

# Secret Key

Basics

Block or Stream?

Secret Key Methods

Salting

AES

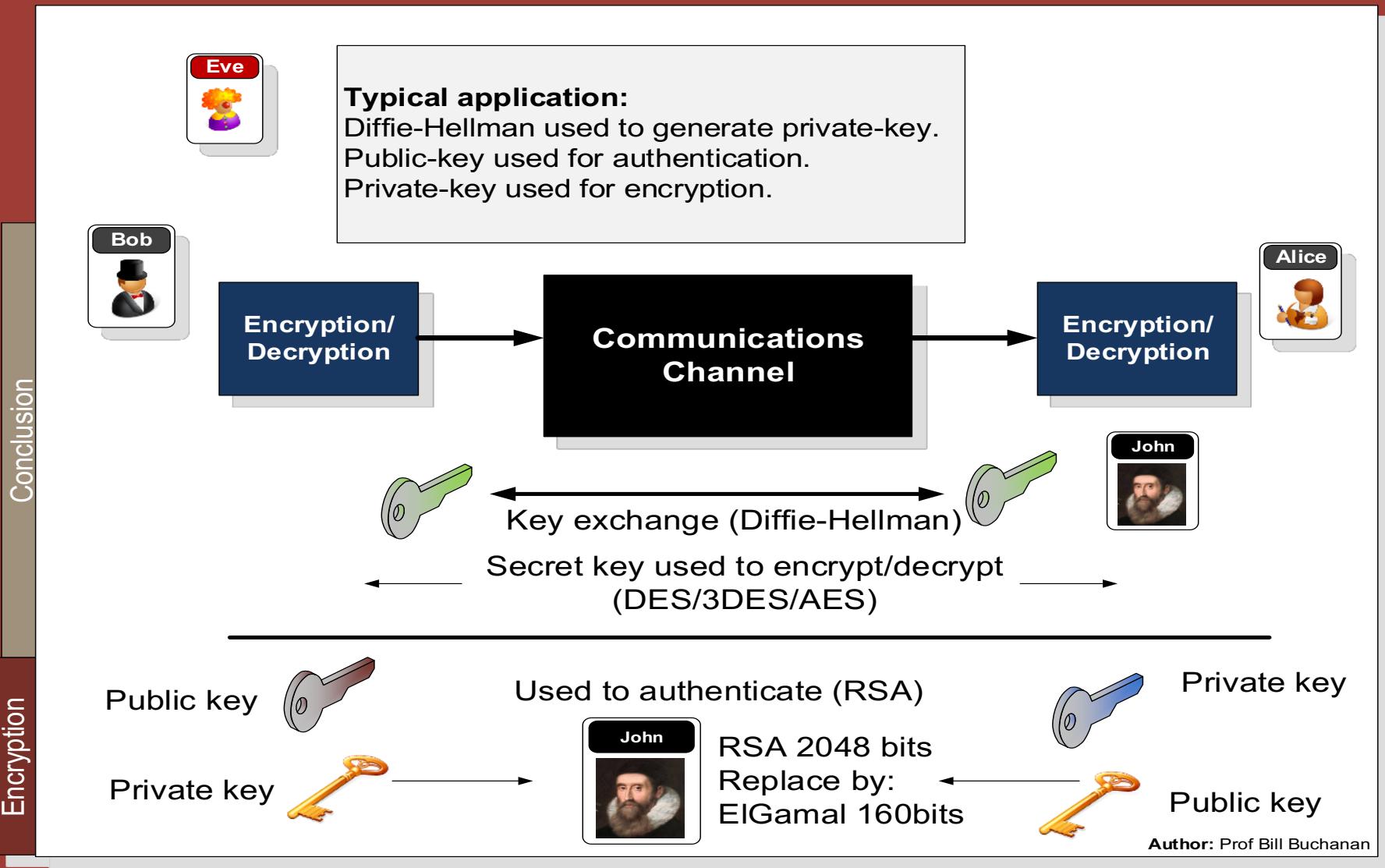
Key Entropy



**Prof Bill Buchanan OBE**

<http://asecuritysite.com/crypto02>

<http://asecuritysite.com/encryption>



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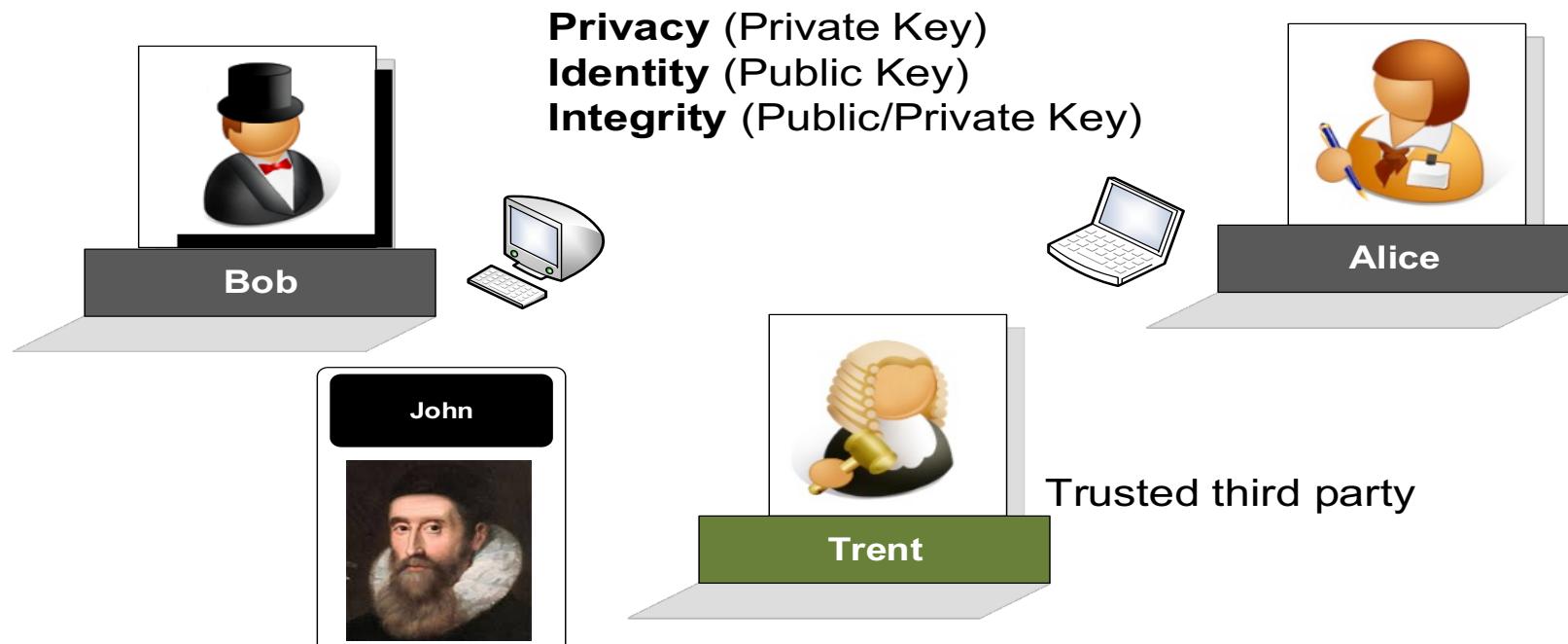
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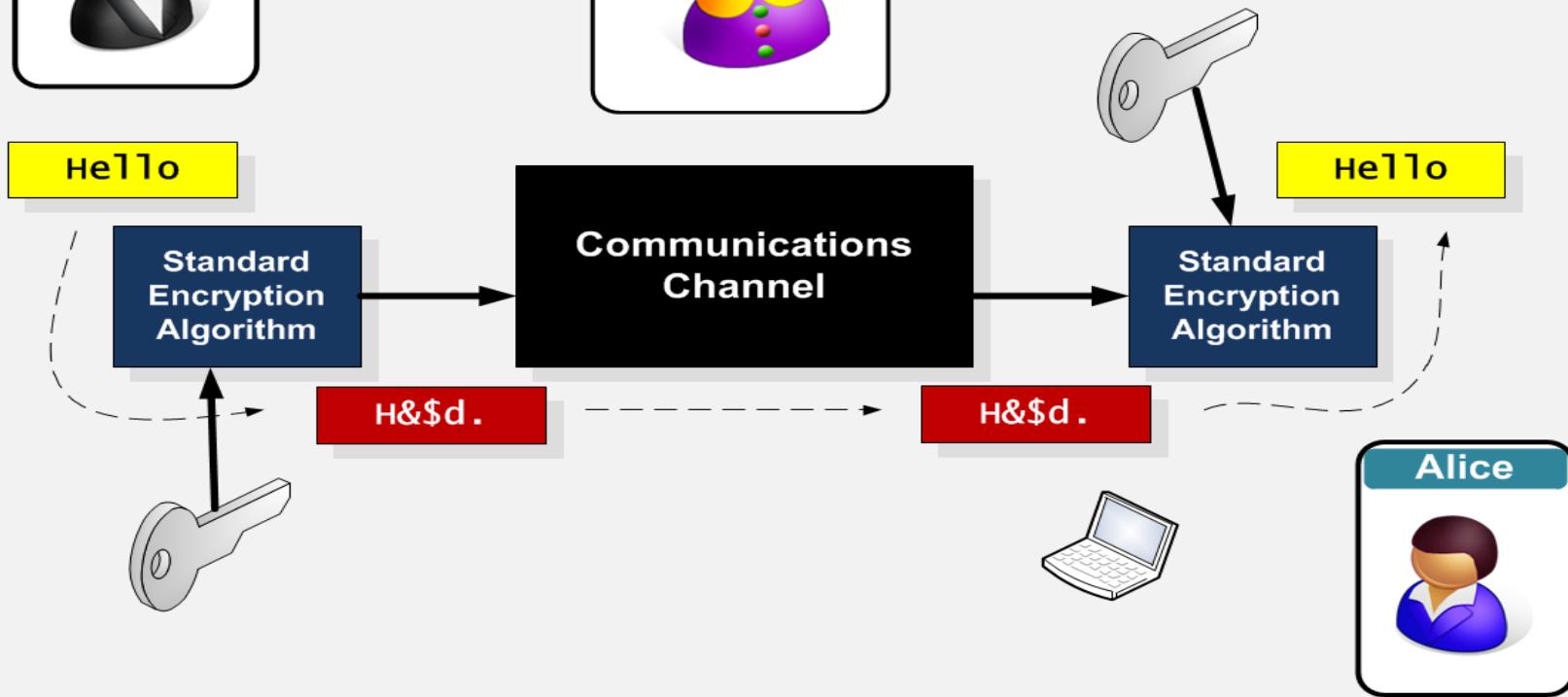
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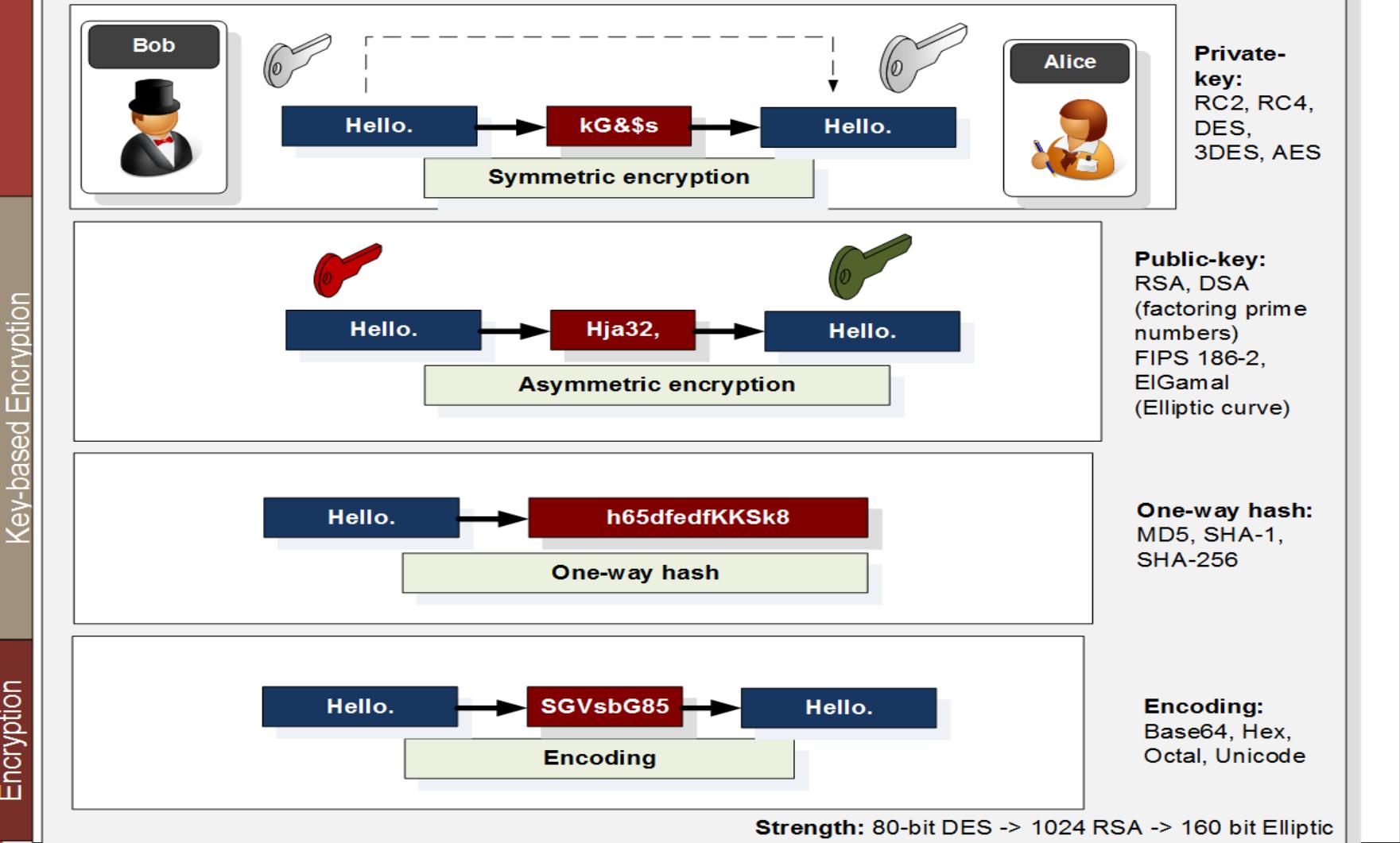




The major problem is that Eve could gain the encoding algorithm.



## Encryption





## Number of keys

The larger the key, the greater the key space.

Code size	Number of keys	Code size	Number of keys	Code size	Number of keys
1	2	12	4,096	52	$4.5 \times 10^{15}$
2	4	16	65,536	56	$7.21 \times 10^{16}$
3	8	20	1,048,576	60	$1.15 \times 10^{18}$
4	16	24	16,777,216	64	$1.84 \times 10^{19}$
5	32	28	$2.68 \times 10^8$	68	$2.95 \times 10^{20}$
6	64	32	$4.29 \times 10^9$	72	$4.72 \times 10^{21}$
7	128	36	$6.87 \times 10^{10}$	76	$7.56 \times 10^{22}$
8	256	40	$1.1 \times 10^{12}$	80	$1.21 \times 10^{24}$
9	512	44	$1.76 \times 10^{13}$	84	$1.93 \times 10^{25}$
10	1024	48	$2.81 \times 10^{14}$	88	$3.09 \times 10^{26}$





Okay... we select a **64-bit key** ...  
which has  $1.84 \times 10^{19}$  combinations

### Time to crack

- It is important to understand the length of time that a message takes to crack as it may need to be secret for a certain time period.

18.4 million million million different keys  
000000000000...0000000000000000  
To  
111111111111....1111111111111111

How long will it take to crack it by brute-force (on average)?



A 64-bit key has  $1.84 \times 10^{19}$  combinations and it could be cracked by brute-force in  $0.9 \times 10^{19}$  goes.

### Time to crack

- It is important to understand the length of time that a message takes to crack as it may need to be secret for a certain time period.

If we use a fast computer such as 1GHz clock (1ns), and say it takes one clock cycle to test a code, the time to crack the code will be:

9,000,000,000 seconds (150 million minutes)  
... 2.5 million hours (285 years)



If it takes 2.5 million hours (285 years) to crack a code. How many years will it take to crack it within a day?

### Time to crack

- It is important to understand the length of time that a message takes to crack as it may need to be secret for a certain time period.

Computers typically improve their performance every year ... so assume a **doubling** of performance each year.

Date	Hours	Days	Years
2017	2,500,000	104,167	285
2018	1,250,000	52,083	143

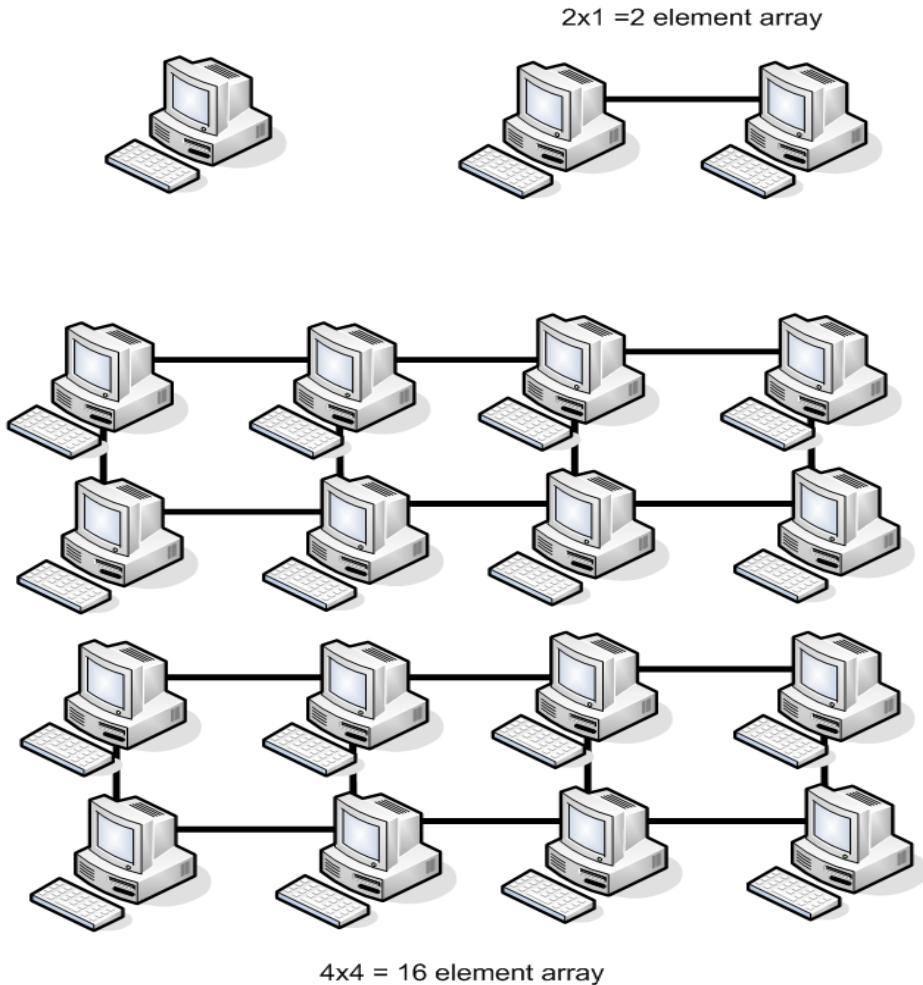


Date	Hours	Days	Years
2017	2,500,000	104,167	285
2018	1,250,000	52,083	143
2019	625,000	26,042	71
2020	312,500	13,021	36
2021	156,250	6,510	18
2022	78,125	3,255	9
2023	39,063	1,628	4
2024	19,532	814	2
+8	9,766	407	1
+9	4,883	203	1
+10	2,442	102	0.3
+11	1,221	51	0.1
+12	611	25	0.1
+13	306	13	0
+14	153	6	0
+15	77	3	0
+16	39	2	0
+17	20	1	0

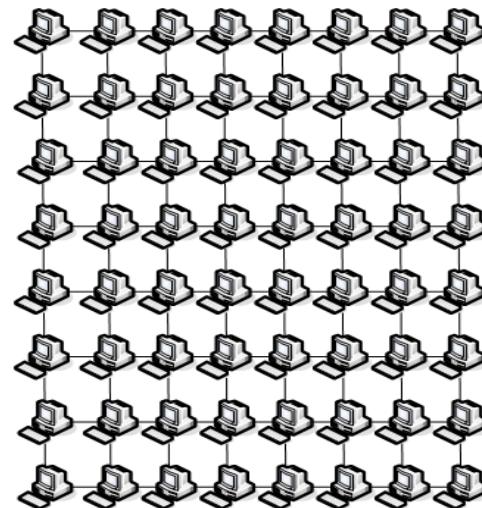
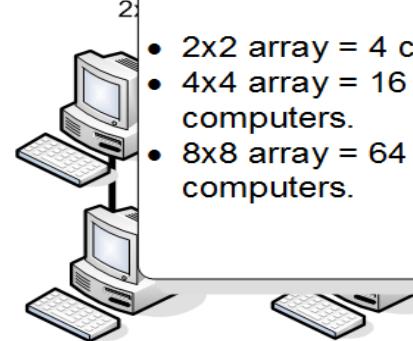
## Time to crack

- From 285 years to 1 day, just by computers increasing their computing power.

56-bit DES:  
Developed  
1975  
30 years ago!  
... now easily  
crackable



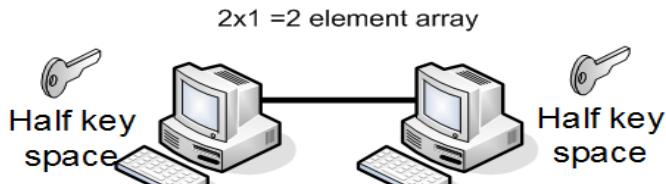
## Parallel processing



16x16 = 256 element array

## Parallel processing

- 64-bit key --- from **104,000 days** (284 years) to one hour or less.



Brute-force

Encryption

<b>Processors</b>	<b>Year 0</b>	<b>Year 1</b>	<b>Year 2</b>	<b>Year 3</b>	<b>Year 4</b>	<b>Year 5</b>
<b>1</b>	104000 days	52000	26000	13000	6500	3250
<b>4</b>	26000	13000	6500	3250	1625	813
<b>16</b>	6500	3250	1625	813	407	204
<b>64</b>	1625	813	407	204	102	51
<b>256</b>	406	203	102	51	26	13
<b>1024</b>	102	51	26	13	7	4
<b>4096</b>	25	13	7	4	2	1
<b>16,384</b>	152hr	76hr	38hr	19hr	10hr	5hr
<b>65,536</b>	38hr	19hr	10hr	5hr	3hr	2hr
<b>262,144</b>	10hr	5hr	3hr	2hr	1hr	
<b>1,048,576</b>	2hr	1hr				

key  
ice

4x4 = 16 element array

16x16 = 256 element array

Author: Prof Bill Buchanan

# Chapter 2: Secret Key

Basics

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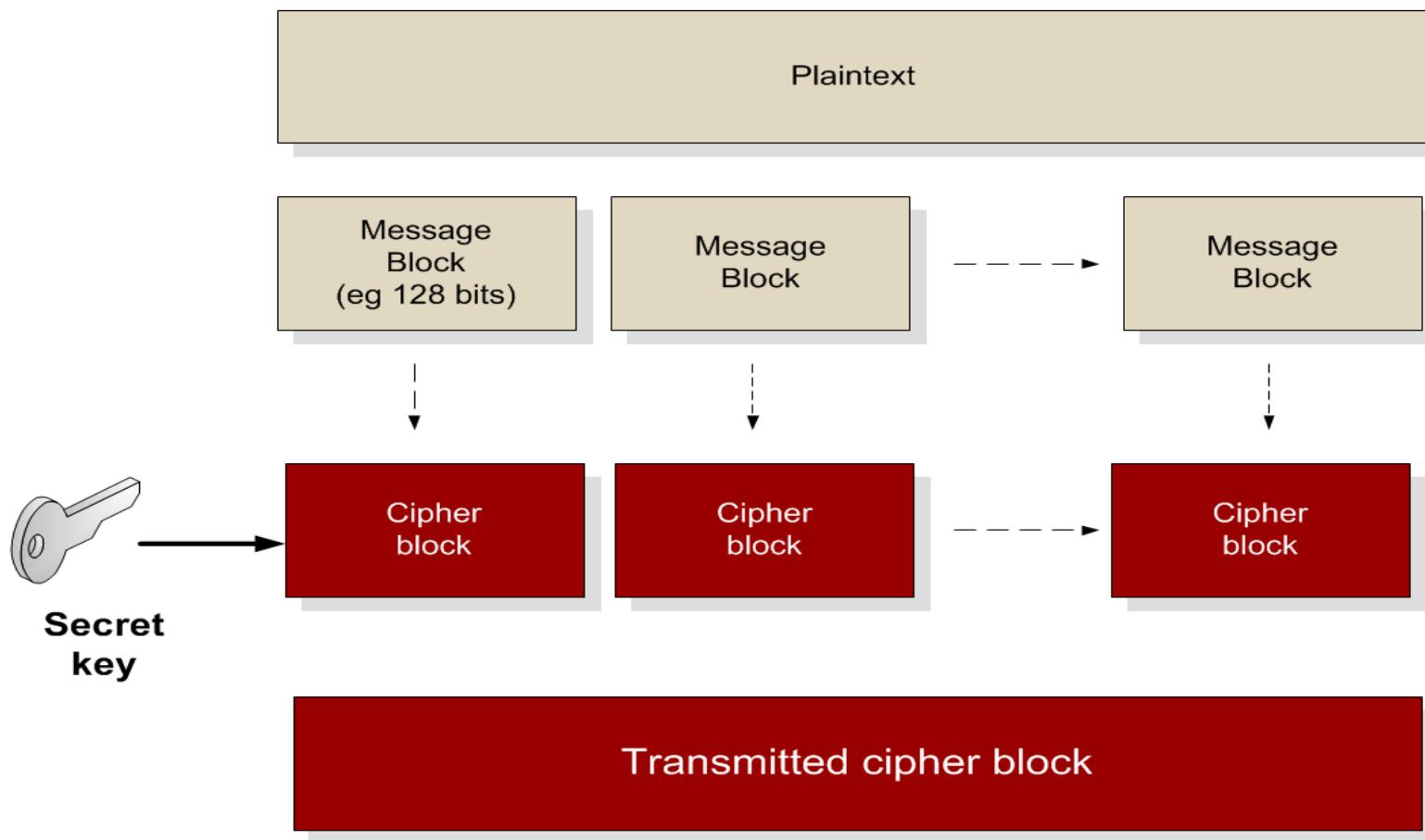
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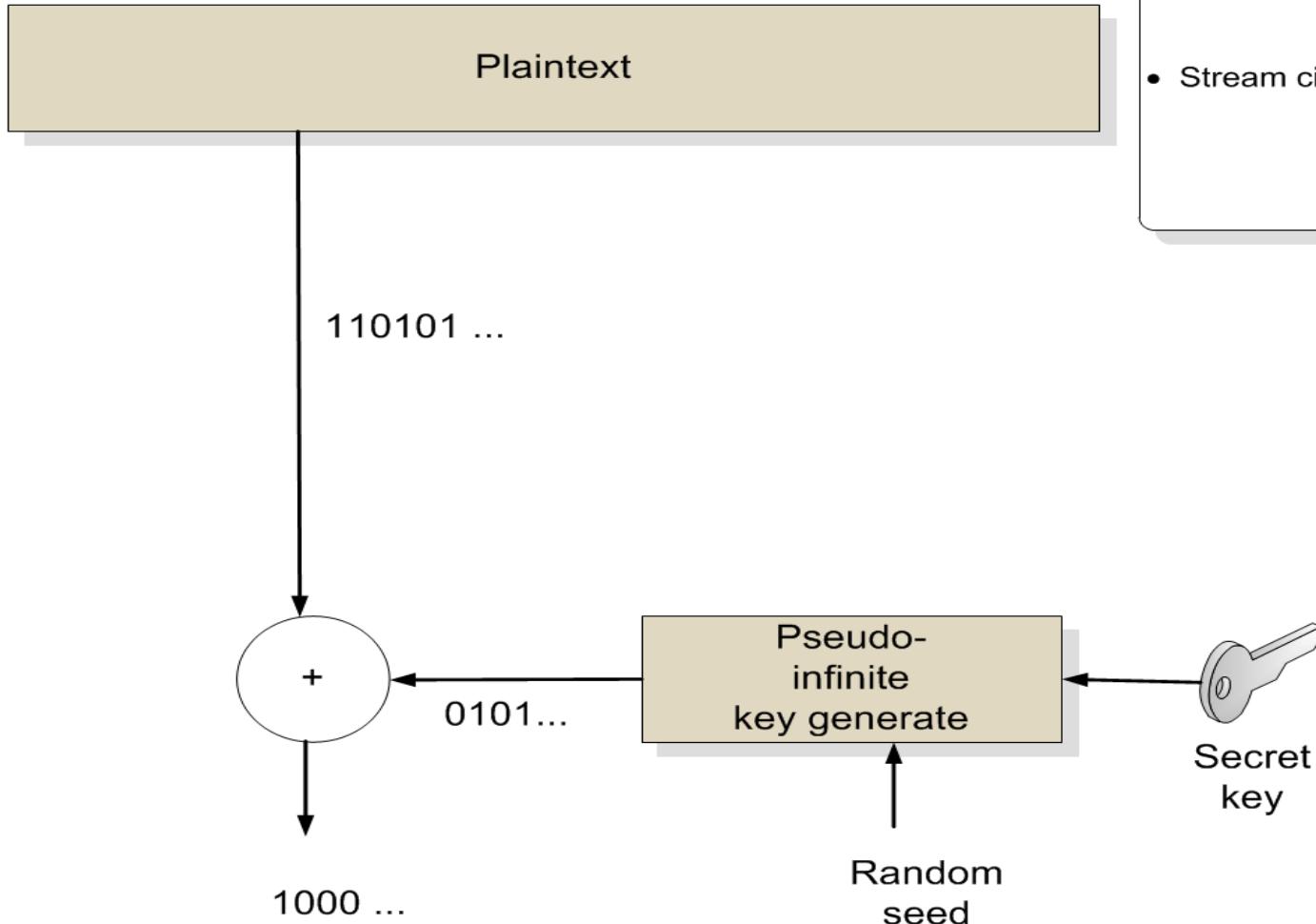
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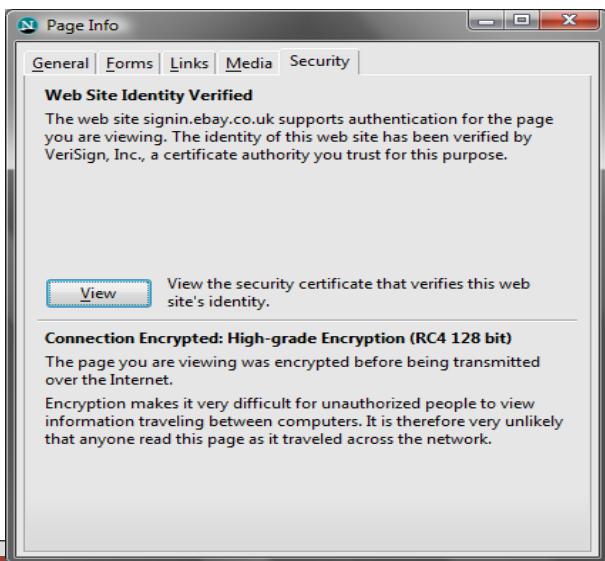
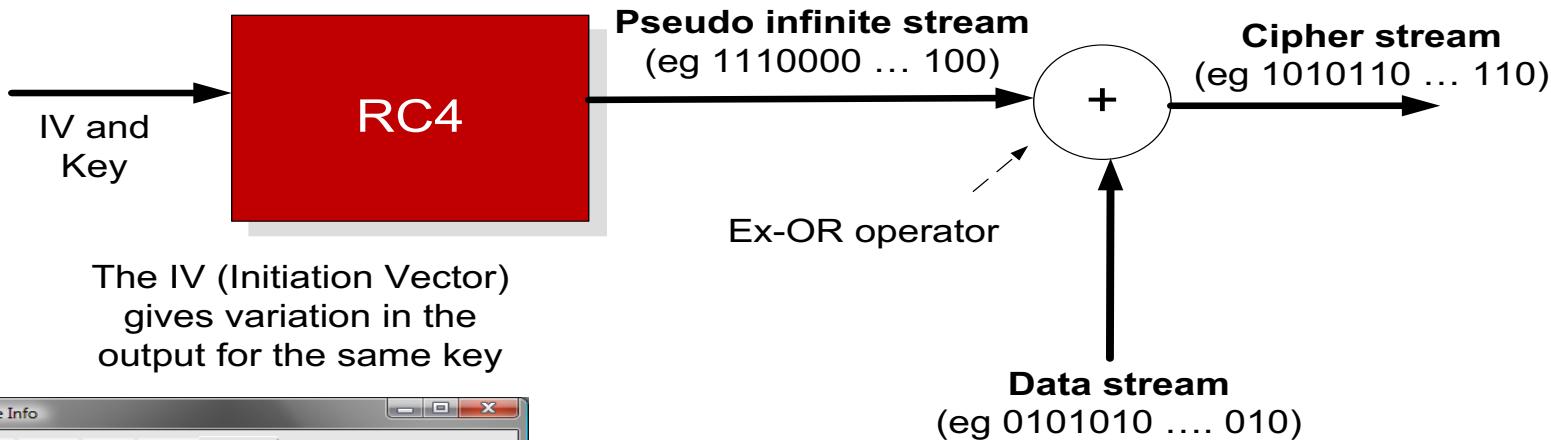


**Stream cipher**

- Stream cipher (RC4)



**RC4.** This is a **stream** encryption algorithm, and is used in wireless communications (such as in WEP) and SSL (Secure Sockets).



Data stream                    0101010 ... 010  
Pseudo infinite stream      1110000 ... 100      +  
Cipher stream                1010110 ... 110

# Padding

- **CMS** (Cryptographic Message Syntax). This pads with the same value as the number of padding bytes. Defined in RFC 5652, PKCS#5, PKCS#7 and RFC 1423 PEM.
- **Bits**. This pads with 0x80 (10000000) followed by zero (null) bytes. Defined in ANSI X.923 and ISO/IEC 9797-1.
- **ZeroLength**. This pads with zeros except for the last byte which is equal to the number (length) of padding bytes.
- **Null**. This pads will NULL bytes. This is only used with ASCII text.
- **Space**. This pads with spaces. This is only used with ASCII text.
- **Random**. This pads with random bytes with the last byte defined by the number of padding bytes.

# Padding

- After padding (CMS): 68656c6c6f0b0b0b0b0b0b0b0b0b0b0b0b0b  
Cipher (ECB): 0a7ec77951291795bac6690c9e7f4c0d
- After padding (Bit): 68656c6f80000000000000000000000000000000  
Cipher (ECB): 731abffc2e3b2c2b5caa9ca2339344f9
- After padding (ZeroLen): 68656c6f000000000000000000000000a  
Cipher (ECB): d28e2f7e8e44e068732b292bde444245
- After padding (Null): 68656c6f00000000000000000000000000000000  
Cipher (ECB): 444797422460453d95856eb2a1520ece
- After padding (Space): 68656c6f00000000000000000000000000000000  
Cipher (ECB): 444797422460453d95856eb2a1520ece
- After padding (Random): 68656c6fffc6ecfd884a38798d62a**0a**  
Cipher (ECB): c2c88b4364d2c2dc6f2cac9ab73c995d

# Chapter 2: Secret Key

Basics

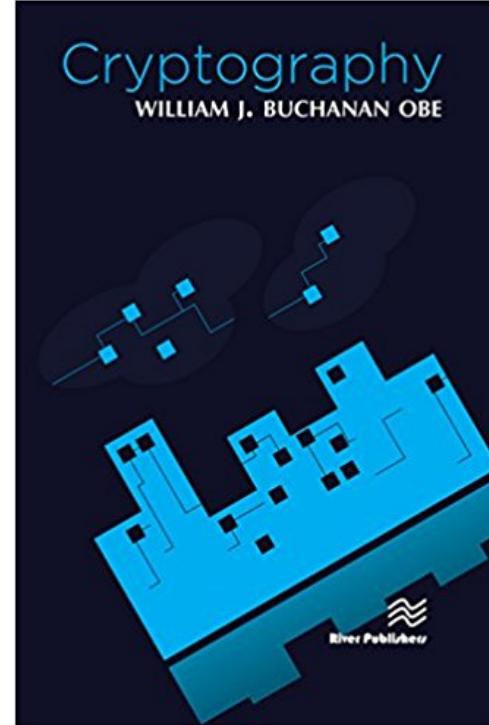
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**Secret Key Methods**

Salting

AES

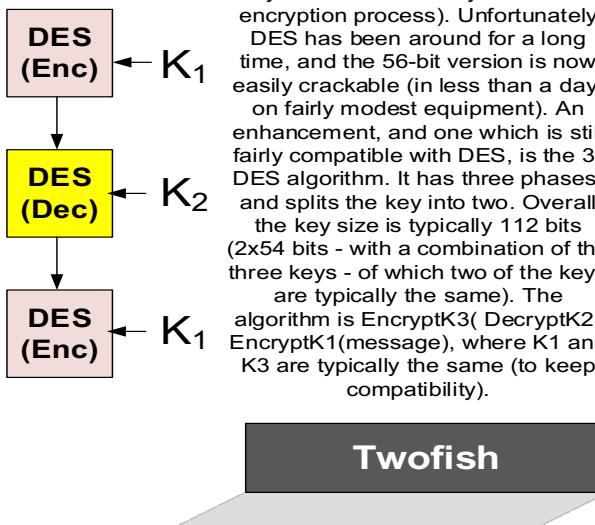
Key Entropy



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<http://asecuritysite.com/crypto02>

<http://asecuritysite.com/encryption>



Bruce Schneier created Twofish with a general-purpose private key block cipher encryption algorithm.

## DES

DES. DES encryption algorithm is block cipher and uses a 64-bit block and a 64-bit encryption key.

3DES. DES encryption algorithm is block cipher and uses a 64-bit block and a 64-bit encryption key (of which only 56 bits are actively used in the encryption process). Unfortunately DES has been around for a long time, and the 56-bit version is now easily crackable (in less than a day, on fairly modest equipment). An enhancement, and one which is still fairly compatible with DES, is the 3-DES algorithm. It has three phases, and splits the key into two. Overall the key size is typically 112 bits (2x54 bits - with a combination of the three keys - of which two of the keys are typically the same). The algorithm is EncryptK3( DecryptK2( EncryptK1(message)), where K1 and K3 are typically the same (to keep compatibility).

## AES

AES. AES (or Rijndael) is a new block cipher, and is the new replacement for DES, and uses 128-bit blocks with 128, 192 and 256 bit encryption keys. It was selected by NIST in 2001 (after a five year standardisation process). The name Rijndael comes from its Belgium creators: Joan Daemen and Vincent Rijmen.

## Blowfish

Blowfish. Bruce Schneier created Blowfish with a general-purpose private key block cipher encryption algorithm. Blowfish (with CBC). Blowfishcbc. With CBC we split the message into blocks and encrypt each block. The input from the first stage is the IV (Initialisation Vector), and the input to the following stages is the output from the previous stage. In this example we will use Blowfish to encrypt, using CBC.

## RC2

RC2. RC2 ("Rivest Cipher") is a block cipher, and is seen as a replacement for DES. It was created by Ron Rivest in 1987, and is a 64-bit block code and can have a key size from 40 bits to 128-bits (in increments of 8 bits). The 40-bit key version is seen as weak, as the encryption key is so small, but is favoured by governments for export purposes, as it can be easily cracked. In this case the key is created from a Key and an IV (Initialisation Vector). The key has 12 characters (96 bits), and the IV has 8 characters (64 bits), which go to make the overall key.

## Others

- Skipjack. Skip jack. Skipjack is a block cipher, using private-key encryption algorithm, and designed by NSA.
- Camellia. Camillia is a block cipher created by Mitsubishi and NTT.
- RC4. RC4 is a stream cipher used in WEP (in wireless encryption).
- Affine. Affine is a stream cipher which uses an equation to encrypt.

**3-DES.** The DES encryption algorithm uses a **64-bit block** and a 64-bit encryption key (of which only **56 bits** are actively used in the encryption process). Unfortunately DES has been around for a long time, and the 56-bit version is now easily crackable (in less than a day, on fairly modest equipment). An enhancement, and one which is still fairly compatible with DES, is the 3-DES algorithm. It has three phases, and splits the key into two. Overall the key size is typically **112 bits** (2x54 bits - with a combination of the three keys - of which two of the keys are typically the same). The algorithm is:

$\text{Encrypt}_{K_3}(\text{Decrypt}_{K_2}(\text{Encrypt}_{K_1}(\text{message})))$

<http://asecuritysite.com/encryption/threedes>

where K1 and K3 are typically the same (to keep compatibility).



**RC-2.** RC2 ("Rivest Cipher") is seen as a replacement for DES. It was created by Ron Rivest in 1987, and is a **64-bit block code** and can have a key size from 40 bits to 128-bits (in increments of 8 bits). The 40-bit key version is seen as weak, as the encryption key is so small, but is favoured by governments for export purposes, as it can be easily cracked. In this case the key is created from a Key and an IV (Initialisation Vector). The key has 12 characters (96 bits), and the IV has 8 characters (64 bits), which go to make the overall key.

<http://asecuritysite.com/encryption/rc2>



**AES/Rijndael.** AES (or Rijndael) is the new replacement for DES, and uses **128-bit blocks** with 128, 192 and 256 bit encryption keys. It was selected by NIST in 2001 (after a five year standardisation process). The name Rijndael comes from its Belgium creators: Joan Daemen and Vincent Rijmen.

<http://asecuritysite.com/encryption/aes>



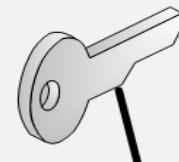


The major problem is that Eve could gain the encoding algorithm.

Hello

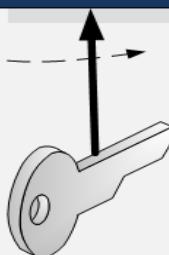
Standard  
Encryption  
Algorithm

Communications  
Channel



Hello

Standard  
Encryption  
Algorithm



H&\$d.

H&\$d.



Alice

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**Salting**

AES

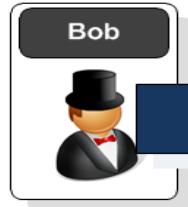
Key Entropy



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Hello. How are you?



kG&\$s &FDsaf \*fd\$

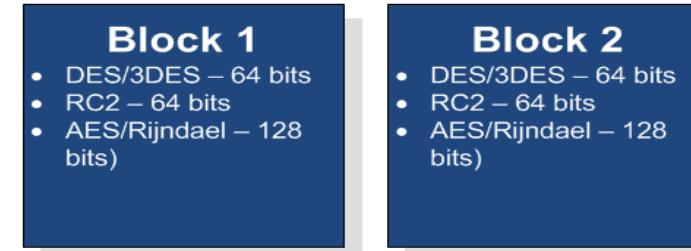


kG&\$s &FDsaf \*fd\$



The solution is to add **salt** to the encryption key, as that it changes its operation from block-to-block (for block encryption) or data frame-to-data frame (for stream encryption)

A major problem in encryption is playback where an intruder can copy an encrypted message and play it back, as the same plain text will always give the same cipher text.

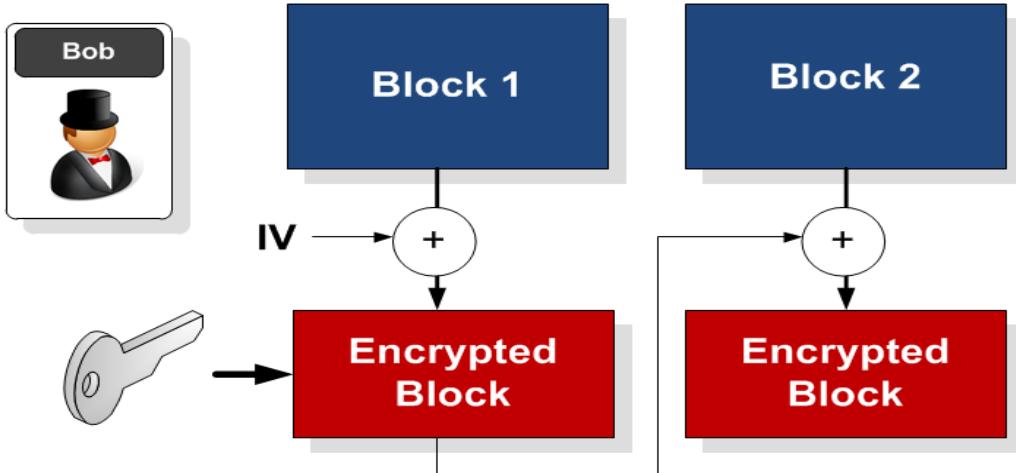


**Electronic Code Book (ECB)** method. This is weak, as the same cipher text appears for the same blocks.

Hello → 5ghd%43f=

Hello → 5ghd%43f=

**Adding salt.** This is typically done with an IV (Initialisation Vector) which must be the same on both sides. In WEP, the IV is incremented for each data frame, so that the cipher text changes.



**Cipher Block Chaining (CBC).** This method uses the IV for the first block, and then the results from the previous block to encrypt the current block.



Original image

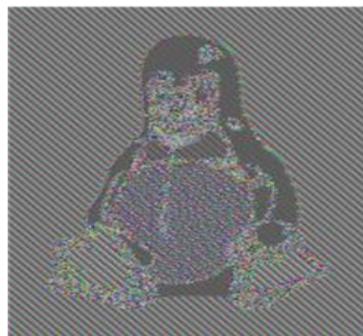


Image with AES using ECB



Image with AES using CBC

Image ref: [http://en.wikipedia.org/wiki/Block\\_cipher\\_modes\\_of\\_operation](http://en.wikipedia.org/wiki/Block_cipher_modes_of_operation)

eeeeeeeeeeeeeeeeeeeeeeeeeeee  
eeeeeeeeeeeeeeeeeeeeeeee

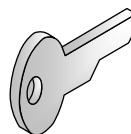
[eeeeeeee] [eeeeeeee] [eeeeeeee][eeeeeeee] [eeeeeeee] [eeeeeeee][eeeeee <PADDING>]

eeeeeeee

eeeeeeee

**Block 1**  
DES (64-bit)

**Block 2**  
DES (64-bit)



**Encrypted Block**



**Encrypted Block**

“bill12345”

ED291A7588D871B1

ED291A7588D871B1

ED291A7588D871B1ED291A7588D871B1ED291A7588D  
871B1ED291A7588D871B1ED291A7588D871B1ED291A  
7588D871B18D6DF6795DDEDACD

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**AES**

Key Entropy

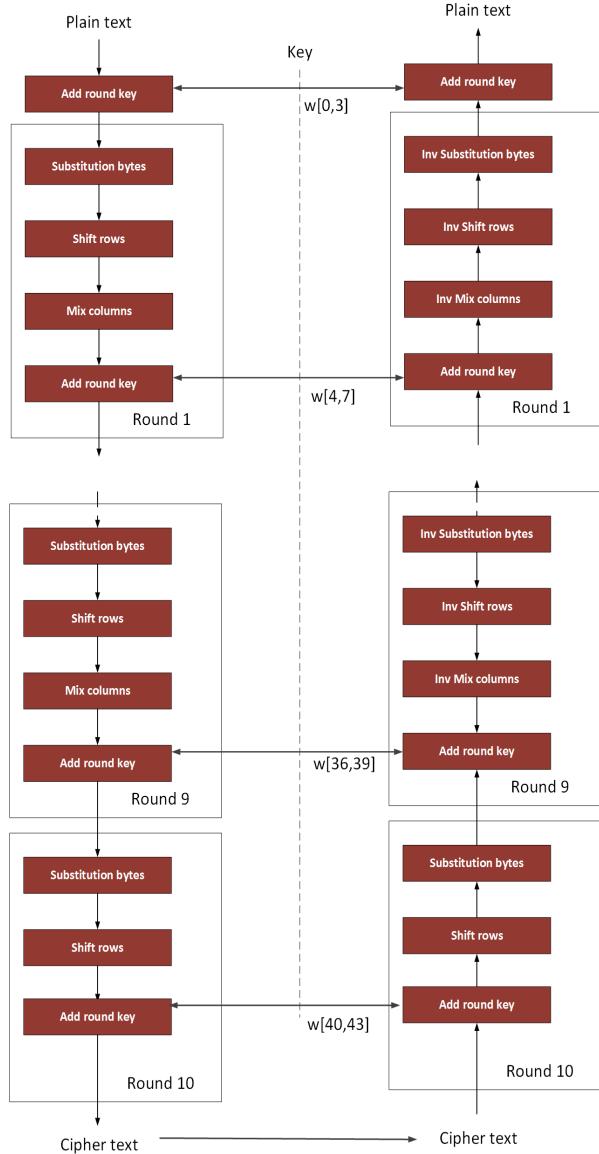


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# AES

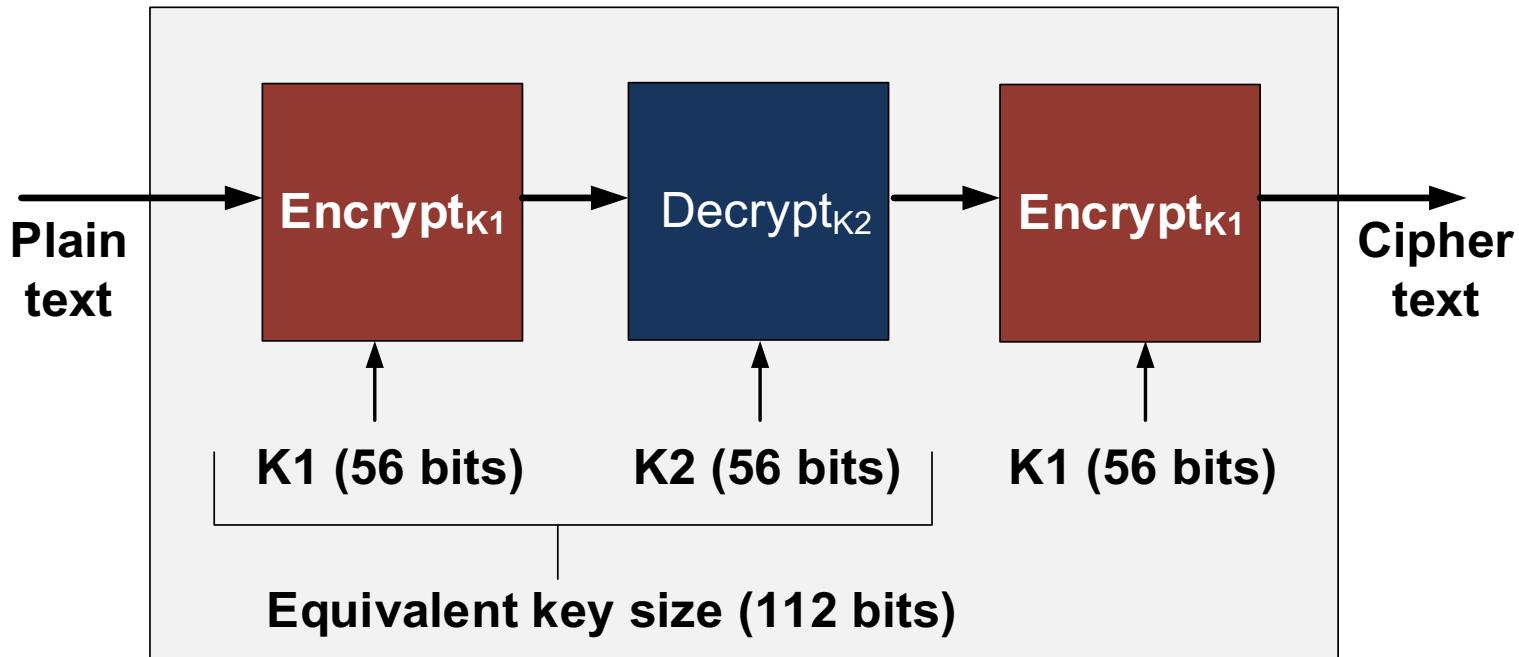


	0x	1x	2x	3x	4x	5x	6x	7x	8x	9x	Ax	Bx	Cx	Dx	Ex	Fx
0x	0x63	0x7c	0x77	0x7b	0xf2	0x6b	0x6f	0xc5	0x30	0x01	0x67	0x2b	0xfe	0xd7	0xab	0x76
1x	0xca	0x82	0xc9	0x7d	0xfa	0x59	0x47	0xf0	0xad	0xd4	0xa2	0xaf	0x9c	0xa4	0x72	0xc0
2x	0xb7	0xfd	0x93	0x26	0x36	0x3f	0xf7	0xcc	0x34	0xa5	0xe5	0xf1	0x71	0xd8	0x31	0x15
3x	0x04	0xc7	0x23	0xc3	0x18	0x96	0x05	0x9a	0x07	0x12	0x80	0xe2	0xeb	0x27	0xb2	0x75
4x	0x09	0x83	0x2c	0x1a	0x1b	0x6e	0x5a	0xa0	0x52	0x3b	0xd6	0xb3	0x29	0xe3	0x2f	0x84
5x	0x53	0xd1	0x00	0xed	0x20	0xfc	0xb1	0x5b	0x6a	0xcb	0xbe	0x39	0x4a	0x4c	0x58	0xcf
6x	0xd0	0xef	0xaa	0xfb	0x43	0x4d	0x33	0x85	0x45	0xf9	0x02	0x7f	0x50	0x3c	0x9f	0xa8
7x	0x51	0xa3	0x40	0x8f	0x92	0x9d	0x38	0xf5	0xbc	0xb6	0xda	0x21	0x10	0xff	0xf3	0xd2
8x	0xcd	0x0c	0x13	0xec	0x5f	0x97	0x44	0x17	0xc4	0xa7	0x7e	0x3d	0x64	0x5d	0x19	0x73
9x	0x60	0x81	0x4f	0xdc	0x22	0x2a	0x90	0x88	0x46	0xee	0xb8	0x14	0xde	0x5e	0x0b	0xdb
Ax	0xe0	0x32	0x3a	0xa0	0x49	0x06	0x24	0x5c	0xc2	0xd3	0xac	0x62	0x91	0x95	0xe4	0x79
Bx	0xe7	0xc8	0x37	0x6d	0x8d	0xd5	0x4e	0xa9	0x6c	0x56	0xf4	0xea	0x65	0x7a	0xae	0x08
Cx	0xba	0x78	0x25	0x2e	0x1c	0xa6	0xb4	0x06	0x8	0x74	0x1f	0x4b	0xbd	0x8b	0x8a	
Dx	0x70	0x3e	0xb5	0x66	0x48	0x03	0xf6	0x0e	0x61	0x35	0x57	0xb9	0x86	0xc1	0x1d	0x9e
Ex	0xe1	0xf8	0x98	0x11	0x69	0xd9	0x8e	0x94	0x9b	0x1e	0x87	0x9	0xce	0x55	0x28	0xdf
Fx	0x8c	0xa1	0x89	0x0d	0xbf	0xe6	0x42	0x68	0x41	0x99	0x2d	0x0f	0xb0	0x54	0xbb	0x16
	0x	1x	2x	3x	4x	5x	6x	7x	8x	9x	Ax	Bx	Cx	Dx	Ex	Fx
0x	0x52	0x09	0x6a	0xd5	0x30	0x36	0x5	0x38	0xb	0x40	0xa3	0x9e	0x81	0xf3	0xd7	0xfb
1x	0x7c	0x03	0x39	0x82	0x9b	0x2f	0xff	0x87	0x34	0x8e	0x43	0x44	0xc4	0xde	0x9	0xcb
2x	0x54	0x7b	0x94	0x32	0xa6	0xc2	0x23	0x3d	0xee	0x4c	0x95	0x0b	0x42	0xfa	0xc3	0x4e
3x	0x08	0x2e	0xa1	0x66	0x28	0xd9	0x24	0xb2	0x76	0x5b	0xa2	0x49	0x6d	0xb8	0xd1	0x25
4x	0x72	0xf8	0xf6	0x64	0x86	0x68	0x98	0x16	0xd4	0xa4	0x5c	0xcc	0x5d	0x65	0xb6	0x92
5x	0x6c	0x70	0x48	0x50	0xfd	0xed	0xb9	0xda	0x5e	0x15	0x46	0x57	0xa7	0x8d	0x9d	0x84
6x	0x90	0xd8	0xab	0x00	0x8c	0xbc	0xd3	0xa	0xf7	0xe4	0x58	0x05	0xb8	0x45	0x46	
7x	0xd0	0x2c	0x1e	0x8f	0xca	0x3f	0x0f	0x02	0xc1	0xaf	0xbd	0x03	0x01	0x13	0x8a	0x6b
8x	0x3a	0x91	0x11	0x41	0x4f	0x67	0xdc	0xea	0x97	0xf2	0xcf	0xce	0xf0	0xb4	0xe6	0x73
9x	0x96	0xac	0x74	0x22	0xe7	0xad	0x35	0x85	0xe2	0xf9	0x37	0xe8	0x1c	0x75	0xdf	0x6e
Ax	0x47	0xf1	0x1a	0x71	0x1d	0x29	0xc5	0x89	0x6f	0xb7	0x62	0x0e	0xaa	0x18	0xbe	0x1b
Bx	0xfc	0x56	0x3e	0x4b	0xc6	0xd2	0x79	0x20	0x9a	0xdb	0xc0	0xfe	0x78	0xcd	0x5a	0xf4
Cx	0x1f	0xdd	0xa8	0x33	0x88	0x07	0xc7	0x31	0xb1	0x12	0x10	0x59	0x27	0x80	0xec	0x5f
Dx	0x60	0x51	0x7f	0xa9	0x19	0xb5	0x4a	0x0d	0x2d	0xe5	0x7a	0x9f	0x93	0xc9	0x9c	0xef
Ex	0xa0	0xe0	0x3b	0x4d	0xae	0x2a	0xf5	0xb0	0xc8	0xeb	0x3c	0x83	0x53	0x99	0x61	
Fx	0x17	0x2b	0x04	0x7e	0xba	0x77	0xd6	0x26	0xe1	0x69	0x14	0x63	0x55	0x21	0x0c	0x7d

Cipher text

Cipher text

# 3-DES



# Chapter 2: Secret Key

Basics

Block or Stream?

Secret Key Methods

Salting

AES

**Key Entropy**



## Prof Bill Buchanan

<http://asecuritysite.com/crypto02>

<http://asecuritysite.com/encryption>

# Key Entropy

$$\text{Key Entropy} = \log_2(\text{Phrases}) = \frac{\log_{10}(\text{Phrases})}{\log_{10}(2)}$$

$$\text{Key Entropy} = \log_2(26^8) = \frac{\log_{10}(26^8)}{\log_{10}(2)} = 37.6 \text{ bits}$$

Password definition	Number of possible characters	Total number of passwords	Entropy (bits)
[0-9]	10	100,000,000	26.6
[a-z]	26	$2.08827 \times 10^{11}$	37.6
[a-zA-Z]	52	$5.34597 \times 10^{13}$	45.6
[a-zA-Z0-9]	62	$2.1834 \times 10^{14}$	47.6
[a-zA-Z0-9\$%!@+=]	68	$4.57163 \times 10^{14}$	48.7

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