Decrypting DPAPI data

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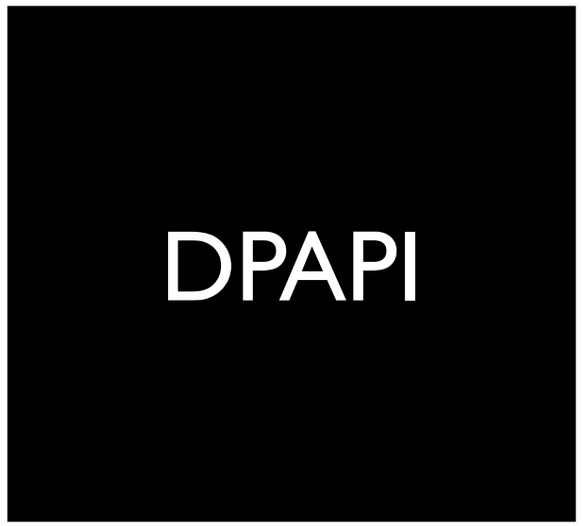
Data Protection API

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

Developer point of view

Application



Developer point of view

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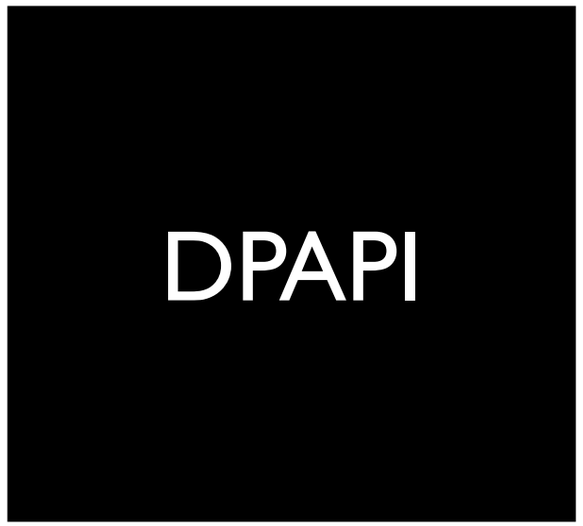

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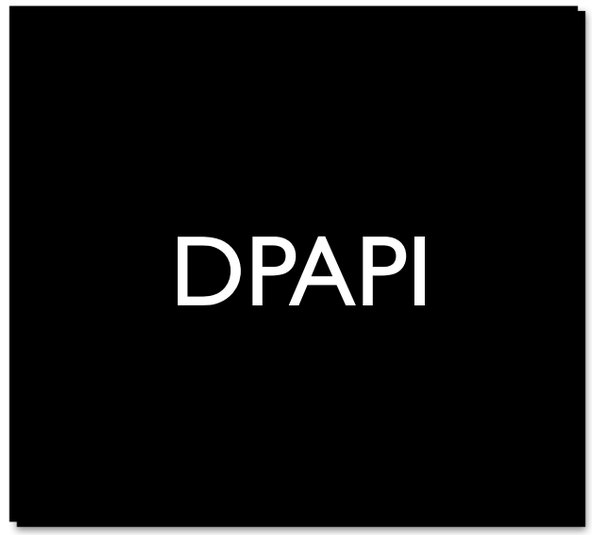
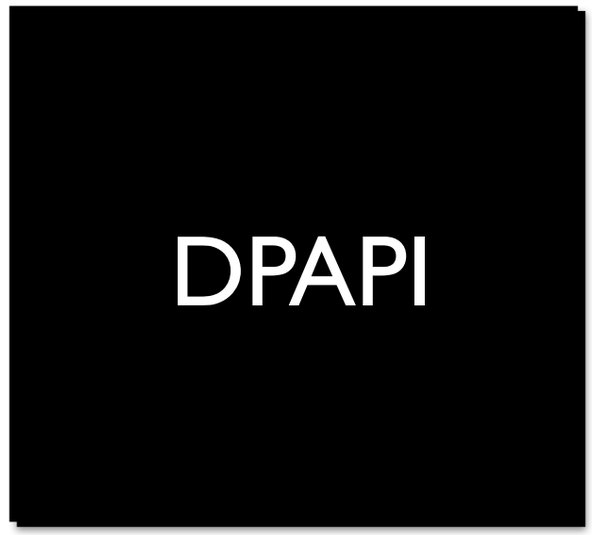


Developer point of view

Application




Wi
Fi

DPAPI is a simple API*

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

Why digging deeper ?

- Offline forensic
- EFS on Linux
- Security ?

Previous work

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

Take away

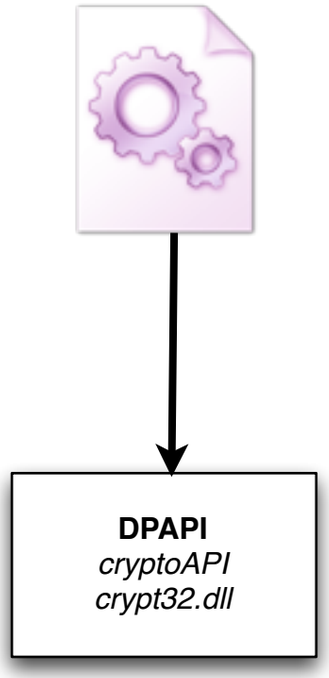
- Decrypt offline sensitive data
- Recovers user previous password
- Do a key escrow attack

Outline

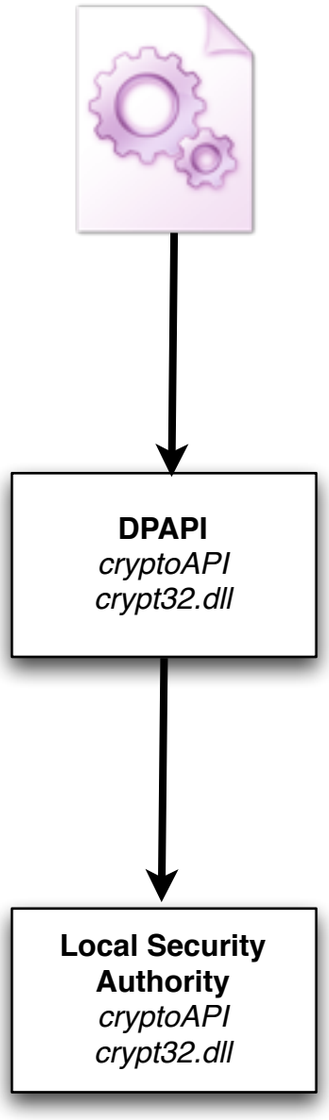
- DPAPI overview
- Decryption process
- Security design implications
- DPAPIck demo

How the system interacts with DPAPI

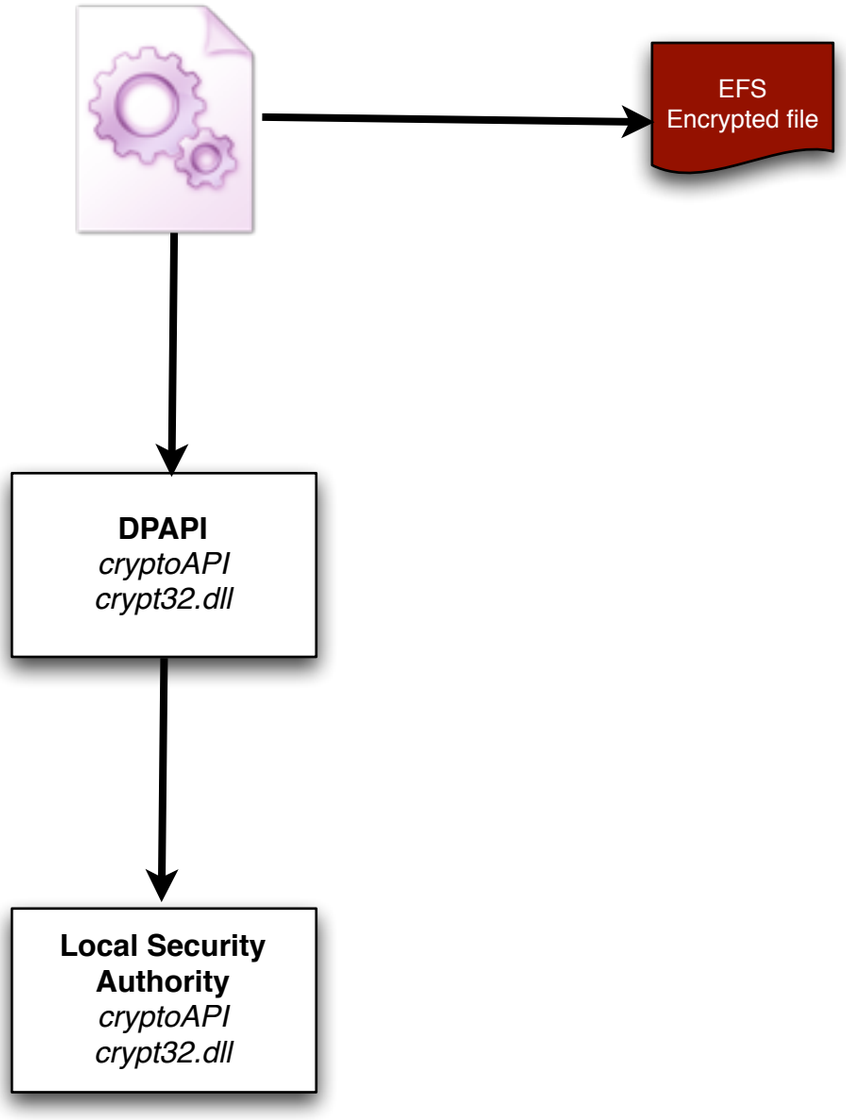
How the system interacts with DPAPI



How the system interacts with DPAPI



How the system interacts with DPAPI



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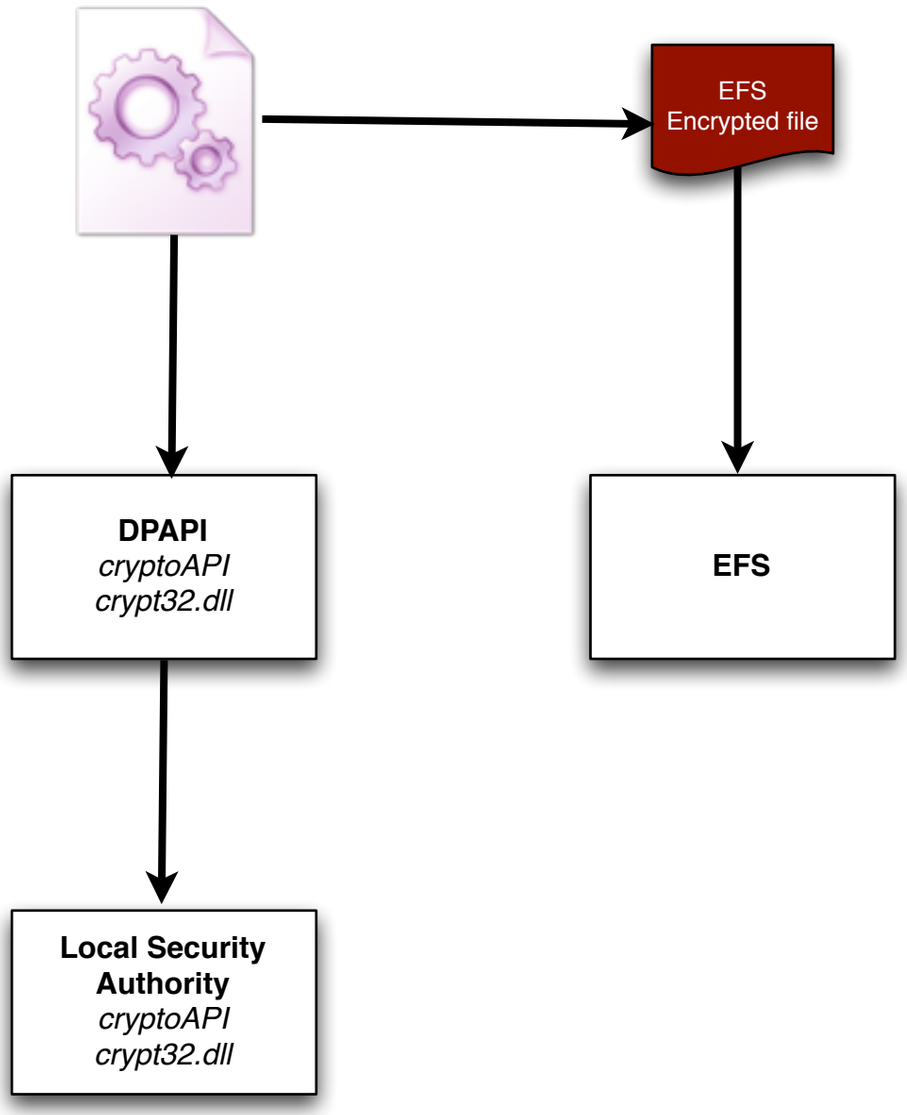
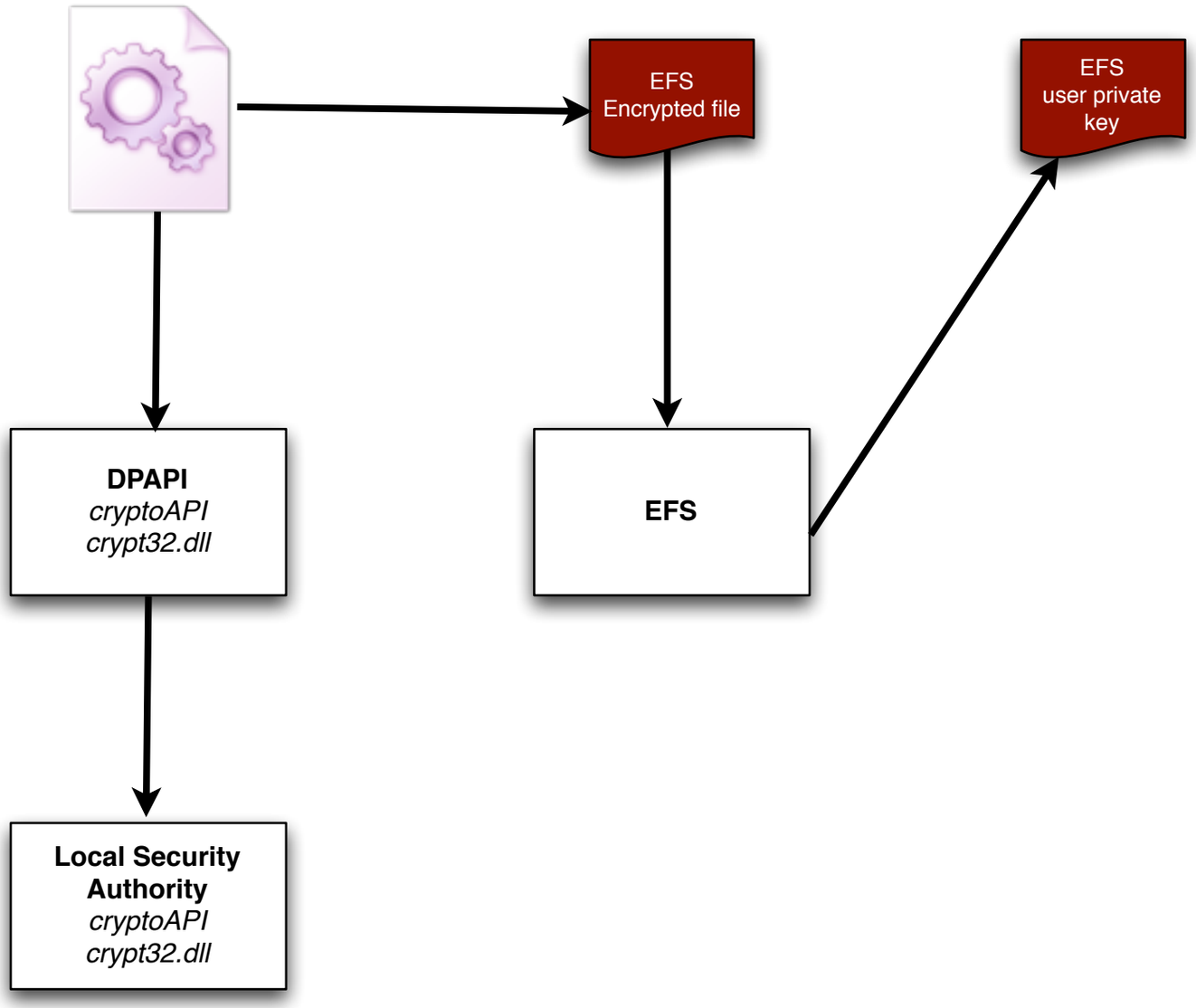
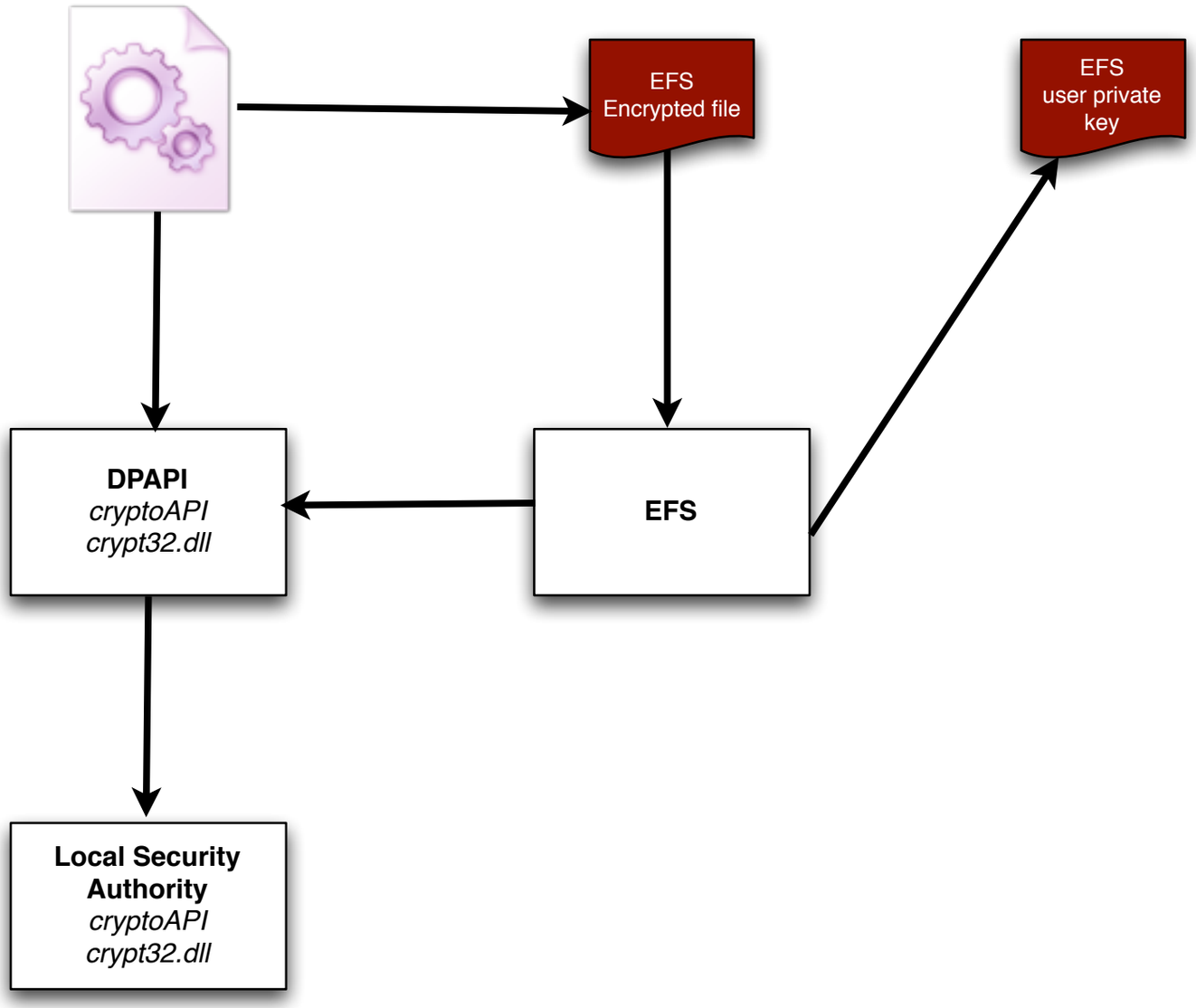


How the system interacts with DPAPI



How the system interacts with DPAPI



DPAPI CryptUnprotecDData Function

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

DPAPI CryptUnprotecDataFunction

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

Encrypted data aka data blob

DPAPI CryptUnprotecDataFunction

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BOOL WINAPI CryptUnprotectData (
  *pDataIn,
  *ppszDataDescr,
  *pOptionalEntropy,
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  *pDataOut
```

Optional description

DPAPI CryptUnprotecDData Function

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BOOL WINAPI CryptUnprotectData (
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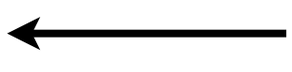

Optional entropy (salt)

DPAPI CryptUnprotecDData Function

```
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  *pDataIn,
  *ppszDataDescr,
  *pOptionalEntropy,
  pvReserved,
  *pPromptStruct,
  dwFlags,
  *pDataOut
```

Optional password

DPAPI CryptUnprotecDataFunction

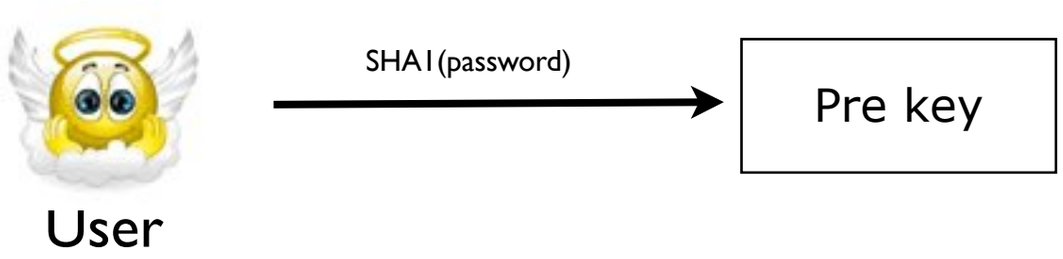
```
BOOL WINAPI CryptUnprotectData (
  *pDataIn,
  *ppszDataDescr,
  *pOptionalEntropy,
  pvReserved,
  *pPromptStruct,
  dwFlags,
  *pDataOut
```

Decrypted data

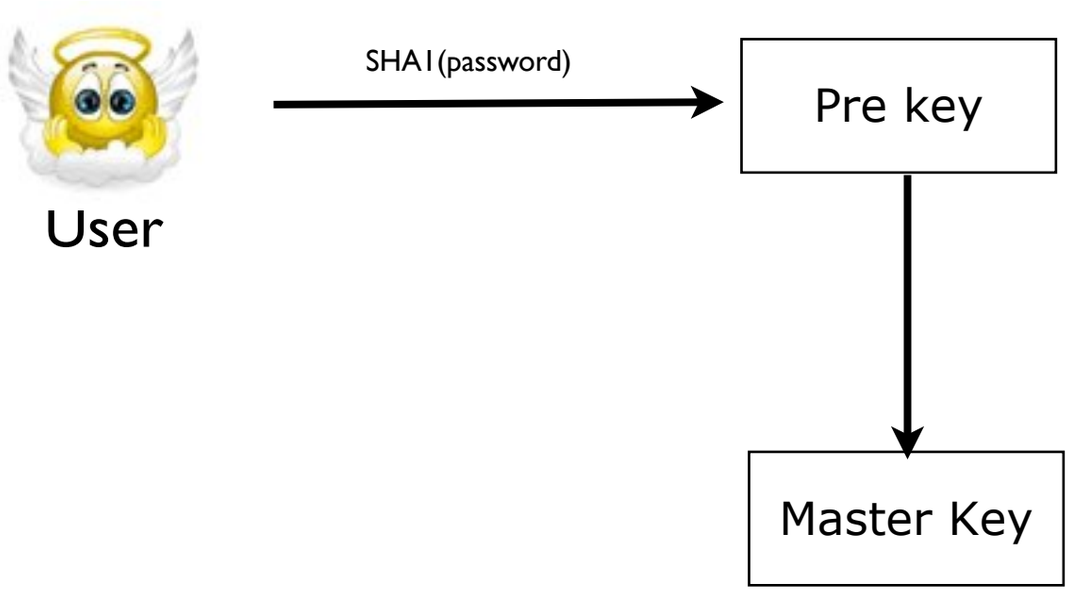
Derivation scheme

User

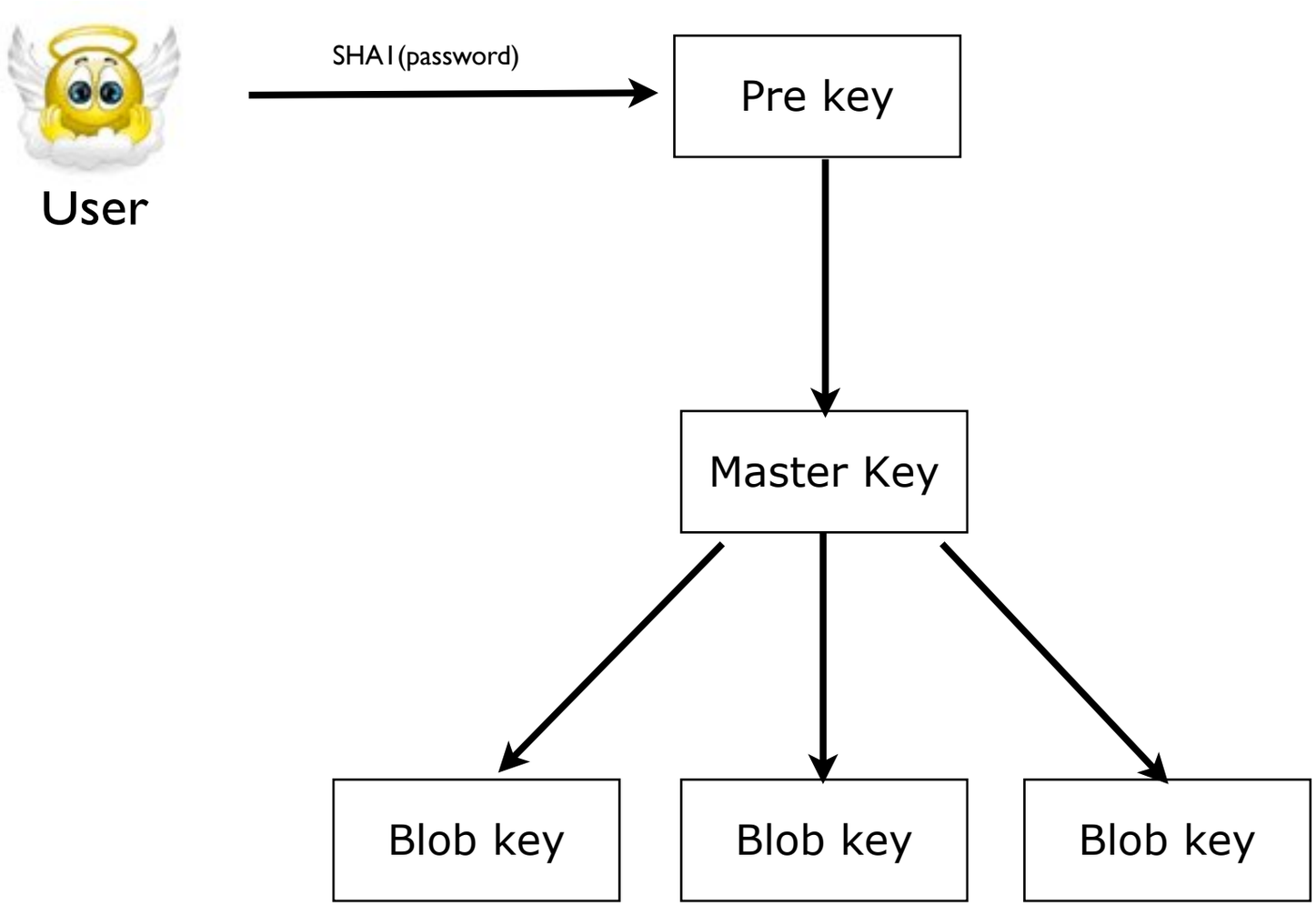
Derivation scheme



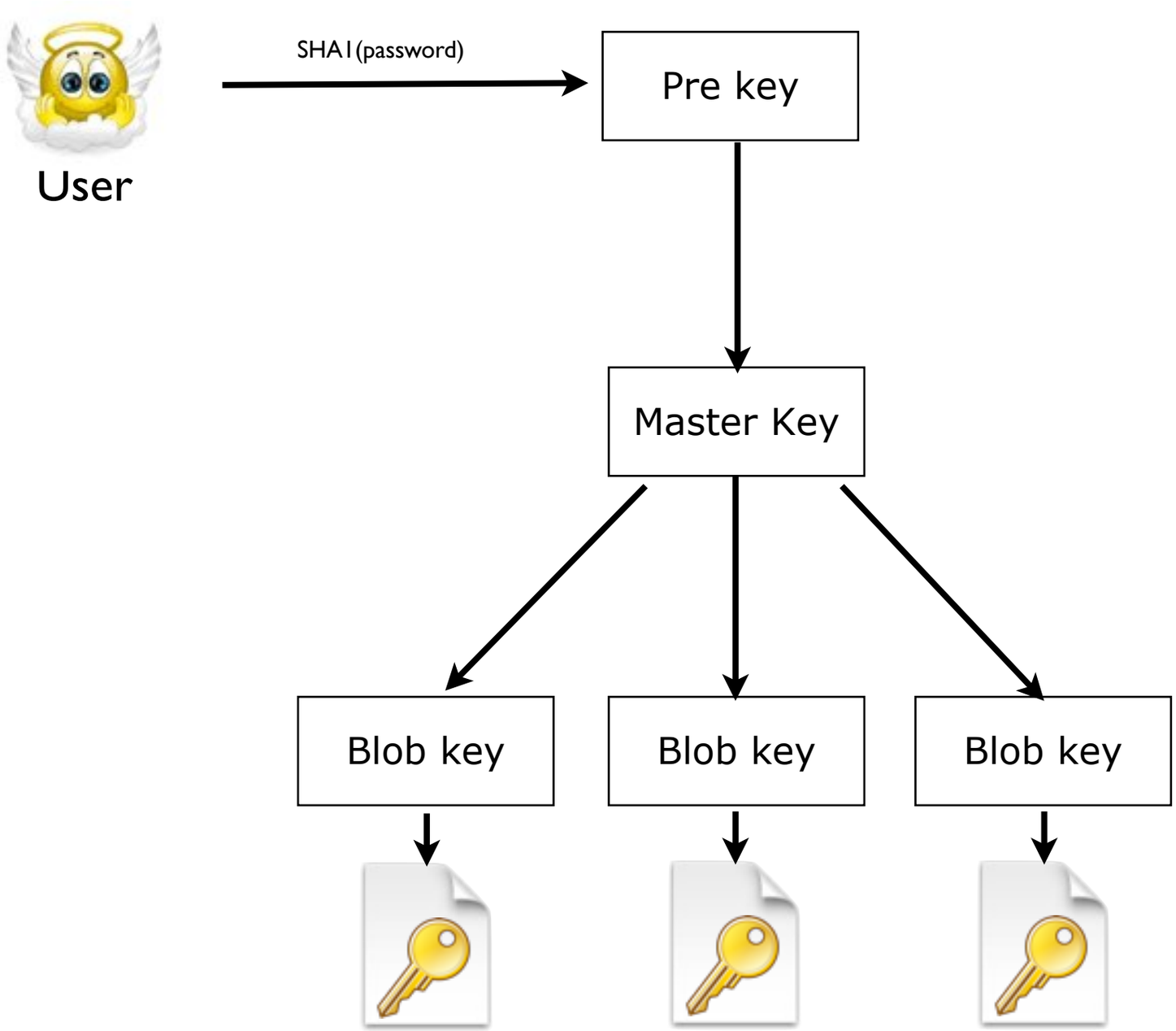
Derivation scheme



Derivation scheme



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        *pbIV;
DWORD       idHashAlgo;
BYTE        *pbSalt;
 BYTE       *pbCipher;
BYTE        *pbHMAC;
```

data blob structure key fields

```
DWORD      cbProviders;
GUID       *arrProviders;
DWORD      cbKeys;
GUID       *arrKeys;
WCHAR      *ppszDataDescr;

DWORD      idCipherAlgo;
BYTE       *pbIV;
DWORD      idHashAlgo;
BYTE       *pbSalt;
 BYTE      *pbCipher;
BYTE       *pbHMAC;
```

Nb of crypto providers

data blob structure key fields

```
DWORD       cbProviders;
GUID        *arrProviders;
DWORD       cbKeys;
GUID        *arrKeys;
WCHAR       *ppszDataDescr;

DWORD       idCipherAlgo;
BYTE        *pbIV;
DWORD       idHashAlgo;
BYTE        *pbSalt;
 BYTE       *pbCipher;
BYTE        *pbHMAC;
```

Crypto providers GUID

data blob structure key fields

```
DWORD       cbProviders;
GUID        *arrProviders;
DWORD       cbKeys;
GUID        *arrKeys;
WCHAR       *ppszDataDescr;

DWORD       idCipherAlgo;
BYTE        *pbIV;
DWORD       idHashAlgo;
BYTE        *pbSalt;
 BYTE       *pbCipher;
BYTE        *pbHMAC;
```

Nb of masters keys

data blob structure key fields

```
DWORD       cbProviders;
GUID        *arrProviders;
DWORD       cbKeys;
GUID        *arrKeys;
WCHAR       *ppszDataDescr;

DWORD       idCipherAlgo;
BYTE        *pbIV;
DWORD       idHashAlgo;
BYTE        *pbSalt;
 BYTE       *pbCipher;
BYTE        *pbHMAC;
```

Masters keys GUID

data blob structure key fields

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

Optional description

data blob structure key fields

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

Encryption algorithm ID

data blob structure key fields

```
DWORD       cbProviders;
GUID        *arrProviders;
DWORD       cbKeys;
GUID        *arrKeys;
WCHAR       *ppszDataDescr;

DWORD       idCipherAlgo;
BYTE        *pbIV;
DWORD       idHashAlgo;
BYTE        *pbSalt;
 BYTE       *pbCipher;
BYTE        *pbHMAC;
```

Initialization vector

data blob structure key fields

```
DWORD       cbProviders;
GUID        *arrProviders;
DWORD       cbKeys;
GUID        *arrKeys;
WCHAR       *ppszDataDescr;

DWORD       idCipherAlgo;
BYTE        *pbIV;
DWORD       idHashAlgo;
BYTE        *pbSalt;
 BYTE       *pbCipher;
BYTE        *pbHMAC;
```

Hash algorithm ID

data blob structure key fields

```
DWORD       cbProviders;
GUID        *arrProviders;
DWORD       cbKeys;
GUID        *arrKeys;
WCHAR       *ppszDataDescr;

DWORD       idCipherAlgo;
BYTE        *pbIV;
DWORD       idHashAlgo;
BYTE        *pbSalt;
BYTE        *pbCipher;
BYTE        *pbHMAC;
```

← Salt generated by DPAPI

data blob structure key fields

```
DWORD       cbProviders;
GUID        *arrProviders;
DWORD       cbKeys;
GUID        *arrKeys;
WCHAR       *ppszDataDescr;

DWORD       idCipherAlgo;
BYTE        *pbIV;
DWORD       idHashAlgo;
BYTE        *pbSalt;
BYTE        *pbCipher;
BYTE        *pbHMAC;
```

Encrypted data

data blob structure key fields

```
DWORD       cbProviders;
GUID        *arrProviders;
DWORD       cbKeys;
GUID        *arrKeys;
WCHAR       *ppszDataDescr;

DWORD       idCipherAlgo;
BYTE        *pbIV;
DWORD       idHashAlgo;
BYTE        *pbSalt;
 BYTE       *pbCipher;
BYTE        *pbHMAC;
```

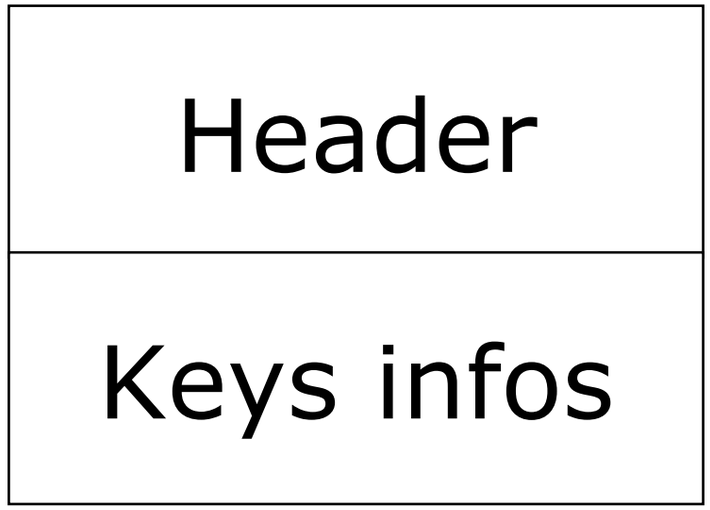
Blob HMAC

Master key structure

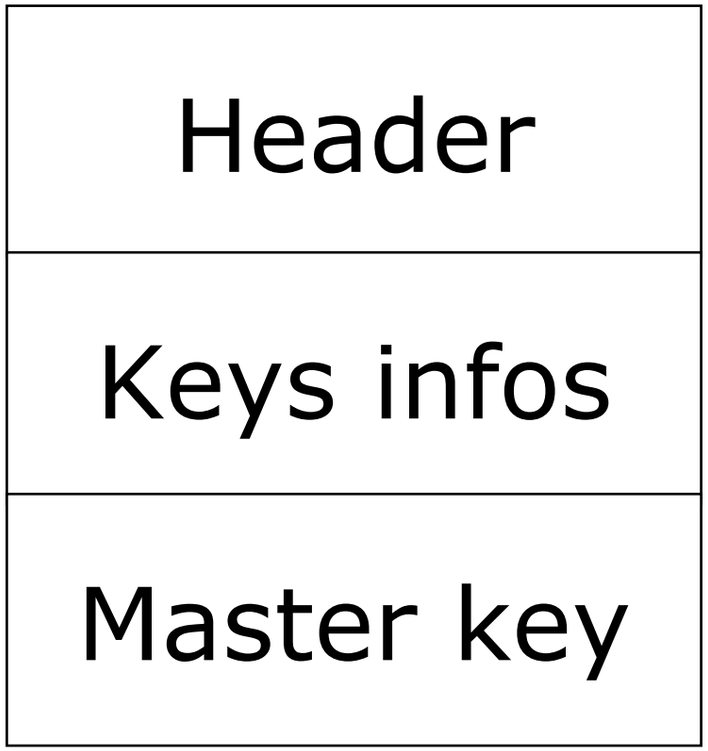
- Store the key used to decrypt blob
- Encrypted with the user password
- Renewed every 3 months

The master key file

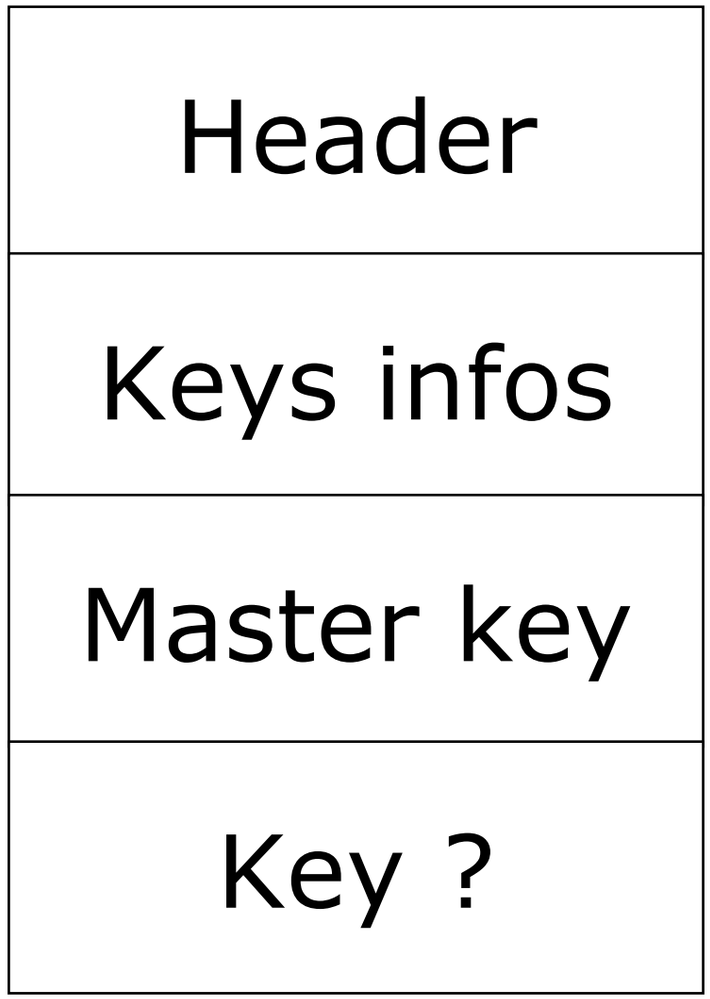
The master key file



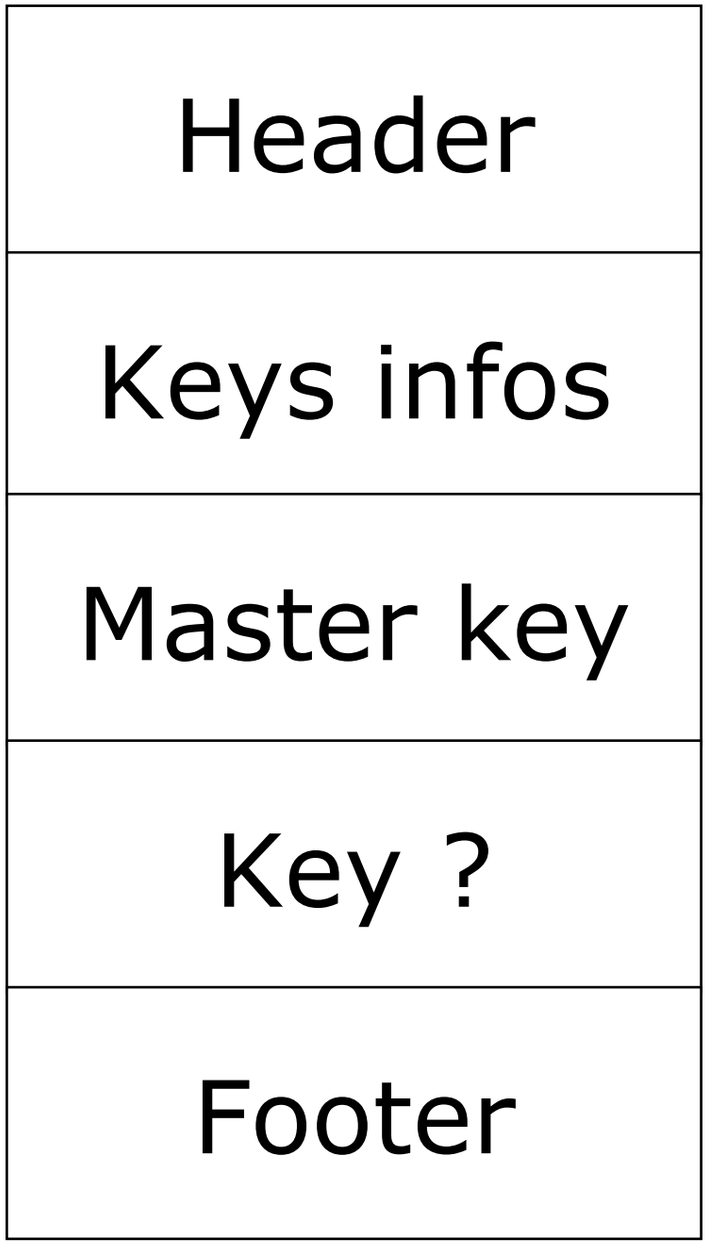
The master key file



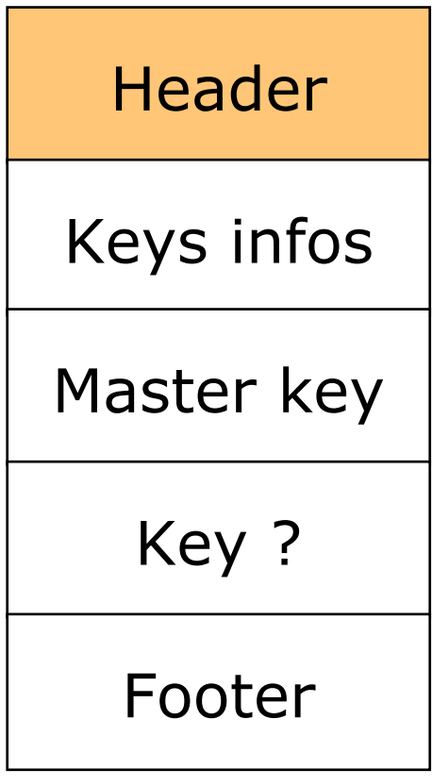
The master key file



The master key file



Header structure



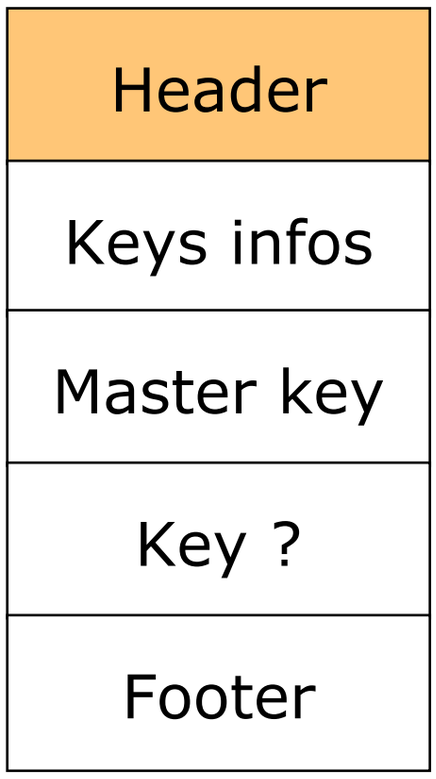
dwVersion;

nullPad1;

szKeyGUID[36];

nullPad2;

Header structure



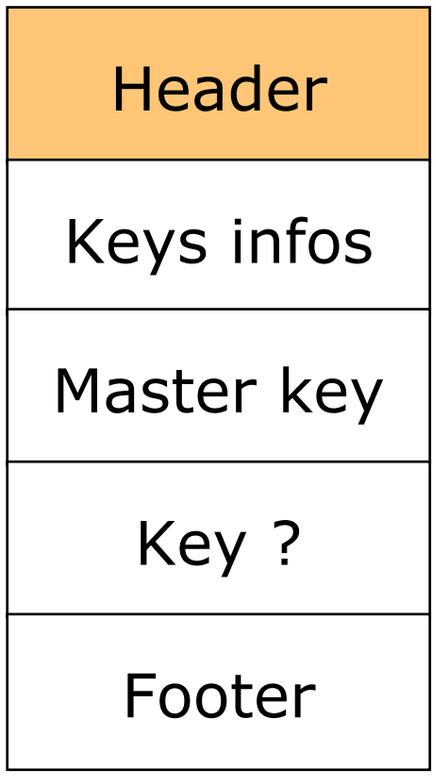
dwVersion; ← File version

nullPad1;

szKeyGUID[36];

nullPad2;

Header structure



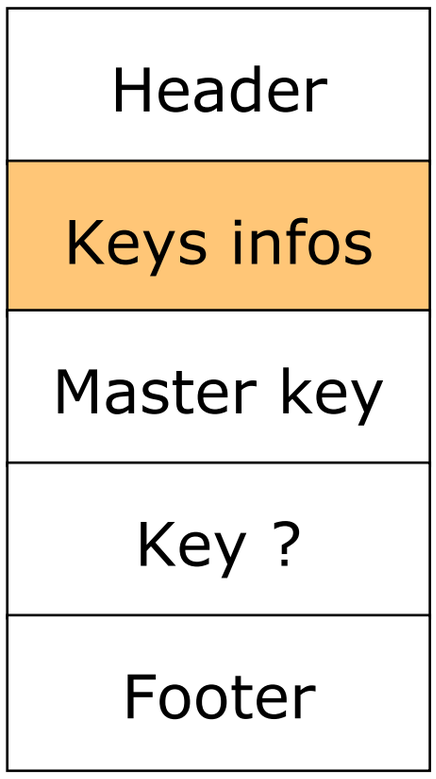
dwVersion;

nullPad1;

szKeyGUID[36]; ← Master key GUID

nullPad2;

Key infos structure



dwUnknown;

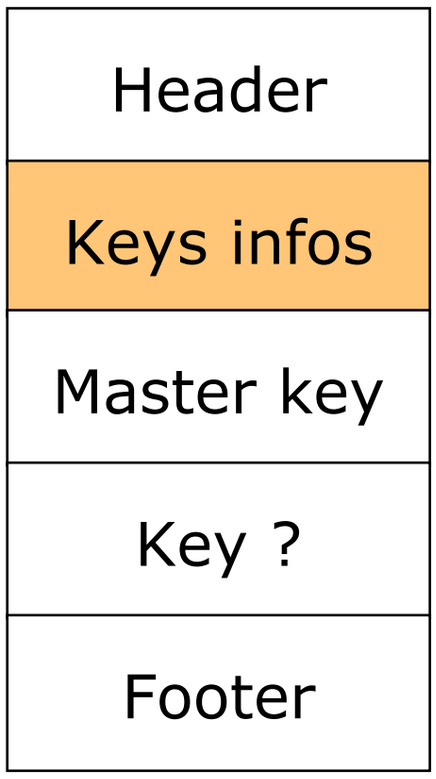
cbMasterKey;

cbMysteryKey;

dwHMACLen;

nullPad3;

Key infos structure



dwUnknown;

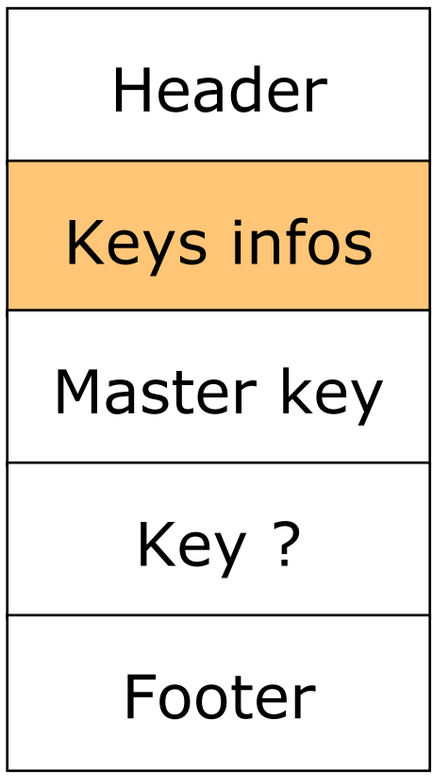
cbMasterKey; ← Master Key struct length

cbMysteryKey;

dwHMACLen;

nullPad3;

Key infos structure



dwUnknown;

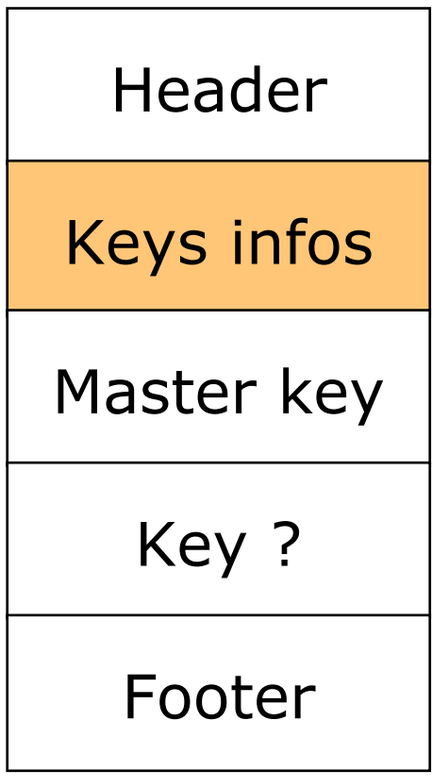
cbMasterKey;

cbMysteryKey; ← Key ? struct length

dwHMACLen;

nullPad3;

Key infos structure



dwUnknown;

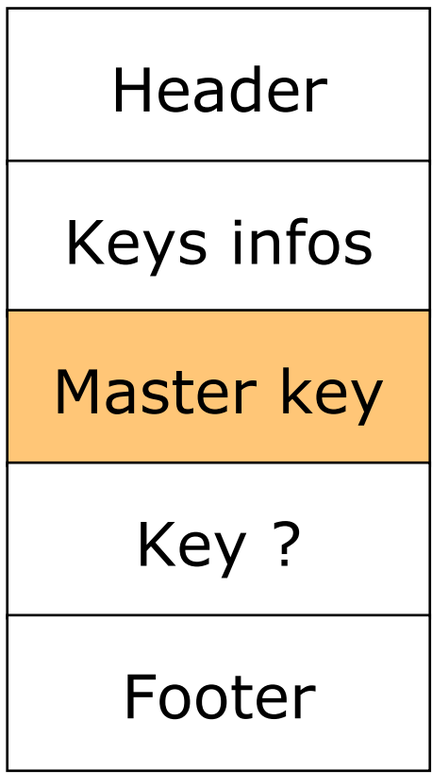
cbMasterKey;

cbMysteryKey;

dwHMACLen; ← HMAC length

nullPad3;

Master key structure



dwMagic;

pbSalt[16];

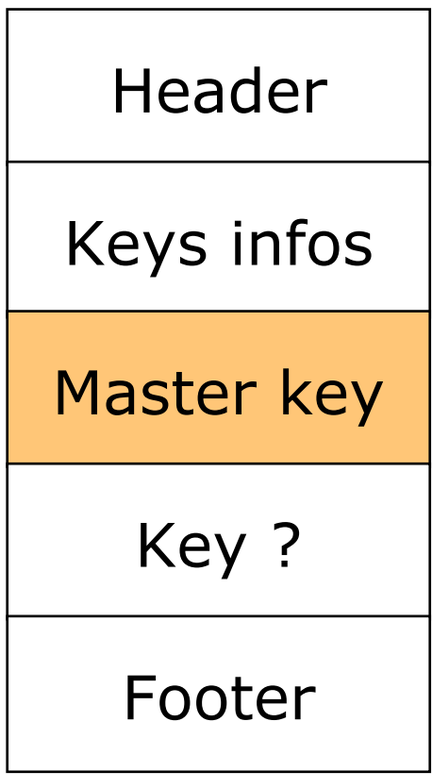
cbIteration;

idMACAlgo;

idCipherAlgo;

pbCipheredKey[];

Master key structure



dwMagic;

pbSalt[16]; ← Key salt

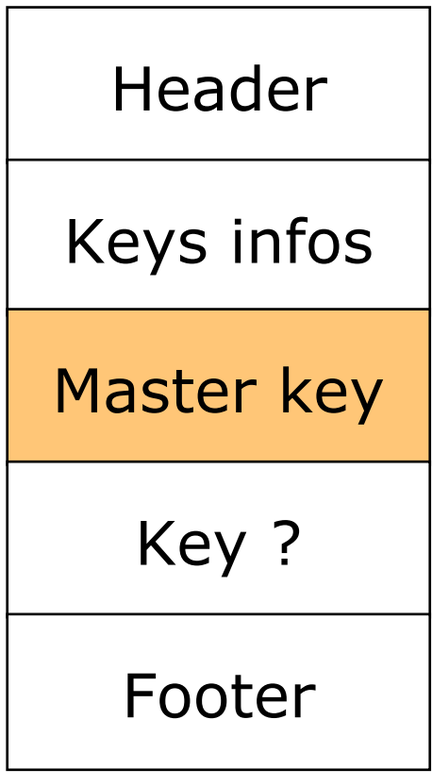
cbIteration;

idMACAlgo;

idCipherAlgo;

pbCipheredKey[];

Master key structure



dwMagic;

pbSalt[16];

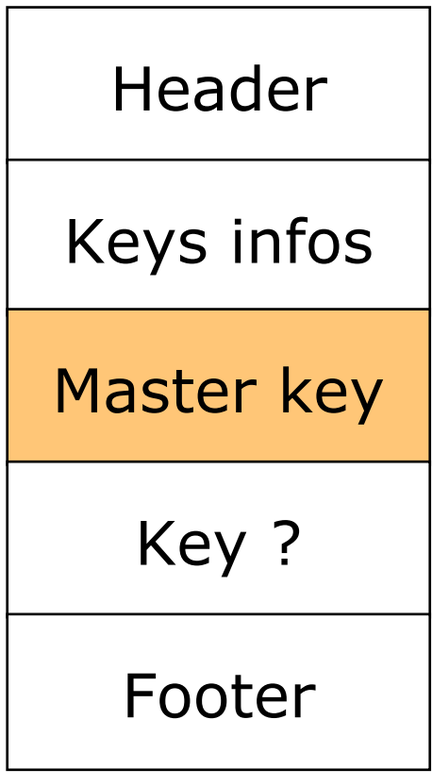
cbIteration; ← PBKDF2 nb rounds

idMACAlgo;

idCipherAlgo;

pbCipheredKey[];

Master key structure



dwMagic;

pbSalt[16];

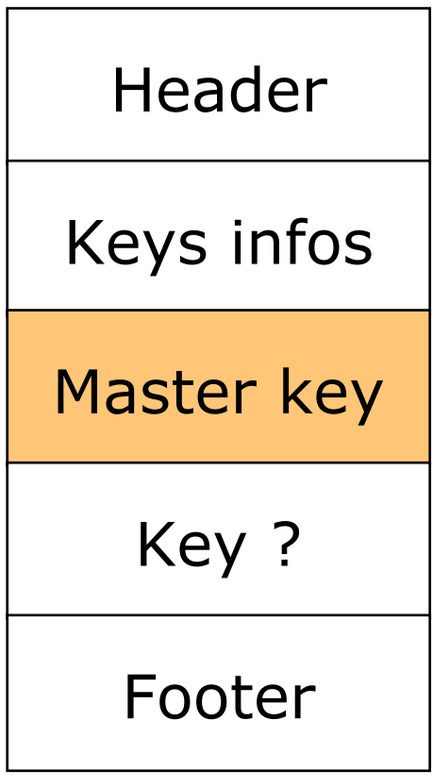
cbIteration;

idMACAlgo; ← HMAC algorithm ID

idCipherAlgo;

pbCipheredKey[];

Master key structure



dwMagic;

pbSalt[16];

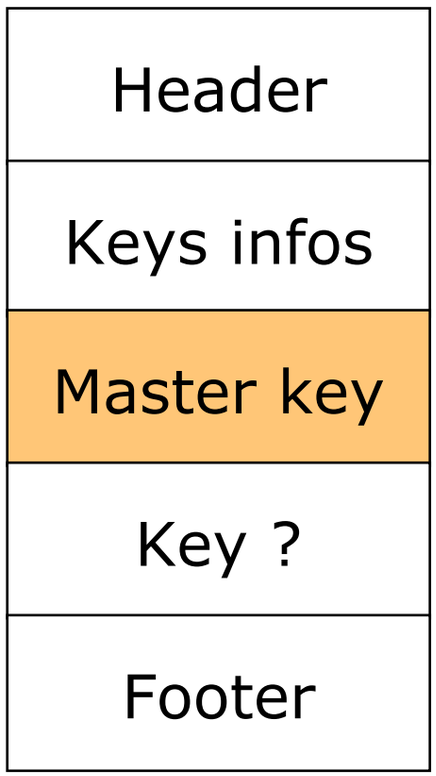
cbIteration;

idMACAlgo;

idCipherAlgo; ← Encryption Algo id

pbCipheredKey[];

Master key structure



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, nblteration)

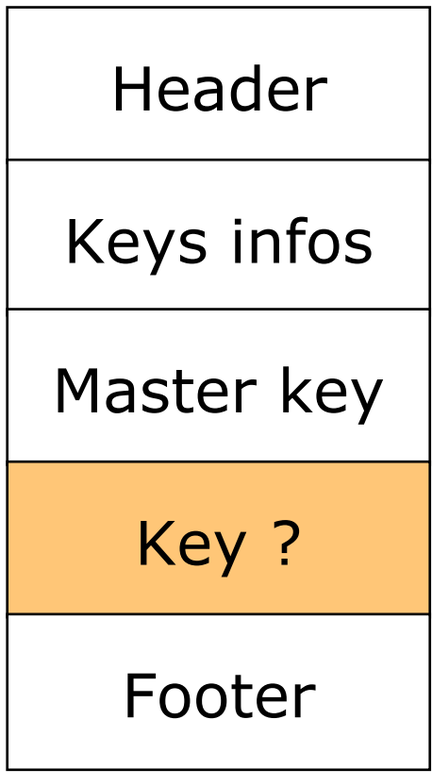
3desKey = pre-key[0 - 23]

3desIV = [24 - 31]

(hmac[0-35], DWORD[36-39], master-key [40-104]) = 3des-cbc(3desKey, iv, encKey)

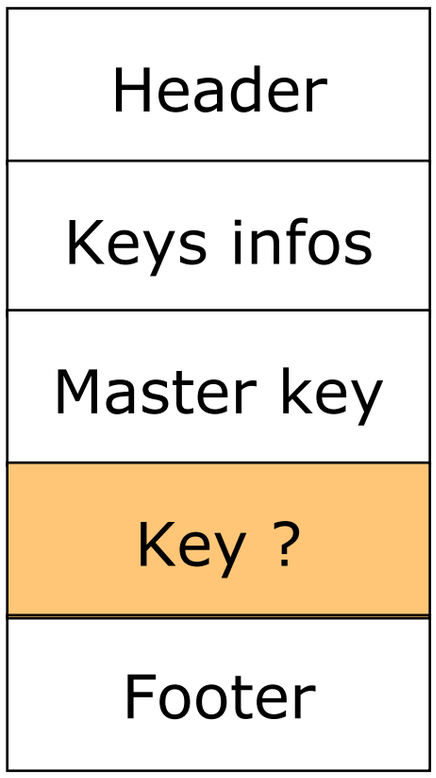
}

key structure



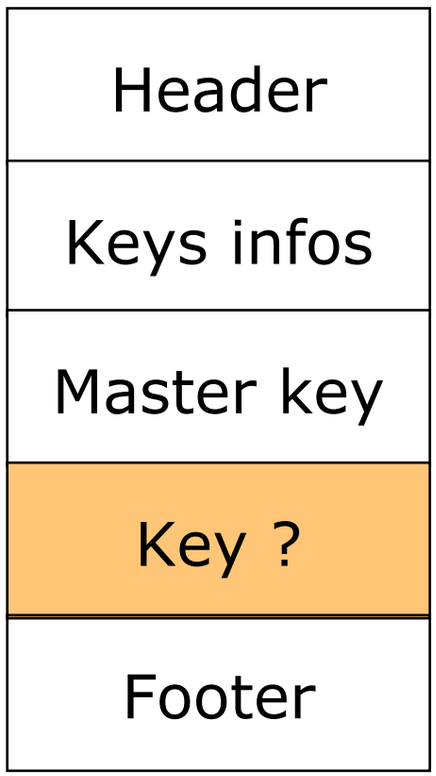
- Seems to have the same structure than the master key
- One round of derivation (XP not Seven)
- 256 bits (half size of the real master-key)

Possible explanation



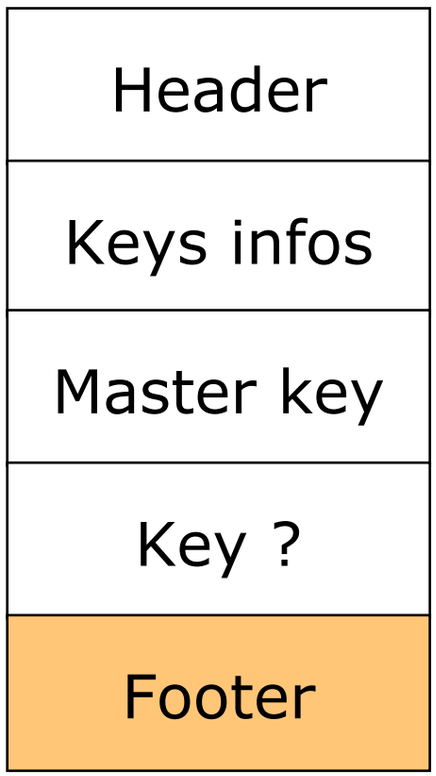
- The documentation state a compatibility mode for windows 2000 exist.
- The registry key to trigger it is unknown
- If we are correct and W2k uses RC4 then the mystery key is possibly a RC4 key (256bits is the correct size).
- PBKDF2 used to compute the IV ??

Possible explanation continued



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

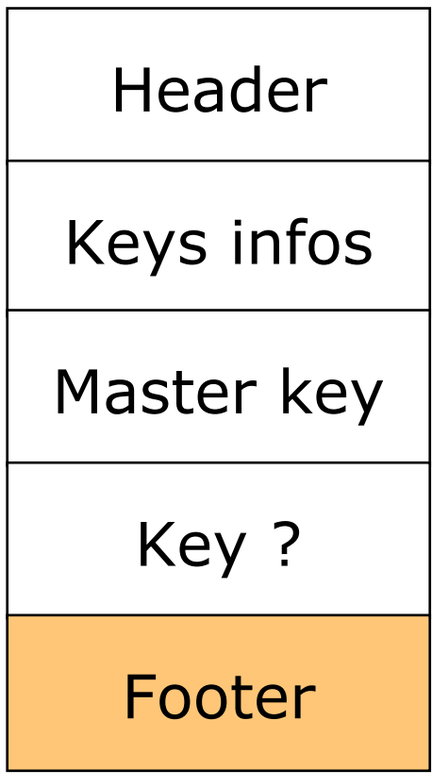
Header structure



dwMagic;

credHist[16];

Header structure



dwMagic;

credHist[16]; ← Password GUID

Differences between windows version

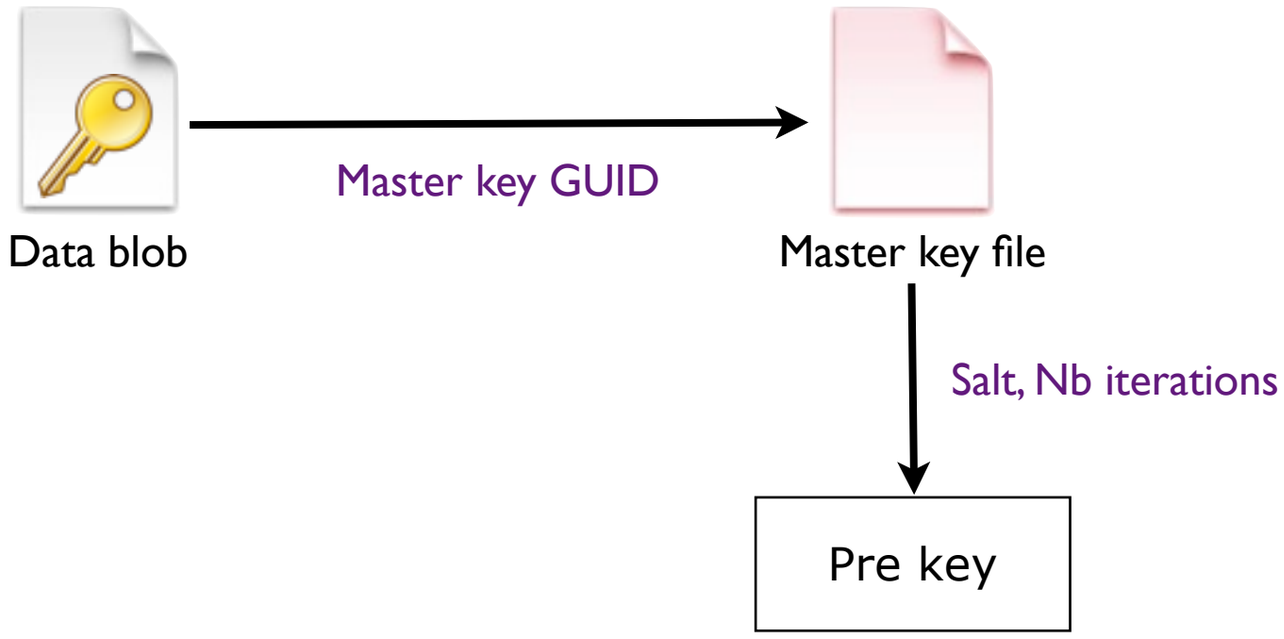
	XP	Vista	Seven
PBKDF2 rounds	4000	24000	Variable (factor ?)
Symmetric algorithm	3DES	3DES	AES
Hash algorithm	SHA1	SHA1	SHA512

Decrypting a blob

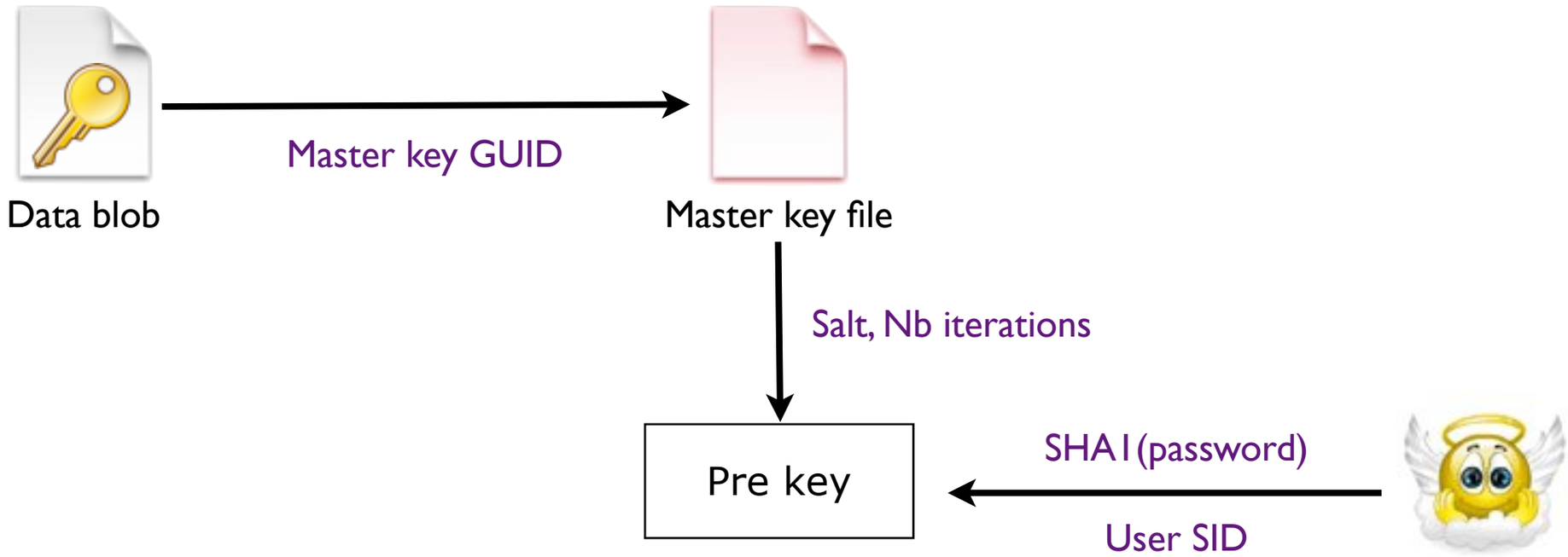
Data blob

Decrypting a blob

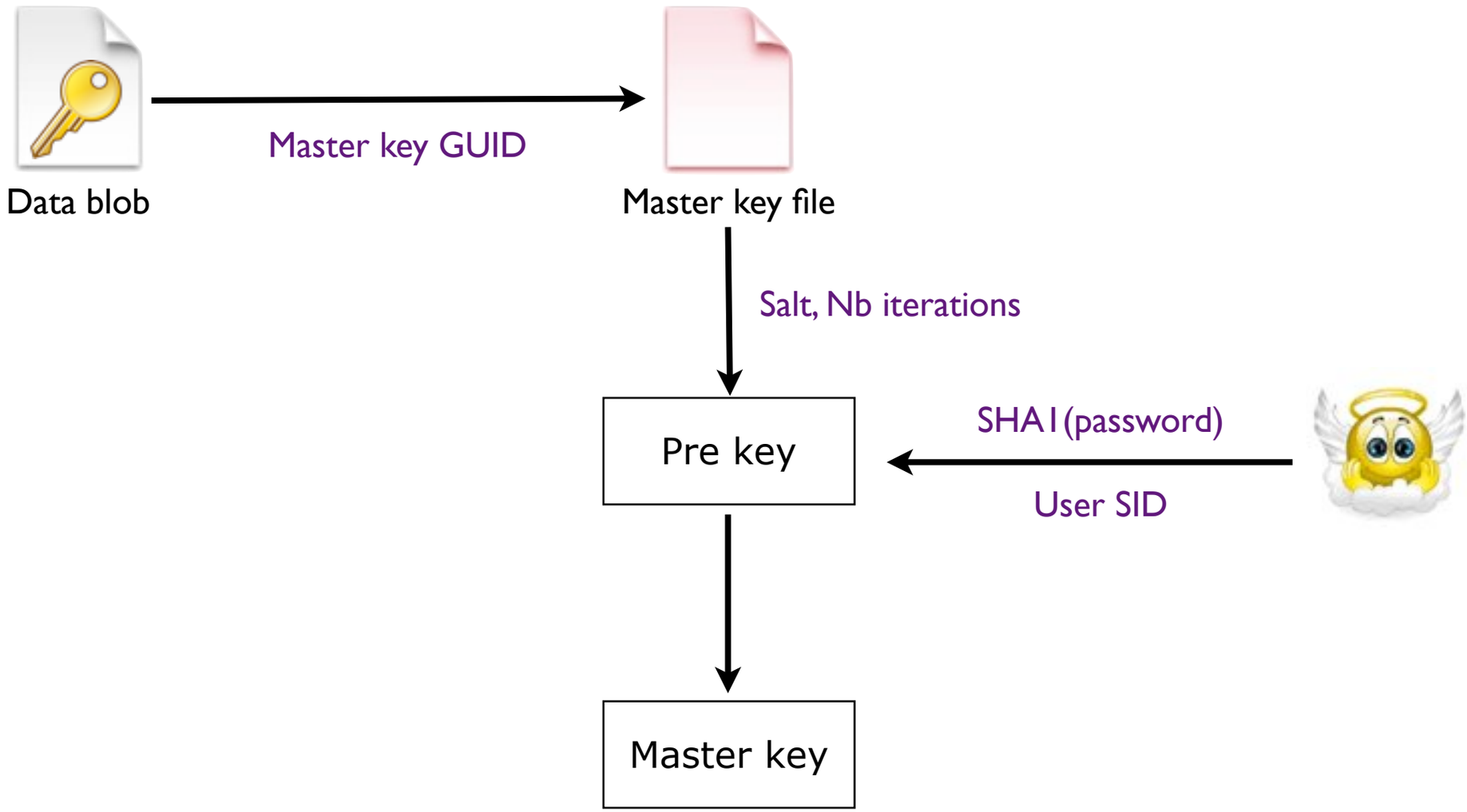
Decrypting a blob



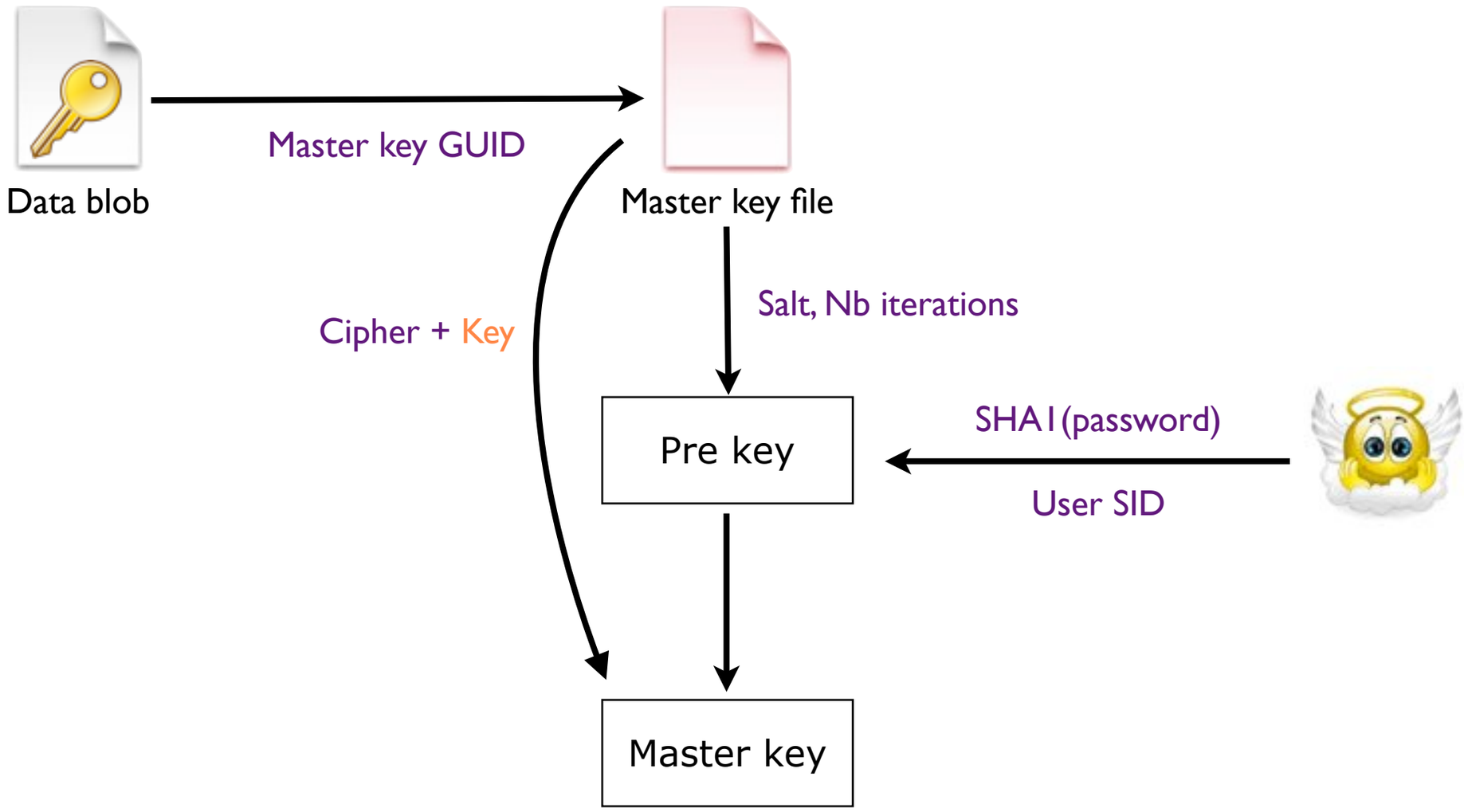
Decrypting a blob



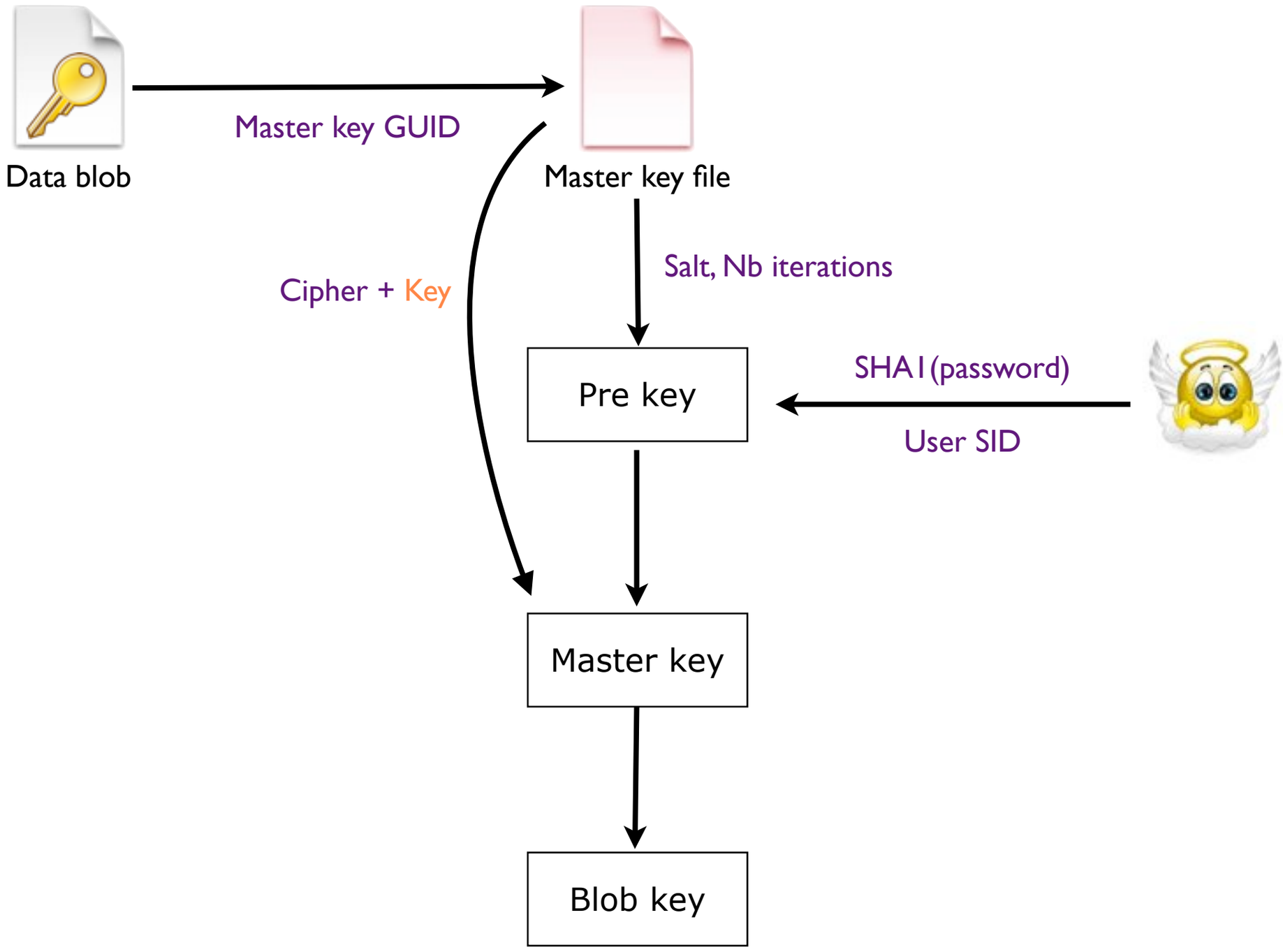
Decrypting a blob



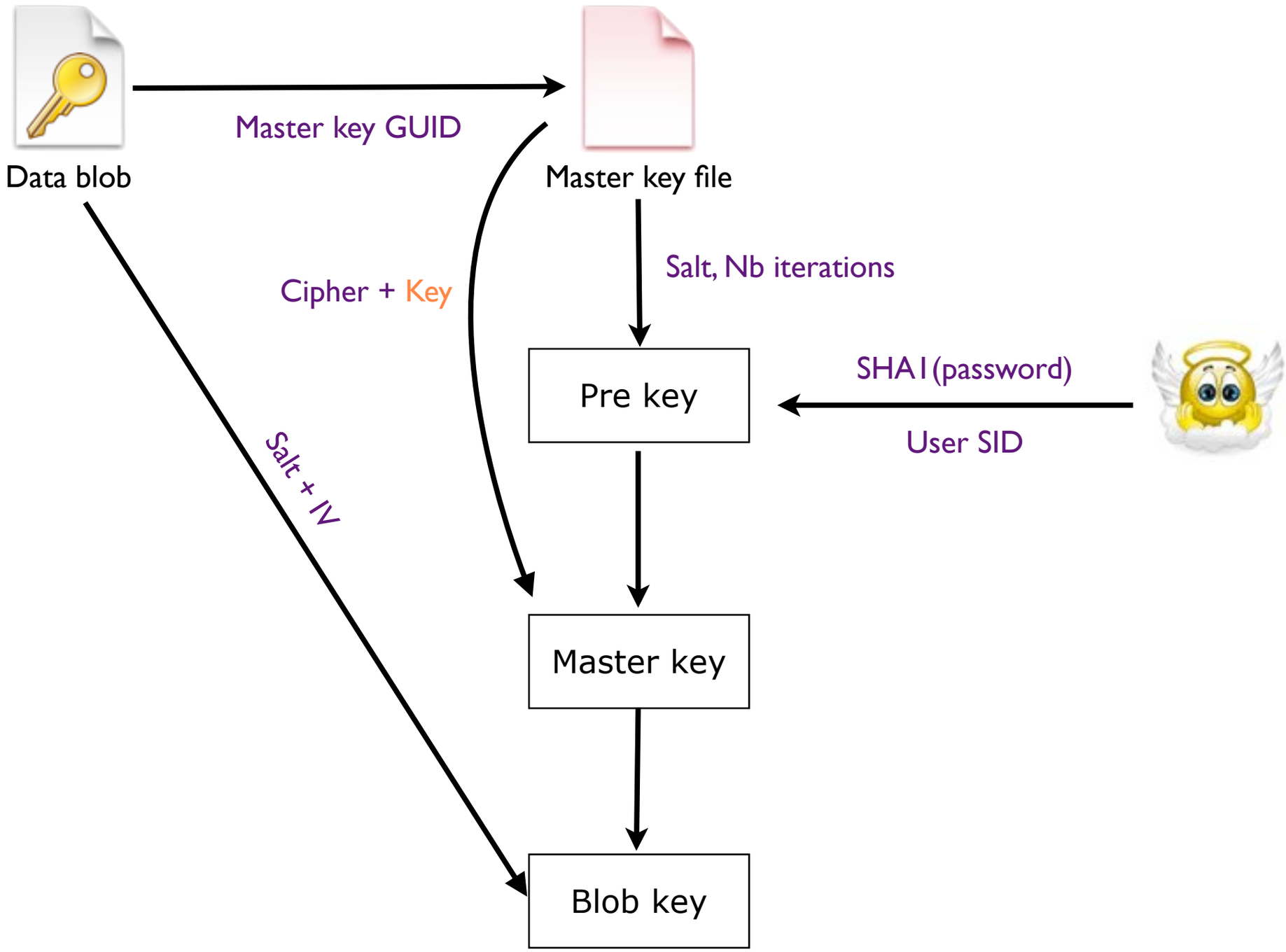
Decrypting a blob



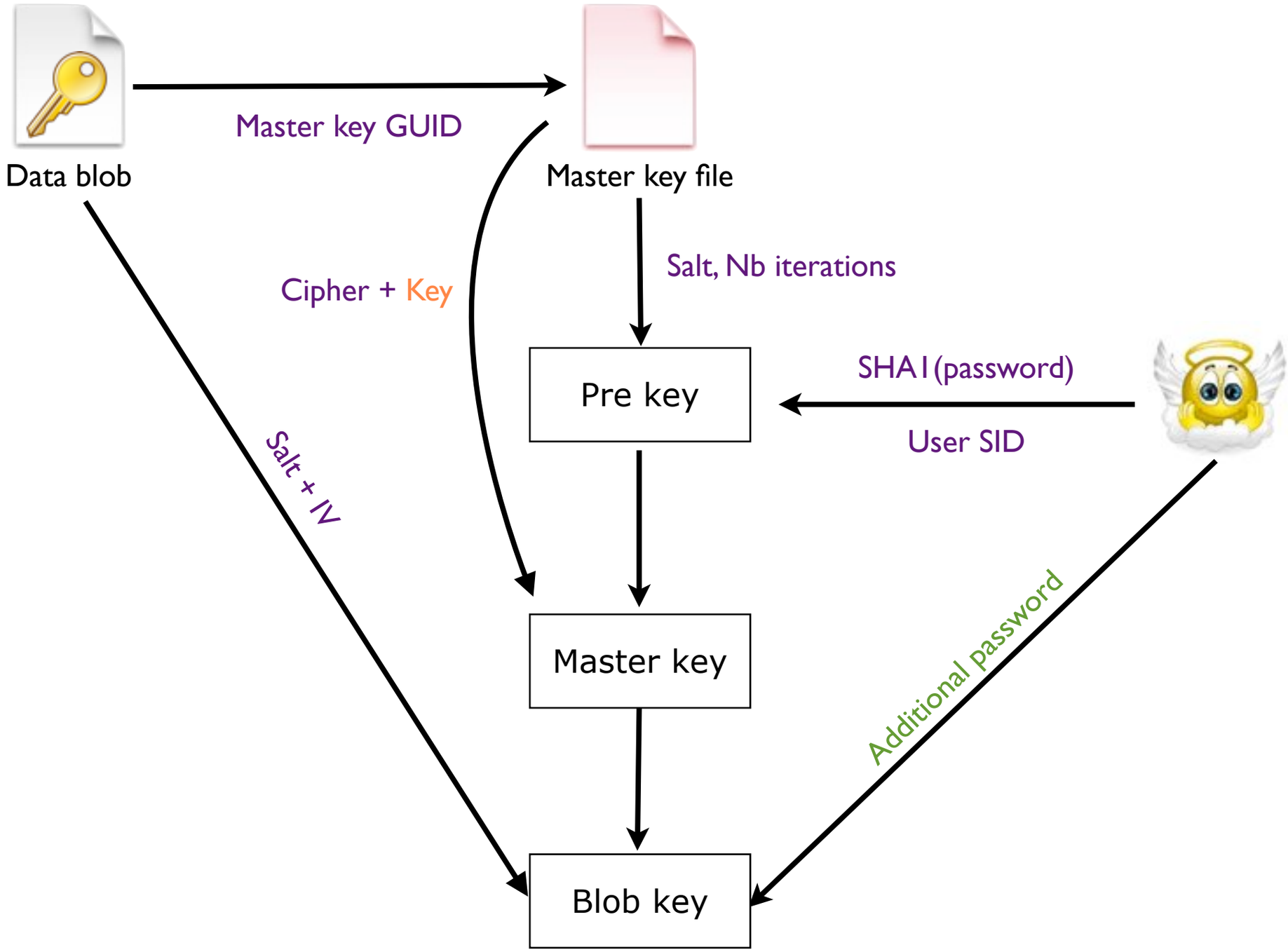
Decrypting a blob



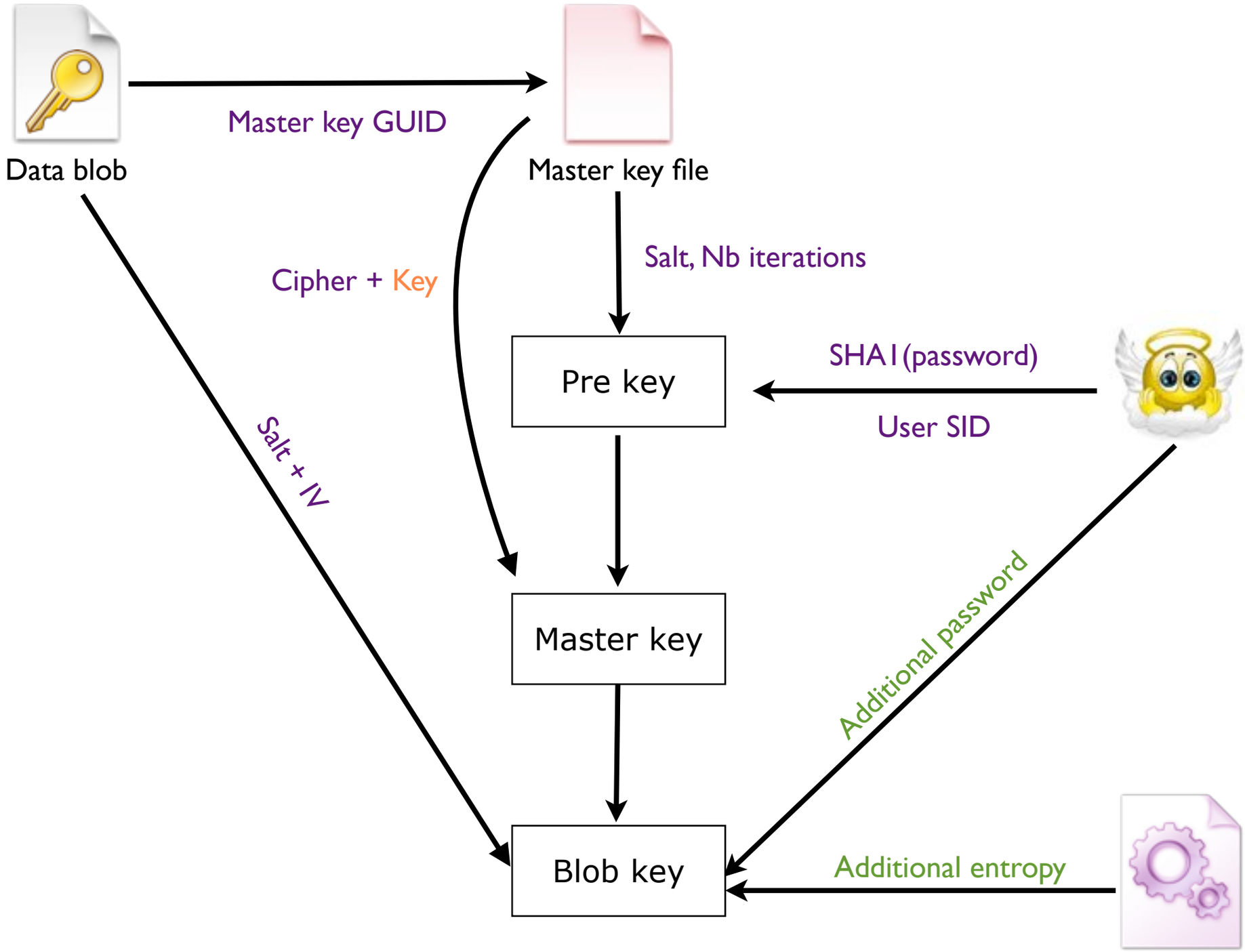
Decrypting a blob



Decrypting a blob



Decrypting a blob



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

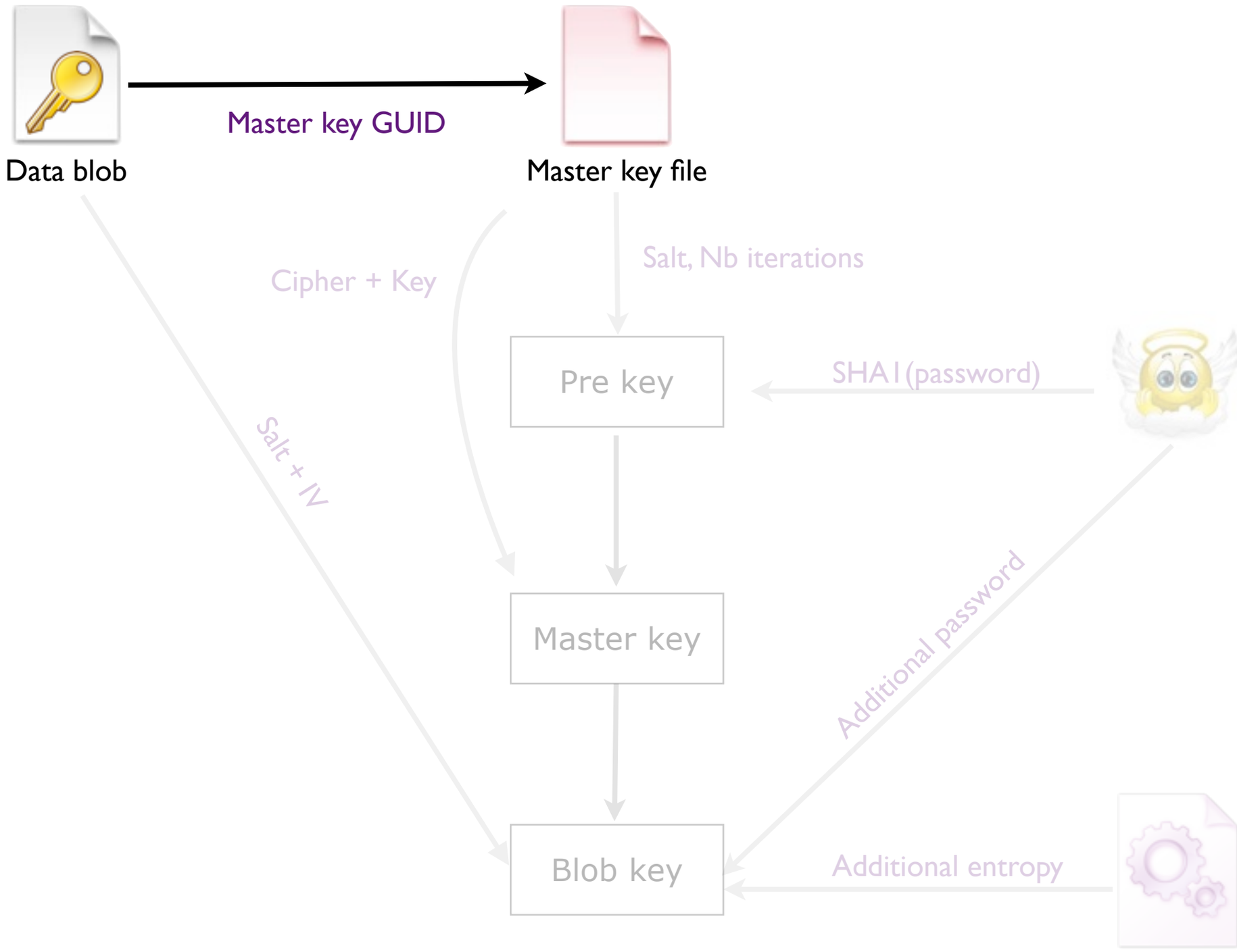
  current time > timestamp

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

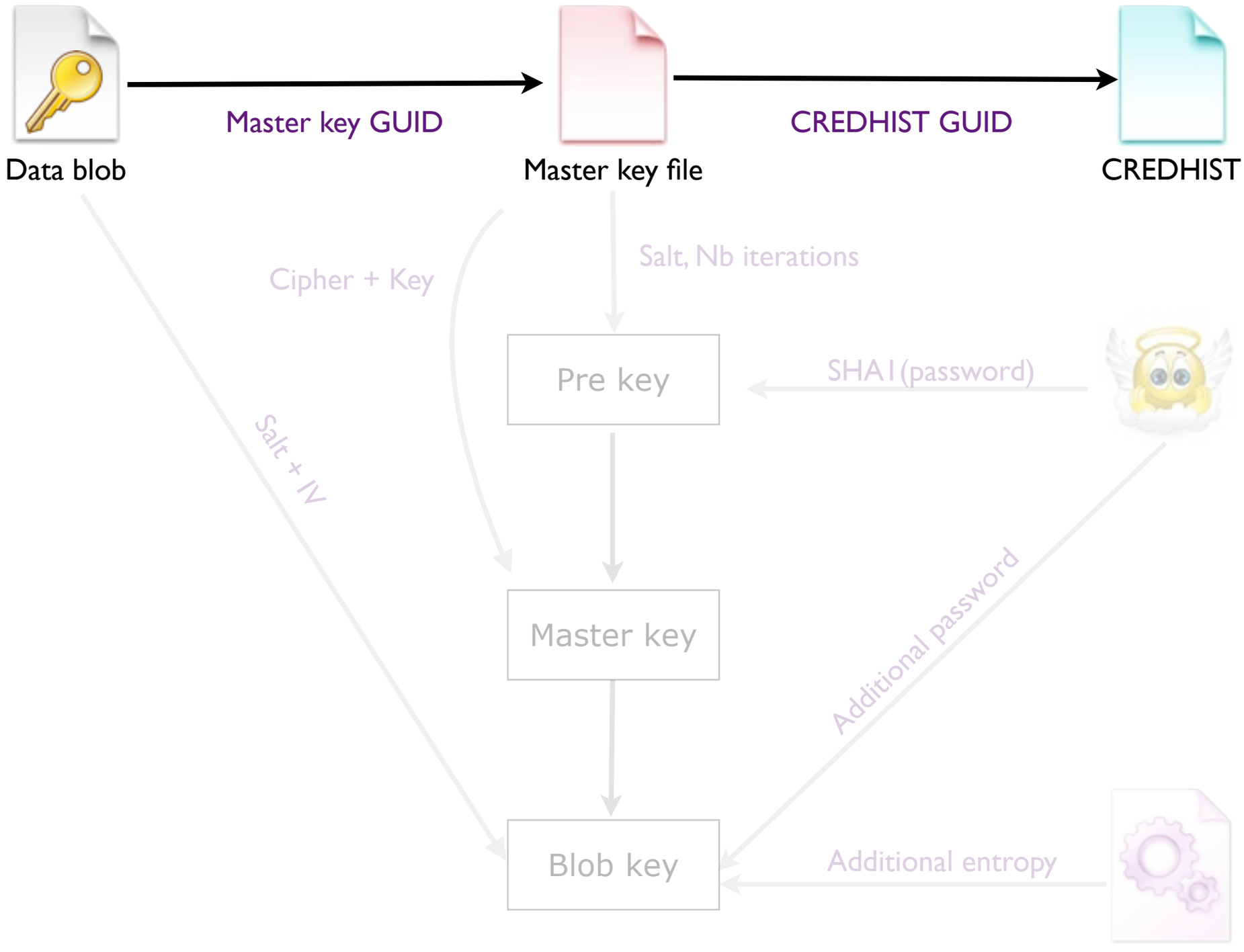
User password renewal

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

Decrypting a blob



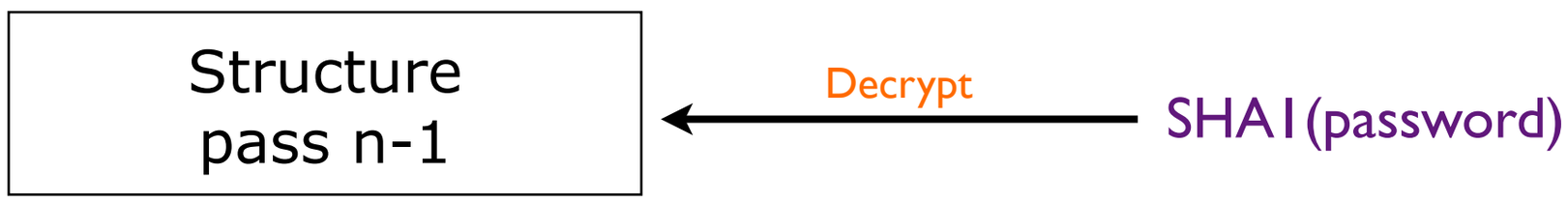
Decrypting a blob



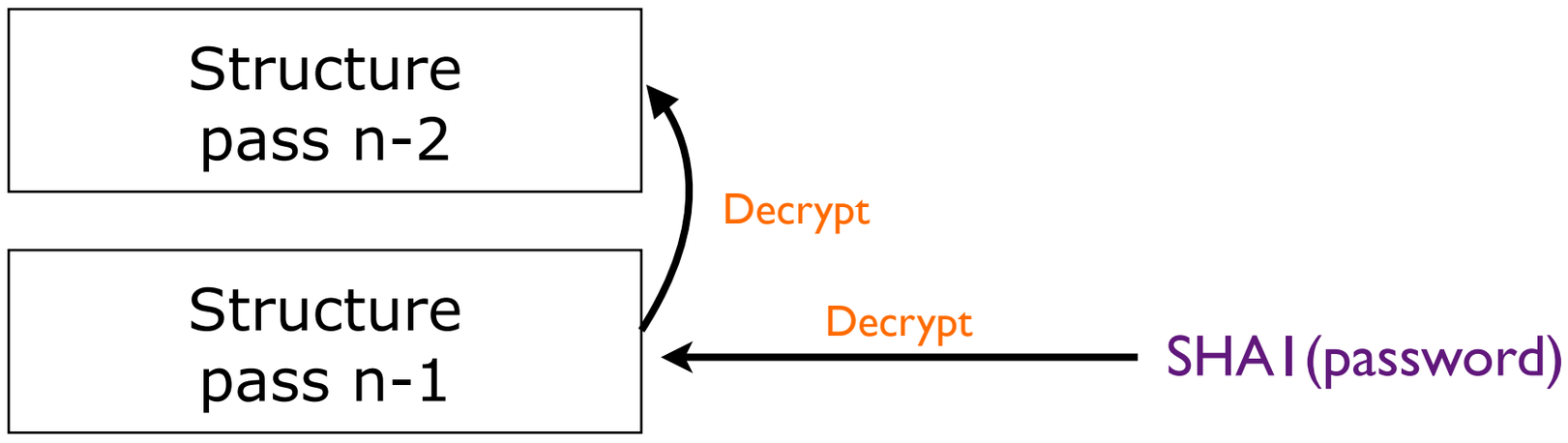
CREDHIST overview

SHA1(password)

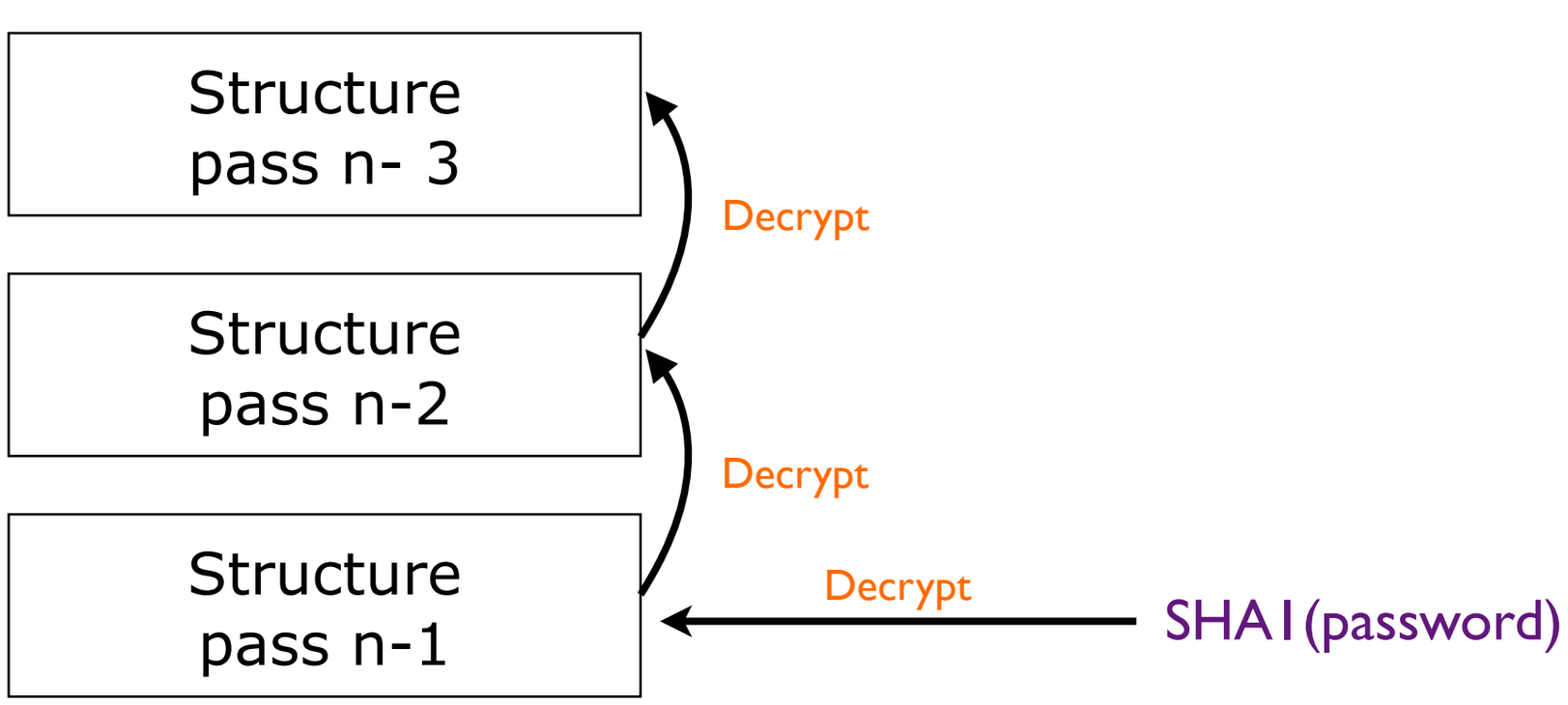
CREDHIST overview



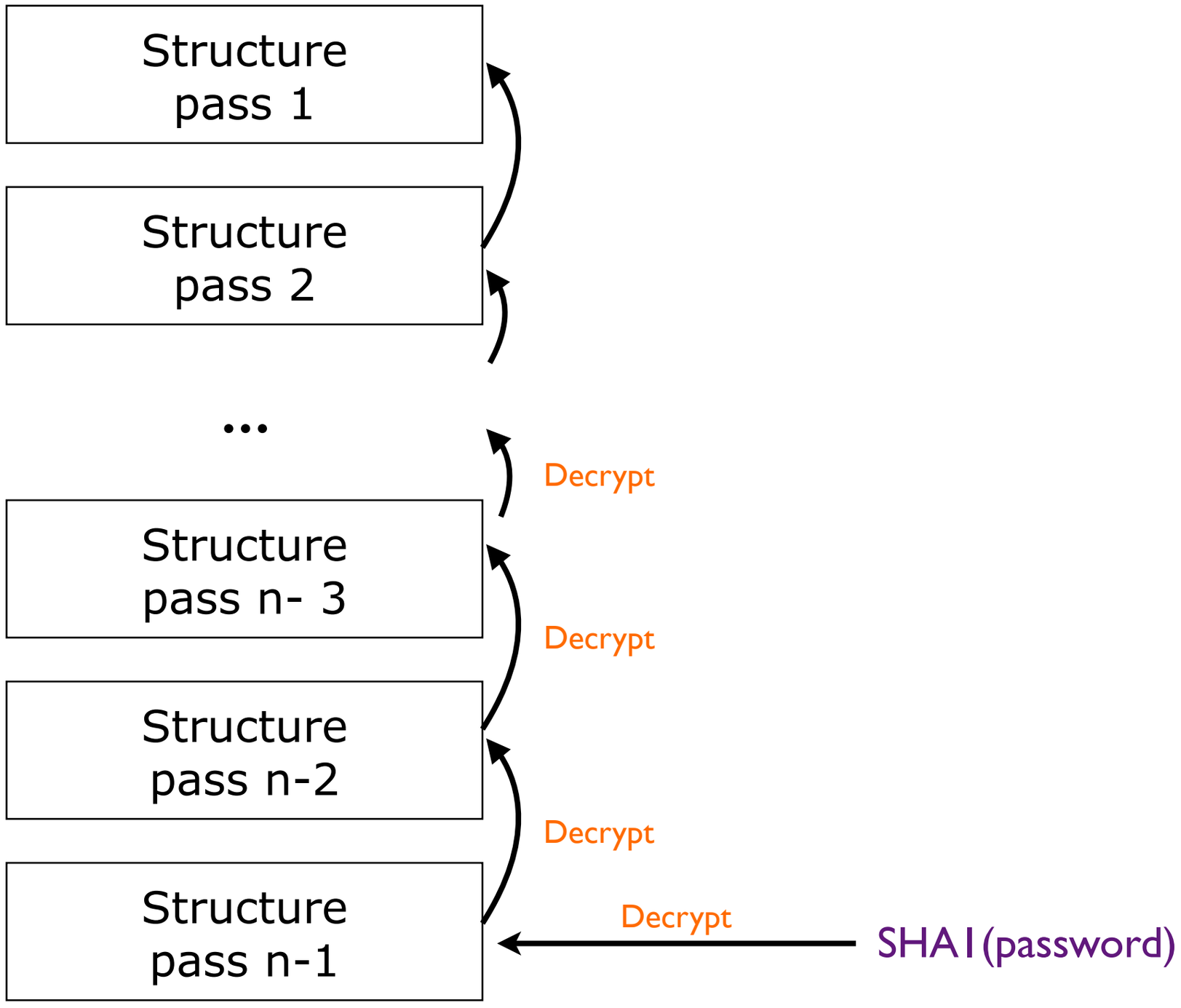
CREDHIST overview



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];

dwAccountID;

bData[28];

bPasswordID[16]

Computer SID

CREDHIST entry structure main fields

idHashAlgo;

dwRounds;

dwCipherAlgo;

bSID[12];

dwComputerSID[3];

dwAccountID;

bData[28];

bPasswordID[16]

Account ID

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

grab a copy from http://dpapick.com

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