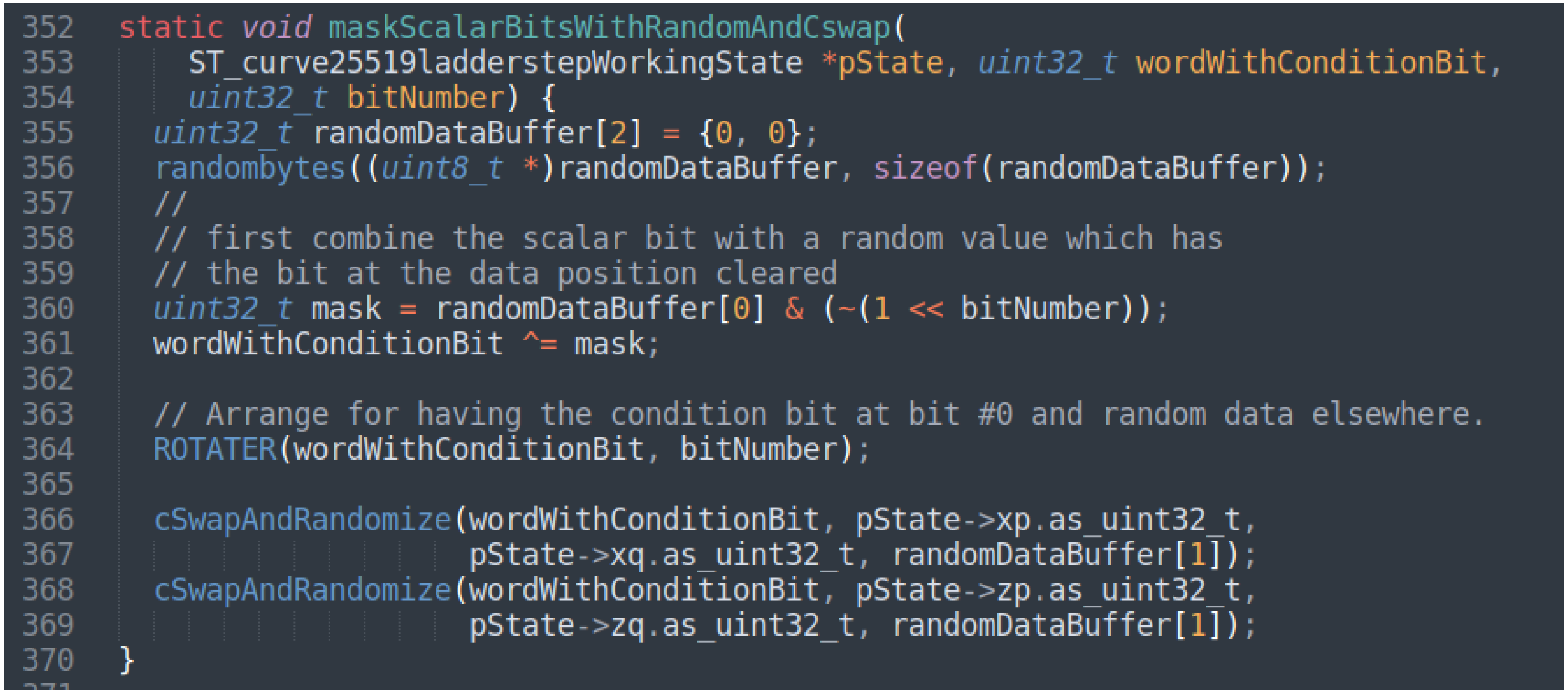
```
    // ### alg. step 5 ###
    INCREMENT_BY_163(fid_counter);

    // Double 3 times before we start. ### alg. step 6 ###
    curve25519_doublePointP(&state);
    curve25519_doublePointP(&state);
    curve25519_doublePointP(&state);

    // ### alg. step 7 ###
    INCREMENT_BY_163(fid_counter);

    if (!fe25519_iszero(&state.zp))   // ### alg. step 8 ###
    {
        goto fail; // ### alg. step 9 ###
    }

    // Optimize for stack usage when implementing  ### alg. step 10 ###
    fe25519_invert_useProvidedScratchBuffers(&state.zp, &state.zp, &state.xq,
                                             &state.zq, &state.x0);
    fe25519_mul(&state.xp, &state.xp, &state.zp);
    fe25519_reduceCompletely(&state.xp);

    fe25519_cpy(&state.x0, &state.xp);
```



```
    fe25519_reduceCompletely(&state.xp);

    INCREMENT_BY_163(fid_counter); // ### alg. step 21 ###

    // ### alg. step 22 ###
    if (fid_counter != (163 * 4 + 251 * 9)) {
    fail:
        retval = -1;
        randombytes(state.xp.as_uint8_t, 32);  // ### alg. step 23 ###
    } else {
        retval = 0;
    }
    fe25519_pack(r, &state.xp);
    return retval;
}
```

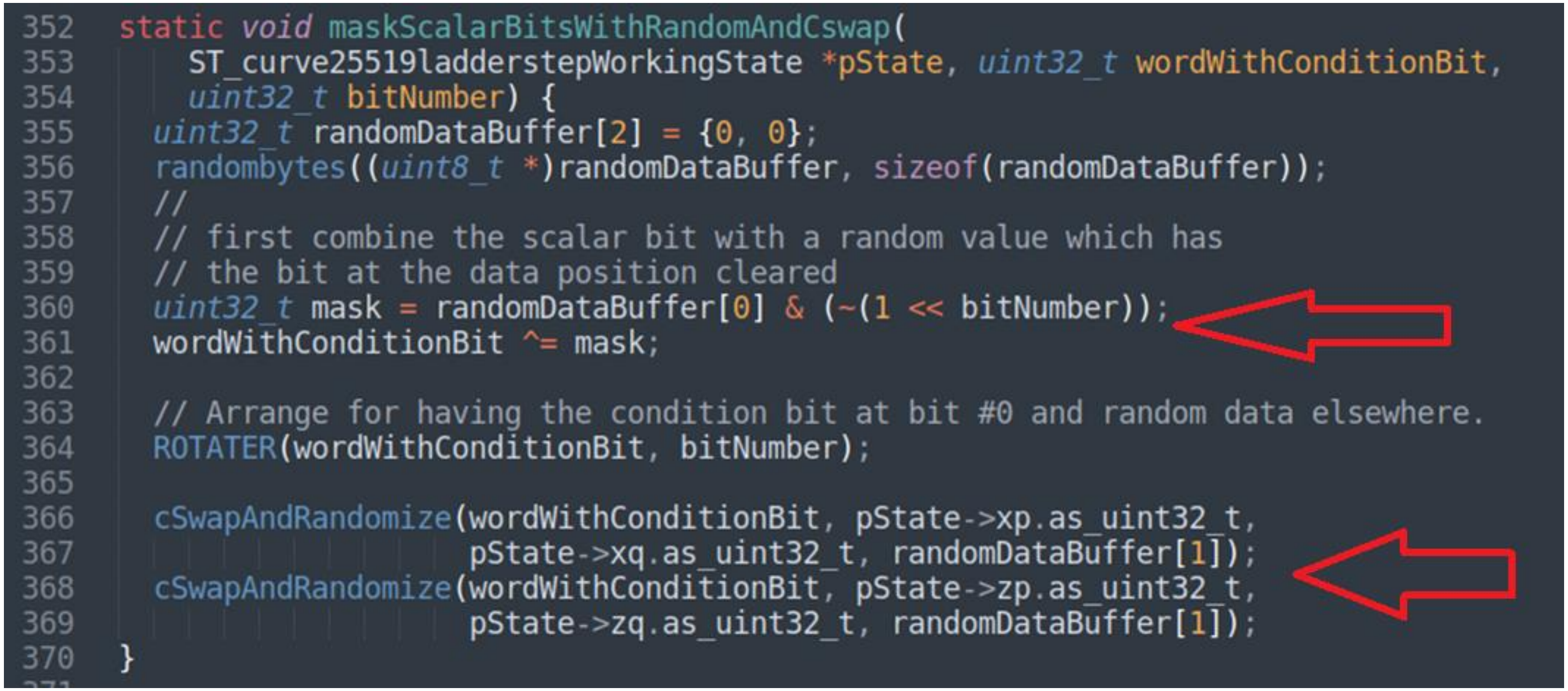
Find the same countermeasure in the static implementation.

Task 2: Ephemeral Crypto Library - SCA



```
static void maskScalarBitsWithRandomAndCswap(
    ST_curve25519ladderstepWorkingState *pState, uint32_t wordWithConditionBit,
    uint32_t bitNumber) {
  uint32_t randomDataBuffer[2] = {0, 0};
  randombytes((uint8_t *)randomDataBuffer, sizeof(randomDataBuffer));
  //
  // first combine the scalar bit with a random value which has
  // the bit at the data position cleared
  uint32_t mask = randomDataBuffer[0] & (~(1 << bitNumber));
  wordWithConditionBit ^= mask;

  // Arrange for having the condition bit at bit #0 and random data elsewhere.
  ROTATER(wordWithConditionBit, bitNumber);

  cSwapAndRandomize(wordWithConditionBit, pState->xp.as_uint32_t,
                    pState->xq.as_uint32_t, randomDataBuffer[1]);
  cSwapAndRandomize(wordWithConditionBit, pState->zp.as_uint32_t,
                    pState->zq.as_uint32_t, randomDataBuffer[1]);
}
```

Task 2: Ephemeral Crypto Library – SCA cont’d



```
static void maskScalarBitsWithRandomAndCswap(
    ST_curve25519ladderstepWorkingState *pState, uint32_t wordWithConditionBit,
    uint32_t bitNumber) {
  uint32_t randomDataBuffer[2] = {0, 0};
  randombytes((uint8_t *)randomDataBuffer, sizeof(randomDataBuffer));
  //
  // first combine the scalar bit with a random value which has
  // the bit at the data position cleared
  uint32_t mask = randomDataBuffer[0] & (~(1 << bitNumber));
  wordWithConditionBit ^= mask;

  // Arrange for having the condition bit at bit #0 and random data elsewhere.
  ROTATER(wordWithConditionBit, bitNumber);

  cSwapAndRandomize(wordWithConditionBit, pState->xp.as_uint32_t,
                    pState->xq.as_uint32_t, randomDataBuffer[1]);
  cSwapAndRandomize(wordWithConditionBit, pState->zp.as_uint32_t,
                    pState->zq.as_uint32_t, randomDataBuffer[1]);
}
```

Task 3: Static Crypto Library – SCA

- Find scalar splitting (similar to blinding):
  1. Generate 64-bit r and computer r^{-1}
  2. Compute P’ = $[r^{-1}*k]*P$
  3. Compute [r]*P’ = [k]P
- Does it work?
- Find this countermeasure in the static SCA code: Steps 2 and 3.

Exercise: Protected Crypto Library 3

Step 2

```c
  // ### alg. step 22 ###
  while (state.nextScalarBitToProcess >= 0) {
    uint8_t limbNo = 0;
    uint8_t bitNo = 0;
#ifdef MULTIPLICATIVE_CSWAP
    {
      limbNo = (uint8_t)(state.nextScalarBitToProcess >> 5);
      bitNo = state.nextScalarBitToProcess & 0x1f;
      // ### alg. step 22 and ###

      maskScalarBitsWithRandomAndCswap(&state, state.s.as_uint32_t[limbNo],
                                       bitNo);
    }
#else
    {
      limbNo = (uint8_t)(state.nextScalarBitToProcess >> 5);
#ifdef ITOH_COUNTERMEASURE
      uint32_t temp = state.s.as_uint32_t[limbNo] ^ itoh.as_uint32_t[limbNo];
      curve25519_cswap_asm(&state, &temp);
      state.s.as_uint32_t[limbNo] <<= 1;
      itoh.as_uint32_t[limbNo] <<= 1;
#else
      curve25519_cswap_asm(&state, &state.s.as_uint32_t[limbNo]);
#endif
    }
#endif
    if (state.nextScalarBitToProcess >= 1)  // ### alg. step 24
    {
      curve25519_ladderstep(&state); // alg. step 25

      INCREMENT_BY_NINE(fid_counter); // alg. step 27

#ifdef MULTIPLICATIVE_CSWAP
#ifdef ITOH_COUNTERMEASURE
      maskScalarBitsWithRandomAndCswap(&state, itohShift.as_uint32_t[limbNo],
                                       bitNo); // ### alg. step 26
#endif
#else
#ifdef ITOH_COUNTERMEASURE
      curve25519_cswap_asm(&state, &itohShift.as_uint32_t[limbNo]);
#endif
#endif
    }
```

Step 3

```c
  while (state.nextScalarBitToProcess >= 0) // ### alg. step 37
  {
    uint8_t limbNo = 0;
    uint8_t bitNo = 0;

#ifdef MULTIPLICATIVE_CSWAP
    {
      limbNo = (uint8_t)(state.nextScalarBitToProcess >> 5);
      bitNo = state.nextScalarBitToProcess & 0x1f;

      // ### alg. step 38
      maskScalarBitsWithRandomAndCswap(&state, state.r.as_uint32_t[limbNo],
                                       bitNo);
    }
#else
    {
      limbNo = (uint8_t)(state.nextScalarBitToProcess >> 5);
#ifdef ITOH_COUNTERMEASURE64
      uint32_t temp = state.r.as_uint32_t[limbNo] ^ itoh64.as_uint32_t[limbNo];
      curve25519_cswap_asm(&state, &temp);
      state.r.as_uint32_t[limbNo] <<= 1;
      itoh64.as_uint32_t[limbNo] <<= 1;
#else
      curve25519_cswap_asm(&state, &state.r.as_uint32_t[limbNo]);
#endif
    }
#endif

    if (state.nextScalarBitToProcess >= 1) // ### alg. step 39
    {
      curve25519_ladderstep(&state); // ### alg. step 40
      INCREMENT_BY_NINE(fid_counter); // ### alg. step 42

#ifdef MULTIPLICATIVE_CSWAP
#ifdef ITOH_COUNTERMEASURE64
      maskScalarBitsWithRandomAndCswap(&state, itoh64Shift.as_uint32_t[limbNo],
                                       bitNo); // ### alg. step 41
#endif
#else
#ifdef ITOH_COUNTERMEASURE64
      curve25519_cswap_asm(&state, &itoh64Shift.as_uint32_t[limbNo]);
#endif
#endif
    }
    state.nextScalarBitToProcess--;
```

Efficiency Demo (Optionally)

Demo Instructions

- Open in a browser: https://github.com/sca-secure-library-sca25519/sca25519
- And follow the instructions from there
  - There are some issues related to the libopencm3 library
- You need a Discover board and an FTDI cable
- git clone https://github.com/sca-secure-library-sca25519/sca25519.git

CONCLUSIONS & QUESTIONS

Assignment 7 – Countermeasures

- This is a programming assignment. Please upload your scripts/code and the required analysis via the course webpage.
- The deadline for submission is Nov. 28, 2024, 8:00.
  - -3 points for each started 24h after the deadline.
- Your code should be contained in one .py file. Please name the submission file as <uco_number>_hw7.zip. Put there both the python code, the analysis document, and all data produced during analysis (as long as the size is reasonable).
- The code must contain comments so that it is reasonably easy to understand how to run the script for evaluating each answer.

Assignment 7 - Tasks

1. Have a look at the RSA_homework.py file. There are some comments for you there too.
   Protect the CRT implementation with exponent blinding in the function TCR_protected! First, test and then modify the code (the result should be the same). In a separate report (max 2 pages), write why the countermeasure works (does not affect the correctness of the result).
   Then, perform a useful analysis of the efficiency cost of the countermeasure (repeat the experiment a number of times and report a percent increase). **[2.0 points]**
2. Protect the CRT implementation with message blinding! Note that this will require knowledge of the public exponent e. In the document, write why the countermeasure works. Then, perform a useful analysis of the cost of the countermeasure. **[3.0 points]**
3. Protect the CRT implementation against fault injection! Any countermeasure is OK. In the document, write why the countermeasure works. Then, perform a useful analysis of the cost of the countermeasure. **[1.5]**
4. Combine all the countermeasures and measure the time of all additional countermeasures and how well they work. Write that in the report. **[1.5 points]**
5. Instead of exponent blinding, implement exponent splitting. How does it compare to blinding efficiency-wise? Order the countermeasures with respect to their efficiency. **[2 point]**
6. **Bonus:**
   - Implement another extra countermeasure (any, it can be either SCA or FI). What is its cost? **[1 point]**
   Remark: we are securing Python code and, for the sake of this exercise, assume that the code is directly executed by the processor (and not interpreted etc.)

Consultation: Friday at 9:00 in A406.

Good luck!!!