OTP and AES: A Historical Transition Between two Systems of Cryptography

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Overview

A Brief Overview of Cryptography

OTP: The One Time Pad

AES: The Advanced Encryption standard
- High Level Structure
- Rounds

A Historical Transition
- Conflicts Throughout History
- Cryptography in Our Society

Questions

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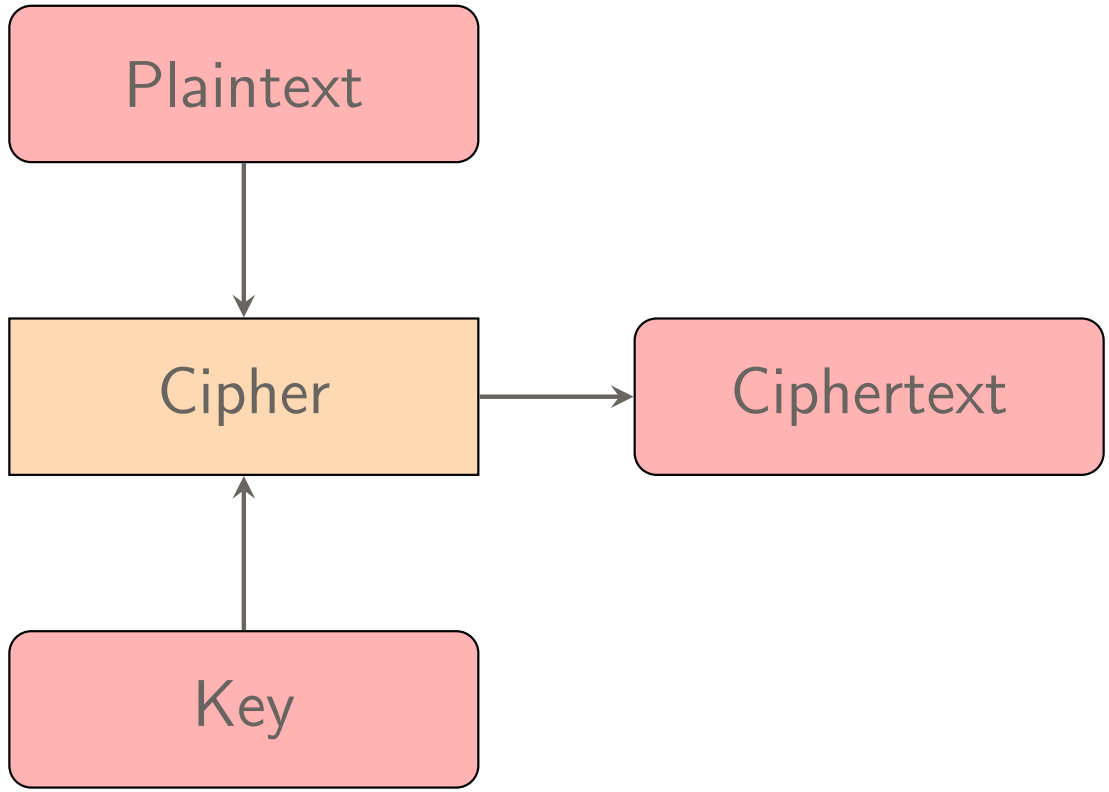
What is Cryptography?



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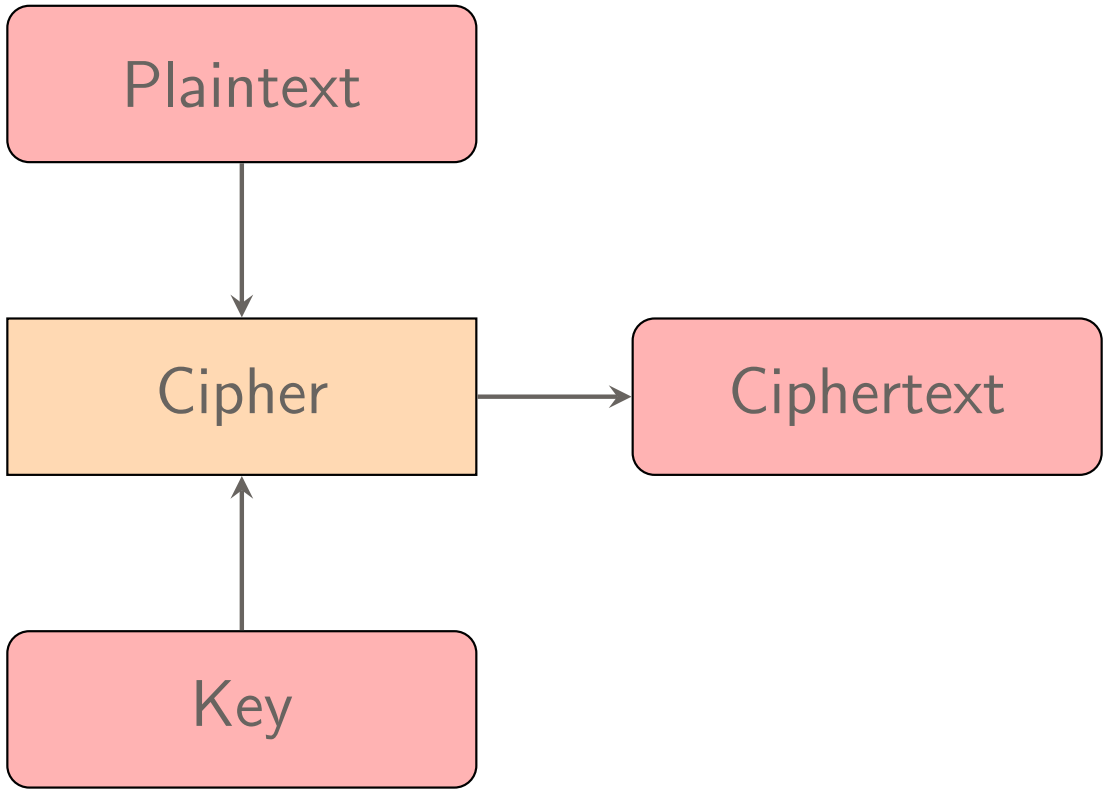


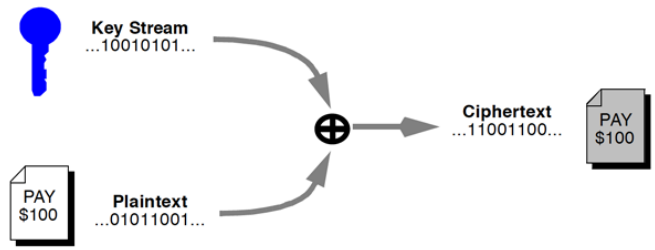
- "The art of writing or solving codes"
- The study of creating or breaking ciphers

OTP: The One Time Pad

- Great historical impact
- Basis for or important part of many of today's modern algorithms
- The key must be disposed of securely after being used once
- Symmetrical cipher: Keeping of a shared secret

OTP: The Cipher

- Stream Cipher
- Key length $\geq$ Message length
- Based on modular addition
- Perfect (forward) secrecy



A stream cipher[1]

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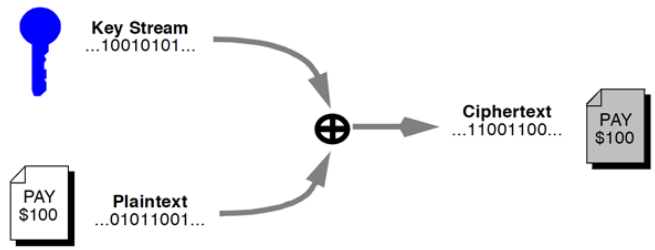


A stream cipher[1]

$$b + d = 1 + 3 = 4 = e$$
$$j + t = 9 + 19 = 28$$
$$(9 + 19) \mod 26 = 2 = c$$

OTP: The Cipher

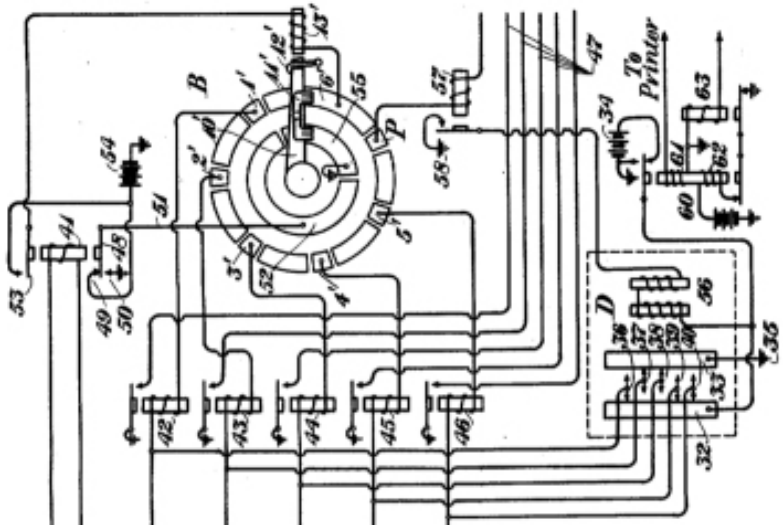
c	r	y	p	t	o	g	r	a	p	h	y
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
2	17	24	15	19	14	6	17	0	15	7	24

s	y	t	r	u	i	f	q	n	i	h	m
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
18	24	19	17	20	8	5	16	13	8	7	12

2+18	17+24	24+19	15+17	19+20	14+8	6+5	17+16
↓	↓	↓	↓	↓	↓	↓	↓
20	15	17	6	13	22	11	7
↓	↓	↓	↓	↓	↓	↓	↓
u	p	r	g	n	w	l	h

OTP: A Precursor to Modern Computer-aided Cryptography

- Gilbert Vernam: Secret signaling system of 1919



Patented 1919: Secret signaling system[2]

OTP: A Precursor to Modern Computer-aided Cryptography

- Gilbert Vernam: Secret signaling system of 1919
- Looping perforated tape: known-plaintext vulnerability
- Bits: Binary digits

Perforated tape[3]

AES: Design Goals

- Confusion: Each bit of the ciphertext should depend on multiple bits of the key
- Diffusion: The "avalanche effect"
- Two different implementations: Computationally or memory efficient

AES: The Advanced Encryption Standard

- Block Cipher
- The current N.I.S.T standard
- Original name: Rijndael; was selected as the successor to DES.

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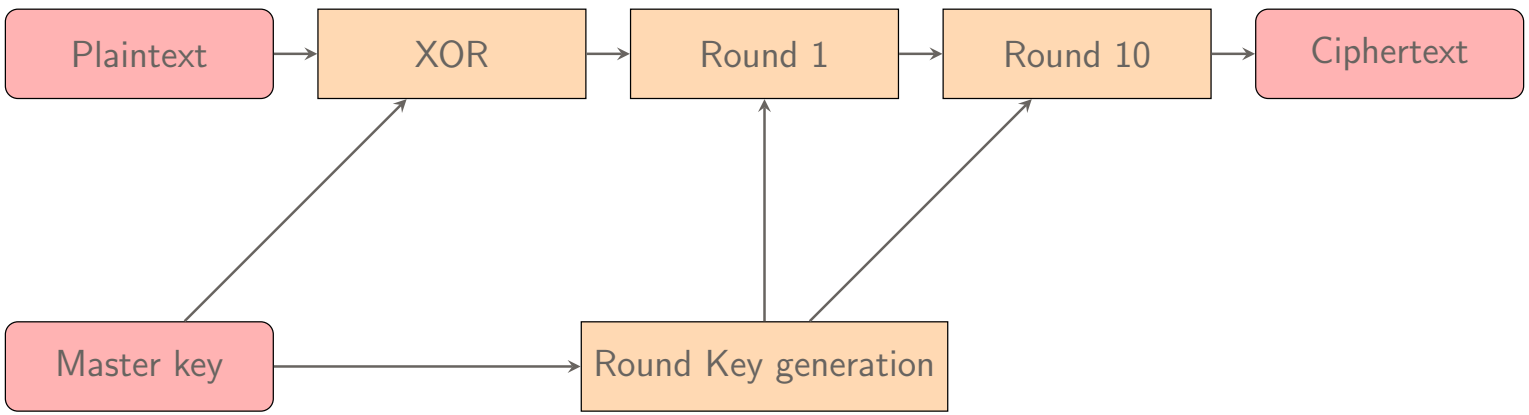
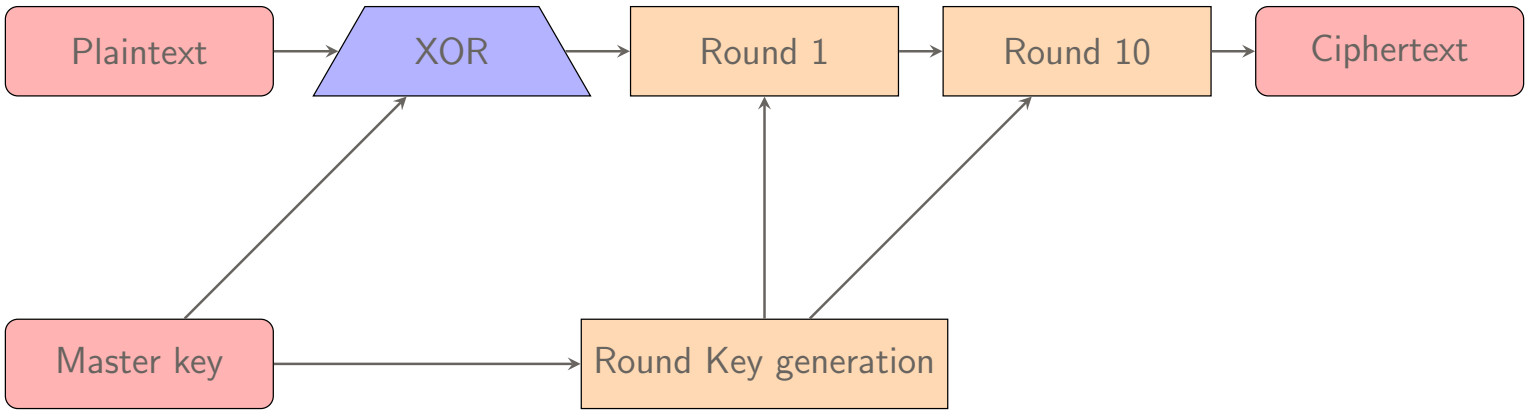
$$\begin{pmatrix} a_0 & a_4 & a_8 & a_{12} \\ a_1 & a_5 & a_9 & a_{13} \\ a_2 & a_6 & a_{10} & a_{14} \\ a_3 & a_7 & a_{11} & a_{15} \end{pmatrix}$$

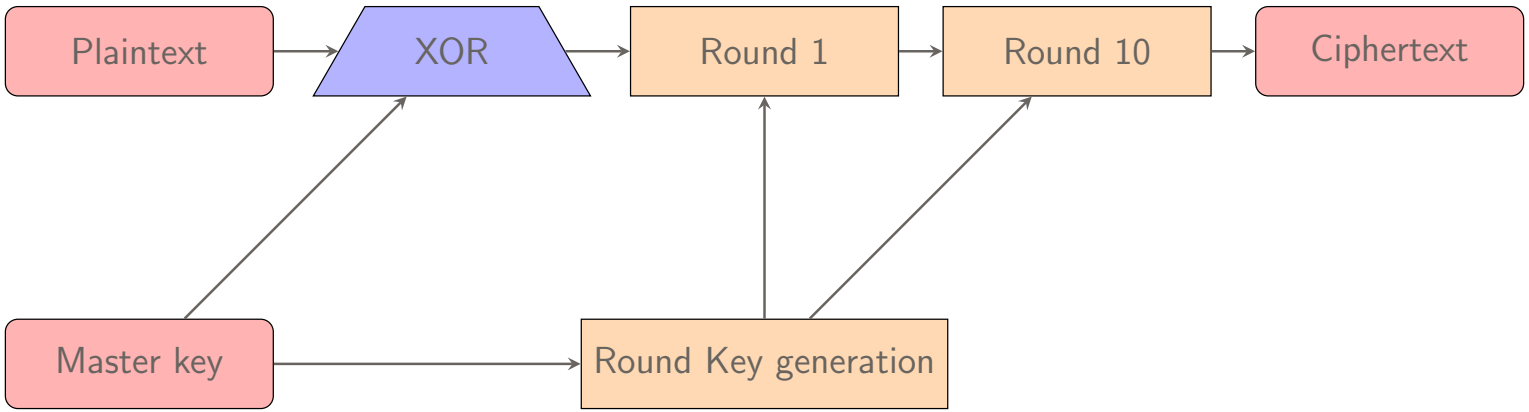
AES: High-Level Structure



AES: Rounds

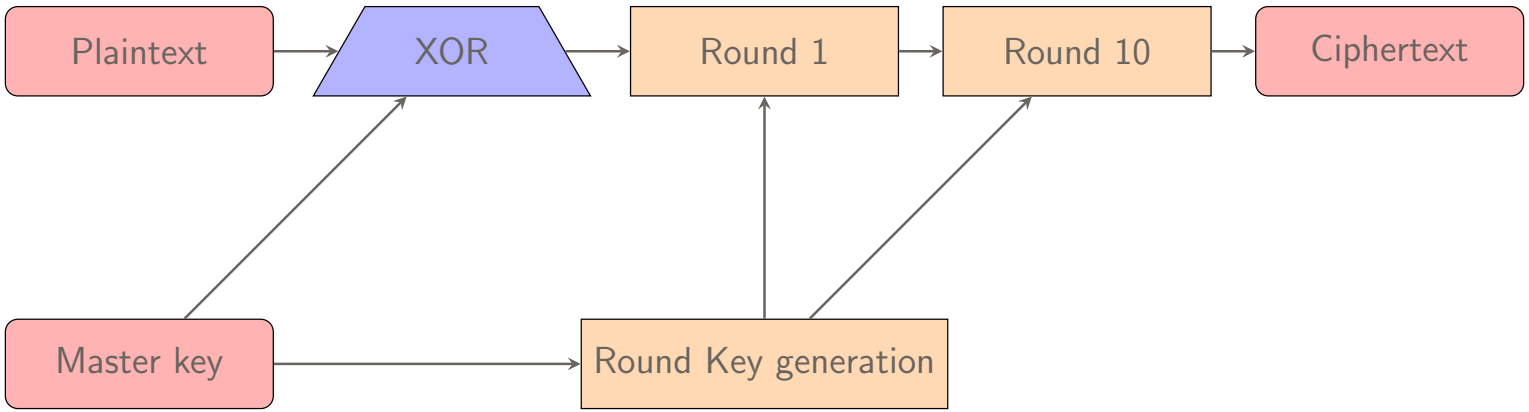

Plaintext
XOR
Round 1
Round 10
Ciphertext
Master key
Round Key generation

AES: Rounds



$$\begin{pmatrix} 1 & 0 & 1 & 0 \\ \oplus & \oplus & \oplus & \oplus \\ 0 & 1 & 1 & 0 \\ = & = & = & = \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

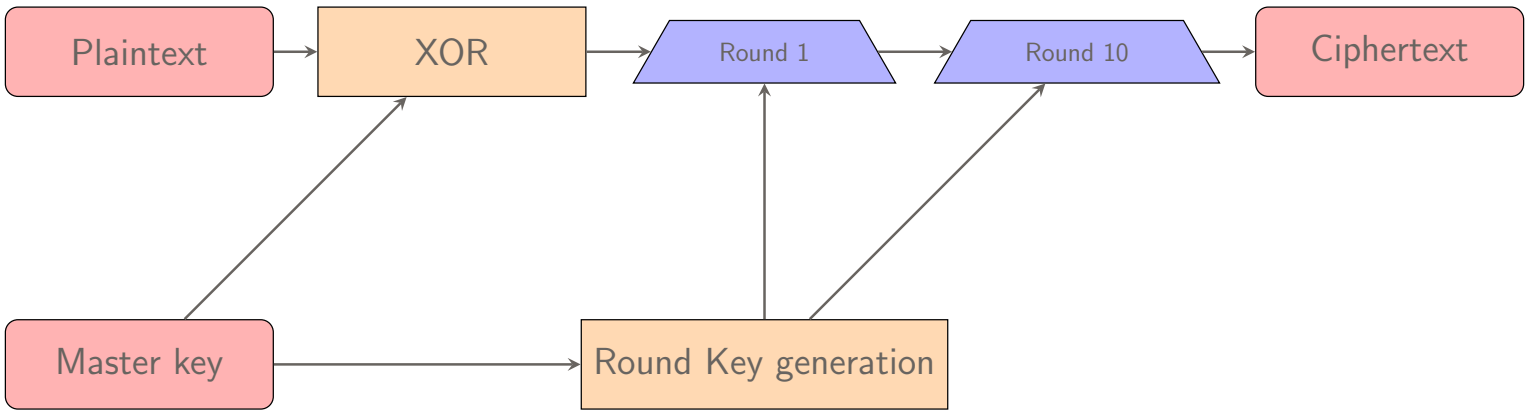
AES: Rounds



$$\begin{pmatrix} 1 & 0 & 1 & 0 \\ \oplus & \oplus & \oplus & \oplus \\ 0 & 1 & 1 & 0 \\ = & = & = & = \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

- Bitwise logical operation; can be performed directly by the CPU
- Addition mod 2
- Can randomize biased input

AES: Rounds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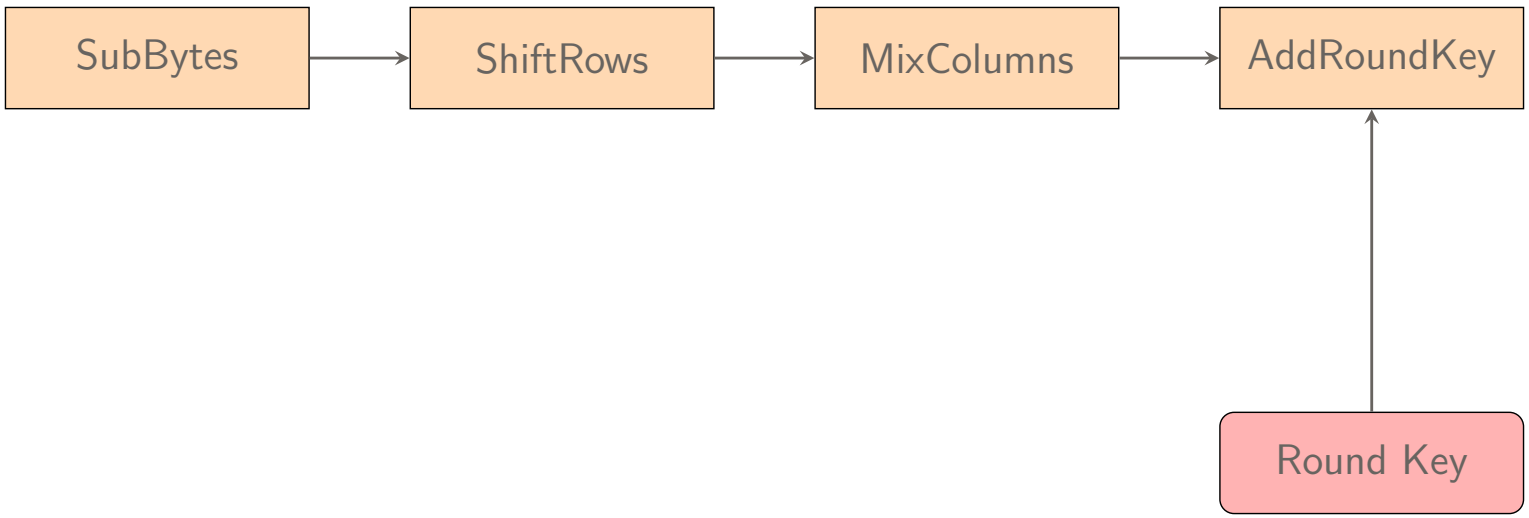

AES: SubBytes

S-Box Values																
S(rs)		s														
		0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
r	0	63	7c	77	7b	f2	6b	6f	c5	30	01	67	2b	fe	d7	ab	76
	1	ca	82	c9	7d	fa	59	47	f0	ad	d4	a2	af	9c	a4	72	c0
	2	b7	fd	93	26	36	3f	f7	cc	34	a5	e5	f1	71	d8	31	15
	3	04	c7	23	c3	18	96	05	9a	07	12	80	e2	eb	27	b2	75
	4	09	83	2c	1a	1b	6e	5a	a0	52	3b	d6	b3	29	e3	2f	84
	5	53	d1	00	ed	20	fc	b1	5b	6a	cb	be	39	4a	4c	58	cf
	6	d0	ef	aa	fb	43	4d	33	85	45	f9	02	7f	50	3c	9f	a8
	7	51	a3	40	8f	92	9d	38	f5	bc	b6	da	21	10	ff	f3	d2
	8	cd	0c	13	ec	5f	97	44	17	c4	a7	7e	3d	64	5d	19	73
	9	60	81	4f	dc	22	2a	90	88	46	ee	b8	14	de	5e	0b	db
	a	e0	32	3a	0a	49	06	24	5c	c2	d3	ac	62	91	95	e4	79
	b	e7	c8	37	6d	8d	d5	4e	a9	6c	56	f4	ea	65	7a	ae	08
	c	ba	78	25	2e	1c	a6	b4	c6	e8	dd	74	1f	4b	bd	8b	8a
	d	70	3e	b5	66	48	03	f6	0e	61	35	57	b9	86	c1	1d	9e
	e	e1	f8	98	11	69	d9	8e	94	9b	1e	87	e9	ce	55	28	df
	f	8c	a1	89	0d	bf	e6	42	68	41	99	2d	0f	b0	54	bb	16

A Rijndael S-Box[4]

AES: ShiftRows

$$\begin{pmatrix} a_{0,0} & a_{0,1} & a_{0,2} & a_{0,3} \\ a_{1,0} & a_{1,1} & a_{1,2} & a_{1,3} \\ a_{2,0} & a_{2,1} & a_{2,2} & a_{2,3} \\ a_{3,0} & a_{3,1} & a_{3,2} & a_{3,3} \end{pmatrix} \xrightarrow{\text{ShiftRows}} \begin{pmatrix} a_{0,0} & a_{0,1} & a_{0,2} & a_{0,3} \\ a_{1,1} & a_{1,2} & a_{1,3} & a_{1,0} \\ a_{2,2} & a_{2,3} & a_{2,0} & a_{2,1} \\ a_{3,3} & a_{3,0} & a_{3,1} & a_{3,2} \end{pmatrix}$$

AES: ShiftRows

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- Bytes are placed into the state in column order, but shifted across rows

AES: MixColumns

$$\begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix} \xrightarrow{\text{MixColumns}} \begin{pmatrix} s_0 \\ s_1 \\ s_2 \\ s_3 \end{pmatrix}$$

AES: MixColumns

$$\begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix} \xrightarrow{\text{MixColumns}} \begin{pmatrix} s_0 \\ s_1 \\ s_2 \\ s_3 \end{pmatrix}$$

$$\begin{aligned} s_0 &= 02a_0 + 03a_1 + 01a_2 + 01a_3 \\ s_1 &= 01a_0 + 02a_1 + 03a_2 + 01a_3 \\ s_2 &= 01a_0 + 01a_1 + 02a_2 + 03a_3 \\ s_3 &= 03a_0 + 01a_1 + 01a_2 + 02a_3 \end{aligned}$$

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- Each new byte is dependent on an entire column of four old bytes

AES: AddRoundKey

- Identical to the initializing XOR
- XORs the round key with the state

$$\begin{pmatrix} a_{0,0} & a_{0,1} & a_{0,2} & a_{0,3} \\ a_{1,0} & a_{1,1} & a_{1,2} & a_{1,3} \\ a_{2,0} & a_{2,1} & a_{2,2} & a_{2,3} \\ a_{3,0} & a_{3,1} & a_{3,2} & a_{3,3} \end{pmatrix} \oplus \begin{pmatrix} k_{0,0} & k_{0,1} & k_{0,2} & k_{0,3} \\ k_{1,0} & k_{1,1} & k_{1,2} & k_{1,3} \\ k_{2,0} & k_{2,1} & k_{2,2} & k_{2,3} \\ k_{3,0} & k_{3,1} & k_{3,2} & k_{3,3} \end{pmatrix}$$

The Crypto War: Past and Present

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Seal of the NSA[5]

Seal of the SVRRF[6]

Motivator for more Powerful Computing

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- Cryptologists vs. Cryptanalysts

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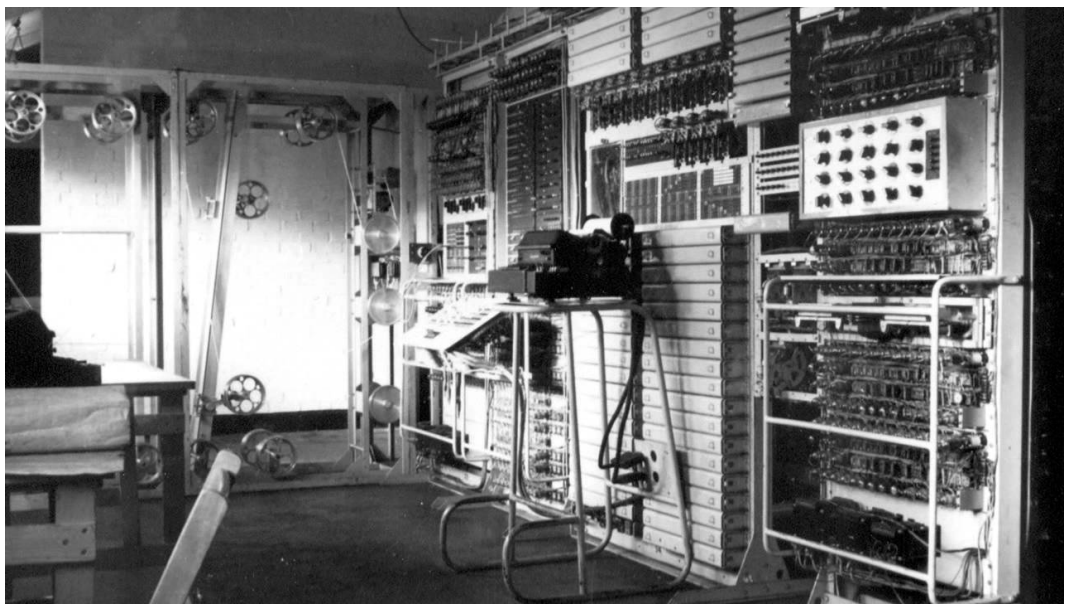
- Colossus: The world's first programmable computer



The Colossus computer[7]

Today's Issues

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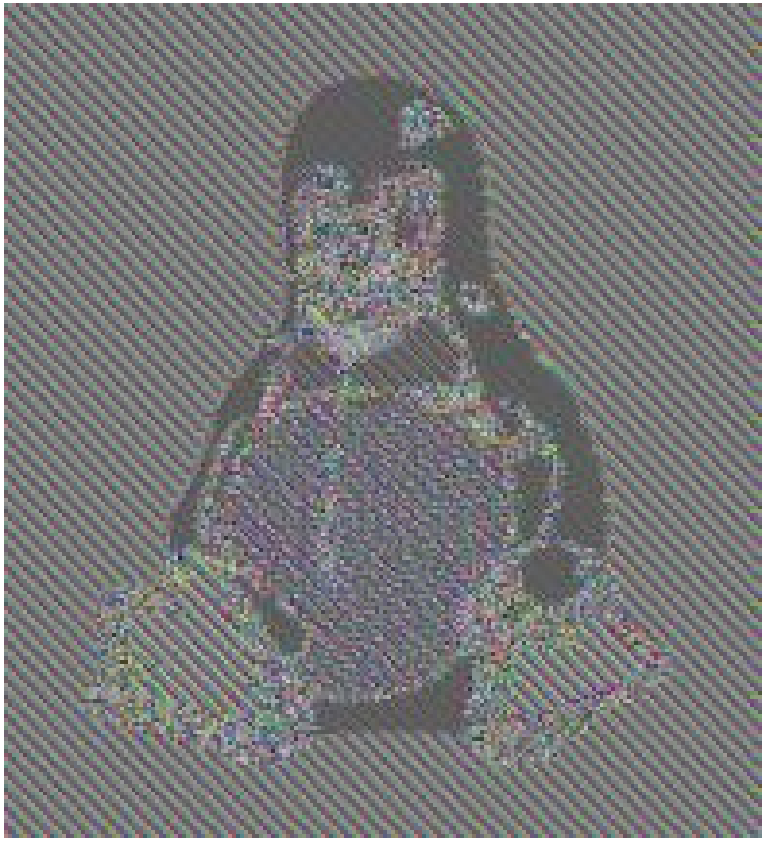
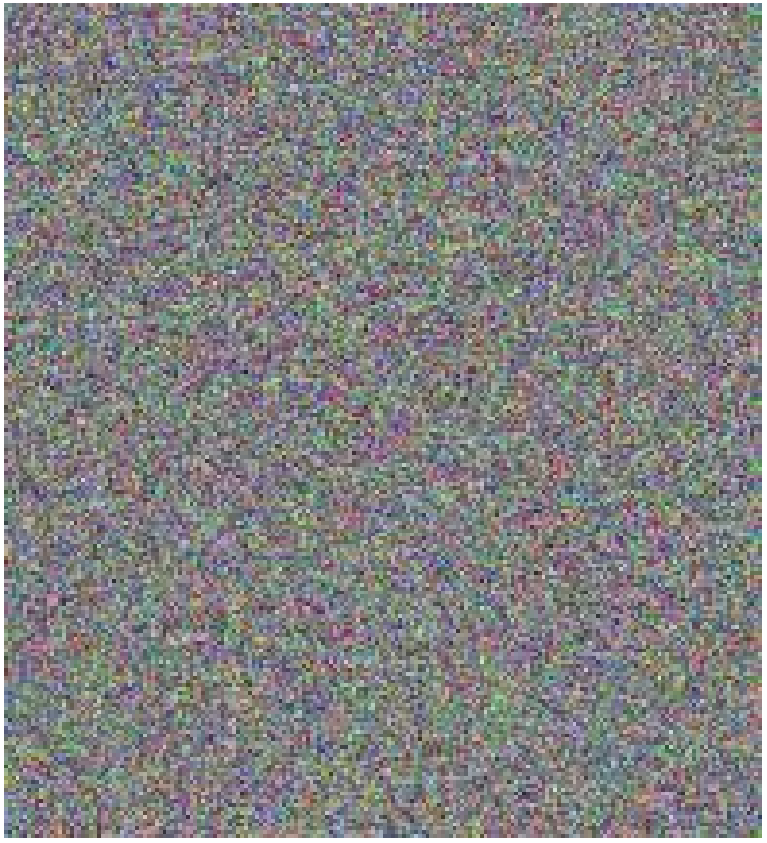


Today's Issues

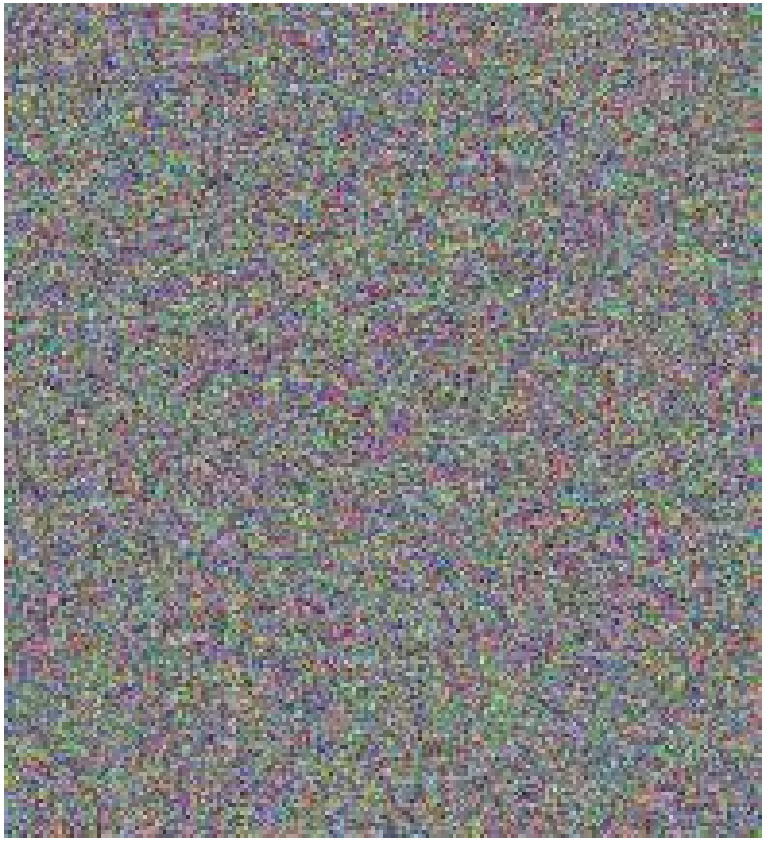
- Mode of operation: ECB
- Pseudo-random result



All pictures from[8]

Today's Issues

- Mode of operation: ECB
- Pseudo-random result
- CBC (Cipher Block Chaining)
- A variety of systems are necessary; key exchange



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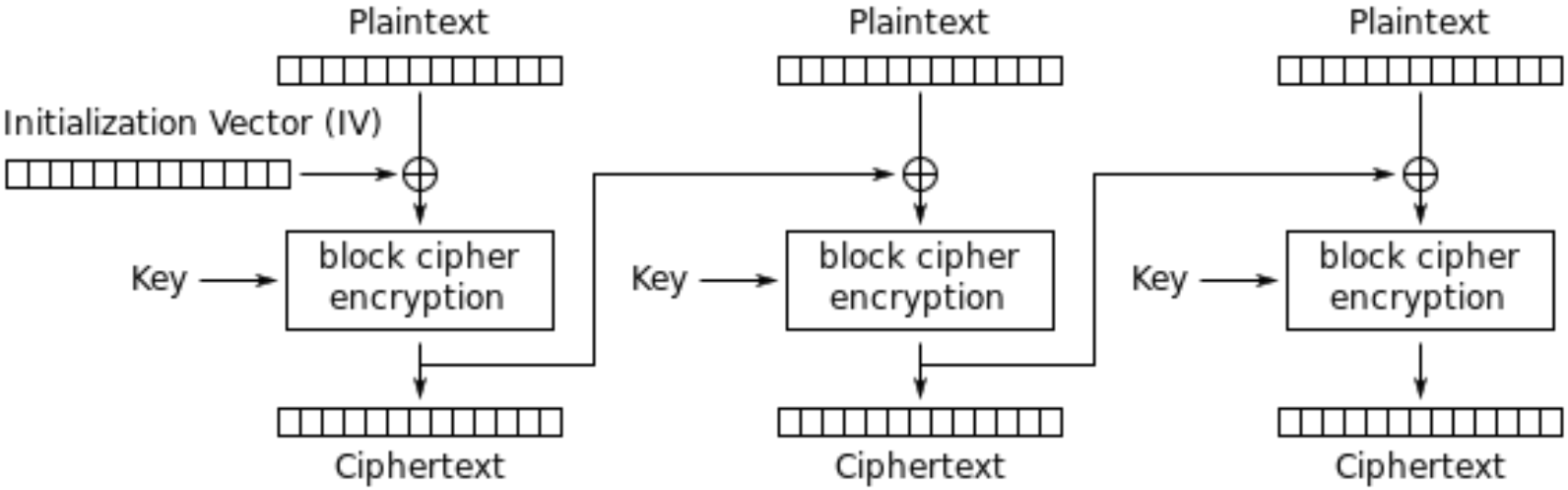

Cipher Block Chaining (CBC) mode encryption

CBC mode of operation[8]

New Possibilities and new Risks

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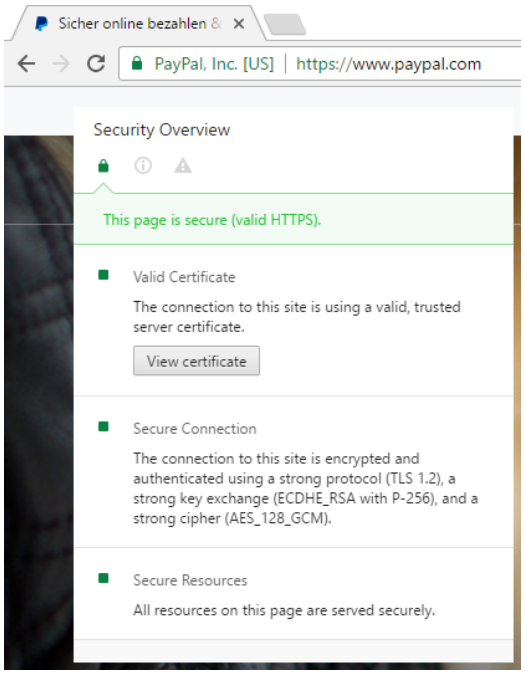
- Technology and social media

New Possibilities and new Risks

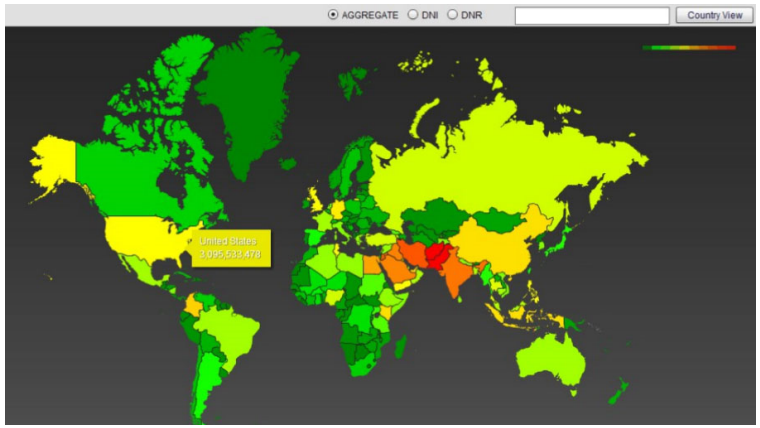
- Technology and social media
- Multiple protocols and algorithms
- Insecure or compromised data can be easily accessed



Mass surveillance

Mass surveillance

Edward Snowden[9]



Boundless Informant[10]

Mass surveillance

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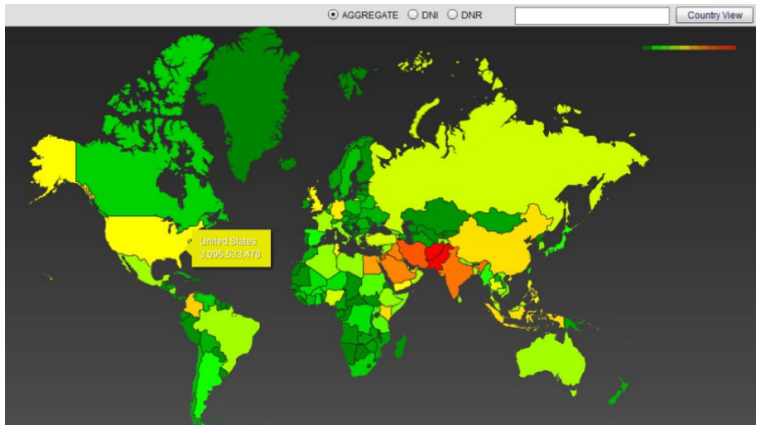
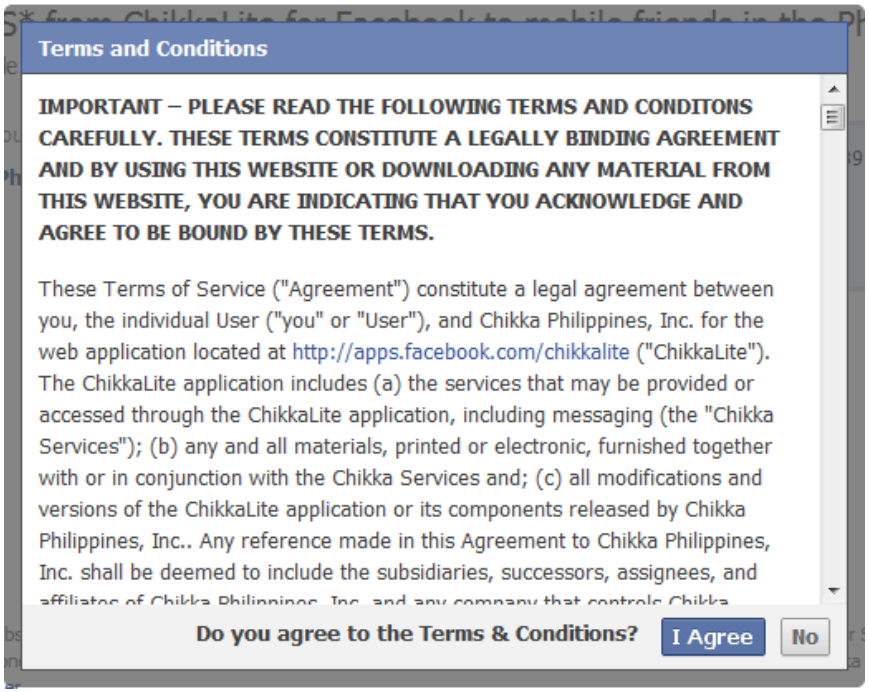


Boundless Informant[10]

- 3 billion data elements were collected over 30 days in the US alone
- Worldwide, including phone call metadata
- Data collection and storage is still active

Privacy: An Outdated Concept?



Facebook's terms and conditions[11]

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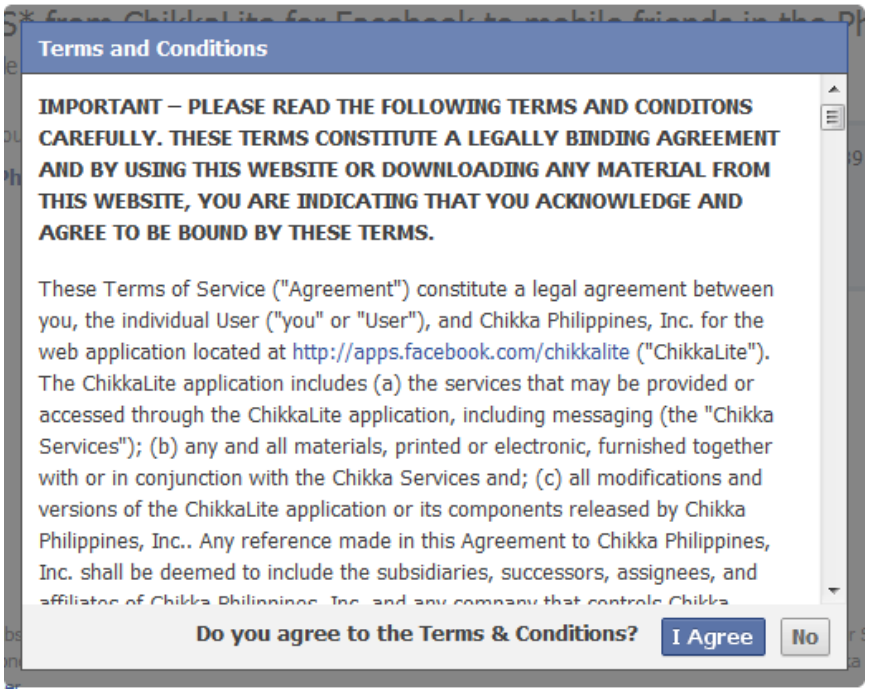

Facebook's terms and conditions[11]

- Historically academic subject
- Thrust into the public eye through recent revelations

Questions

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