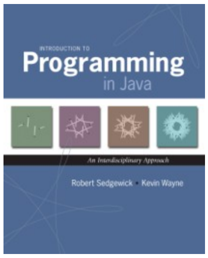
Encryption



Security on msnbc.com

Hidden flaw jeopardizes millions of online transactions

Mathematicians discover weakness in commonly used encryption schemes

By Paul Wagenseil

updated 2/15/2012 6:01:37 PM ET

Mathematicians based in Switzerland and the United States have discovered a small but the most commonly used digital encryption schemes, a flaw that could undermine the secu communication.

COMPUTERWORLD

Blogs

IT Blogwatch

A Daily Digest of IT Blogs from Richi Jennings

February 15, 2012 - 6:00 A.M.

RSA crypto: 'flawed', 'risky', 'quagmire of vulnerabilities'

TAGS: certificate, crypto, cryptography, Diffie-Hellman, encryption, key management, RSA, SSL

IT TOPICS: Applications, Cybercrime & Hacking, Financial IT, Government & Regulation, Internet, Privacy, Security, Security Hardware & Software

A group of six academic researchers have concluded that real-world RSA encryption keys are riskier than Diffie-Hellman-based ones. It seems that some of the random numbers used to generate them weren't, erm, random. In IT Blogwatch, bloggers wonder if the sky is falling.

The Register®

'Predictably random' public keys can be cracked - crypto boffins

Battling researchers argue over whether you should panic

By John Leyden • Get more from this author

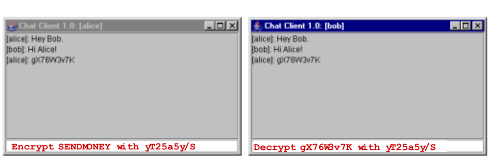
Posted in Enterprise Security, 16th February 2012 13:38 GMT

Analysis Cryptography researchers have discovered flaws in the key generation that underpins the security of important cryptography protocols, including SSL.

Secure Chat

Alice wants to send a secret message to Bob?

- Sometime in the past, they exchange a one-time pad.
- Alice uses the pad to encrypt the message.
- Bob uses the same pad to decrypt the message.



Key point. Without the pad, Eve cannot understand the message.

Encryption Machine

Goal. Design a machine to encrypt and decrypt data.

S	E	N	D	M	O	N	E	Y

encrypt

g	X	7	6	W	3	v	7	K

decrypt

S	E	N	D	M	O	N	E	Y

Encryption Machine

Goal. Design a machine to encrypt and decrypt data.

S	E	N	D	M	O	N	E	Y

encrypt

g	X	7	6	W	3	v	7	K

decrypt

S	E	N	D	M	O	N	E	Y

Enigma encryption machine.
- "Unbreakable" German code during WWII.
- Broken by Turing bombe.
- One of first uses of computers.
- Helped win Battle of Atlantic by locating U-boats.

A Digital World

Data is a sequence of bits. [bit = 0 or 1]
- Text.
- Programs, executables.
- Documents, pictures, sounds, movies, …

File formats. txt, pdf, java, exe, docx, pptx, jpeg, mp3, divx, …

computer with
a lens

computer with
earbuds

computer with
a radio

A Digital World

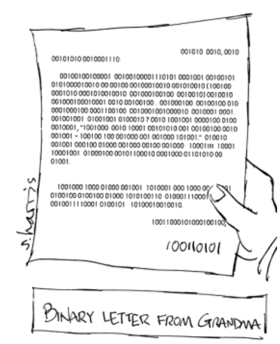
Data is a sequence of bits. [bit = 0 or 1]
- Text.
- Programs, executables.
- Documents, pictures, sounds, movies, …

File formats. txt, pdf, java, exe, docx, pptx, jpeg, mp3, divx, …

computer with
a cash dispenser

computer with
a ballot box

computer with
a heating element



A Digital World

Data is a sequence of bits. [bit = 0 or 1]
- Text.
- Programs, executables.
- Documents, pictures, sounds, movies, …

Base64 encoding. Use 6 bits to represent each alphanumeric symbol.

very weak type of encryption

Binary	Char	Binary	Char	Binary	Char	Binary	Char	Binary	Char	Binary	Char
000000	A	001011	L	010110	W	100001	h	101100	s	110111	3
000001	B	001100	M	010111	X	100010	i	101101	t	111000	4
000010	C	001101	N	011000	Y	100011	j	101110	u	111001	5
000011	D	001110	O	011001	Z	100100	k	101111	v	111010	6
000100	E	001111	P	011010	a	100101	l	110000	w	111011	7
000101	F	010000	Q	011011	b	100110	m	110001	x	111100	8
000110	G	010001	R	011100	c	100111	n	110010	y	111101	9
000111	H	010010	S	011101	d	101000	o	110011	z	111110	+
001000	I	010011	T	011110	e	101001	p	110100	0	111111	/
001001	J	010100	U	011111	f	101010	q	110101	1		
001010	K	010101	V	100000	g	101011	r	110110	2		

One-Time Pad Encryption

Encryption.
- Convert text message to N bits.

Base64 Encoding

char	dec	binary
A	0	000000
B	1	000001
…	…	…
M	12	001100
…	…	…

S	E	N	D	M	O	N	E	Y	message
010010	000100	001101	000011	001100	001110	001101	000100	011000	base64

One-Time Pad Encryption

Encryption.
- Convert text message to N bits.
- Generate N random bits (one-time pad).

S	E	N	D	M	O	N	E	Y	message
01001 0	00010 0	00110 1	00001 1	00110 0	00111 0	00110 1	00010 0	01100 0	base64
11001 0	01001 1	11011 0	11100 1	01101 0	11100 1	10001 0	11111 1	01001 0	random bits

One-Time Pad Encryption

Encryption.
- Convert text message to N bits.
- Generate N random bits (one-time pad).
- Take bitwise XOR of two bitstrings.

sum corresponding pair of bits: 1 if sum is odd, 0 if even

XOR Truth Table

x	y	x ^ y
0	0	0
0	1	1
1	0	1
1	1	0

S	E	N	D	M	O	N	E	Y	message
01001 0	00010 0	00110 1	00001 1	00110 0	00111 0	00110 1	00010 0	01100 0	base64
11001 0	01001 1	11011 0	11100 1	01101 0	11100 1	10001 0	11111 1	01001 0	random bits
10000 0	01011 1	11101 1	11101 0	01011 0	11011 1	10111 1	11101 1	00101 0	XOR

0 ^ 1 = 1

One-Time Pad Encryption

Encryption.
- Convert text message to N bits.
- Generate N random bits (one-time pad).
- Take bitwise XOR of two bitstrings.
- Convert binary back into text.

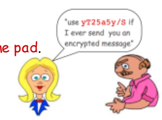
Base64 Encoding

char	dec	binary
A	0	00000 0
B	1	00000 1
…	…	…
W	22	01011 0
…	…	…

S	E	N	D	M	O	N	E	Y	message
01001 0	00010 0	00110 1	00001 1	00110 0	00111 0	00110 1	00010 0	01100 0	base64
11001 0	01001 1	11011 0	11100 1	01101 0	11100 1	10001 0	11111 1	01001 0	random bits
10000 0	01011 1	11101 1	11101 0	01011 0	11011 1	10111 1	11101 1	00101 0	XOR
g	X	7	6	W	3	v	7	K	encrypted

Secure Chat (review)

Alice wants to send a secret message to Bob?
- Sometime in the past, they exchange a one-time pad.
- Alice uses the pad to encrypt the message.
- Bob uses the same pad to decrypt the message.



Key point. Without the pad, Eve cannot understand the message.

One-Time Pad Decryption

Decryption.
- Convert encrypted message to binary.

g	X	7	6	W	3	v	7	K	encrypted

One-Time Pad Decryption

Decryption.
- Convert encrypted message to binary.

Base64 Encoding

char	dec	binary
A	0	00000 0
B	1	00000 1
…	…	…
W	22	01011 0
…	…	…

g	X	7	6	W	3	v	7	K	encrypted
10000 0	01011 1	11101 1	11101 0	01011 0	11011 1	10111 1	11101 1	00101 0	base64

One-Time Pad Decryption

Decryption.
- Convert encrypted message to binary.
- Use same N random bits (one-time pad).

g	X	7	6	W	3	v	7	K	encrypted
10000 0	01011 1	11101 1	11101 0	01011 0	11011 1	10111 1	11101 1	00101 0	base64
11001 0	01001 1	11011 0	11100 1	01101 0	11100 1	10001 0	11111 1	01001 0	random bits

One-Time Pad Decryption

Decryption.
- Convert encrypted message to binary.
- Use same N random bits (one-time pad).
- Take bitwise XOR of two bitstrings.

XOR Truth Table

x	y	x ^ y
0	0	0
0	1	1
1	0	1
1	1	0

g	X	7	6	W	3	v	7	K	encrypted
10000 0	01011 1	11101 1	11101 0	0101 0	11011 1	10111 1	11101 1	00101 0	base64
11001 0	01001 1	11011 0	11100 1	0110 0	11100 1	10001 0	11111 1	01001 0	random bits
01001 0	00010 0	00110 1	00001 1	0011 0	00111 0	00110 1	00010 0	01100 0	XOR

1 ^ 1 = 0

One-Time Pad Decryption

Decryption.
- Convert encrypted message to binary.
- Use same N random bits (one-time pad).
- Take bitwise XOR of two bitstrings.
- Convert back into text.

Base64 Encoding

char	dec	binary
A	0	00000 0
B	1	00000 1
…	…	…
M	12	00110 0
…	…	…

g	X	7	6	W	3	v	7	K	encrypted
10000 0	01011 1	11101 1	11101 0	01011 0	11011 1	10111 1	11101 1	00101 0	base64
11001 0	01001 1	11011 0	11100 1	01101 0	11100 1	10001 0	11111 1	01001 0	random bits
01001 0	00010 0	00110 1	00001 1	00110 0	00111 0	00110 1	00010 0	01100 0	XOR
S	E	N	D	M	O	N	E	Y	message

Why Does It Work?

Crucial property. Decrypted message = original message.

Notation	Meaning
a	original message bit
b	one-time pad bit
^	XOR operator
a ^ b	encrypted message bit
(a ^ b) ^ b	decrypted message bit

Why is crucial property true?
- Use properties of XOR.
- (a ^ b) ^ b = a ^ (b ^ b) = a ^ 0 = a

associativity of ^ always 0 identity

XOR Truth Table

x	y	x ^ y
0	0	0
0	1	1
1	0	1
1	1	0

One-Time Pad Decryption (with the wrong pad)

Decryption.
- Convert encrypted message to binary.

g	X	7	6	W	3	v	7	K	encrypted

One-Time Pad Decryption (with the wrong pad)

Decryption.
- Convert encrypted message to binary.

g	X	7	6	W	3	v	7	K	encrypted
10000 0	01011 1	11101 1	11101 0	01011 0	11011 1	10111 1	11101 1	00101 0	base64

One-Time Pad Decryption (with the wrong pad)

Decryption.
- Convert encrypted message to binary.
- Use wrong N bits (bogus one-time pad).

g	X	7	6	W	3	v	7	K	encrypted
10000 0	01011 1	11101 1	11101 0	01011 0	11011 1	10111 1	11101 1	00101 0	base64
10100 0	01110 0	11010 1	10111 1	01001 0	11100 1	10010 1	10101 0	00101 0	wrong bits

One-Time Pad Decryption (with the wrong pad)

Decryption.
- Convert encrypted message to binary.
- Use wrong N bits (bogus one-time pad).
- Take bitwise XOR of two bitstrings.

g	X	7	6	W	3	v	7	K	encrypted
10000 0	01011 1	11101 1	11101 0	0101 0	11011 1	10111 1	11101 1	00101 0	base64
10100 0	01110 0	11010 1	10111 1	0100 0	11100 1	10010 1	10101 0	00101 0	wrong bits
00100 0	00101 1	00111 0	01010 1	0001 0	00111 0	00101 0	01000 1	00000 0	XOR

One-Time Pad Decryption (with the wrong pad)

Decryption.
- Convert encrypted message to binary.
- Use wrong N bits (bogus one-time pad).
- Take bitwise XOR of two bitstrings.
- Convert back into text: Oops.

g	X	7	6	W	3	v	7	K	encrypted
10000 0	01011 1	11101 1	11101 0	01011 0	11011 1	10111 1	11101 1	00101 0	base64
10100 0	01110 0	11010 1	10111 1	01001 0	11100 1	10010 1	10101 0	00101 0	wrong bits
00100 0	00101 1	00111 0	01010 1	00010 0	00111 0	00101 0	01000 1	00000 0	XOR
I	L	O	V	E	O	K	R	A	wrong message

Goods and Bads of One-Time Pads

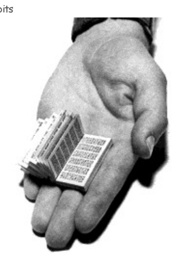
Good.
- Easily computed by hand.
- Very simple encryption/decryption processes.
- Provably unbreakable if bits are truly random. [Shannon, 1940s]

eavesdropper Eve sees only random bits

"one time" means one time only

Bad.
- Easily breakable if pad is re-used.
- Pad must be as long as the message.
- Truly random bits are very hard to come by.
- Pad must be distributed securely.

impractical for Web commerce



a Russian one-time pad

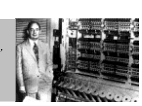
Pseudo-Random Bit Generator

Practical middle-ground.
- Let's make a "random"-bit generator gadget.
- Alice and Bob each get identical small gadgets.

instead of identical large one-time pads

How to make small gadget that produces "random" bits.
- Enigma machine.
- Linear feedback shift register.
- Linear congruential generator.
- Blum-Blum-Shub generator.
- …

" Anyone who considers arithmetical methods of producing random digits is, of course, in a state of sin. "
– Jon von Neumann (left)
– ENIAC (right)



Shift Register

Shift register terminology.

- Bit: 0 or 1.
- Cell: storage element that holds one bit.
- Register: sequence of cells.
- Seed: initial sequence of bits.
- Shift register: when clock ticks, bits propagate one position to left.

0	1	1	0	1	0	0	0	0	1	0	time t
1	1	0	1	0	0	0	0	1	0	?	time t + 1

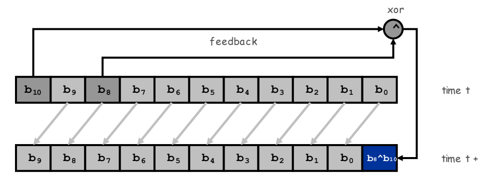
register

Linear Feedback Shift Register (LFSR)

{8, 10} linear feedback shift register.

- Shift register with 11 cells.
- Bit b_0 is is XOR of previous bits b_8 and b_{10}.
- Pseudo-random bit = b_0.

LFSR demo



Random Numbers

Q. Are these 2000 numbers random? If not, what is the pattern?

```
1100100100111101101110010110101110011000101111110100100001001101001011110011001001111111
101110000010101100010000111010100110100001111001001100111011111110101000001000010001010
010101000110000010111100010010011010110111100011010011011100111101011110010001001110101
011101000001010010001000110101010111000000010110000010011100010111011010010101100110000
1111111001100000111111000110000110111100111010011110011100100111011101110101010101000
000000010000000010100000010001000010101010010000000110100000111001000110111010111010100
010100001010001001000101011010100001100001001111001011100111001011110111001001010111011
000010101110010000101110100100101001101100011110111011001010101111000000100110000101111
10010010001110110101101011000110001110111101101010010110000110011100111110111100001010
011001000111111010110000100011100101011011100001101011001110001111101101100010110111010
0110101001111000011100110011011111111101000000010010000010110100010011001010111111100001
000011001010011111000111000110110110111011011010101101100000110111000111010110110100011
011001011101111001010100111000001110110001101011101110001010101101000000110010000111110
10011000100111110101110010001011010101001100000011111000011000110011110111111001010000
111000100110110101111011000100101110101100101000111100010110011010011111100111000011110
11001100101111111100100000011101000011010010011100110111011111010101000100000101010000
1000001001010001011000101001110100011101001011010011001100111111111100000000110000000
11110000011001100011111111011000000101110000100101100101100111100111110011110001110011
0110011111011111000010100011010001011100101001011100011001011011111001101000111110010110
001110011101101111010110100100011001101011111110001000001101010001110000101101100100110
111101111010010100100110001101111101110100010101001010000011000100011110101011001000001
111010001100100101111101100100010111101010010010000110110100111011001110101111101000100
0100101010101100000000111000000110110000111011100110101011111000001000110001010111010
```

A. No. This is output of {8, 10} LFSR with seed 01101000010!

LFSR Encryption

LFSR encryption.

- Convert text message to N bits.
- Initialize LFSR with small seed.
- Generate N bits with LFSR.
- Take bitwise XOR of two bitstrings.
- Convert binary back into text.

Base64 Encoding

char	dec	binary
A	0	000000
B	1	000001
…	…	…
w	22	010110
…	…	…

S	E	N	D	M	O	N	E	Y	message
010010	000100	001101	000011	001100	001110	001101	000100	011000	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	LFSR bits
100000	010111	111011	111010	010110	110111	101111	111011	001010	XOR
g	X	7	6	W	3	v	7	K	encrypted

LFSR Decryption

LFSR Decryption.

- Convert encrypted message to N bits.
- Initialize identical LFSR with same seed.
- Generate N bits with LFSR.
- Take bitwise XOR of two bitstrings.
- Convert binary back into text.

Base64 Encoding

char	dec	binary
A	0	000000
B	1	000001
…	…	…
M	12	001100
…	…	…

g	X	7	6	W	3	v	7	K	encrypted
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	LFSR bits
010010	000100	001101	000011	001100	001110	001101	000100	011000	XOR
S	E	N	D	M	O	N	E	Y	message

Goods and Bads of LFSR Encryption

Goods.

- Easily computed with simple machine.
- Very simple encryption/decryption process.
- Scalable: 20 cells for 1 million bits; 30 cells for 1 billion bits.
  [but need theory of finite groups to know where to put taps]

a commercially available LFSR

Bads.

- Still need secure, independent way to distribute LFSR seed.
- The bits are not truly random.
  [bits in our 11-bit LFSR cycle after $2^{11} - 1 = 2047$ steps]
- Experts have cracked LFSR.
  [more complicated machines needed]

Other LFSR Applications

What else can we do with a LFSR?
- DVD encryption with CSS.
- DVD decryption with DeCSS!
- Subroutine in military cryptosystems.

DVD Jon
(Norwegian hacker)

```
/*     efdtt.c     Author:  Charles M. Hannum <root@ihack.net>              */
/*     Usage is:  cat title-key scrambled.vob | efdtt >clear.vob           */

#define m(i)(x[i]^s[i+84])<<

                    unsigned char x[5]      ,y,s[2048];main(
                    n){for( read(0,x,5      );read(0,s ,n=2048
                              ); write(1   ,s,n)          )if(s
                   [y=s       [13]%8+20]  /16%4   ==1       ){int
                   i=m(       1)17  ^256 +m(0)    8,k       =m(2)
                   0,j=       m(4)   17^ m(3)    9^k*      2-k%8
                   ^8,a      =0,c     =26;for   (s[y]    -=16;
                  --c;j  *=2)a=       a*2^i&    1,i=i /2^j&1
                  <<24;for(j=          127;      ++j<n;c=c>
                                       y)
                                       c

                            +=y=i^i/8^i>>4^i>>12,
                   i=i>>8^y<<17,a^=a>>14,y=a^a*8^a<<6,a=a
                  >>8^y<<9,k=s[j],k           ="7Wo~'G_\216"[k
                  &7]+2^"cr3sfw6v;*k+>/n."[k>>4]*2^k*257/
                        8,s[j]=k^(k&k*2&34)*6^c+~y
                                      ;}}
```

http://www.cs.cmu.edu/~dst/DeCSS/Gallery

A Closing Profound Question

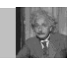
Q. What is a random number?

LFSR does not produce random numbers.
- It is a very simple deterministic machine.
- But not obvious how to distinguish the bits it produces from random.

Q. Are truly random processes found in nature?
- Motion of cosmic rays or subatomic particles?
- Mutations in DNA?

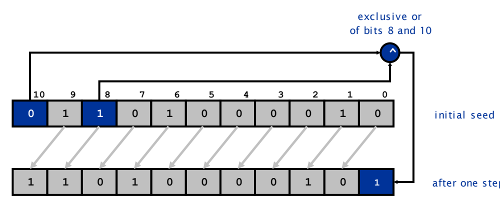
Q. Or, is the natural world a (not-so-simple) deterministic machine?

" God does not play dice. "
– Albert Einstein



Extra Slides

Linear Feedback Shift Register



One step of an 11-bit LFSR with initial seed 01101000010 and tap at position 8