Chapter 3: Hashing

Hashing Types.
Hashing Methods.
Salting.
Collisions.
LM and NTLM Hashes (Windows).
Hash Benchmarks.
Message Authentication Codes (MACs).
OTP/HOTP.

Prof Bill Buchanan OBE

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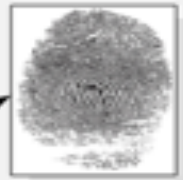
How do we get a finger-print for data?

With a fingerprint we can hopefully tell if Eve has modified any of the data



Solved by Prof Ron Rivest with the MD5 hash signature.

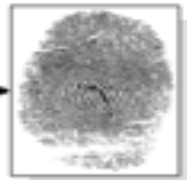
Author: Prof Bill Buchanan

Message Hash

Authentication

MD5 hash algorithm

Hashing Algorithm (MD5)
- 128 bit signature



Message Hash

hello	→	XUFAKrxLKna5cZ2REBfFkg
Hello	→	ixqZU8RhEpaoJ6v4xHgE1w
Hello. How are you?	→	CysDE5j+ZOUbCYZtTdsFiw
Napier	→	j4NXH5Mkrk4j13N1MFXHtg

Base-64

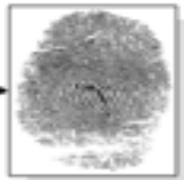
Authentication

hello	→	5D41402ABC4B2A76B9719D911017C592
Hello	→	8B1A9953C4611296A827ABF8C47804D7
Hello. How are you?	→	CC708153987BF9AD833BEBF90239BF0F
Napier	→	8F83571F9324AE4E23D773753055C7B6

Hex

MD5 hash algorithm

Hashing Algorithm (SHA-1)
- 160 bit signature



Message Hash

hello	→	qvTGHdzF6KLavt4PO0gs2a6pQ00=
Hello	→	9/+ei3uy4Jtwk1pdeF4MxdnQq/A=
Hello. How are you?	→	Puh2Am76bhjqE5lbTWtwsqbdFC8=
Napier	→	v4GxNaVod2b09GR2Tqw4yopOuro=

Base-64

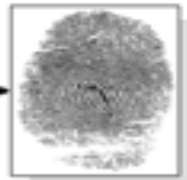
Authentication

hello	→	AAF4C61DDCC5E8A2DABEDE0F3B482CD9AEA9434D
Hello	→	F7FF9E8B7BB2E09B70935A5D785E0CC5D9D0ABF0
Hello. How are you?	→	3EE876026EFA6E18EA13995B4D6370B2A6DD142F
Napier	→	BF81B135A5687766F4F464764EAC38CA8A4EBABA

Hex

SHA-1 hash algorithm

Hashing Algorithm (MD5)
- 128 bit signature



Security and mobility are two of the most important issues on the Internet, as they will allow users to secure their data transmissions, and also break their link with physical connections.

F94FBED3DAE05D223E6B963B9076C4EC

+U++09rgXSI+a5Y7kHbE7A==

Base-64

Security and mobility are two of the mast important issues on the Internet, as they will allow users to secure their data transmissions, and also break their link their physical connections.

8A8BDC3FF80A01917D0432800201CFBF

iovcP/gKAZF9BDKAAgHPvw==

Hex

Message Hash

Authentication

MD5 hash algorithm

OpenSSL

```
root@kali:~# echo -n "hello" | openssl md5
(stdin)= 5d41402abc4b2a76b9719d911017c592

root@kali:~# echo -n "hello" | md5sum
5d41402abc4b2a76b9719d911017c592  -

root@kali:~# openssl md5 pw
MD5(pw)= 859b6a9be3b45262c4414bd1696ba91b

root@kali:~# md5sum pw
859b6a9be3b45262c4414bd1696ba91b  pw
```

Hash methods supported:

md2 md4 md5 rmd160 sha
sha1

Files/folders

Hashing Algorithm (MD5) - 128 bit signature

Hash signature

- Hash signatures are used to gain a signature for files, so that they can be checked if they have been changed.

```
[Path] / filename                    MD 5 sum
-----------------------------------------------------------------
[C:\Windows\System32\]
12520437.cpx                         0a0feb9eb28bde8cd835716343b03b14
12520850.cpx                         d69ae057cd82d04ee7d311809abefb2a
8point1.wav                          beab165fa58ec5253185f32e124685d5
aaclient.dll                         ad45dedfdcf69a28cbaf6a2ca84b5f1e
AC3ACM.acm                           59683d1e4cd0b1ad6ae32e1d627ae25f
Ac3audio.ax                          4b87d889edf278e5fa223734a9bbe79a
ac3filter.cpl                        10b27174d46094984e7a05f3c36acd2a
accessibilitycpl.dll                 ac4cecc86eeb8e1cc2e9fe022cff3ac1
ACCTRES.dll                          58f57f2f2133a2a77607c8ccc9a30f73
acledit.dll                          0bcee3f36752213d1b09d18e69383898
 . . .
ZSHP1020.CHM                         c671ec
ZSHP1020.EXE                         96e45a
ZSHP1020.HLP                         a07693
ZSPOOL.DLL                           fae332
ZTAG.DLL                             7ca836
ZTAG32.DLL                           27b026
```

```
[Path] / filename                    MD 5 sum
-----------------------------------------------------------------
[C:\Windows\system32\]
12520437.cpx                         Cg/rnrKl3c2YNXFjQ7A7FA==
12520850.cpx                         1prgV82C0E7n0xGAmr77Kg==
8point1.wav                          vqsWX6WOxSUxhfMuEkaF1Q==
aaclient.dll                         rUXe39z2mijLr2psqEtfHg==
AC3ACM.acm                           WWg9HkzQsa1q4y4drnriXw==
Ac3audio.ax                          S4fYie3yeCX6IjcOqbvnmg==
```

Message Hash

Authentication

MD5 hash algorithm

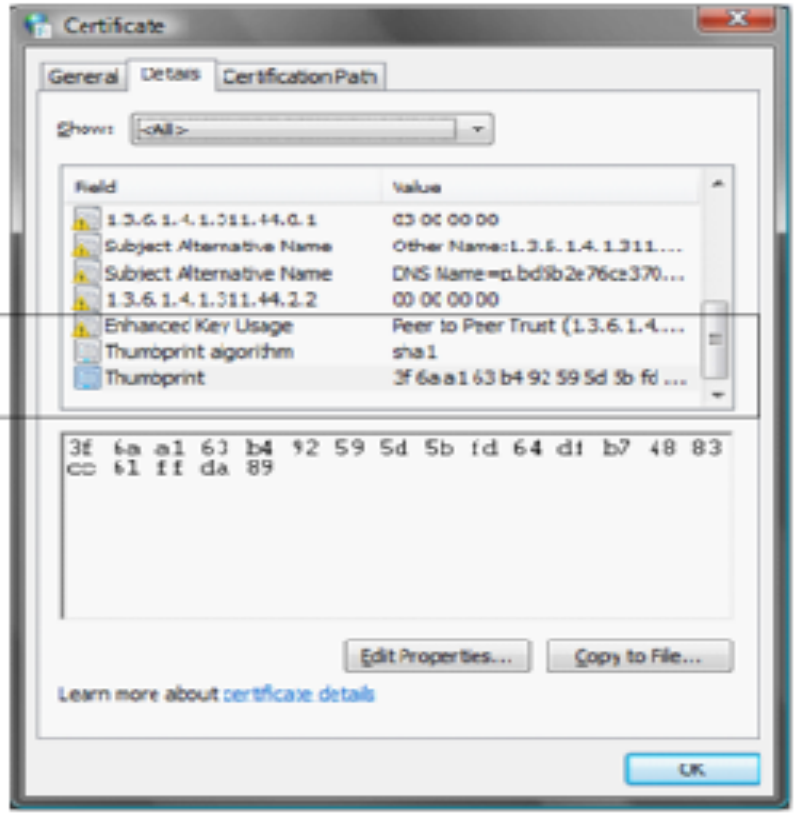
Files/folders

Hashing Algorithm (MD5) - 128 bit signature

Hash signature

- Hash signatures are used to identify that a file/certificate has not been changed.

Bob



The digital certificate has an SHA-1 hash thumbprint (3f6a...89) which will be checked, and if the thumbprint is different, the certificate will be invalid.

Message Hash

Authentication

Author: Prof Bill Buchanan

MD5 hash algorithm

One-way hash

- Hashes are used for digital fingerprints (see the next unit) and for secure password storage.
- Typical methods are NT hash, MD4, MD5, and SHA-1.

Windows login/ authentication

mypass → NT hash (MD4) → fa1bfa14fa13fa12fa10fa1ffa14fa12

NT-password hash for Windows NT, XP and Vista

Cisco password storage (MD5)

mypass →

MD5 encoded password →

```
# config t
(config)# enable secret test

Current configuration : 542 bytes
!
version 12.1
no service single-slot-reload-enable
service timestamps debug uptime
service timestamps log uptime
no service password-encryption
!
hostname Router
!
enable secret 5 $1$/Nwk$knsEQYxZVenGjWOGj/TGk0
```

One-way hash

- Hashing suffers from dictionary attacks, thus it is important that any passwords are not standard words, such as to change **password** for **pA55wOrd**.

Windows login/ authentication

mypass → NT hash (MD4) → fa1bfa14fa13fa12fa10fa1ffa14fa12

NT-password hash for Windows NT, XP and Vista

Hashing suffers from **dictionary attacks** where the signatures of well know words are stored in a table, and the intruders does a lookup on this

mypast	cffahd13fa12fa10fgffa1ffa14fa144
mypass	fa1bfa14fa13fa12fa10fa1ffa14fa12
mypose	ff12189043210954deffff0123444512d

test1	aabbfce023215546dfeddd0101001cd

Risk 4: One Password Fits All

Edinburgh Napier UNIVERSITY

Adobe

150 million accounts compromised

#	Count	Ciphertext	Plaintext
1.	1911938	EQ7fIpT7i/Q=	123456
2.	446162	j9p+HWtWWT86aMjgZFLzYg==	123456789
3.	345834	L8qbHD3jl3jioXGbCatH3W==	password
4.	211659	8B4eEX+b2xLioxG6CaLH3w==	adobe123
5.	201580	j9p+HWtWWT/ioxG6CaLH3w==	12345678
6.	130832	Sdjv7zCI2ws=	qwerty
7.	124253	dQ:0zsWPYvQ=	1234567
8.	113884	7LqY2KVeq3I=	111111
9.	83411	PMDTbPQLZxu03SwrFUvYGA==	photoshop
10.	82694	e6MPXQ5G6a8=	123123

TJ maxx Marshalls

47 million accounts

LinkedIn

6.5 million accounts (June 2013)

Windows Live

One account hack … leads to others

1 million accounts – in plain text. 77 million compromised

Dropbox compromised 2013

citigroup

200,000 client accounts

Brute Force - How many hash codes?

- 7 digit password with [a-z] … how many?
  - Ans:
  - Time to crack - 100 billion per second:
- 7 digit with [a-zA-z] … how many?
  - Ans:
  - Time to crack – 100 billion per second:
- 7 digit with [a-zA-z!@#$%^&*()] … how many?
  - Ans:
  - Time to crack – 100 billion per second:

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LM Hash

LM Hash. LM Hash is used in many version of Windows to store user passwords that are fewer than 15 characters long.

SHA-3

SHA-3. SHA-3 was known as Keccak and is a hash function designed by Guido Bertoni, Joan Daemen, Michaël Peeters, and Gilles Van Assche. MD5 and SHA-0 have been shown to be susceptible to attacks, along with theoretical attacks on SHA-1. NIST thus defined there was a need for a new hashing method which did not use the existing methods for hashing, and setup a competition for competing algorithms. In October 2012, Keccak won the NIST hash function competition, and is proposed as the SHA-3 standard.

Tiger

Bcrypt

Bcrypt. This creates a hash value which has salt.

RIPEMD

RIPEMD (RACE Integrity Primitives Evaluation Message Digest) and GOST. RIPEM160. RIPEMD is a 128-bit, 160-bit, 256-bit or 320-bit cryptographic hash function, and was created by Hans Dobbertin, Antoon Bosselaers and Bart Preneel. It is used on TrueCrypt, and is open source. The 160-bit version is seen as an alternative to SHA-1, and is part of ISO/IEC 10118

Tiger. Tiger is a 192-bit hash function, and was designed by Ross Anderson and Eli Biham in 1995. It is often used by clients within Gnutella file sharing networks, and does not suffer from known attacks on MD5 and SHA-0/SHA-1. Tiger2 is an addition, in which the message is padded with a byte of 0x80 (in a similar way to MD4, MD5 and SHA), whereas in Tiger it is 0x01. Otherwise the two methods are the same in their operation.

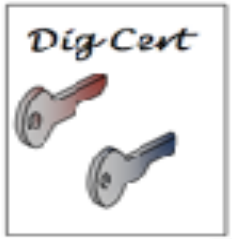
Author: Prof Bill Buchanan

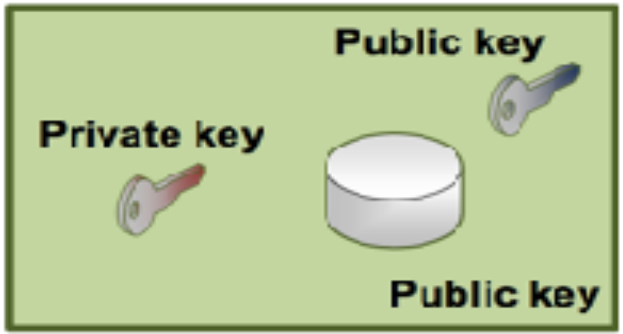
Murmur

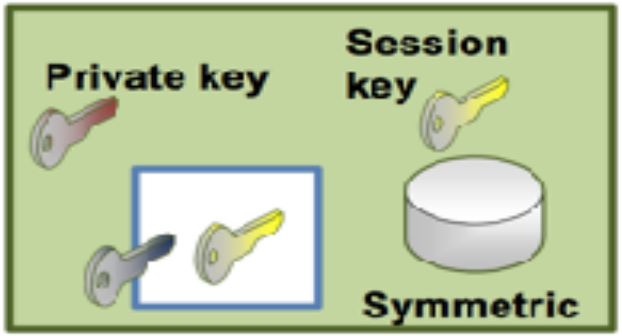
While hashing methods such as MD5 and SHA-1 use cryto methods, the Murmur and FNV hashes uses a non-cryptographic hash function. The Murmur hash, designed by Austin Appleby, uses a non-cryptographic hash function. This can be used for general hash-based lookups. It has a good performance compared with other hashing methods, and generally provide a good balance between performance and CPU utilization. Also it performs well in terms of hash collisions.

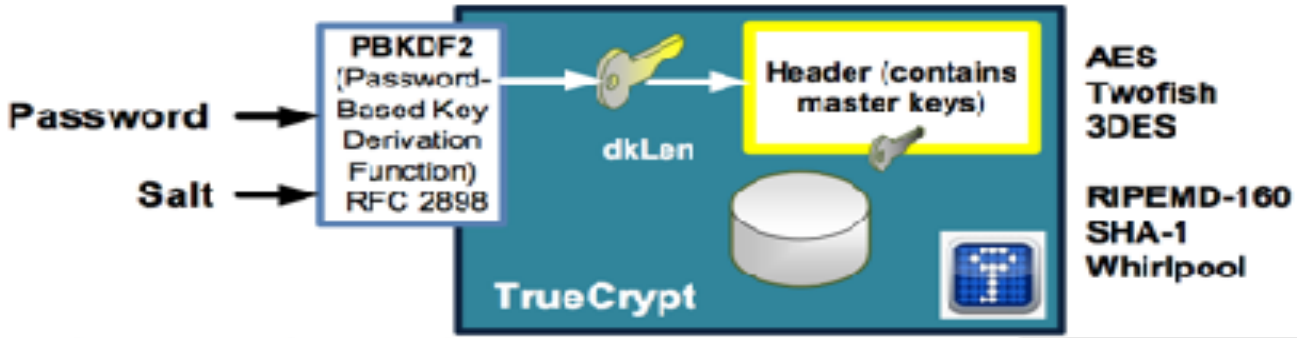
FNV

FNV (Fowler–Noll–Vo) is a 64-bit non-cryptographic hash function developed by Glenn Fowler, Landon Curt Noll, and Phong Vo. There are two main versions, of which 1a is the most up-to-date version.









DK = PBKDF2(PRF, Password, Salt, c, dkLen)
DK = PBKDF2(HMAC-SHA1, passphrase, ssid, 4096, 256)

Encrypting disks

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Adding salt

- Salt increases the range of the possible signatures

mypass → NT hash (MD4) → fa1bfa14fa13fa12fa10fa1ffa14fa12

NT-password hash for Windows NT, XP and Vista

Salt increase the range of the signatures

mypast

effahd13fa12fa10fgffa1ffa14fa144

caaahdd3fa12ccfae342345500011aff

Ddde432969450310403010d0ae000100

password

1fred$bATAk8UUH/IDAp9sd6IUv/

1

fred

bATAk8UUH/IDAp9sd6IUv/

password

bATAk8UUH/IDAp9sd6IUv/

fred

```
C:\openssl>openssl passwd -1 -salt fred password
$1$fred$bATAk8UUH/IDAp9sd6IUv/
```

Author: Prof Bill Buchanan

OpenSSL

Cryptography and SSL/TLS Toolkit

```
# cat /etc/shadow
root:$1$Etg2ExUZ$F9NTP7omafhKIlqaBMqng1:15651:0:99999:7:::
# openssl passwd -1 -salt Etg2ExUZ redhat
$1$Etg2ExUZ$F9NTP7omafhKIlqaBMqng1
```

```
$ openssl version
OpenSSL 1.0.1f 6 Jan 2014

$ openssl dgst -md5  file
MD5(file)= b194Gac92492d2347c6235b4d2611184

$ openssl genrsa -out mykey.pem 1024
Generating RSA private key, 1024 bit long modulus
.....................................................................++++++
...++++++
e is 65537 (0x10001

$ openssl rsa -in mykey.pem -pubout > mykey.pub
writing RSA key

$ cat mykey.pub
-----BEGIN PUBLIC KEY-----
MIGfMA0GCSqGSIb3DQEBAQUAA4GNADCBiQKBgQDXv9H5FkpM+ZoOQcpdHBZiUwX8
EZIKm0nsgjc5ZTYVaF9CMLtmKOTzep7aQX9o9nKepFtlkQ73Ta9vOPd6CX51/cgY
Xy2tShwOimrtFaVDFjX+7kLmcOuWbFFCoZMtJxIaXaa9SV2kARx0CTJ2uOjRTCCe
XUO9IJGHnIhSNJeIJQIDAQAB
-----END PUBLIC KEY-----

$ cat /etc/shadow
root:$1$Etg2ExUZ$F9NTP7omafhKIlqaBMqng1:15651:0:99999:7:::

$ openssl passwd -1 -salt Etg2ExUZ redhat
$1$Etg2ExUZ$F9NTP7omafhKIlqaBMqng1
```

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A major factor with hash signatures is:

- **Collision.** This is where another match is found, no matter the similarity of the original message. This can be defined as a **Collision attack**.
- **Similar context**. This is where part of the message has some significance to the original, and generates the same hash signature. The can be defined as a Pre-image attack.
- **Full context**. This is where an alternative message is created with the same hash signature, and has a direct relation to the original message. This is an extension to a Pre-image attack.

In 2006 it was shown that MD5 can produce collision within less than a minute.

A 50% probability of a collision is:

$$\sqrt{N(signatures)} = \sqrt{2^n} = 2^{\frac{n}{2}}$$

where n is the number of bits in the signature. For example, for MD5 (128-bit) the number of operations that would be required for a better-than-50% chance of a collision is:

$$2^{64}$$

Note, in 2006, for SHA-1 the best time has been 18 hours

```
d131dd02c5e6eec4693d9a0698aff95c
2fcab58712467eab4004583cb8fb7f89
55ad340609f4b30283e488832571415a
085125e8f7cdc99fd91dbdf280373c5b
d8823e3156348f5bae6dacd436c919c6
dd53e2b487da03fd02396306d248cda0
e99f33420f577ee8ce54b67080a80d1e
c69821bcb6a8839396f9652b6ff72a70
```

```
d131dd02c5e6eec4693d9a0698aff95c
2fcab50712467eab4004583cb8fb7f89
55ad340609f4b30283e4888325f1415a
085125e8f7cdc99fd91dbd7280373c5b
d8823e3156348f5bae6dacd436c919c6
dd53e23487da03fd02396306d248cda0
e99f33420f577ee8ce54b67080280d1e
c69821bcb6a8839396f965ab6ff72a70
```

The MD5 signature gives the same result

79054025255FB1A26E4BC422AEF54EB4

Nat McHugh

- 10 hours of computing on the Amazon GPU Cloud.
- Cost: 60 cents
- Used: Hashcat (on CUDA)
- Birthday attack: A group size of only 70 people results in a 99.9% chance of two people sharing the same birthday.
- M-bit output there are 2^m messages, and the same hash value would only require 2^(m/2) random messages. 18,446,744,073,709,551,616.

C:\openssl>openssl md5 hash01.jpg
MD5(hash01.jpg)= **e06723d4961a0a3f950e7786f3766338**

C:\openssl>openssl md5 hash02.jpg
MD5(hash02.jpg)= **e06723d4961a0a3f950e7786f3766338**

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```
C:> user2sid \pluto guest
S-1-5-21-7623811015-3361044348-030300820-501
C:> sid2user 5 21 7623811015 3361044348 030300820 500
Name is Fred
Domain is PLUTO
```

Revision level

Sub-authority (21 – NT Non unique)

SA Domain ID

SA

SIDs are used to uniquely identify users and their group memberships – identifies User, Group and Computer accounts

S-1-5-21-7623811015-3361044348-030300820-501

Identifier Authority (48 bits)
5 = Login ID

SA

Relative User ID (RID):
500 = Admin
501 = Guest
502 = Kerberos
1000 = First user
1001 = Second user

S – Security ID (SID)

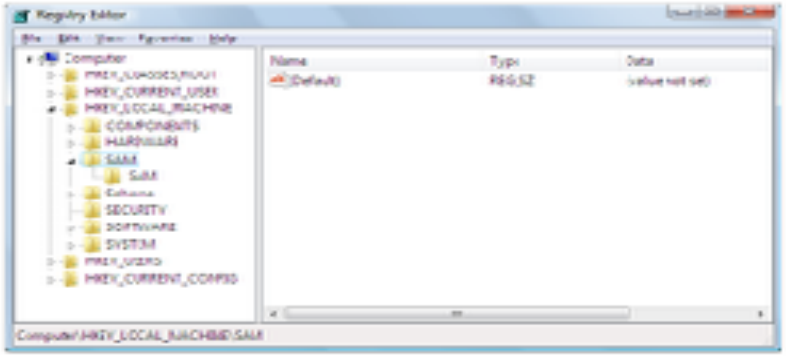
Windows

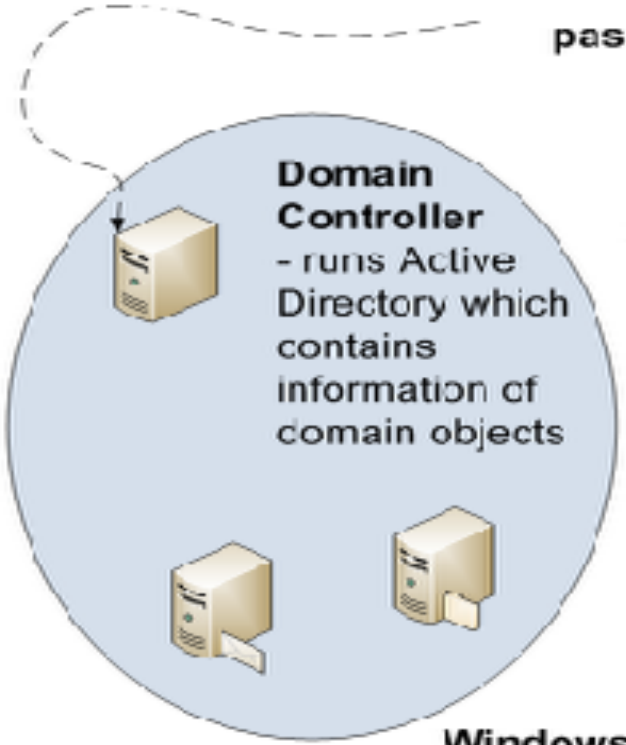
CEH

SID and RID

HKLM\SAM

SAM Database (stores usernames and passwords)





Local Authority Subsystem (Lsass) – Windows Security mechanism – Attached by Sasser Worm which exploited a buffer overflow

Responsible for local security policy

- Controls access.
- Managing password policies.
- User authentication.
- Audit messages.

Registry:
HKEY_LOCAL_MACHINE\SAM


```
C:\Windows\System32\config>dir
 Volume in drive C has no label.
 Volume Serial Number is A2B3-7C7A

 Directory of C:\Windows\System32\config
05-Oct-14  05:52 PM          262,144 SAM
05-Oct-14  05:56 PM          262,144 SECURITY
05-Oct-14  08:39 PM      149,946,368 SOFTWARE
05-Oct-14  08:40 PM       15,728,640 SYSTEM
```

- LM Hash (Windows XP, 2003)
- NTLMv2 (Windows 7, 8, etc) – connect to Active Directory
- NTLM (Windows 7, 8, etc) – No salt

- bkhive - dumps the syskey bootkey from a Windows system hive.
- samdump2 - dumps Windows 2k/NT/XP/Vista password hashes.

hashme gives: FA-91-C4-FD-28-A2-D2-57-AA-D3-B4-35-B5-14-04-EE FF2A43841C84518A18795AB6E3C8A62E (NTLM)

napier gives: 12-B9-C5-4F-6F-E0-EC-80-AA-D3-B4-35-B5-14-04-EE 307E40814E7D4E103F6A69B04EA78F3D (NTLM)

<user>:<id>:<LM hash>:<NTLM hash>:<comment>:<homedir>:

```
Root@kali:~# cat pw
myuser:500:12B9C54F6FE0EC80AAD3B435B51404EE:307E40814E7D4E103F6A69B04EA78F3D:::
Root@kali:~# john  pw
Loaded 1 password hash (LM DES [128/128 BS SSE2])
NAPIER           (napier)
guesses: 1  time: 0:00:00:00 100% (1)  c/s: 4850  trying: NAPIER - N4PI3R
Use the "--show" option to display all of the cracked passwords reliably
```

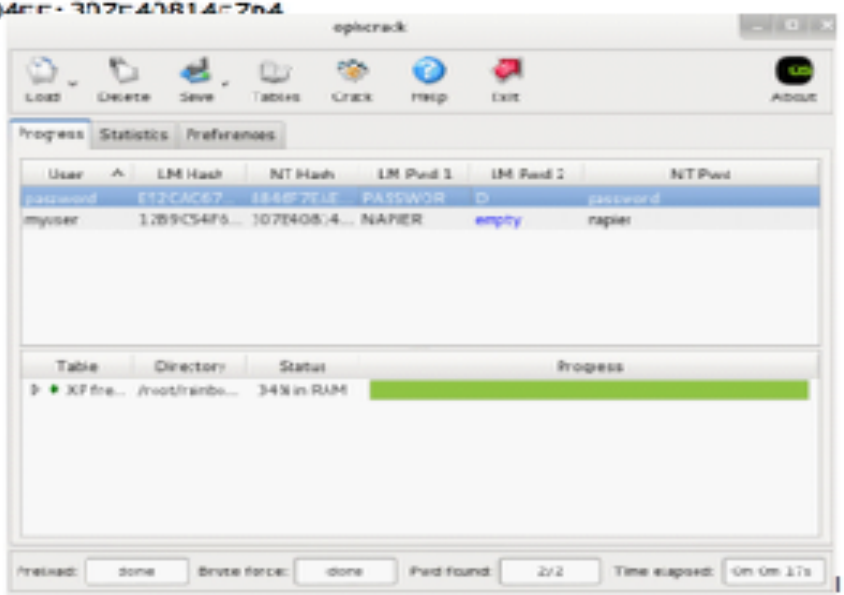
Author: Prof Bill Buchanan

SAM

Registry:
HKEY_LOCAL_MACHINE\SAM

```
Root@kali:~# cat pw
myuser:500:12B9C54F6FE0EC80AAD3B435B51404EE:307E40814E7D4E103F6A69B04EA78F3D:::
Root@kali:~# john  pw
Loaded 1 password hash (LM DES [128/128 BS SSE2])
NAPIER           (napier)
guesses: 1  time: 0:00:00:00 100% (1)  c/s: 4850  trying: NAPIER - N4PI3R
Use the "--show" option to display all of the cracked passwords reliably
```

```
<user>:<id>:<LM hash>:<NTLM hash>:<comment>:<homedir>:
password:500:E52CAC67419A9A224A3B108F3FA6CB6D:8846F7EAEE8
FB117AD06BDD830B7586C:$
myuser:500:12B9C54F6FE0EC80AAD3B435B51404EE:307E40814E7D4
E103F6A69B04EA78F3D:::
```



ophcrack

Hash Crackers/Bit Coin Miners

Fast Hash One

- 1.536TH/s – Cost 3-5,000 dollars.

25 GPU Hash Cracker

- An eight character NTLM password cracked in 5.5 hours. 14 character LM hash cracked in six minutes. 350 billion hashes per second.

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Benchmark

```
Ulta fast:
Murmur:          545,716 hashes per second

Fast:
SHA-1:           134,412
SHA-256:         126,323
MD5:             125,741
SHA-512:          76,005
SHA-3 (224-bit): 72,089

Medium speed:
LDAP (SHA1):     13,718
MS DCC:           9,582
NT Hash:          7,782
MySQL:            7,724
Postgres (MD5):   7,284

Slow:
PBKDF2 (SHA-256): 5,026
Cisco PIX:        4,402
MS SQL 2000:      4,225
LDAP (MD5):       4,180
Cisco Type 7:     3,775
PBKDF2 (SHA1):    2,348

Ulta-slow:
LM Hash:          733
APR1:             234
Bcrypt:           103
DES:               88
Oracle 10:         48
```

Hashes “The quick brown fox jumps over the lazy dog:

SHA-1:	2fd4e1c67a2d28fced849ee1bb76e7391b93eb12
SHA-256:	d7a8fbb307d7809469ca9abcb0082e4f8d5651e46d3cdb762d02d0bf37c9e592
SHA-512:	07e547d9586f6a73f73fbac0435ed76951218fb7d0c8d788a309d7 85436bbb642e93a252a954f23912547d1e8a3b5ed6e1bfd7097821233fa0538f3db854fee6

MD-5:	9e107d9d372bb6826bd81d3542a419d6
DES:	ZDeS94Lcq/6zg
Bcrypt:	$2a$05$2czCv5GYgkx3aobmEyewB.ejV2hePMdbvTdCyNaSzWtlGPPjB2xx6
APR1:	$apr1$ZDzPE45C$3PvRanPycmNc6c2G9wT9b/
PBKDF2 (SHA1):	$pbkdf2$5$WkR6UEU0NUM$0RB2bimWrMY.EPYibpaBT2q3HFg
PBKDF2 (SHA-256):	$pbkdf2-sha256$5$WkR6UEU0NUM$yrJz2oJix7uBJZwZ/50vWUgdE I/i0ffqeU4obqC0pk4
LM Hash:	a7b07f9948d8cc7f97c4b0b30cae500f
NT Hash:	4e6a076ae1b04a815fa6332f69e2e231
MS DCC:	efa9778bbc94a7360f664eb7d7144725
LDAP (MD5):	{MD5}9e107d9d372bb6826bd81d3542a419d6
LDAP (SHA1):	{SHA}2fd4e1c67a2d28fced849ee1bb76e7391b93eb12
MS SQL 2000:	0x0100BF77CE595DCD1FC87A37B3DEBC27A8C97355CB96B8BAB 63E602662BA5D5D33B913E422499BE72FF3D9BB65DE
MySQL:	*A4E4D26FD0C6455E23E2187C3AABE844332AA1B3
Oracle 10:	4CDA2299FCAD0499
Postgres (MD5):	md5d44c15daa11770f25c5350f7e5408dd1
Cisco PIX:	kGyKN5CqdFQ1qJUs
Cisco Type 7:	15260309443B3E2D2B3875200108010D41505640135E1B0E080 519574156401540035E460B594D1D53020B5C

Benchmark

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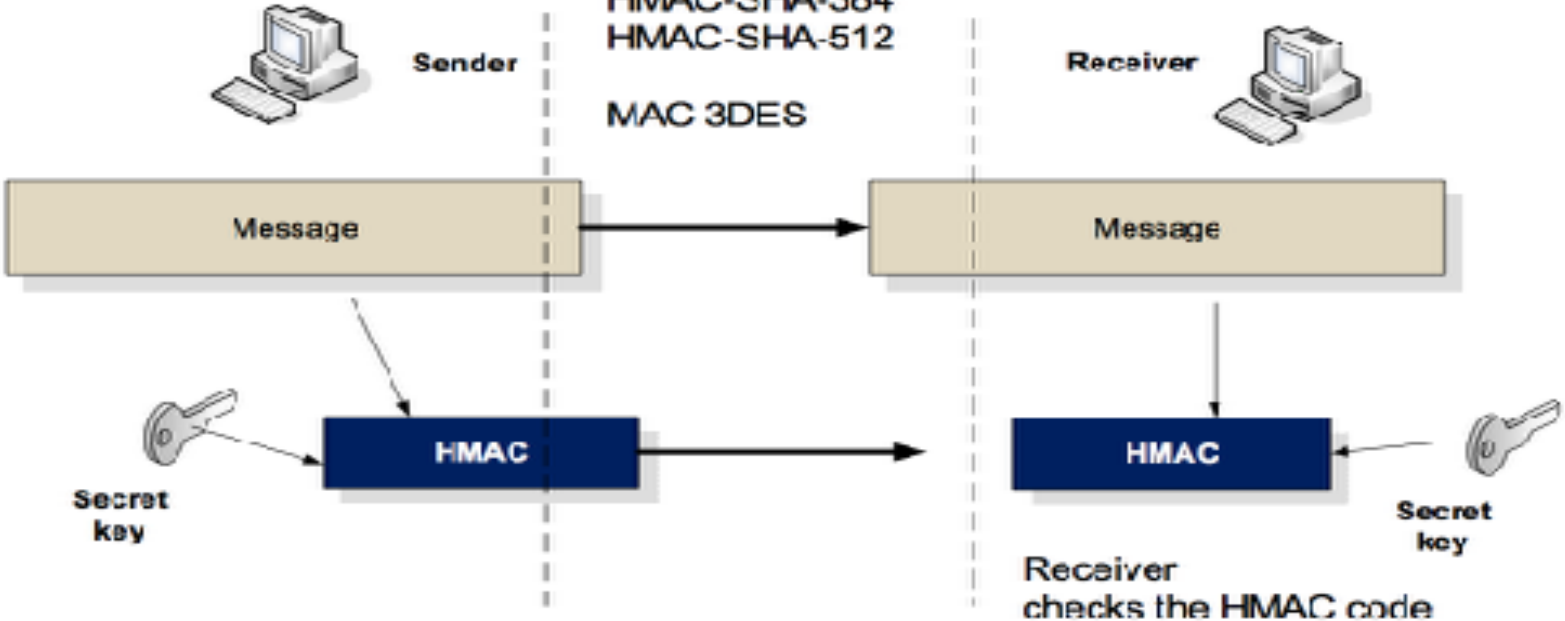
"testing123" and a key of "hello", and you should get:
AC2C2E614882CE7158F69
B7E3B12114465945D01

HMAC-MD5
HMAC-SHA-1
HMAC-SHA-256
HMAC-SHA-384
HMAC-SHA-512

MAC 3DES



Receiver
checks the HMAC code
against received one –
if they match the sender is
validated, and the message
is also confirmed

Author: Prof Bill Buchanan

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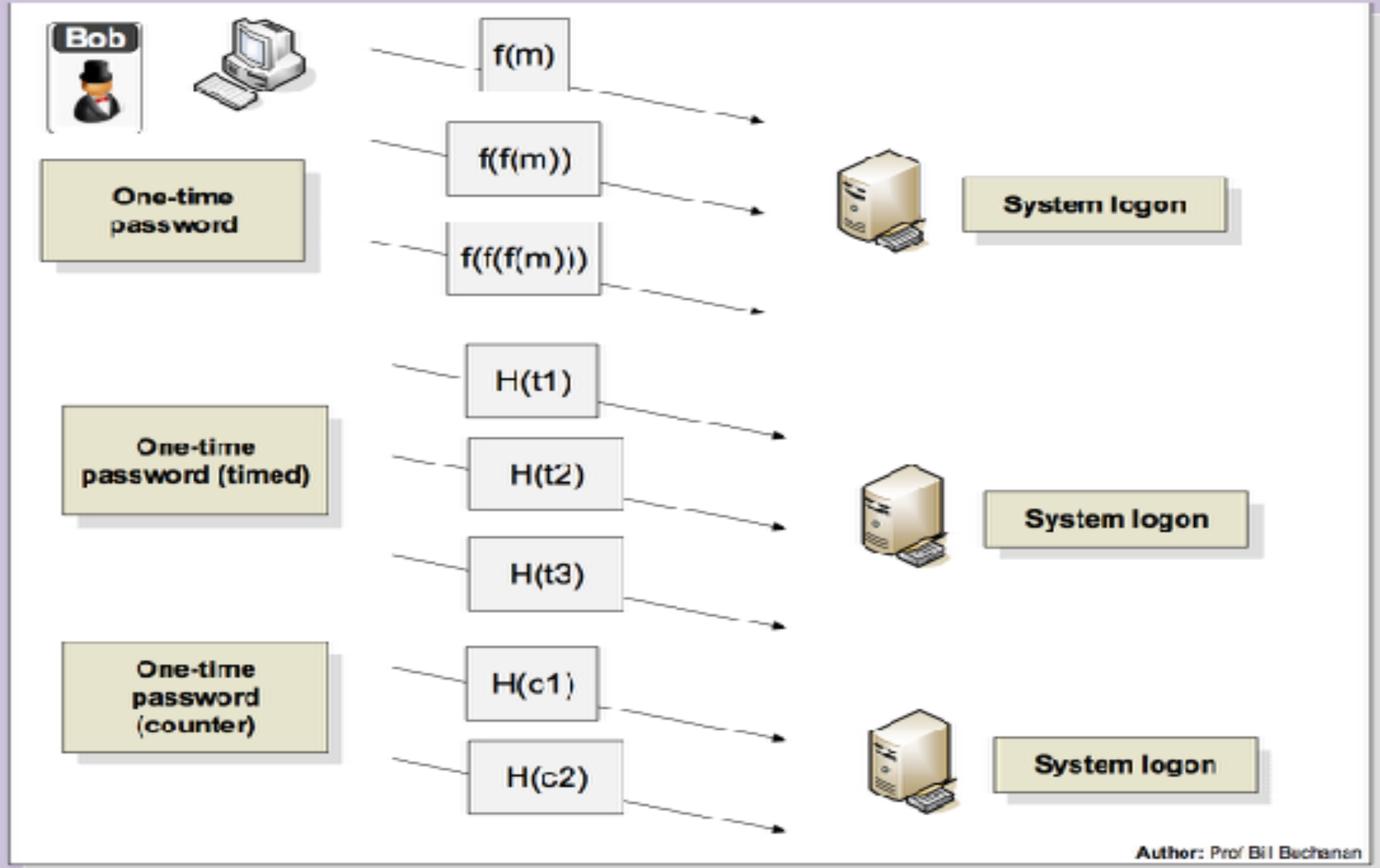
Bob
One-time password
f(m)
f(f(m))
f(f(f(m)))
System logon
One-time password (timed)
H(t1)
H(t2)
H(t3)
System logon
One-time password (counter)
H(c1)
H(c2)
System logon
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