Decrypting DPAPI data

Jean-Michel Picod, Elie Bursztein
EADS, Stanford University

Data Protection API

- Introduced in Windows 2000
- Aim to be an easy way for application to store safely data on disk
- Tie encryption key to user password and the account SID

Developer point of view

Application

DPAPI

DPAPI is a simple API*

*http://msdn.microsoft.com/en-us/library/ms995355.aspx

Why digging deeper ?

- Offline forensic
- EFS on Linux
- Security / cool things ?

Previous work

- Multiples attempts to analyze DPAPI
  - Some incomplete (Wine)
  - Some close source (Nir Sofer - NirSoft)

Take away

- Decrypt offline sensitive data
- Recover user previous passwords (Yes all of them)
- Do a key escrow attack

Outline

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- DPAPI overview

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- Decryption process

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- Security design implications

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- Decryption process
- Security design implications
- DPAPIck demo

Crypto 911 HMAC

- HMAC (Message authentication code)
  - Usually used to detect data tampering
  - Used here to derive encrypt key and IV

ipad = 0x36 xor key

opad = 0x5c xor key

HMAC= (opad . SHA1(ipad.data))

Crypto 911: PBKDF2

- PBKDF2 = Password based key derivation function
- Basically it is a hash function (SHA1 for us) applied n times to slow down the computation.
- Used to defend against brute-force
- Salt is used against rainbow tables attacks.

Crypto 911 : 3DES

- 3DES : Triple DES encryption
  - Encrypt, Decrypt, Encrypt
  - Exist in two flavor : 2 keys or 3 keys (64 bits each)
  - Windows use the strong version with 3 keys

How the system interacts with DPAPI

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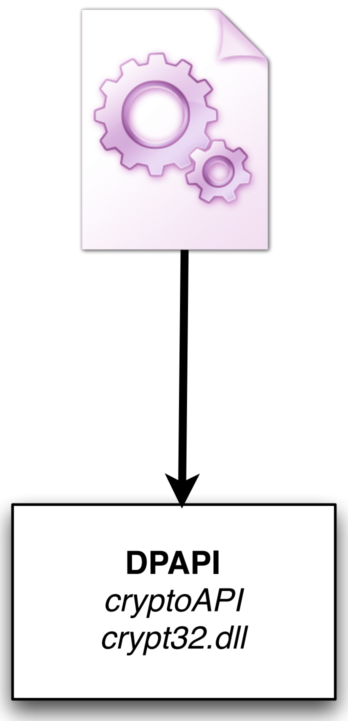
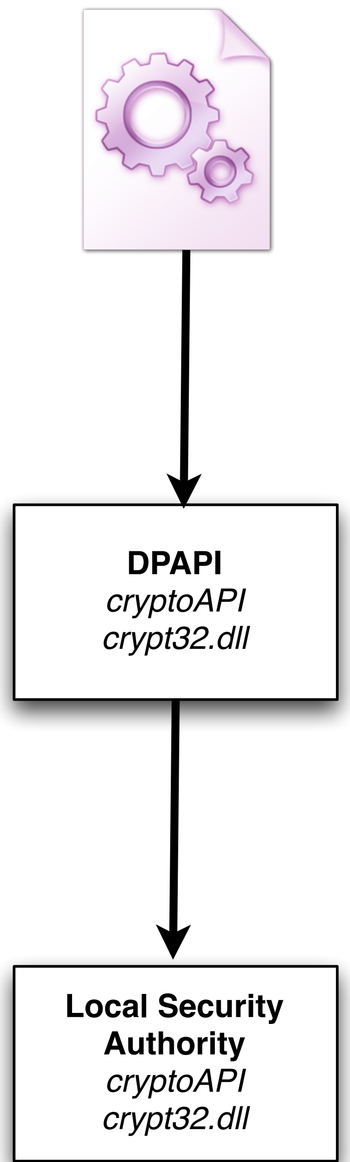


How the system interacts with DPAPI



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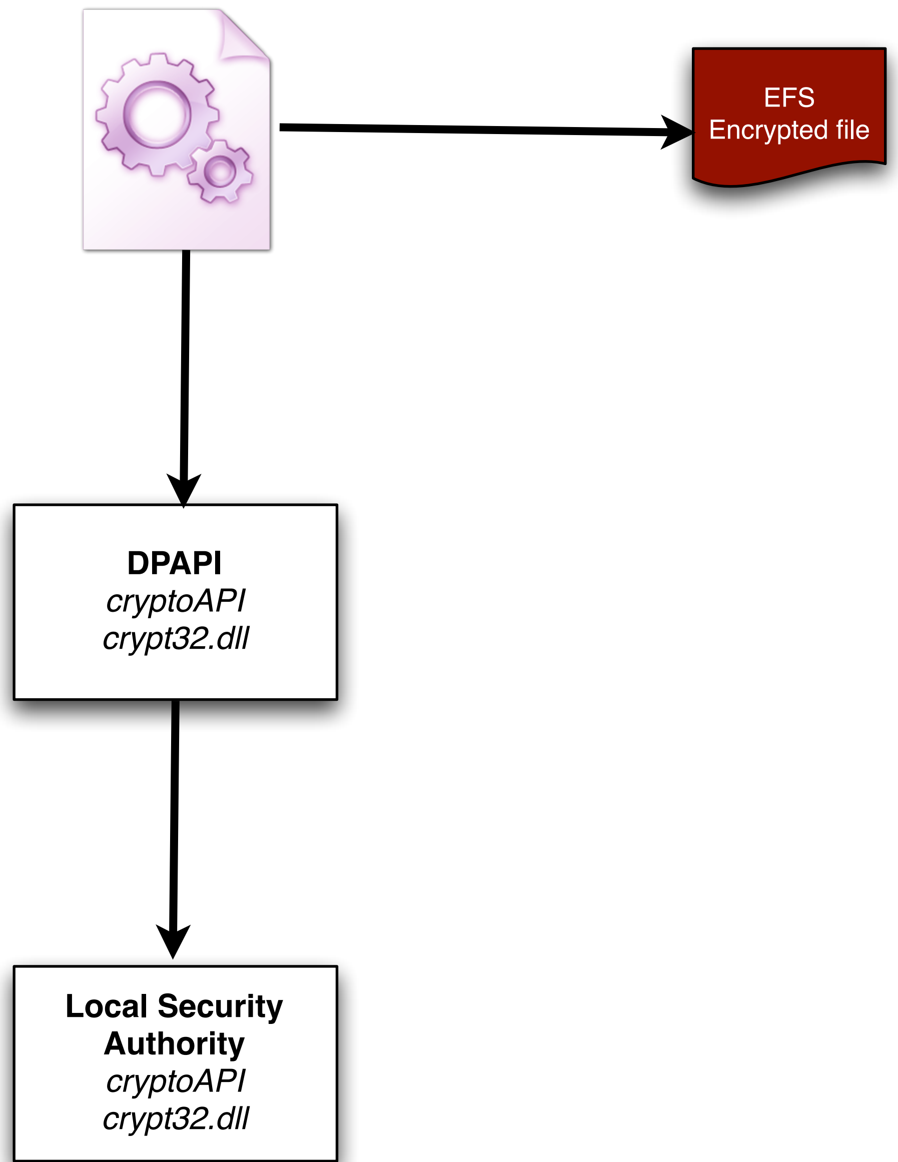

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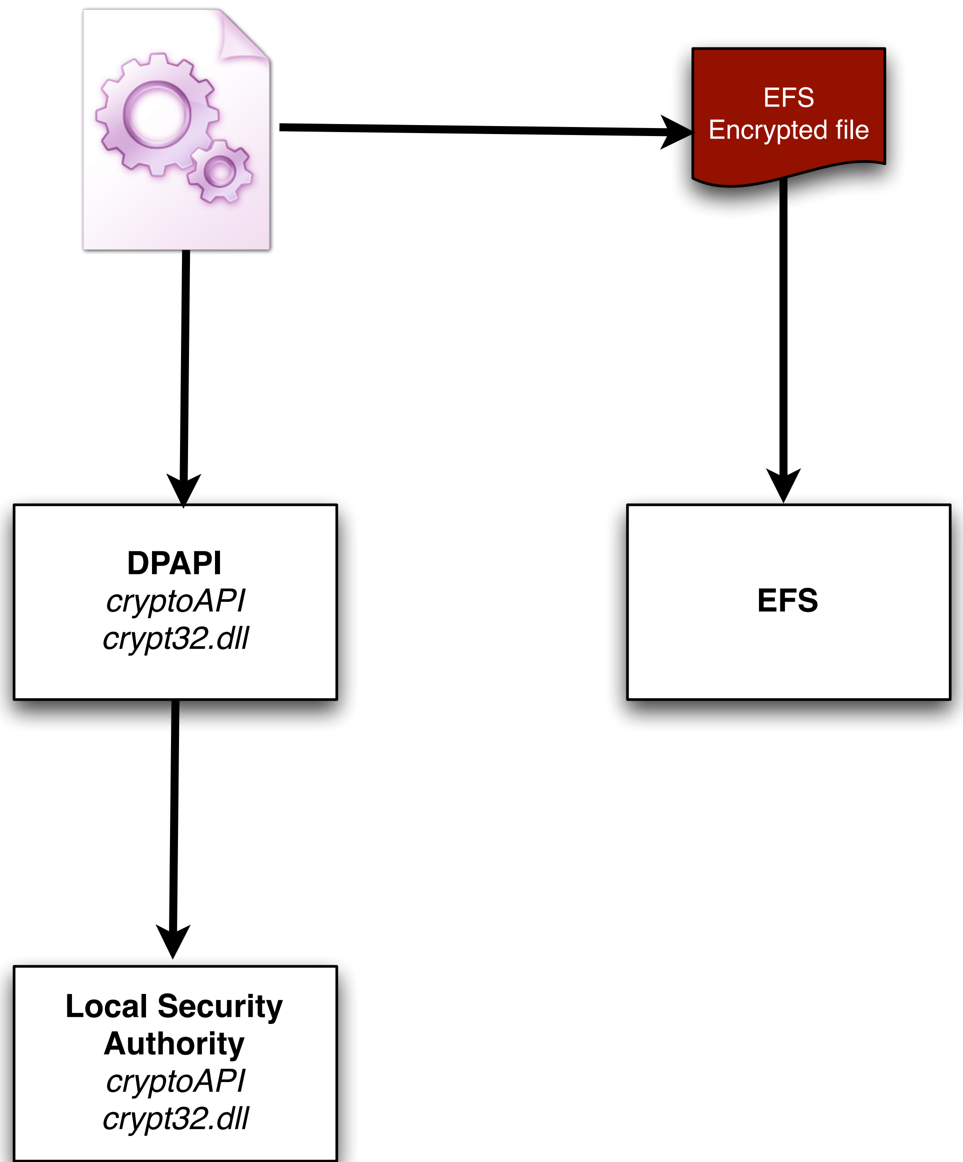

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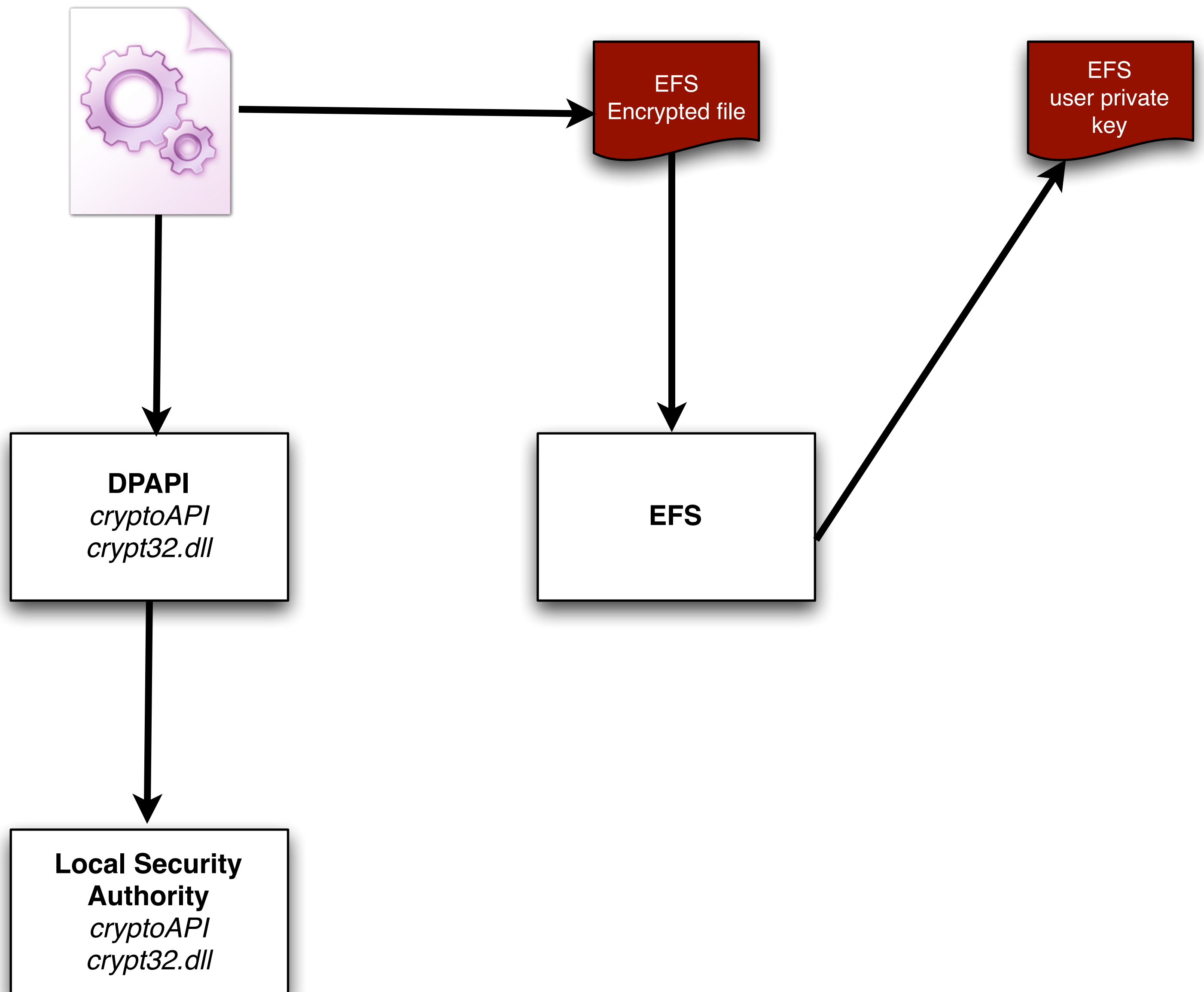
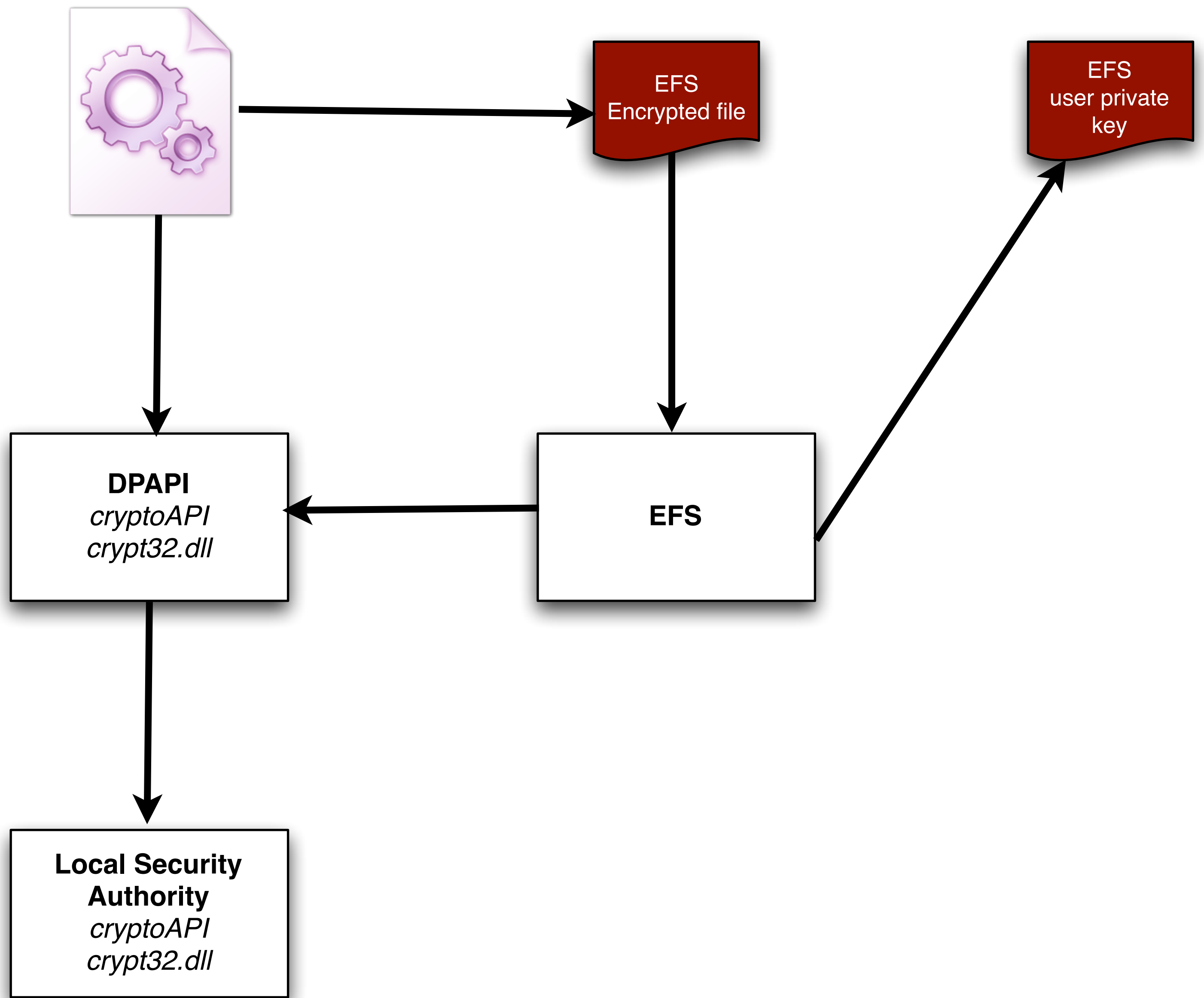


How the system interacts with DPAPI



DPAPI CryptUnprotecData Function

```
BOOL WINAPI CryptUnprotectData (
  *pDataIn,
  *ppszDataDescr,
  *pOptionalEntropy,
  pvReserved,
  *pPromptStruct,
  dwFlags,
  *pDataOut
```

DPAPI CryptUnprotecData Function

BOOL WINAPI CryptUnprotectData (

*pDataIn, ← Encrypted data aka data blob

*ppszDataDescr,

*pOptionalEntropy,

pvReserved,

*pPromptStruct,

dwFlags,

*pDataOut

DPAPI CryptUnprotecData Function

```
BOOL WINAPI CryptUnprotectData (
  *pDataIn,
  *ppszDataDescr,        ←  Optional description
  *pOptionalEntropy,
  pvReserved,
  *pPromptStruct,
  dwFlags,
  *pDataOut
```

DPAPI CryptUnprotecData Function

BOOL WINAPI CryptUnprotectData (

*pDataIn,

*ppszDataDescr,

*pOptionalEntropy, ← Optional entropy (salt)

pvReserved,

*pPromptStruct,

dwFlags,

*pDataOut

DPAPI CryptUnprotecData Function

BOOL WINAPI CryptUnprotectData (

*pDataIn,

*ppszDataDescr,

*pOptionalEntropy,

pvReserved,

*pPromptStruct, ← Optional password

dwFlags,

*pDataOut

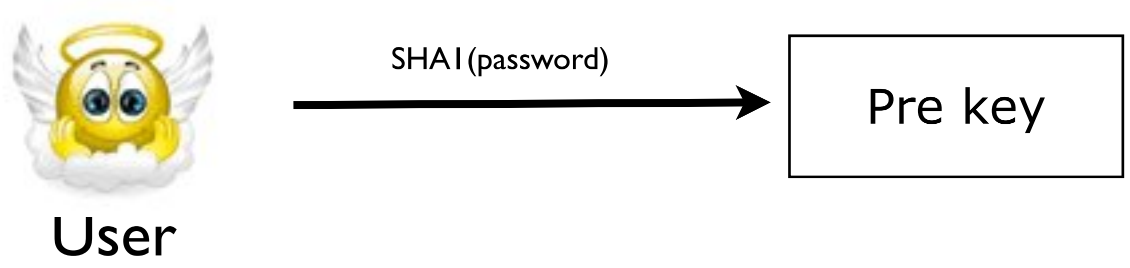
DPAPI CryptUnprotecData Function

```
BOOL WINAPI CryptUnprotectData (
  *pDataIn,
  *ppszDataDescr,
  *pOptionalEntropy,
  pvReserved,
  *pPromptStruct,
  dwFlags,
  *pDataOut          ← Decrypted data
```

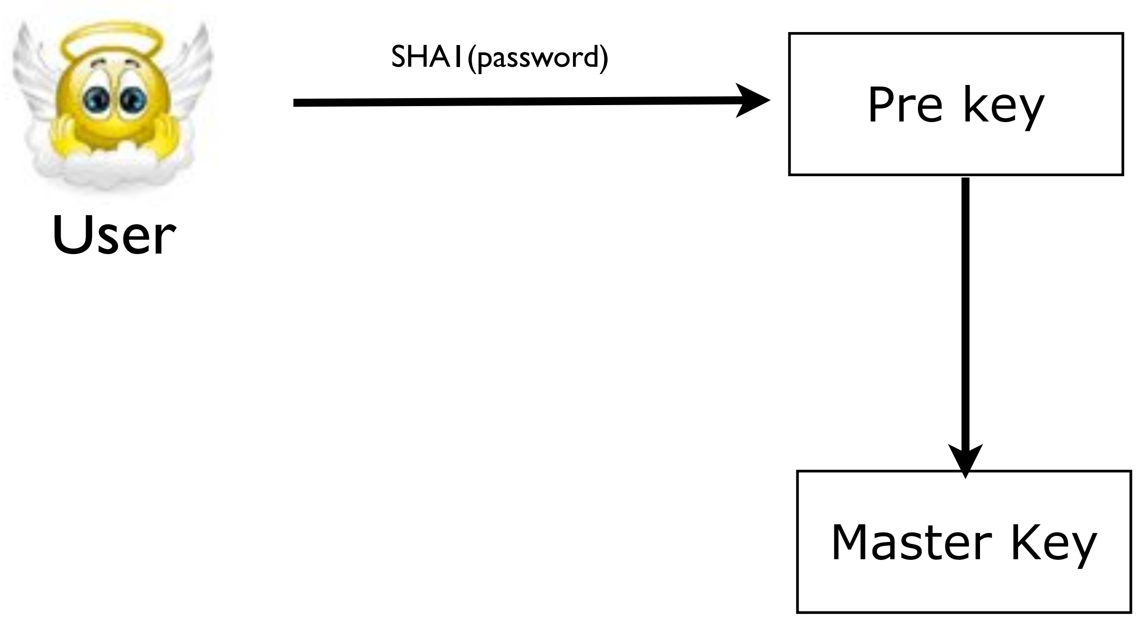
Derivation scheme

User

Derivation scheme



Derivation scheme



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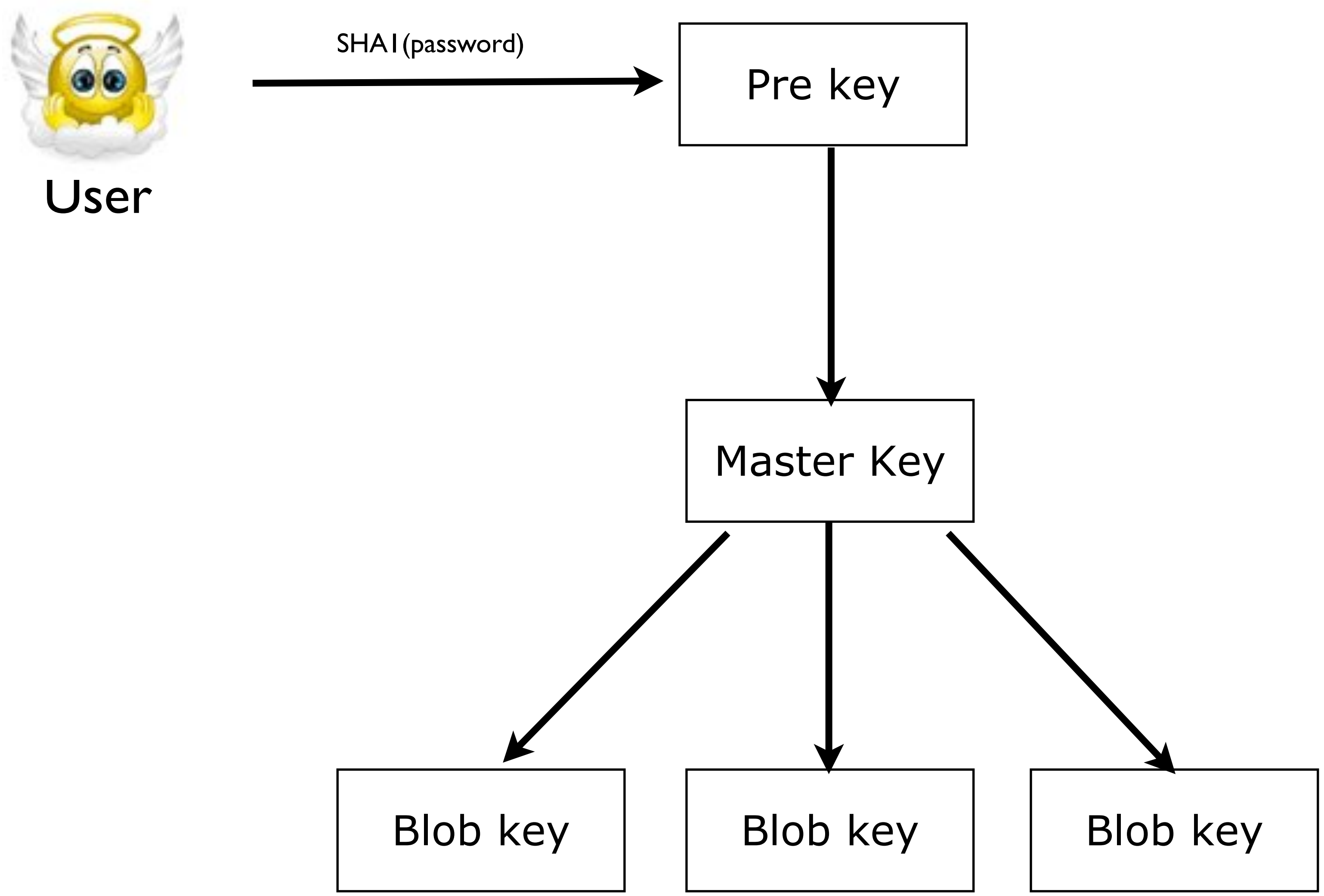
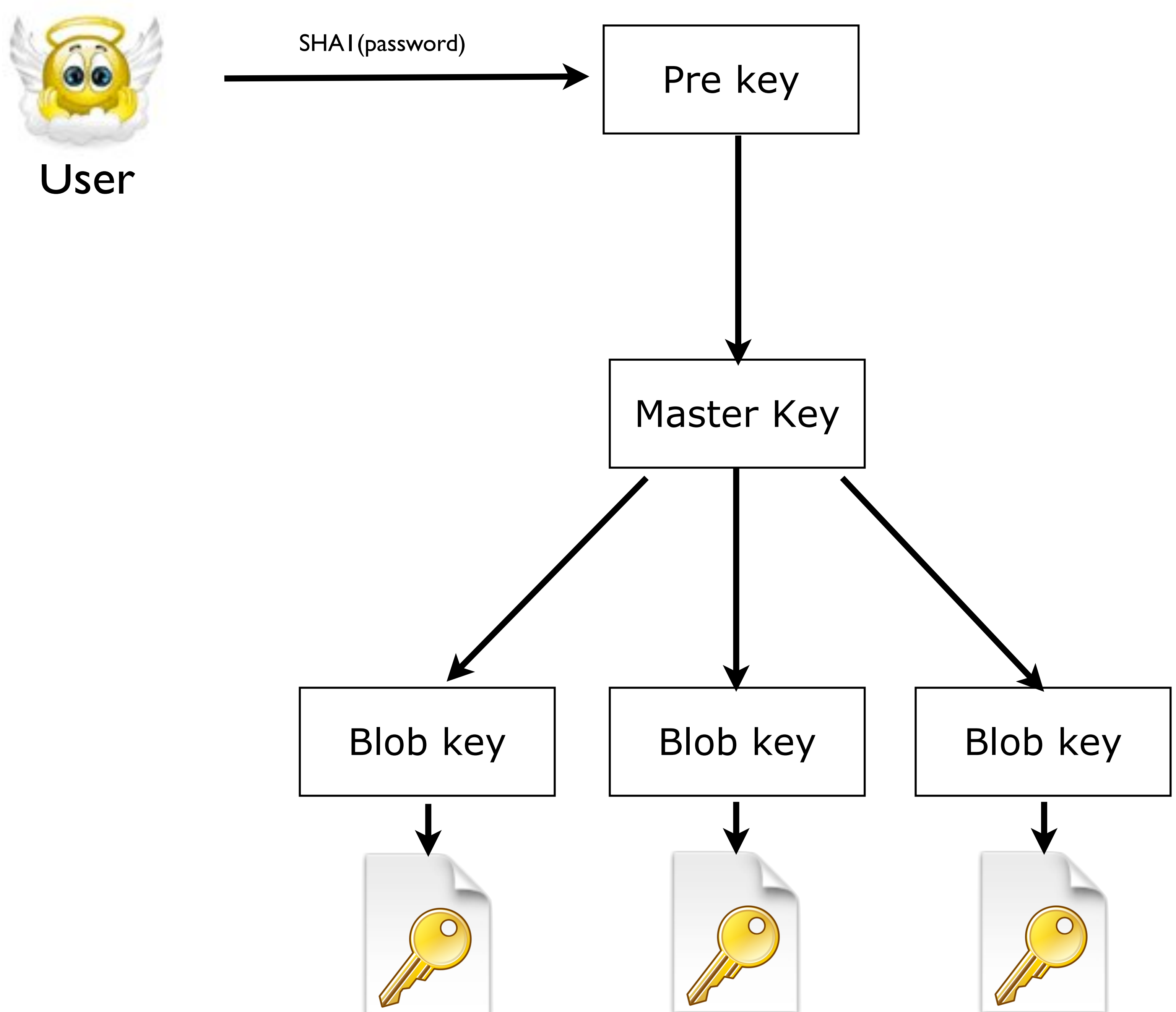


Derivation scheme



Blob structure

- Returned to the application (opaque structure)
- Store user encrypted data
- Contains decryption parameters

key subtleties

- SHA1 password are in UTF-16LE
- SID for HMAC are also in UTF-16LE (don't forget the \0 !)
- Windows 2000 do not use SHA1/3DES. We think it uses SHA1/RC4 (Anyone want to try ?).

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;
GUID     *arrKeys;
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;
BYTE     *pbHMAC;
```

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;
GUID     *arrKeys;
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;
BYTE     *pbHMAC;
```

Nb of crypto providers

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;      <—— Crypto providers GUID
DWORD    cbKeys;
GUID     *arrKeys;
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;
BYTE     *pbHMAC;
```

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;          <-- Nb of masters keys
GUID     *arrKeys;
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;
BYTE     *pbHMAC;
```

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;
GUID     *arrKeys;          ←  Masters keys GUID
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;
BYTE     *pbHMAC;
```

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;
GUID     *arrKeys;
WCHAR    *ppszDataDescr;   ←   Optional description
DWORD    idCipherAlgo;
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;
BYTE     *pbHMAC;
```

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;
GUID     *arrKeys;
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;      ← Encryption algorithm ID
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;
BYTE     *pbHMAC;
```

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;
GUID     *arrKeys;
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;
BYTE     *pbSalt;          ← Salt generated by DPAPI
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;
BYTE     *pbHMAC;
```

data blob structure key fields

```
DWORD   cbProviders;
GUID    *arrProviders;
DWORD   cbKeys;
GUID    *arrKeys;
WCHAR   *ppszDataDescr;
DWORD   idCipherAlgo;
BYTE    *pbSalt;
DWORD   idHashAlgo;      <---- Hash algorithm ID
BYTE    *pbUnknown;
BYTE    *pbCipher;
BYTE    *pbHMAC;
```

data blob structure key fields

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DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;
GUID     *arrKeys;
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;      ← Unknown data
BYTE     *pbCipher;
BYTE     *pbHMAC;
```

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;
GUID     *arrKeys;
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;       ← Encrypted data
BYTE     *pbHMAC;
```

data blob structure key fields

```
DWORD    cbProviders;
GUID     *arrProviders;
DWORD    cbKeys;
GUID     *arrKeys;
WCHAR    *ppszDataDescr;
DWORD    idCipherAlgo;
BYTE     *pbSalt;
DWORD    idHashAlgo;
BYTE     *pbUnknown;
BYTE     *pbCipher;
BYTE     *pbHMAC;     ←—— Blob HMAC
```

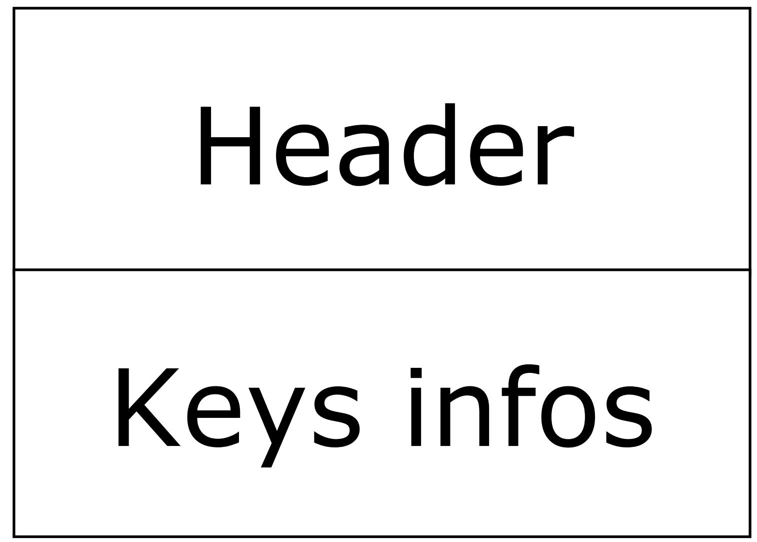
Master key structure

- Store the key used to decrypt blob
- Encrypted with the user password
- Renewed every 3 months

The master key file

Header

The master key file



The master key file

Header
Keys infos
Master key

The master key file

Header
Keys infos
Master key
Key ?

The master key file

Header
Keys infos
Master key
Key ?
Footer

Header structure

Header
Keys infos
Master key
Key ?
Footer

dwVersion;

nullPad1;

szKeyGUID[36];

nullPad2;

Header structure

Header
Keys infos
Master key
Key ?
Footer

dwVersion; ← File version

nullPad1;

szKeyGUID[36];

nullPad2;

Header structure

Header
Keys infos
Master key
Key ?
Footer

dwVersion;

nullPad1;

szKeyGUID[36]; ← Master key GUID

nullPad2;

Key infos structure

Header
Keys infos
Master key
Key ?
Footer

dwUnknown;

cbMasterKey;

cbMysteryKey;

dwHMACLen;

nullPad3;

Key infos structure

Header
Keys infos
Master key
Key ?
Footer

dwUnknown;

cbMasterKey; ← Master Key struct length

cbMysteryKey;

dwHMACLen;

nullPad3;

Key infos structure

Header
Keys infos
Master key
Key ?
Footer

dwUnknown;

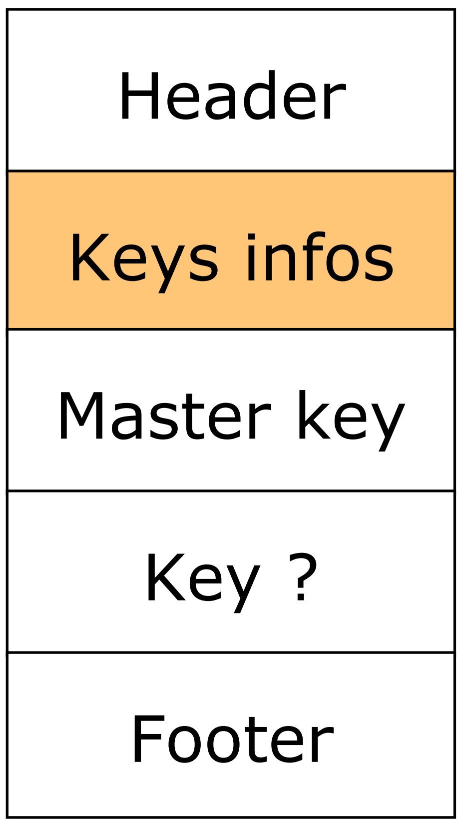
cbMasterKey;

cbMysteryKey; ← Key ? struct length

dwHMACLen;

nullPad3;

Key infos structure



dwUnknown;

cbMasterKey;

cbMysteryKey;

dwHMACLen; ← HMAC length

nullPad3;

Master key structure

Header
Keys infos
Master key
Key ?
Footer

dwMagic;

pbSalt[16];

cbIteration;

idMACAlgo;

idCipherAlgo;

pbCipheredKey[];

Master key structure

Header
Keys infos
Master key
Key ?
Footer

dwMagic;

pbSalt[16]; ← Key salt

cbIteration;

idMACAlgo;

idCipherAlgo;

pbCipheredKey[];

Master key structure

Header
Keys infos
Master key
Key ?
Footer

dwMagic;

pbSalt[16];

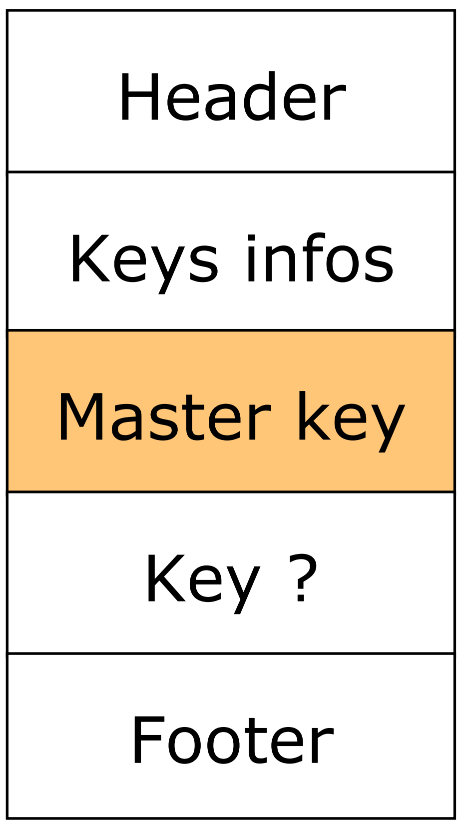
cbIteration; ← PBKDF2 nb rounds

idMACAlgo;

idCipherAlgo;

pbCipheredKey[];

Master key structure



dwMagic;

pbSalt[16];

cbIteration;

idMACAlgo; ← HMAC algorithm ID

idCipherAlgo;

pbCipheredKey[];

Master key structure

Header
Keys infos
Master key
Key ?
Footer

dwMagic;

pbSalt[16];

cbIteration;

idMACAlgo;

idCipherAlgo; ← Encryption Algo id

pbCipheredKey[];

Master key structure

Header
Keys infos
Master key
Key ?
Footer

dwMagic;

pbSalt[16];

cbIteration;

idMACAlgo;

idCipherAlgo;

pbCipheredKey[]; ← Encrypted key

Decrypting the Master key

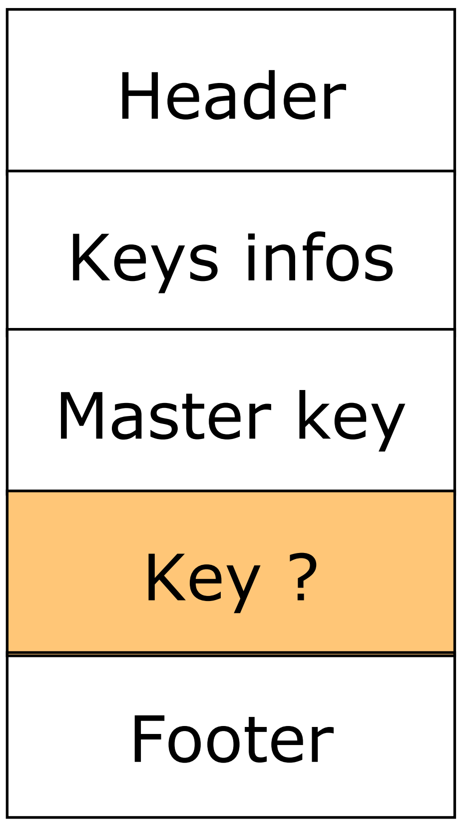
```
DPAPIDecryptKey(sha1, encKey) {
    tmp-key = HMAC(sha1, SID)
    pre-key = PBKDF2(decryptKey,  Salt, ID_ALGO,
    nbIteration)
    3desKey = pre-key[0 - 23]
    3desIV = [24 - 31]
    (hmac[0-35], DWORD[36-39], master-key
    [40-104]) = 3des-cbc(3desKey, iv, encKey)
}
```

key structure

Header
Keys infos
Master key
Key ?
Footer

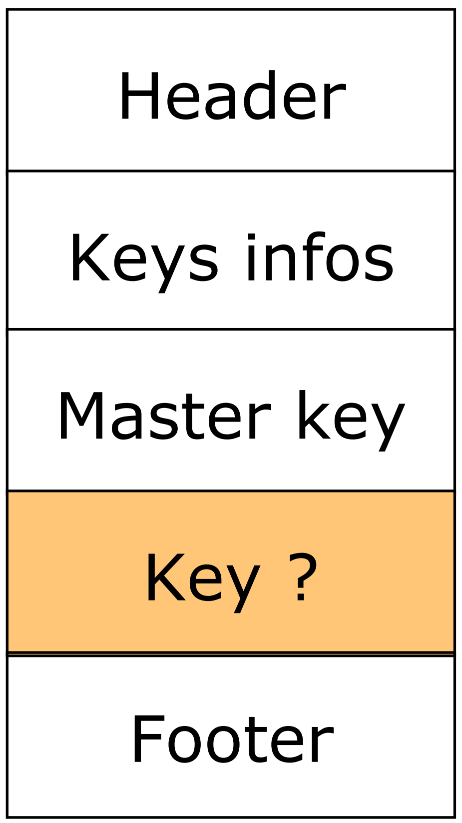
- Seems to have the same structure than the master key
- One round of derivation (XP not Seven)
- 256 bits (half size of the real master-key)

Possible explanation



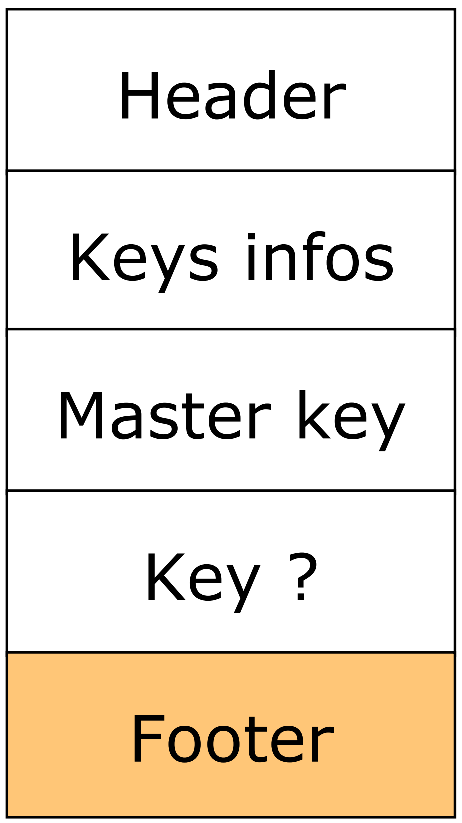
- The documentation state a compatibility mode for windows 2000 exist.
- The registry key to trigger it is unknown
- If we are correct and W2k uses RC4 then the mystery key is possibly a RC4 key (256bits is the correct size).
- PBKDF2 used to compute the IV ??

Possible explanation continued



- We know that RC4 have a weak key scheduling algorithm (remember WEP ?)
- Might be a potential weakness (or not)

Header structure



dwMagic;

credHist[16];

Header structure

Header
Keys infos
Master key
Key ?
Footer

dwMagic;

credHist[16]; ← Password GUID

Differences between windows version

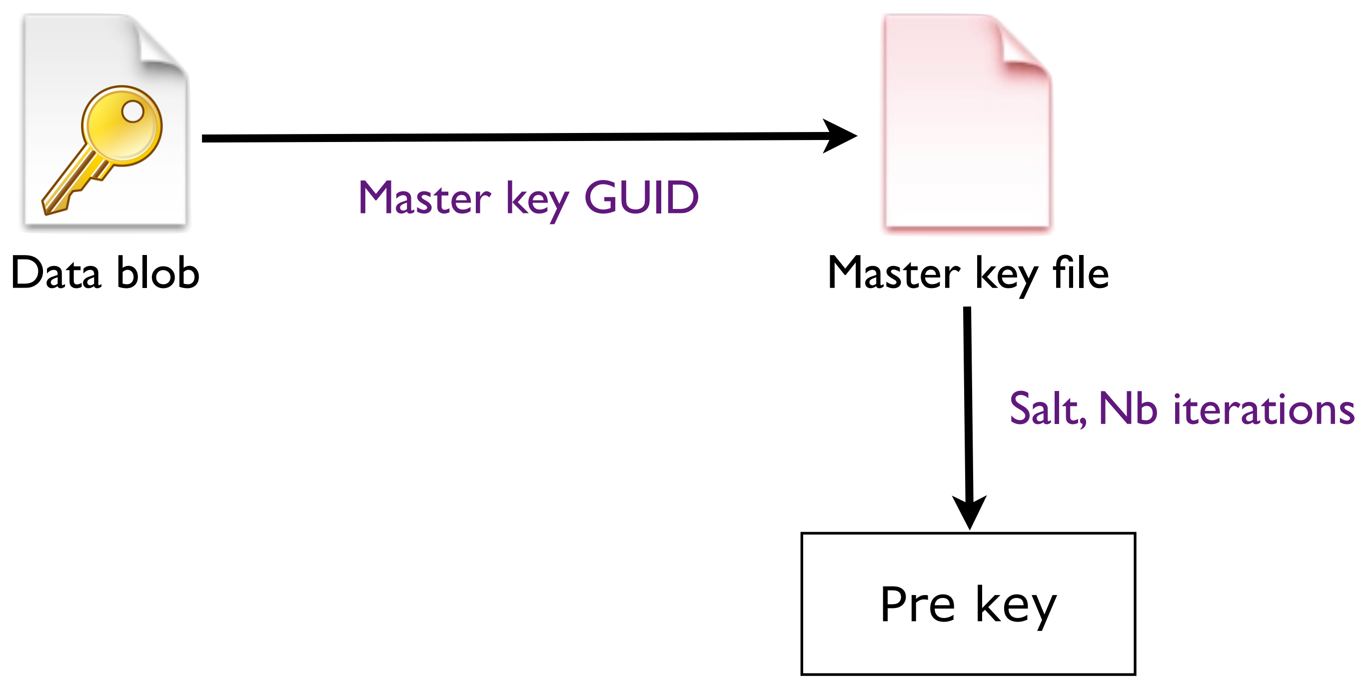
	XP	Vista	Seven
PBKDF2 rounds	4000	24000	Variable (factor ?)
Symmetric algorithm	3DES	3DES	AES
Hash algorithm	SHA1	SHA1	SHA512

Decrypting a blob

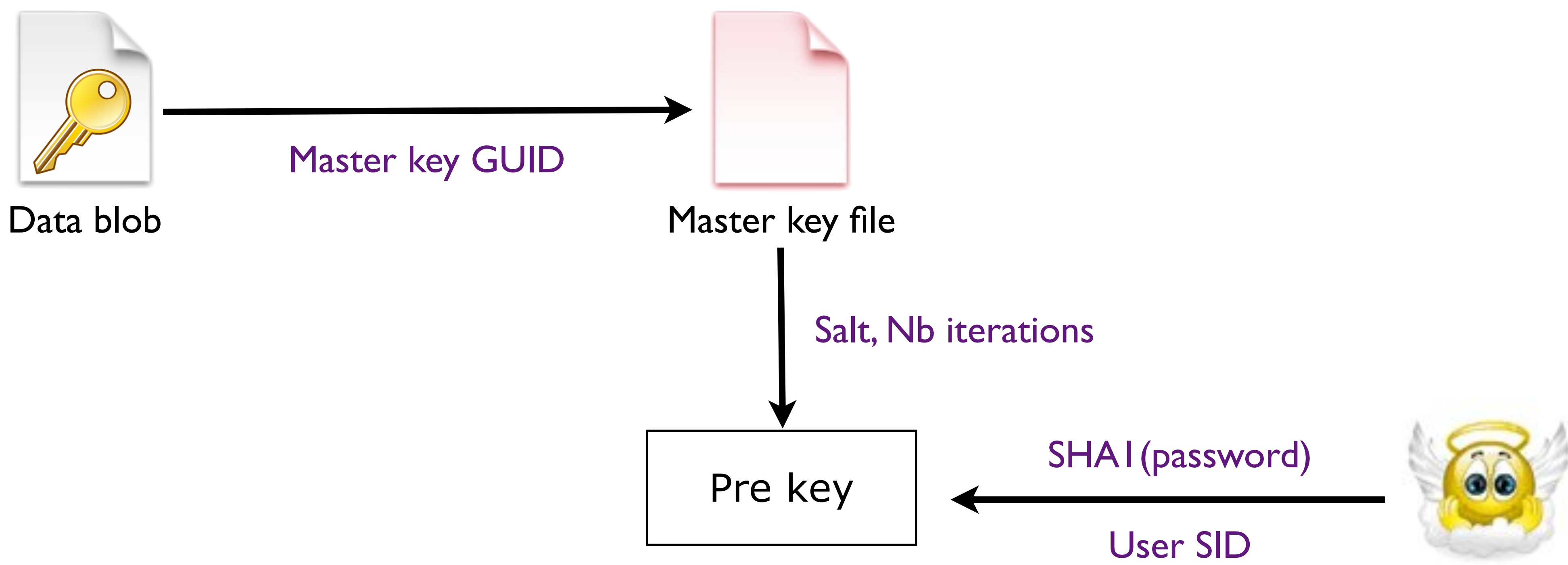
Data blob

Decrypting a blob

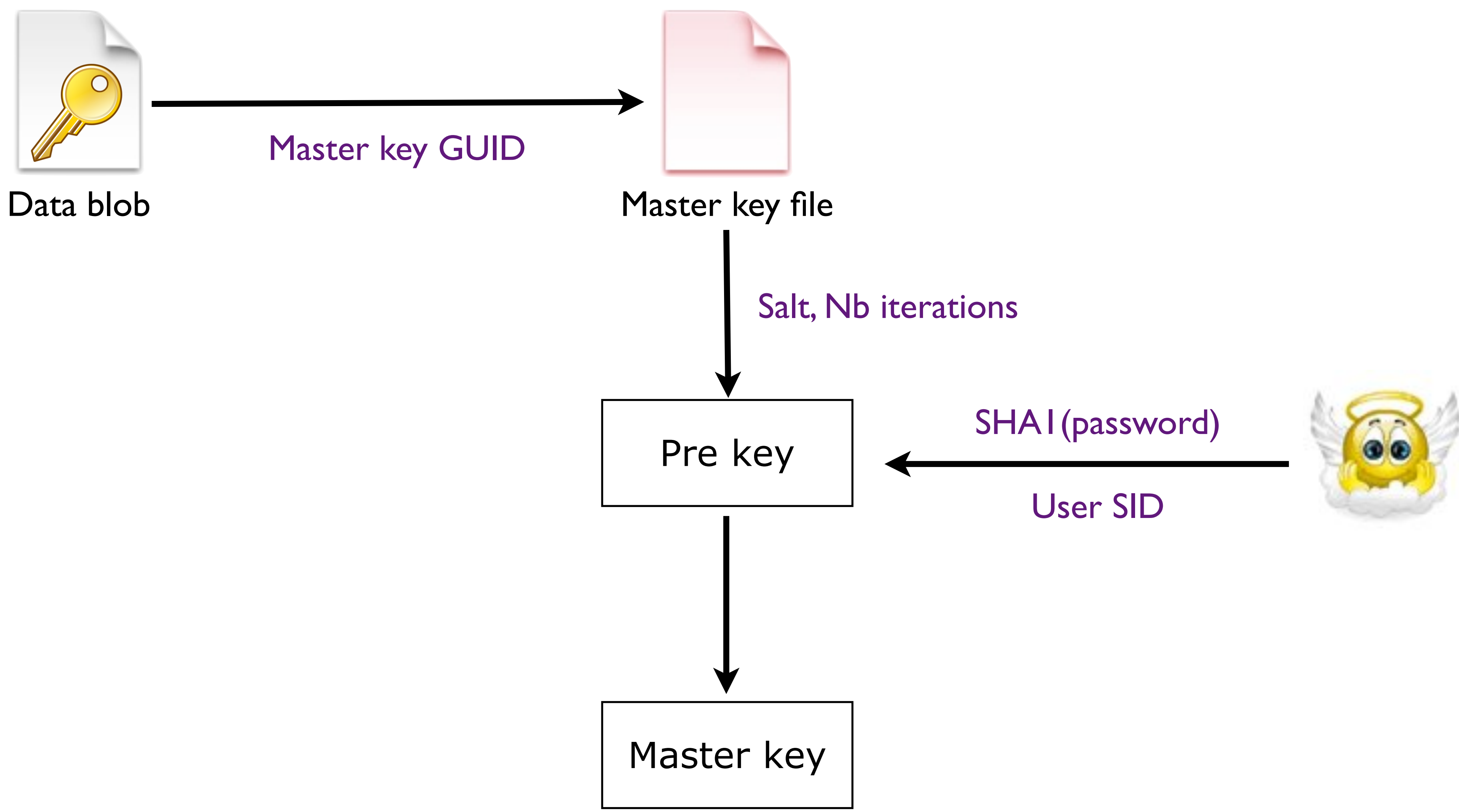
Decrypting a blob



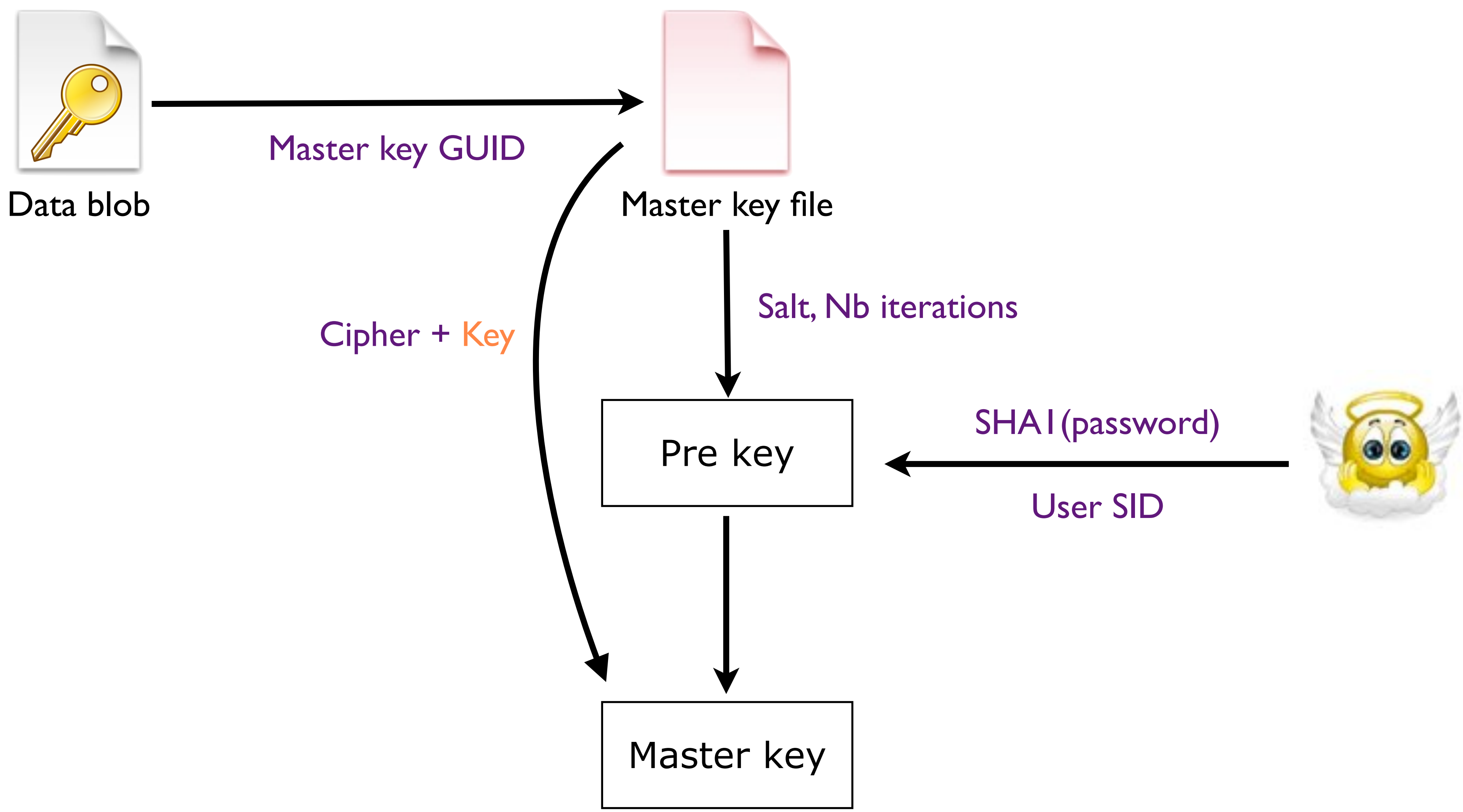
Decrypting a blob



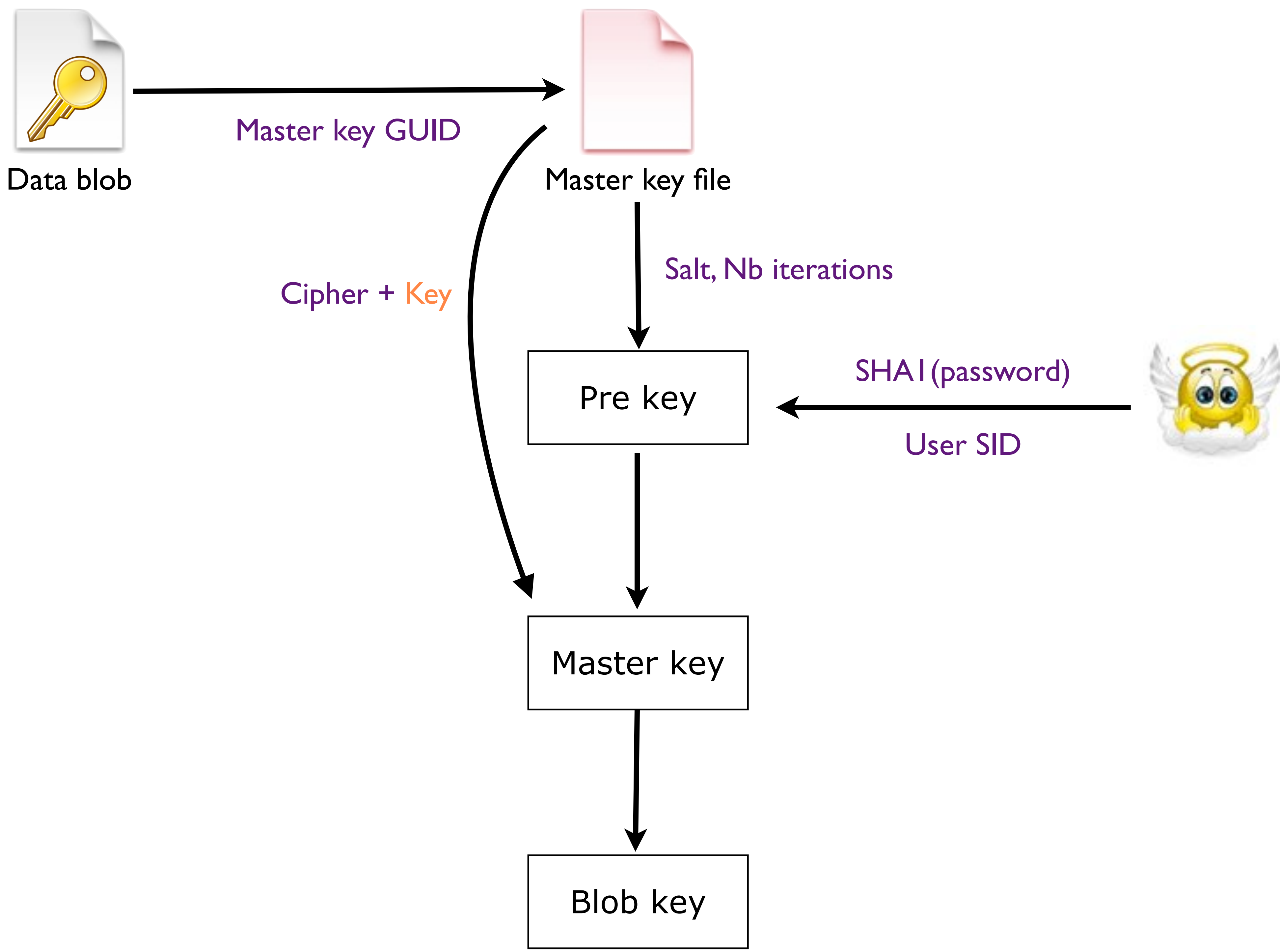
Decrypting a blob



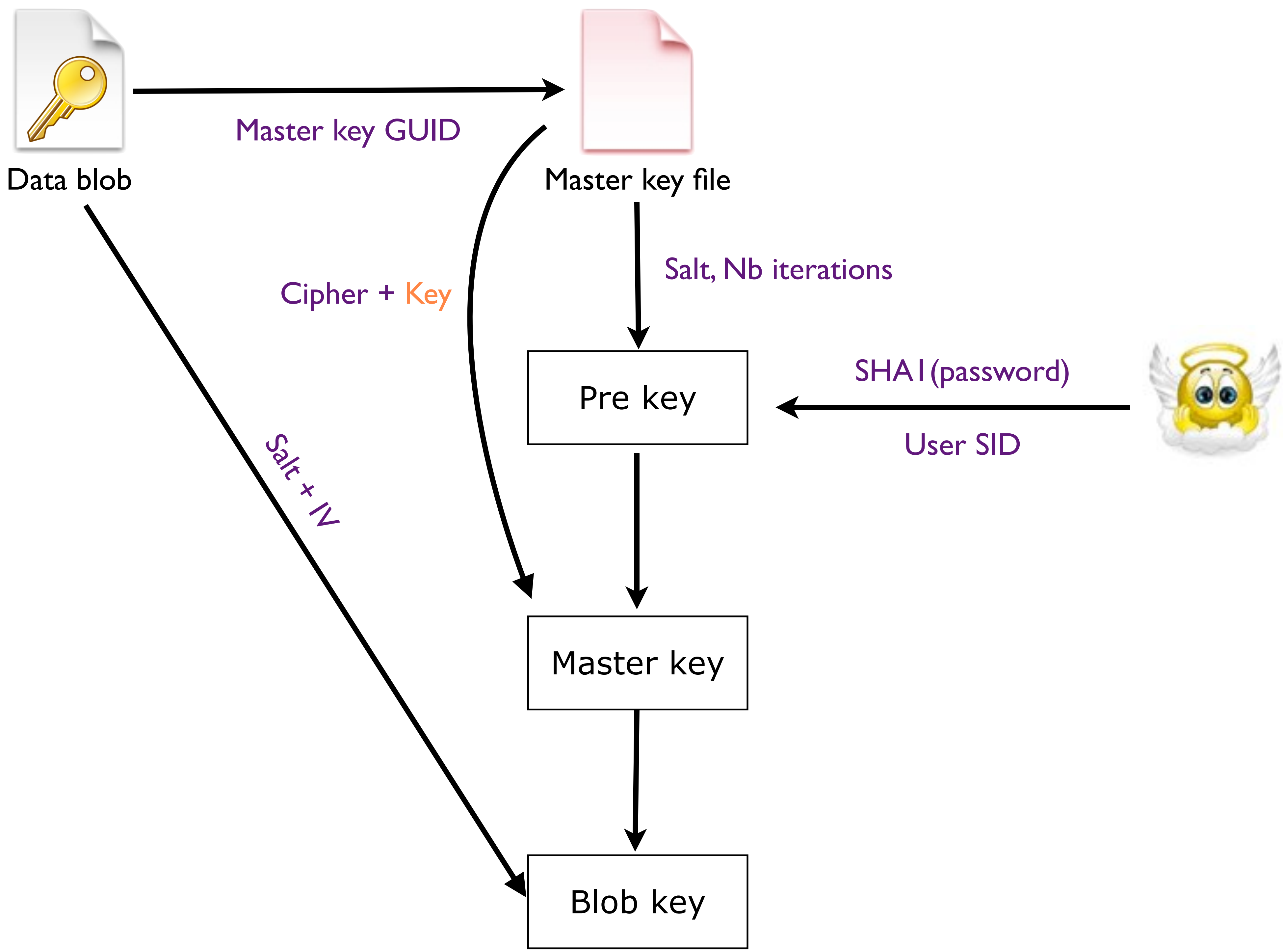
Decrypting a blob



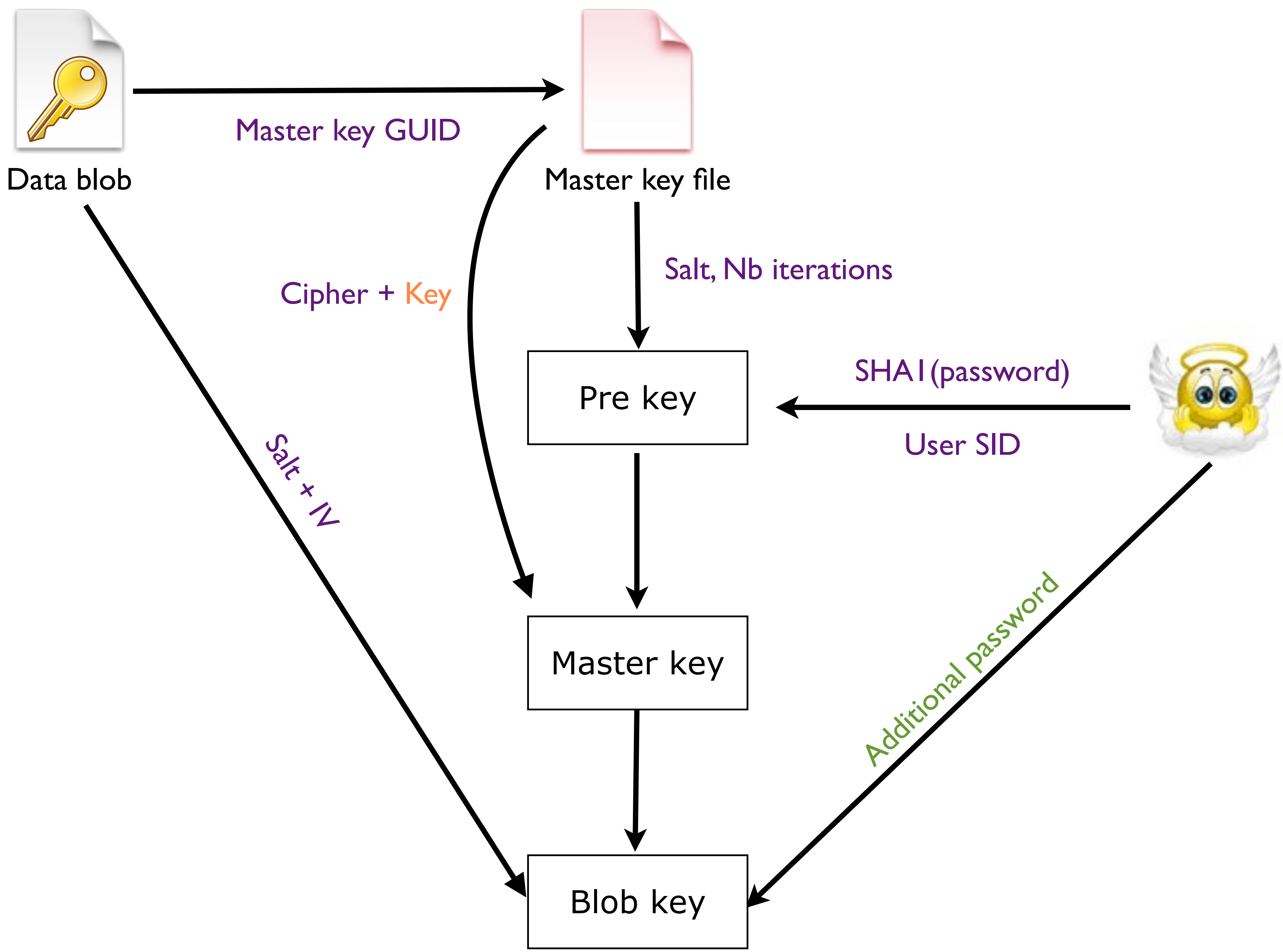
Decrypting a blob



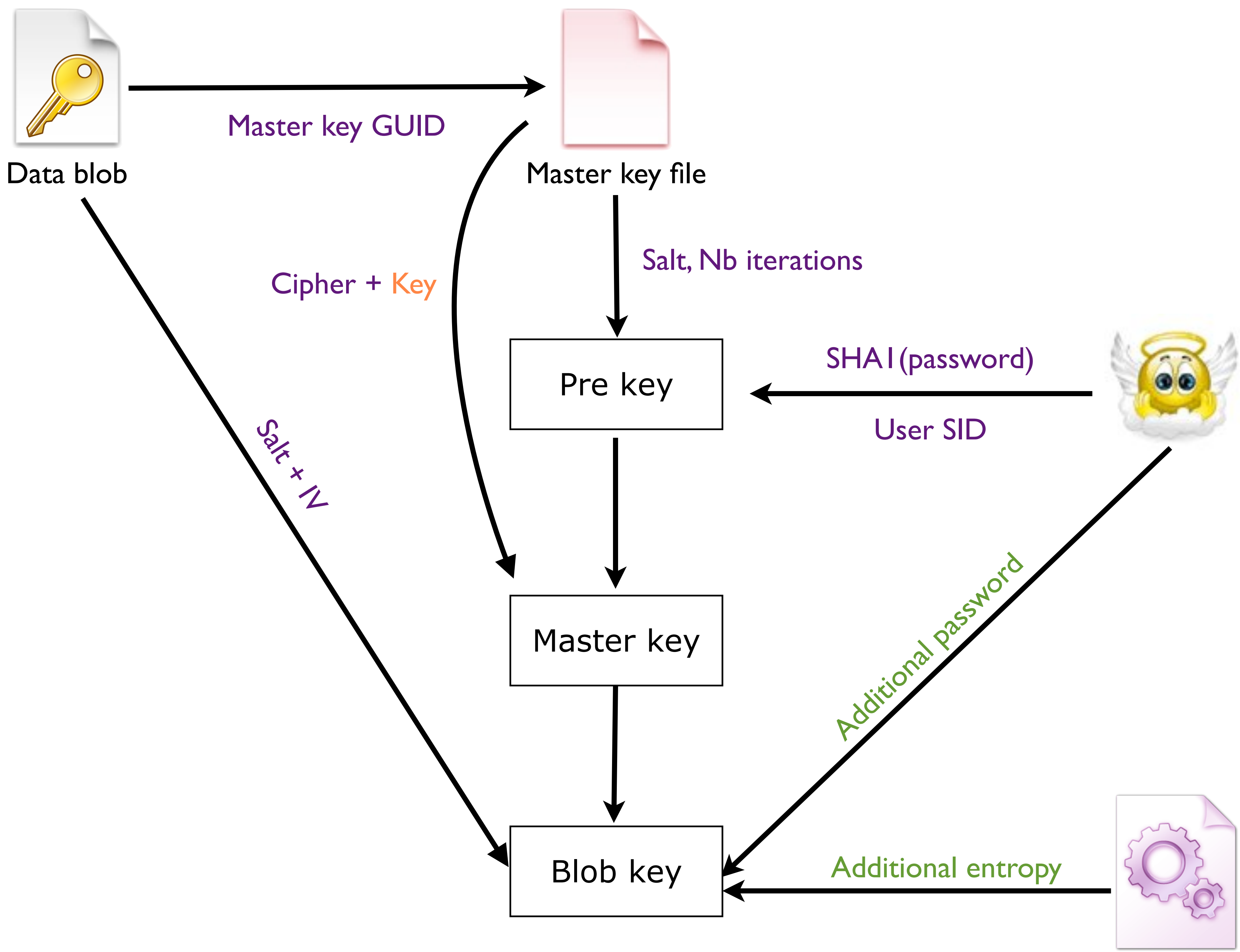
Decrypting a blob



Decrypting a blob



Decrypting a blob



Decrypt blob aka the strange HMAC

```
DecryptBlob() {
kt = SHA1(masterkey)
opad = 0x5c xor kt
ipad = 0x36 xor kt
i = SHA1(opad.SHA1(ipad . salt).entropyCond)
kd = CryptDeriveKey(i) //not reversed (yet)
CryptDecrypt(data, kd)
}
```

Did I miss something ?

Did I miss something ?

- How the OS knows the current master key ?

Did I miss something ?

- How the OS knows the current master key ?
- How the OS decides to renew the master key ?

Did I miss something ?

- How the OS knows the current master key ?
- How the OS decides to renew the master key ?
- What happen when the user changes his password ?

Key renewal process

- Renewed every 3 months automatically
  - Passive process: executed when CryptProtect called
  - Hardcoded limit (location unknown)
    - Possibly in psbase.dll (MS crypto provider)
    - Can be reduced by using registry override

Master key selection

- All master keys are kept because Windows can’t tell if a key is still used
- Keys are stored in %APPDATA%/Microsoft/Protect/[SID]
- Current master key is specified in the Preferred file

The Preferred file

- Simply contains :

  “GUID master key” . “timestamp”

- The key is renewed when

  current time > timestamp

The Preferred file

- Simply contains :

“GUID master key” . “timestamp”

- The key is renewed when

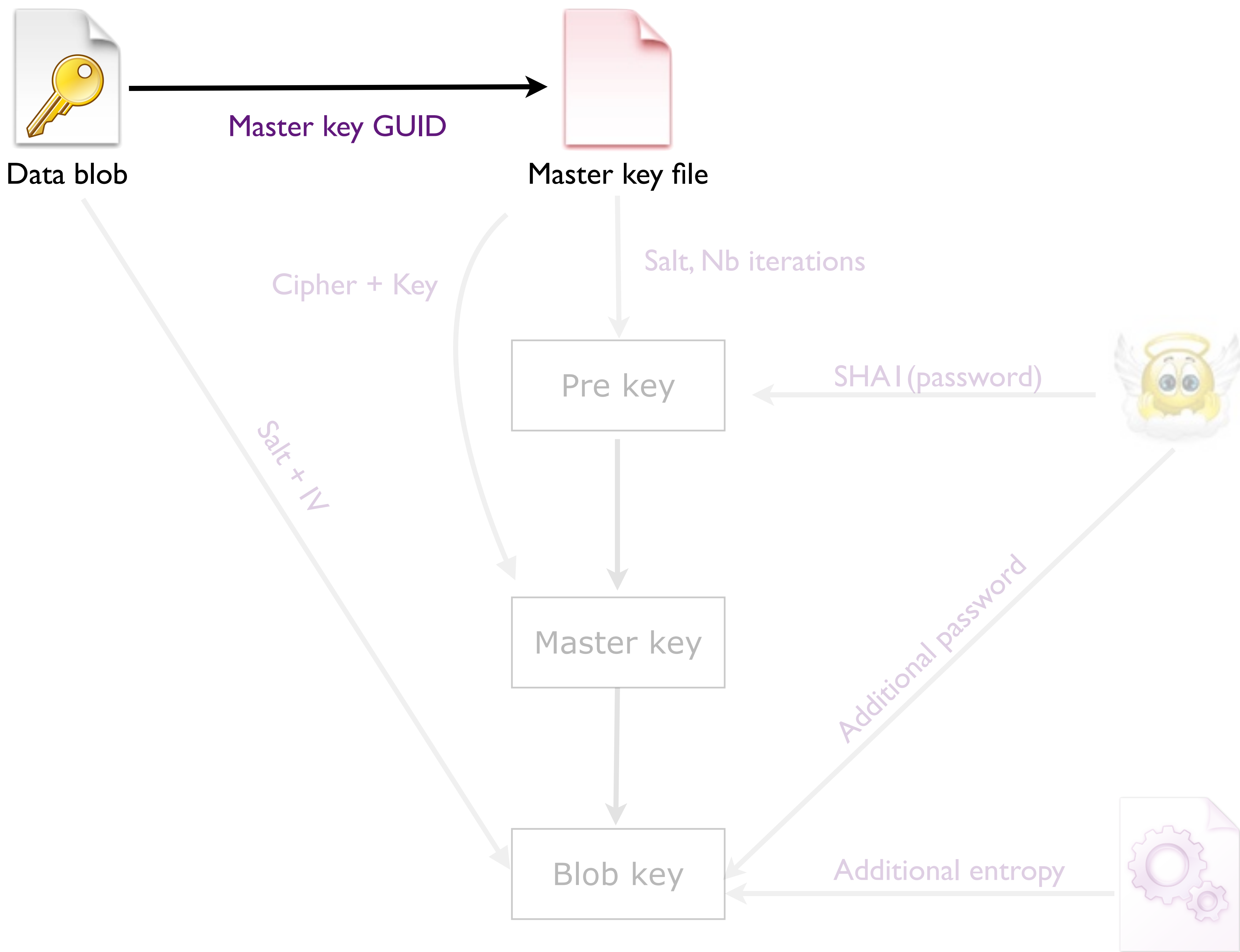
current time > timestamp

➡ Key escrow attack : Plant a key and update the Preferred file every 3 months (e.g using the task scheduler)

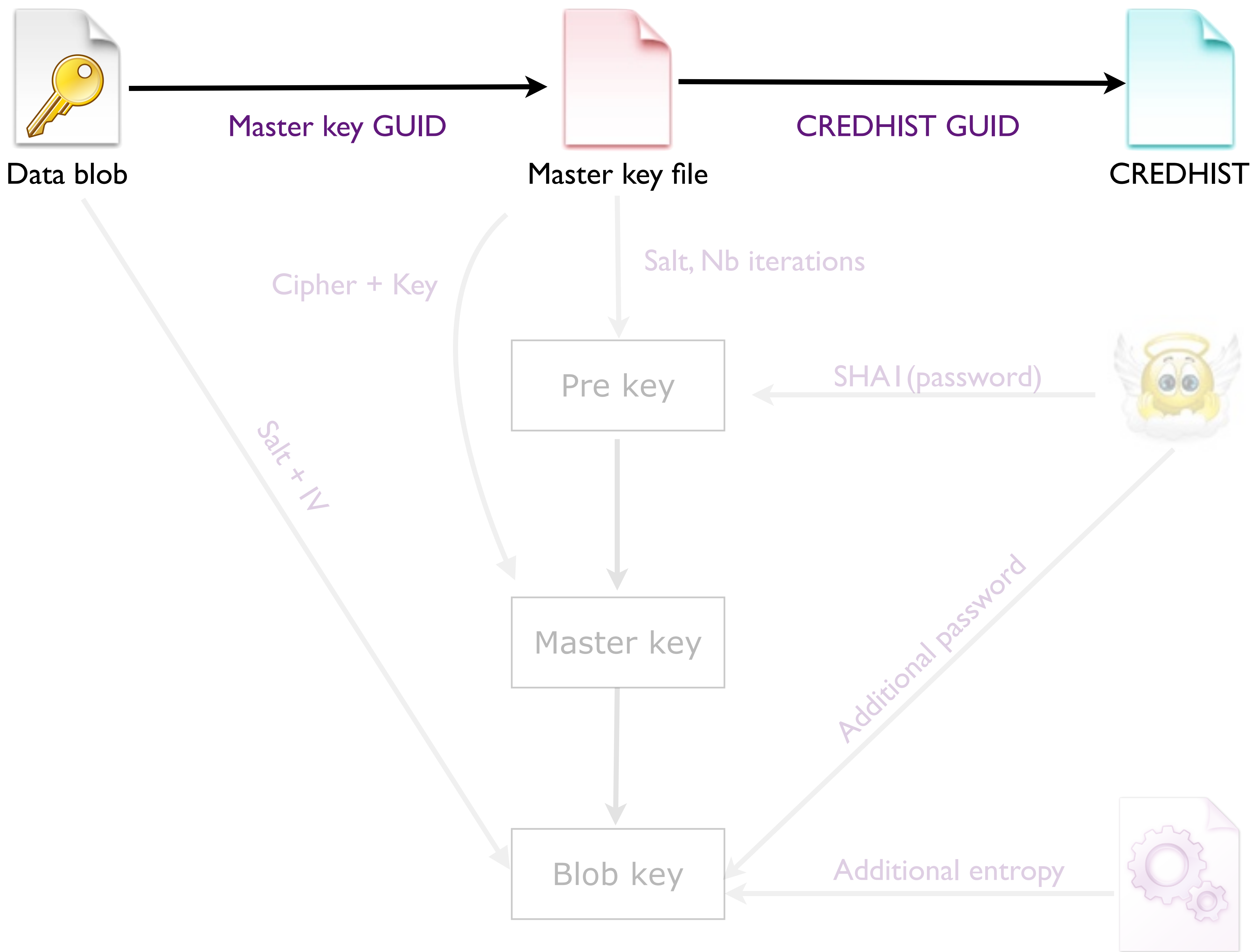
User password renewal

- Master keys are re-encrypted when the password change
- Experimentally not all of them, just the last few ones

Decrypting a blob



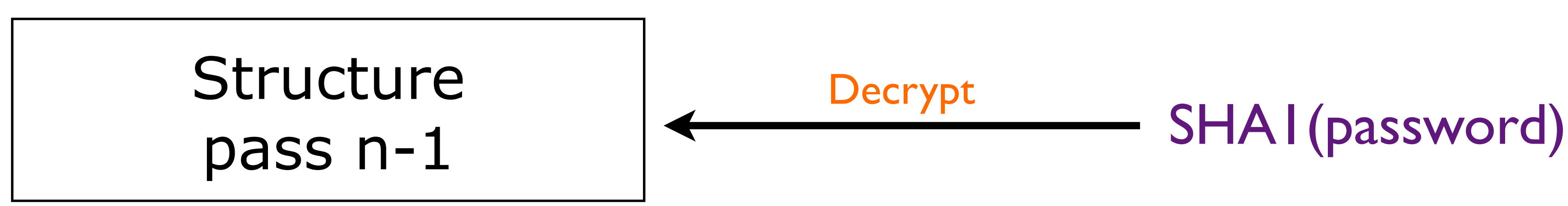
Decrypting a blob



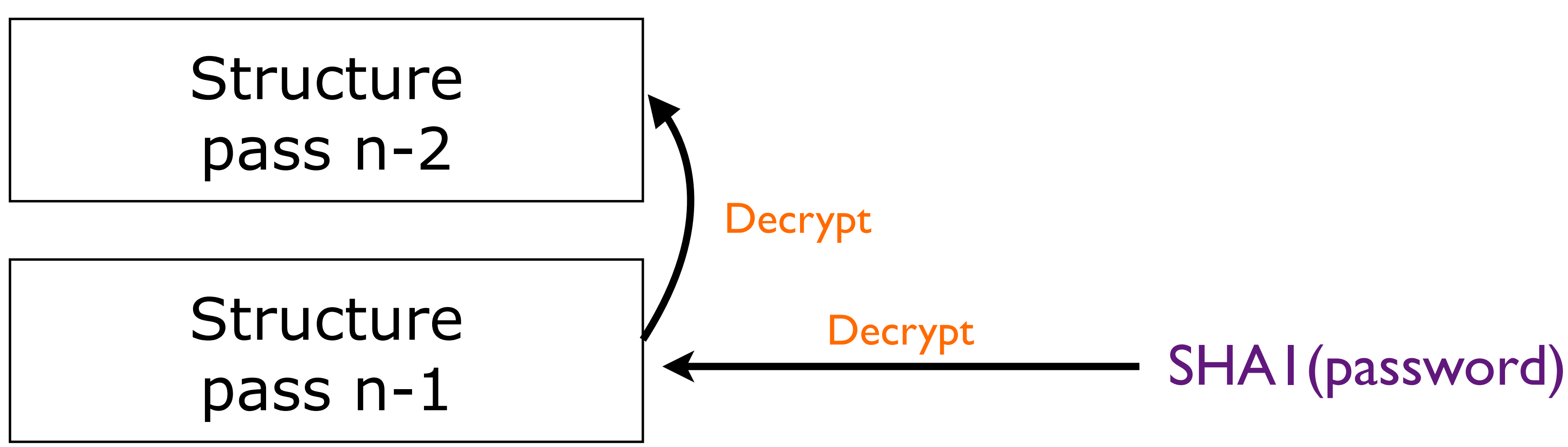
CREDHIST overview

SHA1(password)

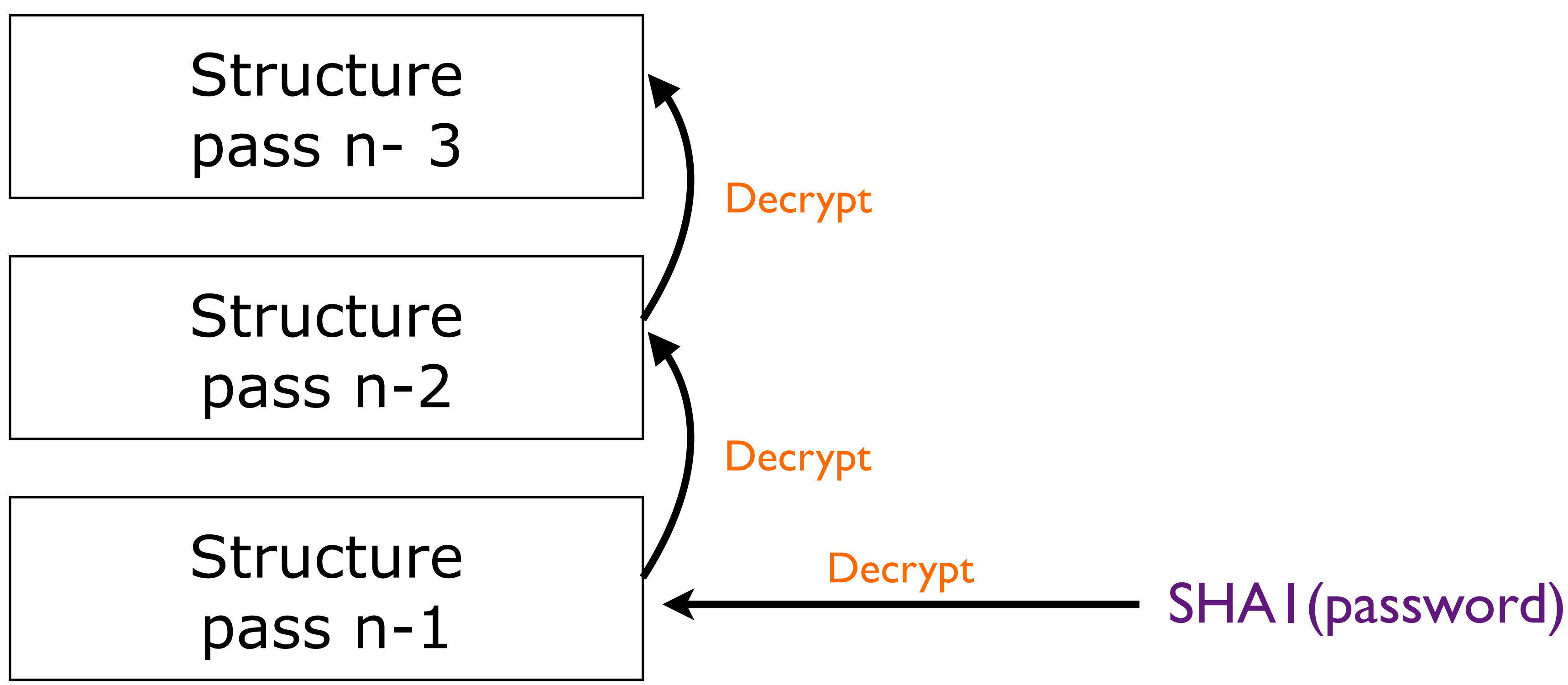
CREDHIST overview



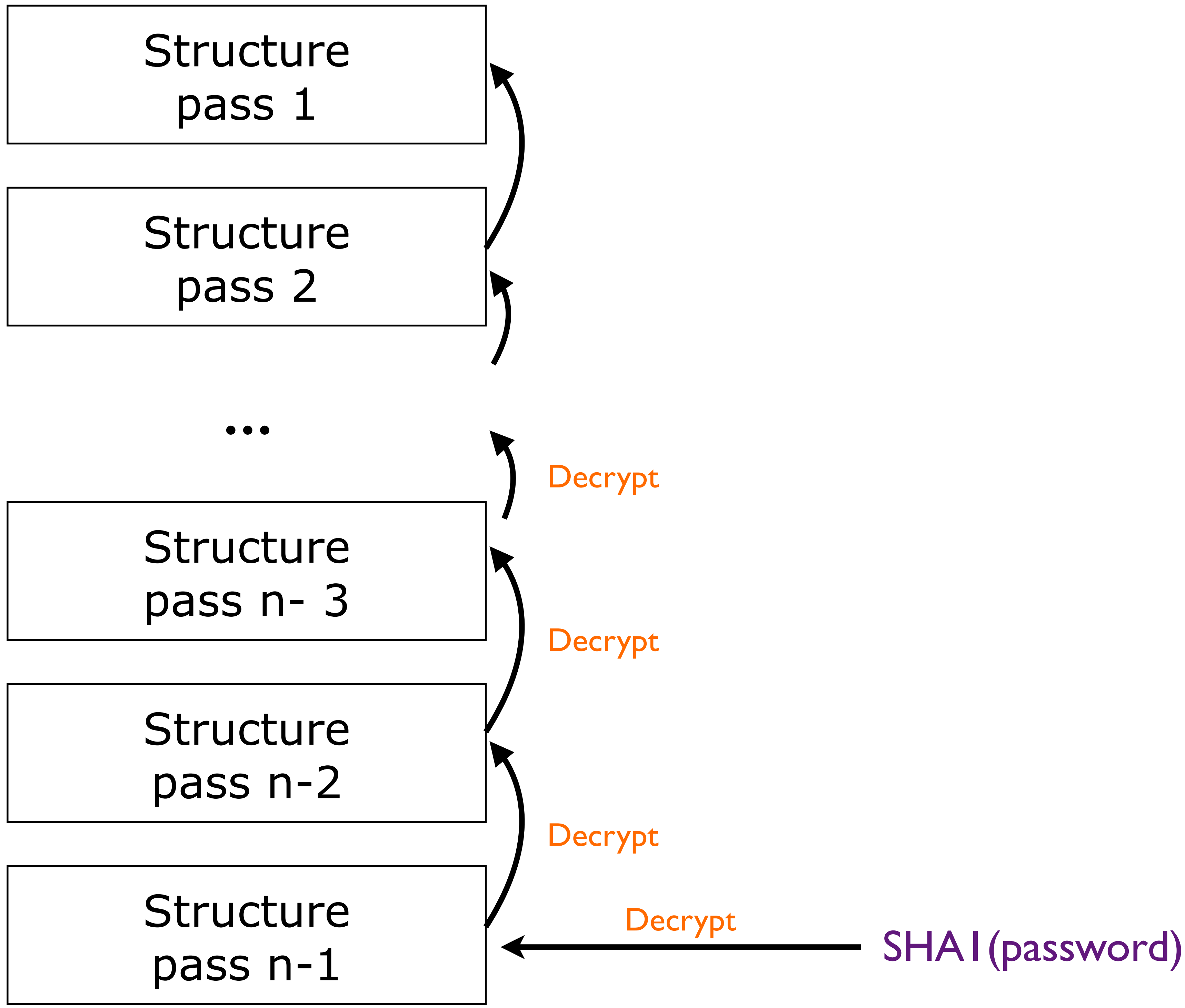
CREDHIST overview



CREDHIST overview



CREDHIST overview



CREDHIST entry structure main fields

idHashAlgo;

dwRounds;

dwCipherAlgo;

bSID[12];

dwComputerSID[3];

dwAccountID;

bData[28];

bPasswordID[16]

CREDHIST entry structure main fields

idHashAlgo; ← Hash algo ID

dwRounds;

dwCipherAlgo;

bSID[12];

dwComputerSID[3];

dwAccountID;

bData[28];

bPasswordID[16]

CREDHIST entry structure main fields

idHashAlgo;

dwRounds; ← Nb rounds

dwCipherAlgo;

bSID[12];

dwComputerSID[3];

dwAccountID;

bData[28];

bPasswordID[16]

CREDHIST entry structure main fields

idHashAlgo;

dwRounds;

dwCipherAlgo; ← Encryption Algorithm ID

bSID[12];

dwComputerSID[3];

dwAccountID;

bData[28];

bPasswordID[16]

CREDHIST entry structure main fields

idHashAlgo;

dwRounds;

dwCipherAlgo;

bSID[12]; ← User USID

dwComputerSID[3];

dwAccountID;

bData[28];

bPasswordID[16]

CREDHIST entry structure main fields

idHashAlgo;

dwRounds;

dwCipherAlgo;

bSID[12];

dwComputerSID[3]; ⟵ Computer SID

dwAccountID;

bData[28];

bPasswordID[16]

CREDHIST entry structure main fields

idHashAlgo;

dwRounds;

dwCipherAlgo;

bSID[12];

dwComputerSID[3];

dwAccountID; ← Account ID

bData[28];

bPasswordID[16]

CREDHIST entry structure main fields

idHashAlgo;

dwRounds;

dwCipherAlgo;

bSID[12];

dwComputerSID[3];

dwAccountID;

bData[28]; ← Encrypted password SHA1

bPasswordID[16]

CREDHIST entry structure main fields

idHashAlgo;

dwRounds;

dwCipherAlgo;

bSID[12];

dwComputerSID[3];

dwAccountID;

bData[28];

bPasswordID[16] ← Password GUID

Decryption algorithm overview

DecryptCredhist{

SID = (USID-ComputerID-AccountID)

tmp-key = HMAC(sha1, SID)

pre-key = PBKDF2(decryptKey, Salt, ID_ALGO, nbIteration)

3desKey = pre-key[0 - 23]

3desIV = [24 - 31]

(SHA1[0-19], HMAC[20-39]) = 3des-cbc (3desKey, iv, encKey)

DPAPIck demo

Warning

- DPAPIck is in ALPHA stage. Use it at your own risk ! You have been warned. It is just a POC
- Know bugs :
  - No HMAC checks -> No key check.
  - No Seven support, tested only on XP
  - No conditional entropy / strong password in UI
  - Don’t choose the correct master key by itself
  - Buffer overflows :)

DPAPIck future

- We made the choice to release early so you know we are telling the truth and everyone can start playing.
- We will provide a more robust version and eventually open the source code so one day Linux will read EFS files :)
- It just too soon for this.

LSA

- LSASS secret contains a DPAPI_SYSTEM value
- Length == 2 * SHA1
- Usage are unknown
- We think that 1 of them is used as a SYSTEM account "password"
- Need to be confirmed

EFS

- Certificate private key is encrypted with DPAPI
- Key are stored in
- To read EFS file offline, we just need to import the user certificate and its private keys in our key store.
- Work in progress in DPAPIck

What is next

- Can we build a rogue crypto provider ?
- What are the two SHA1 stored in the LSA ?
- Where is stored the renewal hard lime ?
- CryptDeriveKey needed to be reversed to have a fully portable implementation (Everything else is already portable)

Conclusion

- Open the door to offline forensic
- First step toward EFS on alternative systems
- CREDHIST allows to recover previous passwords
- DPAPIck : http://dpapick.com
- Some things remain unknown

Questions ?

Thanks to the nightingale team