OBJECTIF SÉCURITÉ
Architecte de la sécurité informatique

Exposing crypto bugs through reverse engineering

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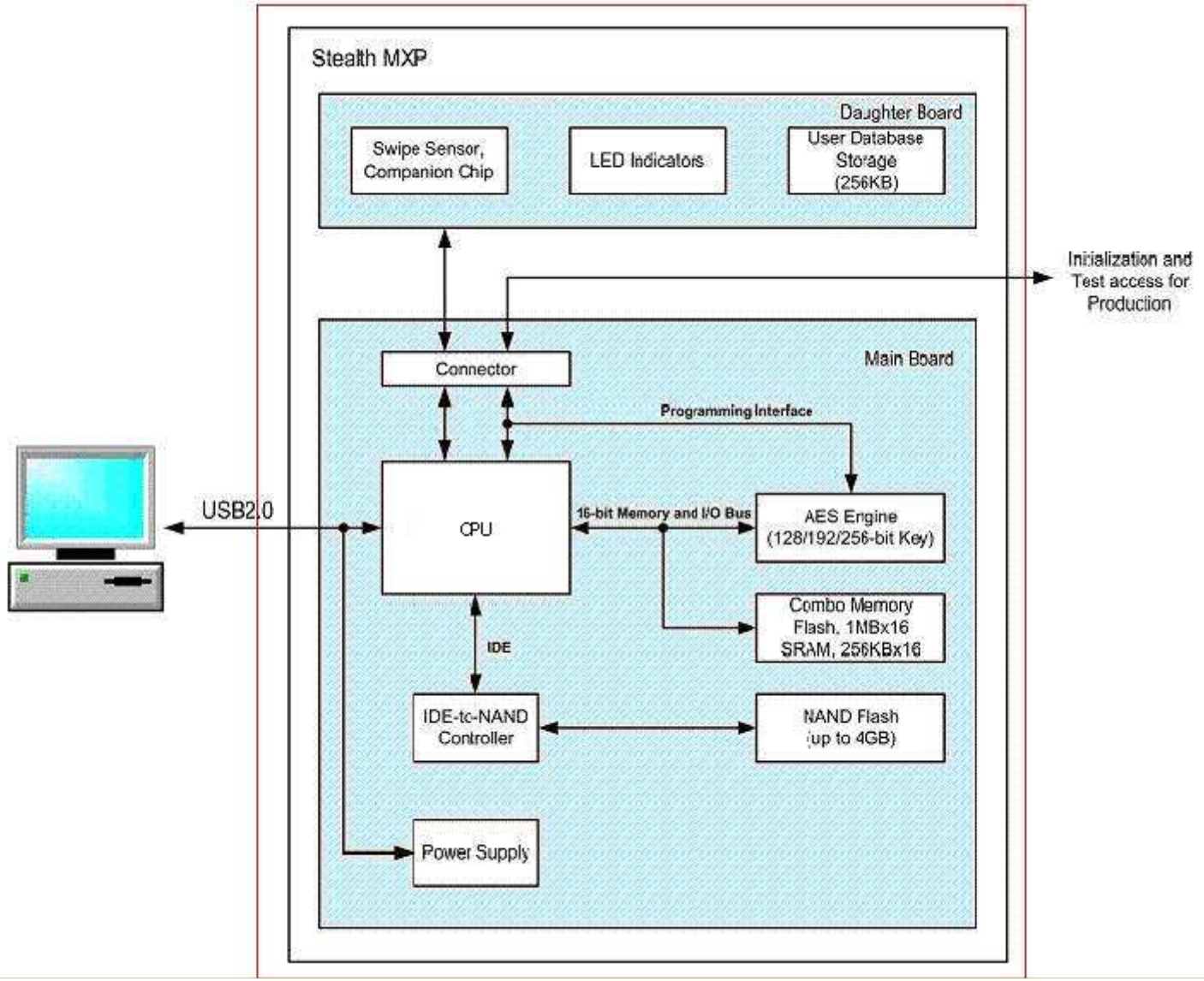
Cracking crypto systems…

- Cryptanalysis is hard, but so is the correct implementation of cryptography
- A good way to crack a commercial crypto system is thus to reverse engineer it in order to find the implementation errors:
  - MXI Stealth
  - EISST E-capsule PrivateSafe
  - Data Becker Privat Safe

MXI Stealth MXP

- FIPS 142-3 level 2 certified USB Key
  - AES on-chip encryption
  - Authentication through password (windows application) or fingerprint (OS independent)
  - Upon connection a first removable drive with a locked contents appears
  - Upon successful authentication a second drive appears

MXI Stealth MXP

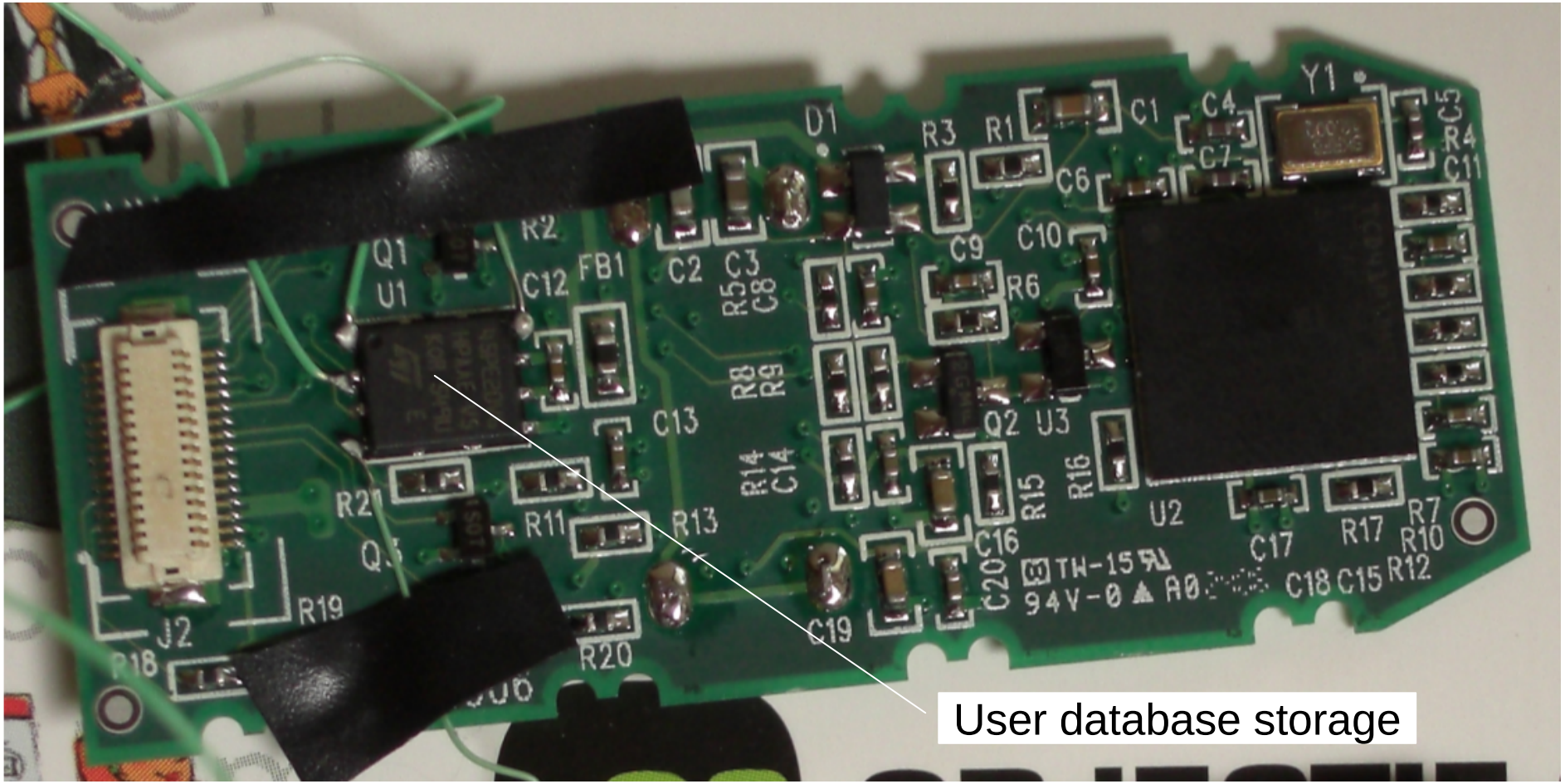


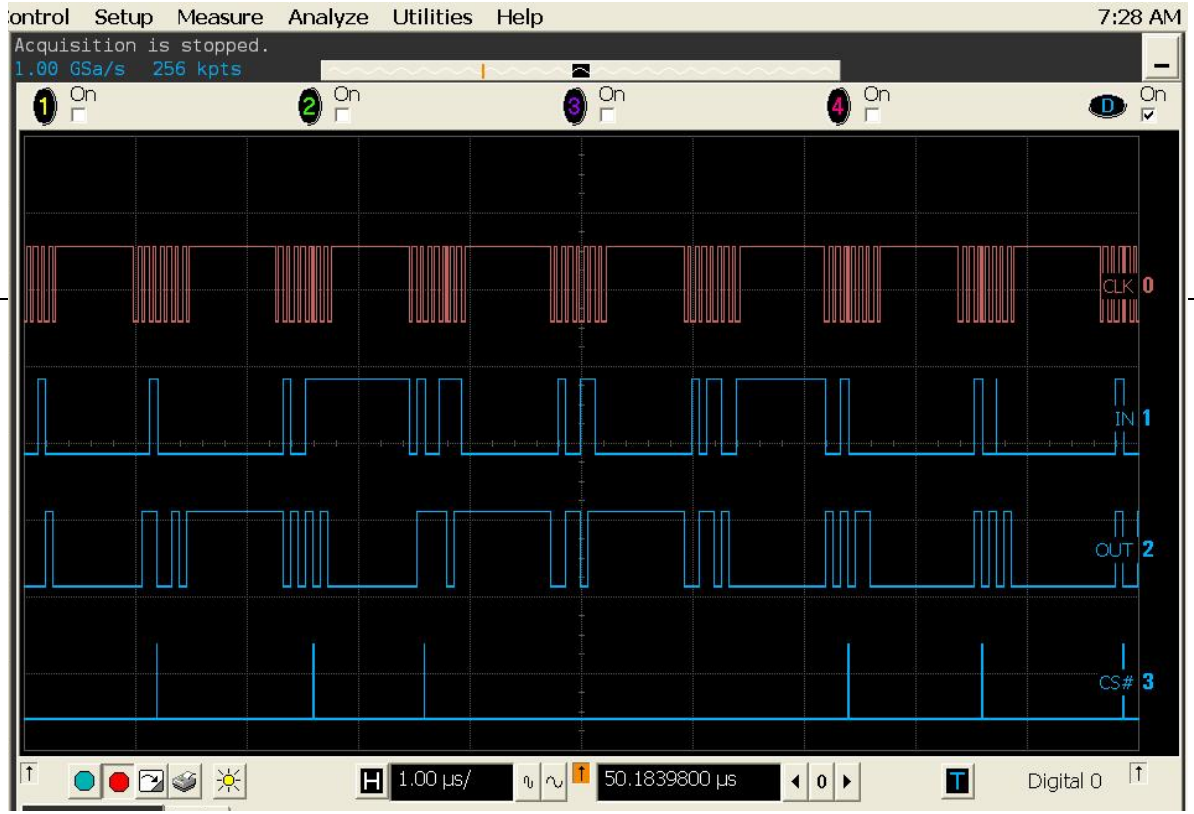
Password protection

Passwords are injected upon creation from the external USB interface. A random salt is also injected as plain text through the USB interface and stored in EEPROM. The password is combined with the salt, then hashed using the SHA256 algorithm and stored in EEPROM associated with the user. The password is then deleted from memory. Password authentication and verification is done by

Upon a failed password attempt, there is a delay of 500 milliseconds. Note that this delay also applies when a password verification operation is done. This delay allows a maximum of 120 tries per minute. Therefore the probability of a random

Reading the user database






```
00000000  00 00 00 00 00 00 02 08  20 01 65 aa 7b 37 34 ac  ........ .e.{74.
00000010  2a 26 02 65 aa 7b 37 34  ac 2a 26 76 e1 98 fd 39  *&.e.{74.*&v...9
00000020  3f 31 1b 71 dc b7 78 be  01 d9 32 cc de 14 08 fd  ?1.q..x...2.....
00000030  1e 32 7b 68 eb eb 7d 5d  f5 bc 18 20 a8 9b b5 17  .2{h..}]... ....
00000040  a8 a1 ad dc be ec 06 da  25 56 ed 01 02 2f 83 18  ........%V.../..
00000050  2d 7d 5d fe d5 32 12 f4  65 0e 8f b5 00 00 00 00  -}]..2..e.......
00000060  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  ................
00000070  00 00 00 00 00 00 00 00  00 00 00 00 03 00 00 00  ................
00000080  01 fe 00 ff ff ff ff ff  ff ff ff ff ff 5f 41 64  ............._Ad
00000090  6d 69 6e 00 00 00 00 00  00 00 00 00 00 00 00 00  min.............
000000a0  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  ................
000000b0  00 00 00 00 00 ff 00 00  00 00 00 00 00 00 00 00  ................
000000c0  08 00 00 00 00 00 00 55  38 37 34 31 32 35 32 35  .......U87412525
000000d0  35 37 37 32 35 37 39 00  00 00 00 00 00 00 00 00  5772579.........
000000e0  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  ................
```

Reverse engineering the software

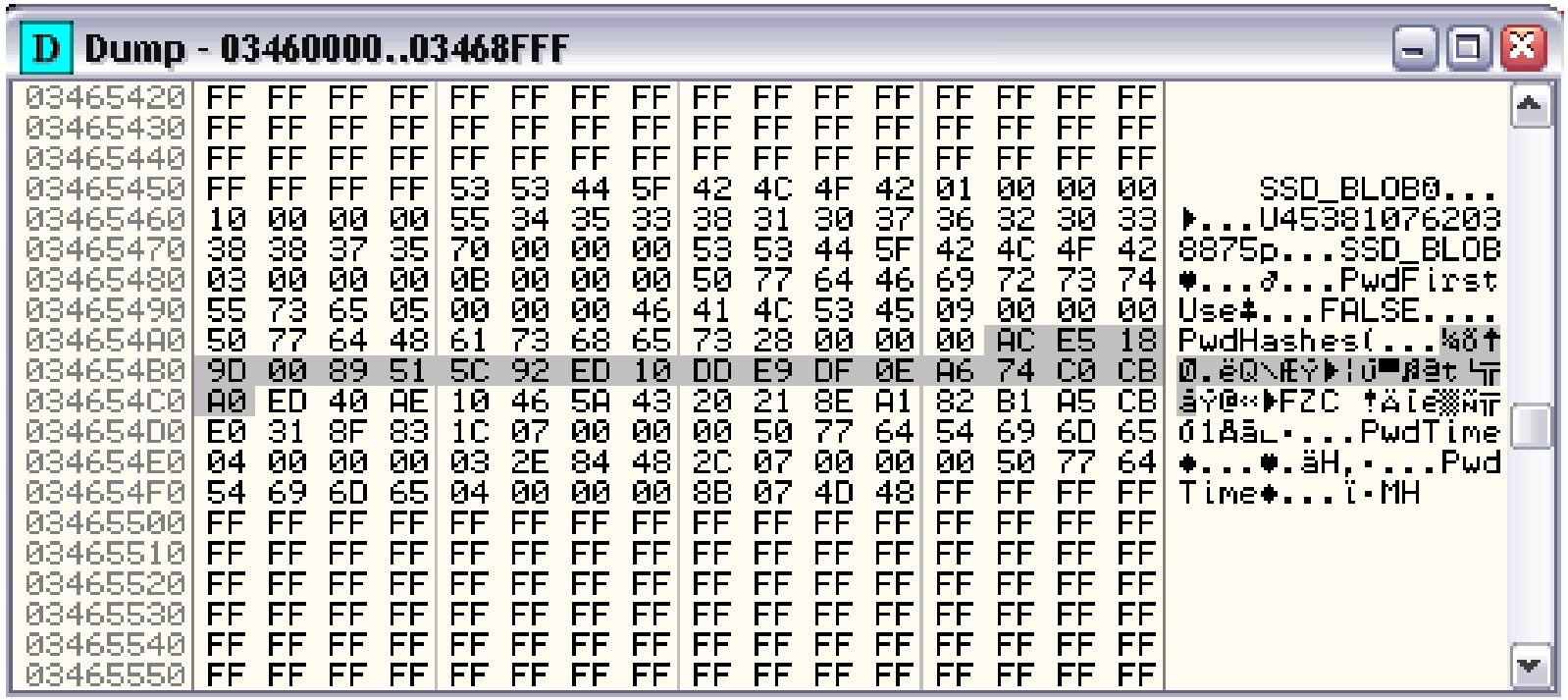
- There is a library to exchange encrypted messages with the key
  - Apparently the password is encrypted and sent to the key
  - After some messages are exchanged the protected disk is activated
- A logging function is implemented.
  - It does not write log messages into a log file but they can bee seen in the memory.
  - A simple patch of the code can reactivate the log file

MXI Demo

- What is this blob in the memory???

Surprise

- A blob received from the key has the following content:



Hashes!

- The 60 byte string are three SHA1 hashes
  - The current password
  - The previous 2 passwords
- The "enterprise" version of the software needs this info to make sure the user does not reuse the current and last *n* passwords
- This information is received by the software even *before* the user has authenticated

Correcting the issues

- The validation of the password should have been done in hardware
- If done in software, the hashes should at least have been stored in a secure area protected by the hardware and only accessible with proper authentication
- MXI issued a patch within a week to correct the issue

Example: EISST E-capsule PrivateSafe

- PrivateSafe is a software that creates encrypted containers
- There are 4 passwords:

1. The admin password allows managing the container
2. The public password reveals one part of the content
3. The private passwod gives access to the rest of the content
4. The panic password deletes all files and gives access to an empty container

Files:

- There are 2 files:
  - the encrypted file system
  - a control file

```
philippe@os-philippe$ hd safe.eck
00000000  0000000400000001 30000000000000d0 |........0.......|
00000010  cc02bff06f1fabd5 0b557c25376e3508 |....o....U|%7n5.|
00000020  b11896880c63fe4b 7d9267399e3120d9 |.....c.K}.g9.1 .|
00000030  b878da285895a7b5 4e192f7eb22a1454 |.x.(X...N./~.*.T|
00000040  9cb536a459555fdd c38d5a2d724700ec |..6.YU_...Z-rG..|
00000050  ae8e827cd88d78b6 f928cf48c948c507 |...|..x..(.H.H..|
00000060  35eda128be2f906b dc50b6b43c6a6ccc |5..(./.k.P..<jl.|
00000070  3cbe31ab1f1c035b 6ce95b6ab7d0f403 |<.1....[l.[j....|
00000080  f48c08e55cb66501 a051444aed60b679 |....\.e..QDJ.‘.y|
00000090  68b8324d482e58d6 c8c32e3fe810a75e |h.2MH.X....?...^|
000000a0  644e3eb29f33427d f65ad86647245014 |dN>..3B}.Z.fG$P.|
000000b0  ac9d77179292688a 38ca3ad869c5ead0 |..w...h.8.:.i...|
000000c0  f47bcce8383d2c26 3896eef1986a2af9 |.{..8=,&8....j*.|
000000d0  dc32fbf1702bde8e 3fba5cdb9231b392 |.2..p+..?.\..1..|
000000e0  0000000131000000 00000060c272e084 |....1.....‘.r..|
000000f0  330ea76a36b22bb0 d5fd646ccad138d8 |3..j6.+...dl..8.|
00000100  929f55ee16f639a6 a17a94fc539b1b0e |..U...9..z..S...|
00000110  100d5b03ef2e9992 2a611359a4fc91a0 |..[.....*a.Y....|
00000120  1387f4cbc8e9ca7a 832f4887f3d963ab |.......z./H...c.|
00000130  cff256d38cb636c4 7bda1aab9e8911cf |..V...6.{.......|
00000140  ad3ebcaba2539036 2e3a338f00000001 |.>...S.6.:3.....|
00000150  3200000000000060 bd4a85a3e1daffe7 |2.....‘.J......|
00000160  59c91f0c1e1117e1 ea5cafe2901615ef |Y........\......|
00000170  7b8c3b8a5d10a3e3 7d9cdd9dbc8b4eea |{.;.]...}.....N.|
00000180  d26d2735ecb3a04d 6620dd5ae99daae2 |.m’5...Mf .Z....|
00000190  f2c2848d394bb620 a3afa1bb5a70fafa |....9K. ....Zp..|
000001a0  03ae6776738bec3a 3517424f844f1125 |..gvs..:5.BO.O.%|
000001b0  05e076b76d971562 0000000133000000 |..v.m..b....3...|
000001c0  0000006048b1012f 47fb2881dd726864 |...‘H../G.(..rhd|
```

Funny crypto

- Through reverse engineering we find that
  - Each block of the control file is encrypted with AES 256 CTS mode
  - The key is the SHA256 hash of the corresponding password
  - The IV is the ripemd160 hash of the password
  - The clear text of blocks 1,2 and 3 are the same
    - Block 0 corresponds to the admin key

Decryption by hand

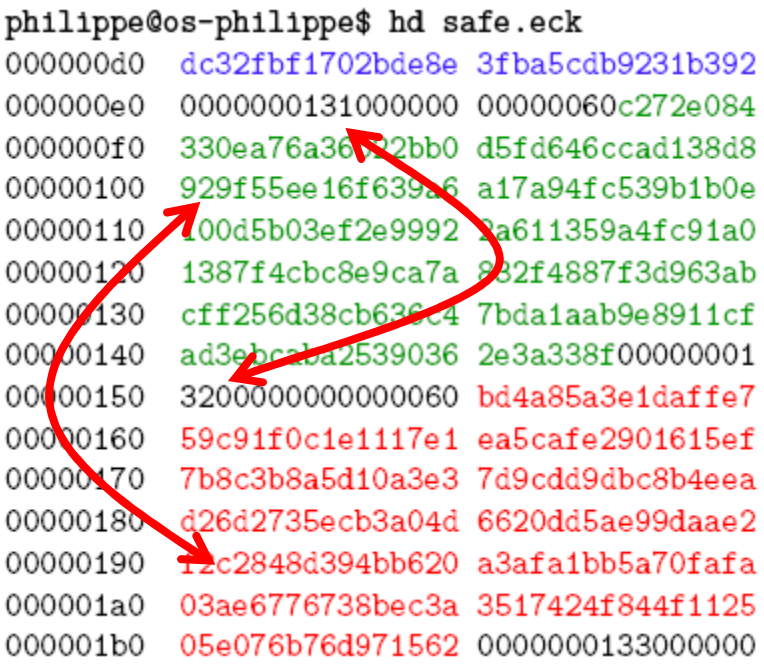
```
philippe@os-philippe:~/tmp$ hd block1

00000000  7e d2 8b bd c5 26 1e d9  d2 79 c2 e9 5a 5b 68 a7  |~....&...y..Z[h.|
00000010  3a ba 6c 90 53 ee 24 e7  9c c6 18 2f 6a 81 9c 34  |:.l.S.$..../j..4|
00000020  a5 62 b6 6a 8b 1d f4 93  a9 44 20 42 ae 03 1c 0a  |.b.j.....D B....|
00000030  ff e5 e3 f6 5b dc 06 d7  e2 90 3a 5a 8c c9 fb 68  |....[.....:Z...h|
00000040  f3 73 3a 9d 3a 0d 9b 3e  93 b5 a2 4d 32 29 c9 1a  |.s:.:..>...M2)..|
00000050  89 43 99 2c f6 83 aa 0c  f4 71 11 14 05 c1 4e 5f  |.C.,.....q....N_|
00000060

philippe@os-philippe:~/tmp$ pw=public; cat block1 |  openssl enc -aes-256-cbc
-d -K `echo -n $pw | openssl dgst -sha256 -hex` -iv `echo -n $pw | openssl
dgst -ripemd160 -hex | cut -b1-32`  -nopad | hd

00000000  00 00 00 03 00 00 00 08  75 73 65 72 6e 61 6d 65  |........username|
00000010  00 00 00 08 50 68 69 6c  69 70 70 65 00 00 00 08  |....Philippe....|
00000020  68 61 72 64 77 61 72 65  00 00 00 14 32 8b 0a 83  |hardware....2...|
00000030  69 f9 de 0d 86 28 23 1b  ab 67 8a d3 22 42 b7 e4  |i....(#..g.."B..|
00000040  00 00 00 08 73 6f 66 74  77 61 72 65 00 00 00 14  |....software....|
00000050  dc ef 7d af 03 85 6f 97  da 4c f9 e0 a8 92 ef 99  |..}...o..L......|
00000060
philippe@os-philippe:~/tmp$
```

The four blocks

```
00 00 00 07 00 00 00 08  75 73 65 72 6e 61 6d 65  |........username|
00 00 00 04 75 73 65 72  00 00 00 01 30 00 00 00  |....user....0...|
00 00 00 05 61 64 6d 69  6e 00 00 00 00 00 00 01  |....admin.......|
31 00 00 00 00 00 00 06  70 75 62 6c 69 63 00 00  |1.......public..|
00 00 00 01 32 00 00 00  00 00 00 07 70 72 69 76  |....2.......priv|
61 74 65 00 00 00 00 01  33 00 00 00 00 00 00 05  |ate.....3.......|
73 68 72 65 64 00 00 00  00 00 00 08 68 61 72 64  |shred.......hard|
77 61 72 65 00 00 00 14  11 d9 4c 53 80 fa 07 bd  |ware......LS....|
ee 88 9e 20 44 e9 ae be  ac 12 41 e5 00 00 00 08  |... D.....A.....|
8b e6 0b ec 3f 81 04 3e  bf bd 03 6f 76 29 78 ce  |....?..>...ov)x.|
a8 2b be 0d 64 98 08 15  1b 3e 2c 91 00 6b d7 b0  |.+..d....>,..k..|

00 00 00 03 00 00 00 08  75 73 65 72 6e 61 6d 65  |........username|
00 00 00 04 75 73 65 72  00 00 00 08 68 61 72 64  |....user....hard|
77 61 72 65 00 00 00 14  11 d9 4c 53 80 fa 07 bd  |ware......LS....|
ee 88 9e 20 44 e9 ae be  ac 12 41 e5 00 00 00 08  |... D.....A.....|
53 08 5b fc 7c ff 75 d9  00 db ac a7 ad 26 8d 07  |S.[.|.u......&..|
ae f8 42 df 69 9c 3e 8b  83 44 27 04 3f c7 ea 7e  |..B.i.>..D'.?..~|

00 00 00 03 00 00 00 08  75 73 65 72 6e 61 6d 65  |........username|
00 00 00 04 75 73 65 72  00 00 00 08 68 61 72 64  |....user....hard|
77 61 72 65 00 00 00 14  11 d9 4c 53 80 fa 07 bd  |ware......LS....|
ee 88 9e 20 44 e9 ae be  ac 12 41 e5 00 00 00 08  |... D.....A.....|
90 0c 92 84 09 51 6b 85  04 e4 1c 17 30 2a 96 a0  |.....Qk.....0*..|
86 40 1d ec 3d be 2c 01  2b 7b a2 27 8d 14 b0 02  |.@..=.,.+{.'....|

00 00 00 03 00 00 00 08  75 73 65 72 6e 61 6d 65  |........username|
00 00 00 04 75 73 65 72  00 00 00 08 68 61 72 64  |....user....hard|
77 61 72 65 00 00 00 14  11 d9 4c 53 80 fa 07 bd  |ware......LS....|
ee 88 9e 20 44 e9 ae be  ac 12 41 e5 00 00 00 08  |... D.....A.....|
fb 83 31 52 36 8a a4 c7  95 a9 34 68 4b 7a aa f7  |..1R6.....4hKz..|
b2 8e 16 6a 68 26 b4 84  bc 61 81 5c ee 63 6f a8  |...jh&...a.\.co.|
```

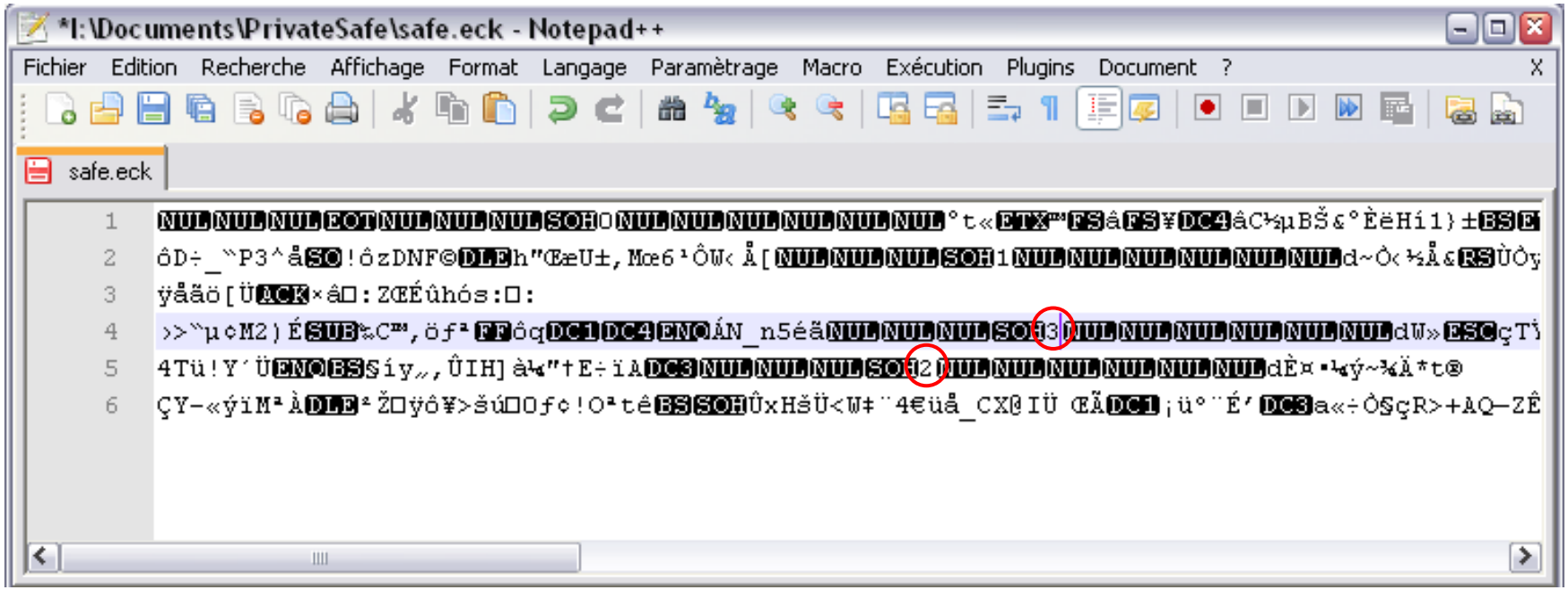
The trick

- Exchanging two blocks in the control file inverts the role of their keys
  - e.g. private ←→public
- Worse
  - Shred ←→ private!
- Actually, exchanging just the single ascii characters that identify the blocks is enough..
- But… the software works as advertized



EISST demo:

- Accessing the private data with the shred password



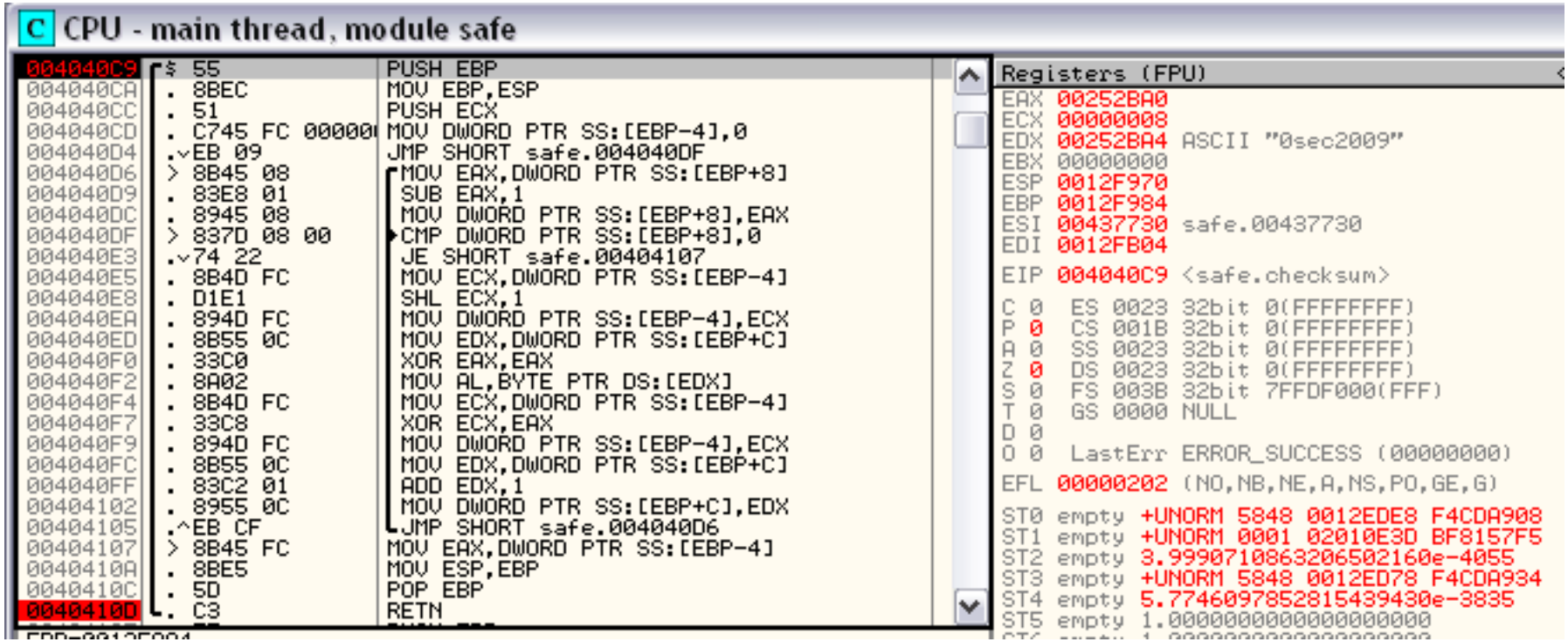
DataBecker PrivateSafe

Gute software muss nicht teuer sein…

- This software creates an encrypted data container
- The control block is at the beginning of the file
- The encrypted file system is encrypted with blowfish CBC in blocks of 4096 bytes
- The IV of all blocks is the same
- The key is the user password
- The first 8 bytes of a block are its number
  - They are not ordered but the numbers are small (lots of 0 bits)

DataBecker demo:

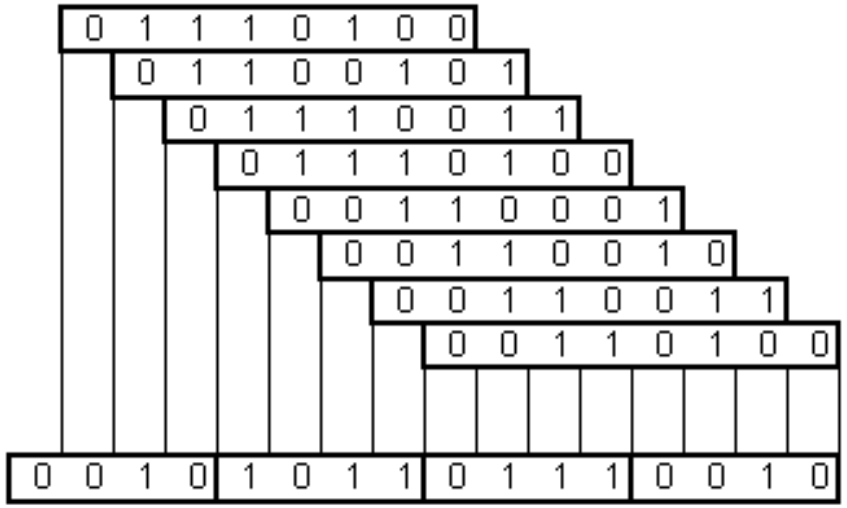
- What does this routine do?



Checksum !

- Before decrypting the file system the software verifies that the key matches a checksum…
- The checksum is made by xor-ing all characters of the password shifted by one bit each.

Password	Ascii
t	116
e	101
s	115
t	116
1	49
2	50
3	51
4	52
checksum	
2B72	



Attack

- The checksum gives us:
  - A minimum of the pw length
  - 1 bit per character of the pw
  - The last character of the pw
- Simple attack:
  - Generate all passwords, verify the checksum before attempting decryption
- Efficient attack
  - Generate only passwords that match the checksum
    - Use two alphabets (even and odd parity)
    - Use the alphabet corresponding the previous characters and the checksum
    - Calculate the last character from the checksum

```
for (i2=0; i2<HALF_SETSIZE; i2++) {
  key[2]=i2[((ck&0x40)?chars1:chars0)];
  ck^=(key[2]<<6);

  for (i1=0; i1<HALF_SETSIZE; i1++) {
    key[1]=i1[((ck&0x80)?chars1:chars0)];
    ck^=(key[1]<<7);

    key[0] = ck>>8;

    if (key[0] > 96) { /* only lowercase letter as first */
      Blowfish_Init (&ctx, (unsigned char*)key, 9);
      L = L0, R=R0;
      Blowfish_Decrypt(&ctx, &L, &R);
      if (((R&0x00ffffff)==0x00543210) &&
          ((L&0x00ffffff)==0x00dcba98)) {
            printf("\n%d: Key found!!!!!! --> %s <---",n,key);
            printf("  plaintext: %08x %08x\n\n",
                   L^0xfedcba98, R^0x76543210);
            exit(9);
          }
    }
```

Result

- Blowfish has a complex key setup
  - Key setup is very slow
  - 25'000 pws per second on a single core
- For a 9 character alphanum password we gain a factor of 15'872 in time
- In our case we cracked a nine lowercase letter password in 2.5 hours instead of 1.7 years

Quiz …

- Besides their funny cryptographic specialities, all shown systems have a fundamental crypto flaw
  - Which flaw is it?
- None of them uses a random salt or initialisation vector!
- We could thus build Rainbow Tables for each of this systems

Conclusions

- Crypto is hard to implement correctly
  - Who would have thought this…
- If no source code is given, only reverse engineering can find the errors
- When possible, prefer open source solutions over closed source, they are easier (and cheaper) to verify.