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

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# Overview

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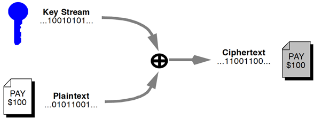
- Basis for or important part of many of today's modern algorithms
- The key must be disposed of securely after being used once
- Symmetrical cipher: Keeping of a shared secret

# OTP: The Cipher

- Stream Cipher



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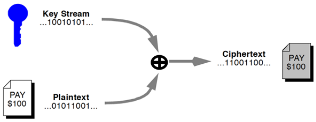

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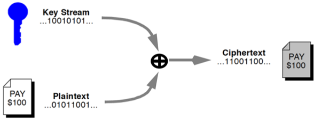


$b + d = 1 + 3 = 4 = e$

$j + t = 9 + 19 = 28$ A letter can't be assigned to 28!

$(9 + 19) \mod 26 = 2 = c$

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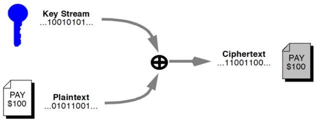
- Stream Cipher
- Key length $\geq$ Message length
- Based on modular addition
- Perfect (forward) secrecy

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# OTP: The Cipher

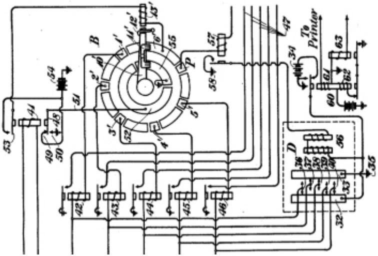
$$\begin{array}{cccccccccccc}
c & r & y & p & t & o & g & r & a & p & h & y \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
2 & 17 & 24 & 15 & 19 & 14 & 6 & 17 & 0 & 15 & 7 & 24
\end{array}$$

$$\begin{array}{cccccccccccc}
s & y & t & r & u & i & f & q & n & i & h & m \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
18 & 24 & 19 & 17 & 20 & 8 & 5 & 16 & 13 & 8 & 7 & 12
\end{array}$$

$$\begin{array}{cccccccc}
2+18 & 17+24 & 24+19 & 15+17 & 19+20 & 14+8 & 6+5 & 17+16 \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
20 & 15 & 17 & 6 & 13 & 22 & 11 & 7 \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
u & p & r & g & n & w & l & h
\end{array}$$

# OTP: A Precursor to Modern Computer-aided Cryptography

- Gilbert Vernam: Secret signaling system of 1919



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- Bits: Binary digits

OTP

AES: The Advanced Encryption standard

High Level Structure

Rounds

A Historical Transition

Conflicts Throughout History

Cryptography in Our Society

Questions

# AES: Terminology

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- Bit: Boolean value first conclusively described by Claude Shannon
- Byte: 8 Bits; can represent any number from 0-255

$0 \vee 1$

$(2^7 + 2^6 + 2^5 + 2^4 + 2^3 + 2^2 + 2^1 + 2^0)_b$
$(00000011)_b = 1 \cdot 2^1 + 1 \cdot 2^0 = 3$
$(16 + 1)_h$ $1 - 9; A; B; C; D; E; F$

$(B4)_h = 16 \cdot 11 + 4 \cdot 1 = 180$

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- Two different implementations: Computationally or memory efficient

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- Block Cipher

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

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# AES: The Advanced Encryption Standard

- Block Cipher
- The current N.I.S.T standard for SECRET and TOP-SECRET designated files
- Original name: Rijndael; was selected as the successor to DES.

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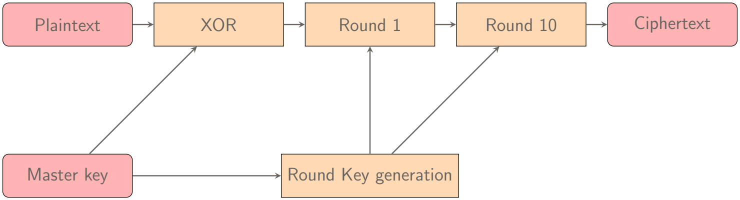
# AES: High-Level Structure



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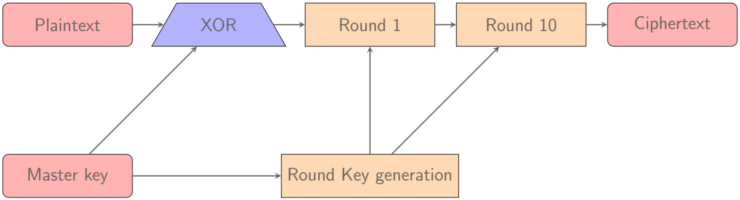
Plaintext
XOR
Round 1
Round 10
Ciphertext
Master key
Round Key generation

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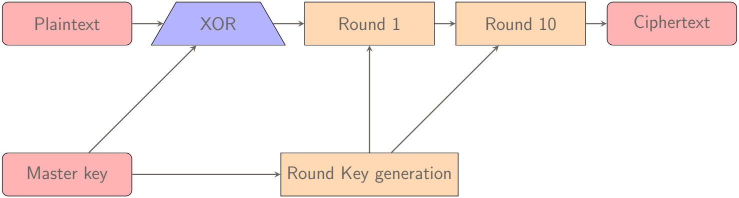


$$\begin{pmatrix} 1 & 0 & 1 & 0 \\ \bigoplus & \bigoplus & \bigoplus & \bigoplus \\ 0 & 1 & 1 & 0 \\ = & = & = & = \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

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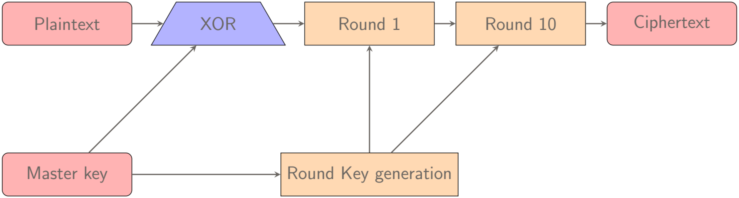


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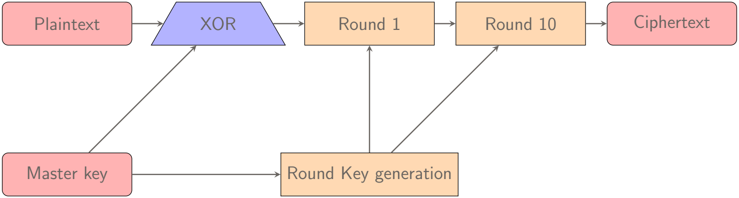


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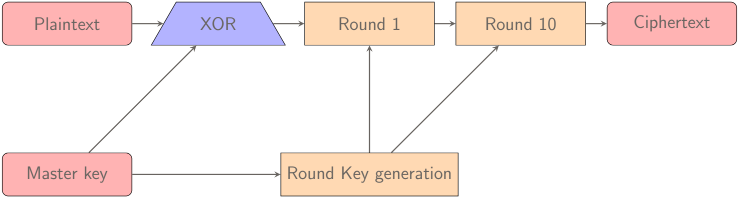


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- bitwise logical operation; can be performed directly by the CPU
- addition mod 2
- can randomize biased input

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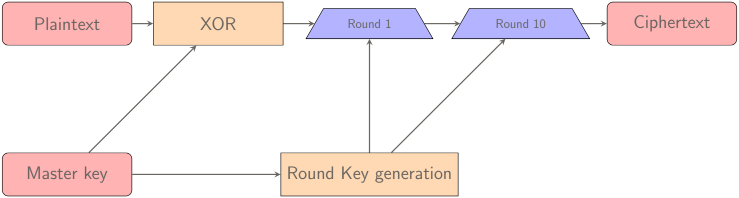
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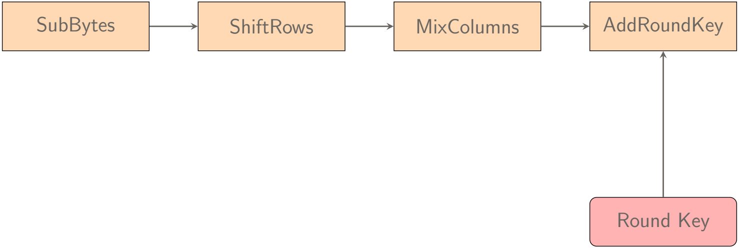

# AES: SubBytes

**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 |

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- Key-independence is accepted in return for non-linearity; this eliminates one of DES' major weaknesses
- Utilization of the multiplicative inverse: if $a \cdot b = 1$ then $b = a^{-1}$
- Maximizes non-linearity, but negatively impacts diffusion: $0^{-1} = 0$ and $1^{-1} = 1$

# AES: ShiftRows

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

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- One of the two primary sources of diffusion
- One small change to the plaintext should result in a large change to the ciphertext
- Bytes are placed into the state in column order, but shifted across rows

# AES: MixColumns

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

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

# AES: AddRoundKey

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

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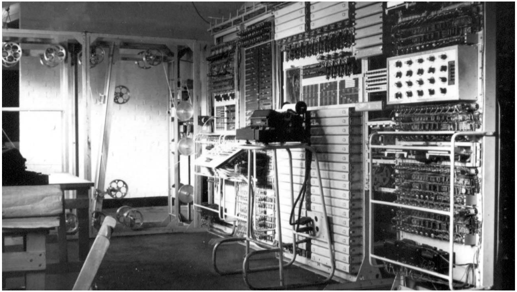
- Colossus: The world's first programmable computer



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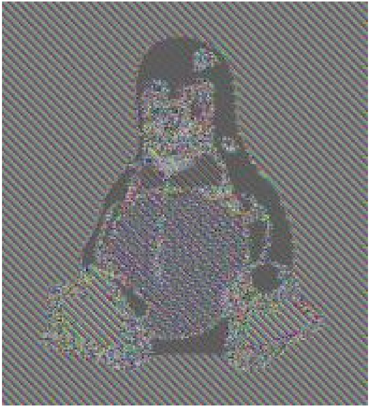

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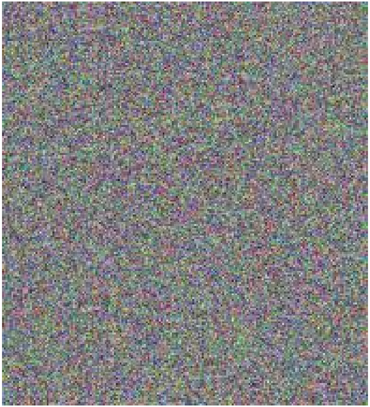

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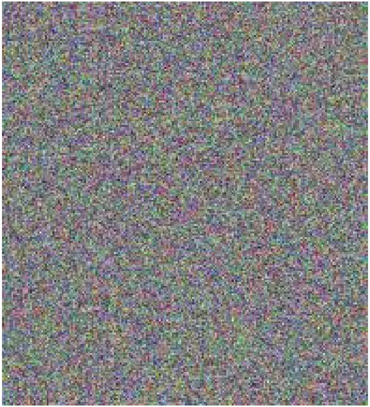

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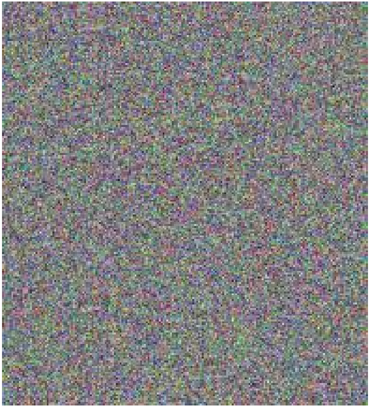
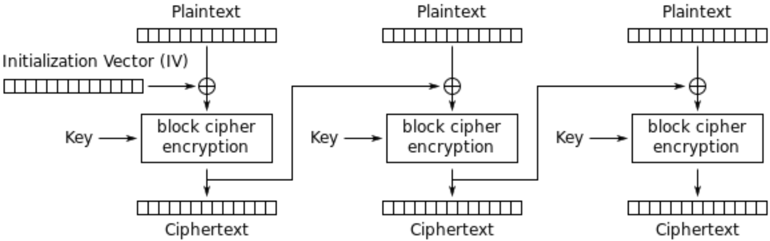
- A variety of systems are necessary; key exchange






Cipher Block Chaining (CBC) mode encryption

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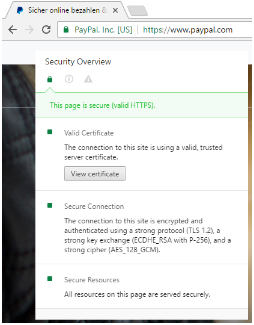

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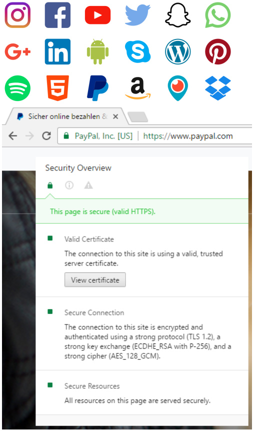
- Insecure or compromised data can be easily accessed



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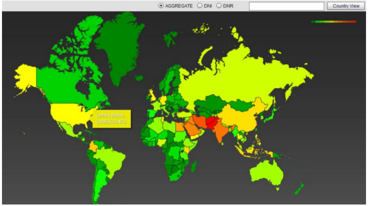
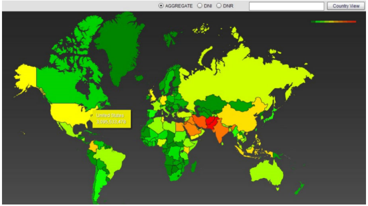


# Mass surveillance

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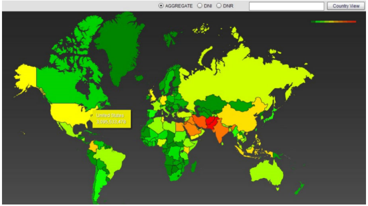


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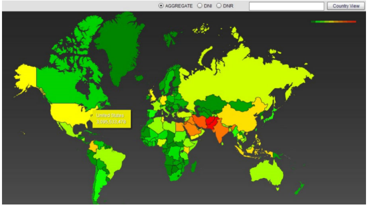
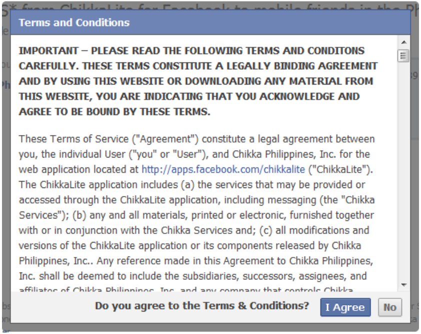



- 3 billion data elements were collected over 30 days in the US alone
- Data collection took place worldwide, including phone call metadata
- Data collection and storage is still active

# Privacy: An Outdated Concept?



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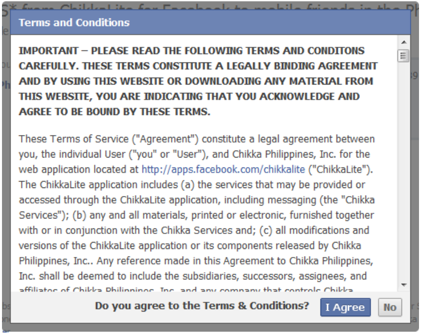


- Historically academic subject

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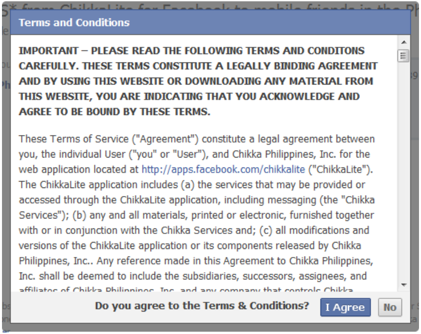


- Historically academic subject
- Thrust into the public eye through recent revelations

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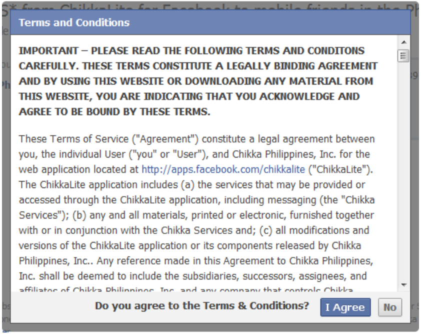


- Historically academic subject
- Thrust into the public eye through recent revelations
- Highly relevant to the daily lives of regular people for the first time

# Questions

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