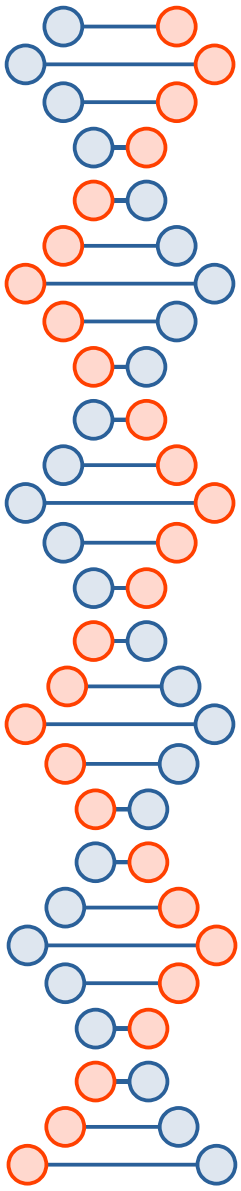
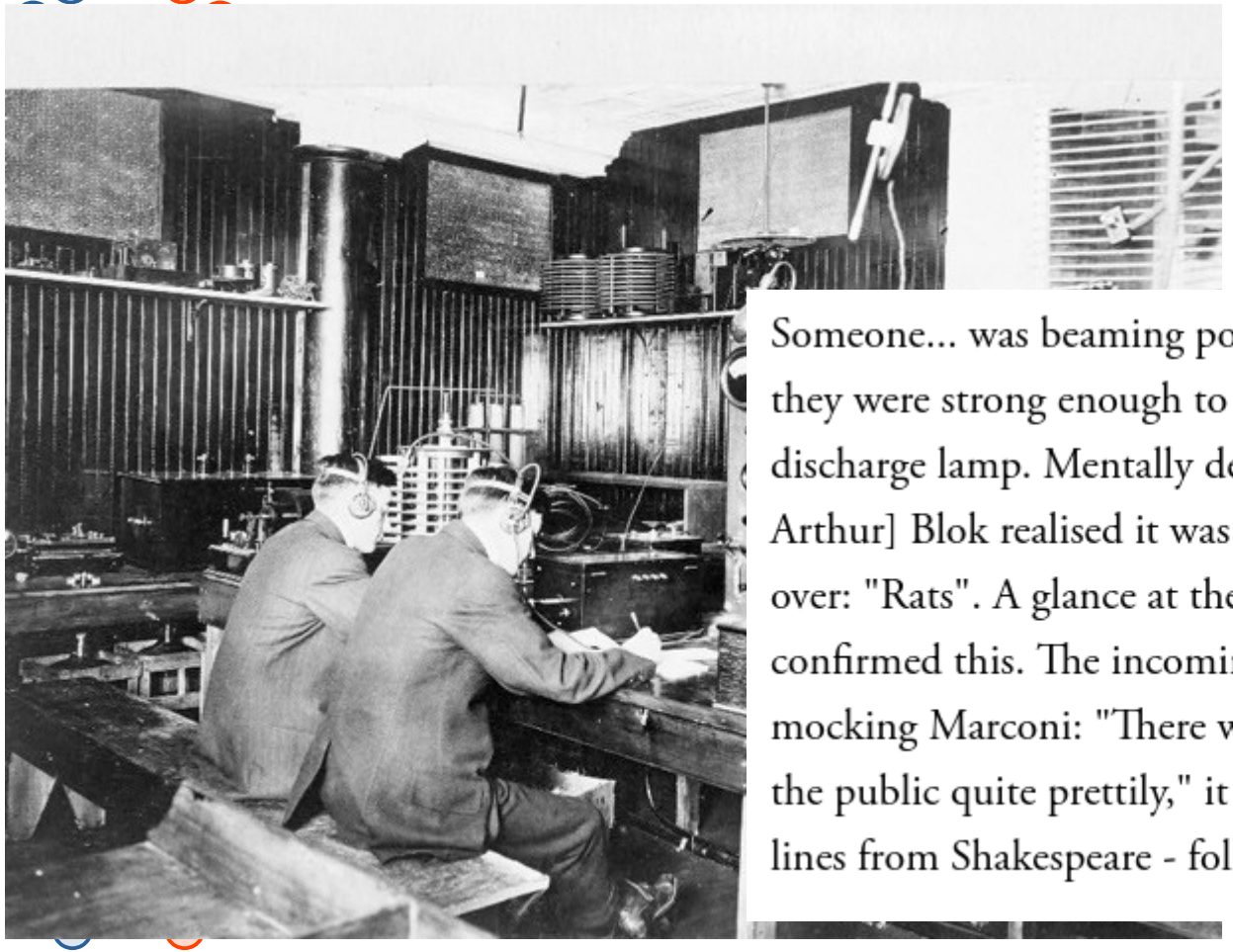


Symmetric Cryptography (Through the 1980s or so...)

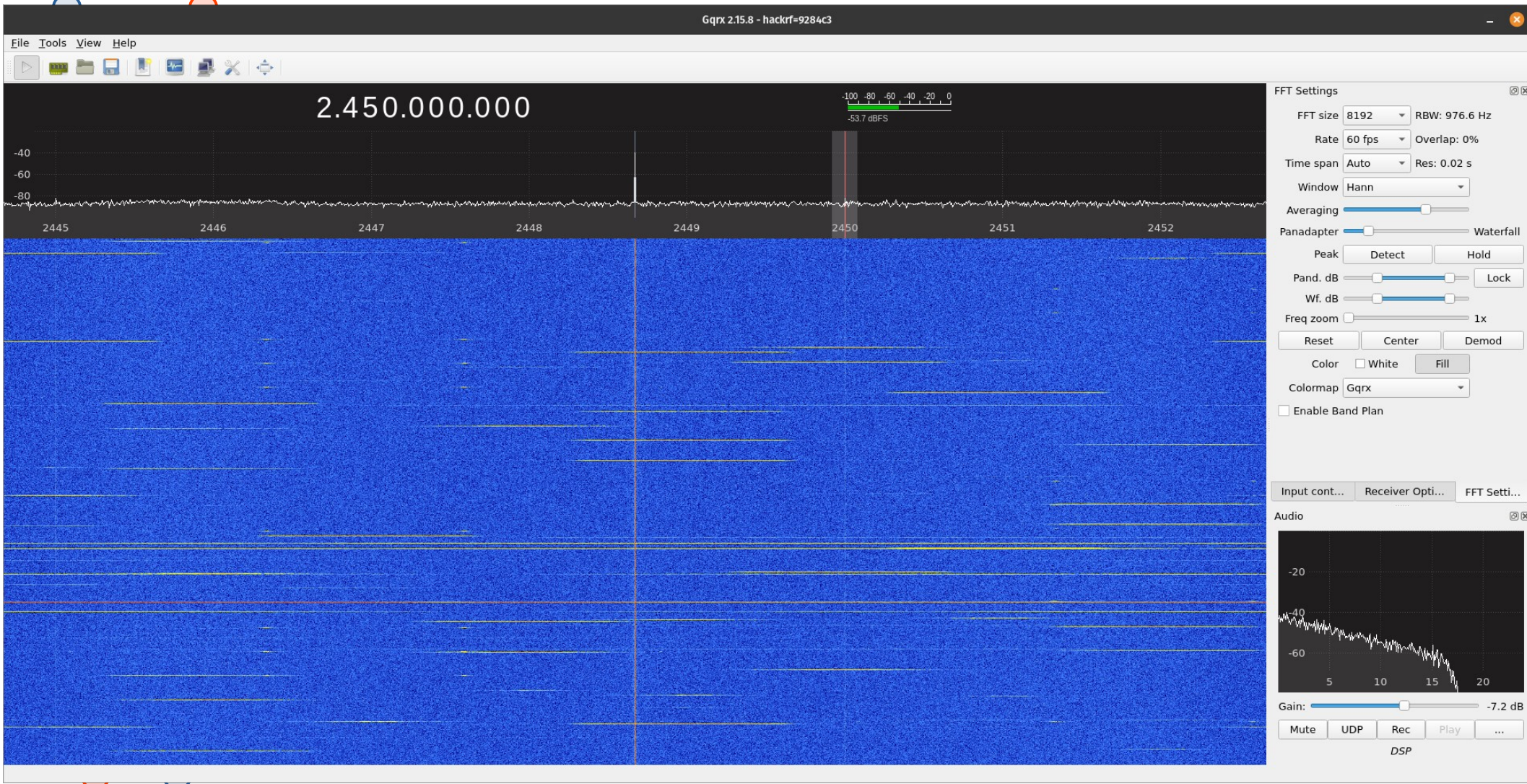
CSE 548 Spring 2024

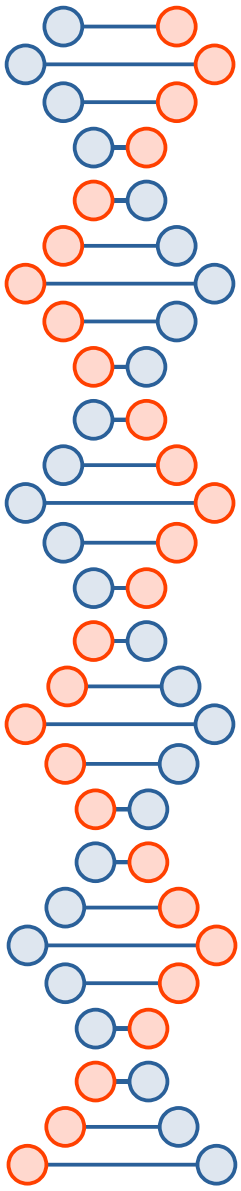
jedimaestro@asu.edu



Someone... was beaming powerful wireless pulses into the theatre and they were strong enough to interfere with the projector's electric arc discharge lamp. Mentally decoding the missive, [Fleming's assistant Arthur] Blok realised it was spelling one facetious word, over and over: "Rats". A glance at the output of the nearby Morse printer confirmed this. The incoming Morse then got more personal, mocking Marconi: "There was a young fellow of Italy, who diddled the public quite prettily," it trilled. Further rude epithets - apposite lines from Shakespeare - followed.

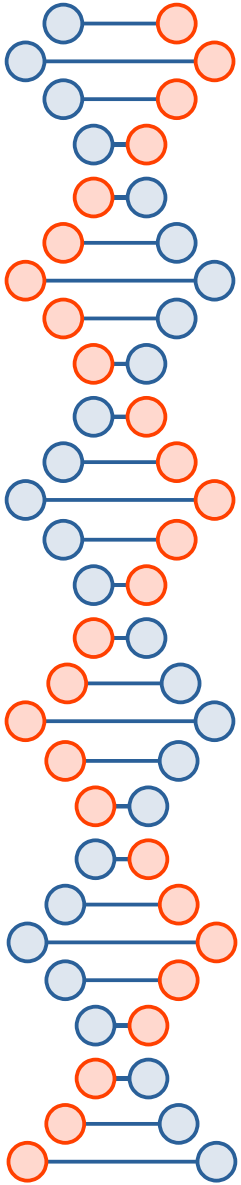
https://www.theatlantic.com/technology/archive/2011/12/the-great-wireless-hack-of-1903/250665/


Gqrx 2.15.8 - hackrf=9284c3
File Tools View Help
2.450.000.000
-100 -80 -60 -40 -20 0
-53.7 dBFS
-40
-60
-80
2445
2446
2447
2448
2449
2450
2451
2452
FFT Settings
FFT size 8192
RBW: 976.6 Hz
Rate 60 fps
Overlap: 0%
Time span Auto
Res: 0.02 s
Window Hann
Averaging
Panadapter
Waterfall
Peak
Detect
Hold
Pand. dB
Lock
Wf. dB
Freq zoom
1x
Reset
Center
Demod
Color
White
Fill
Colormap Gqrx
Enable Band Plan
Input cont...
Receiver Opti...
FFT Setti...
Audio
-20
-40
-60
5
10
15
20
Gain:
-7.2 dB
Mute
UDP
Rec
Play
...
DSP



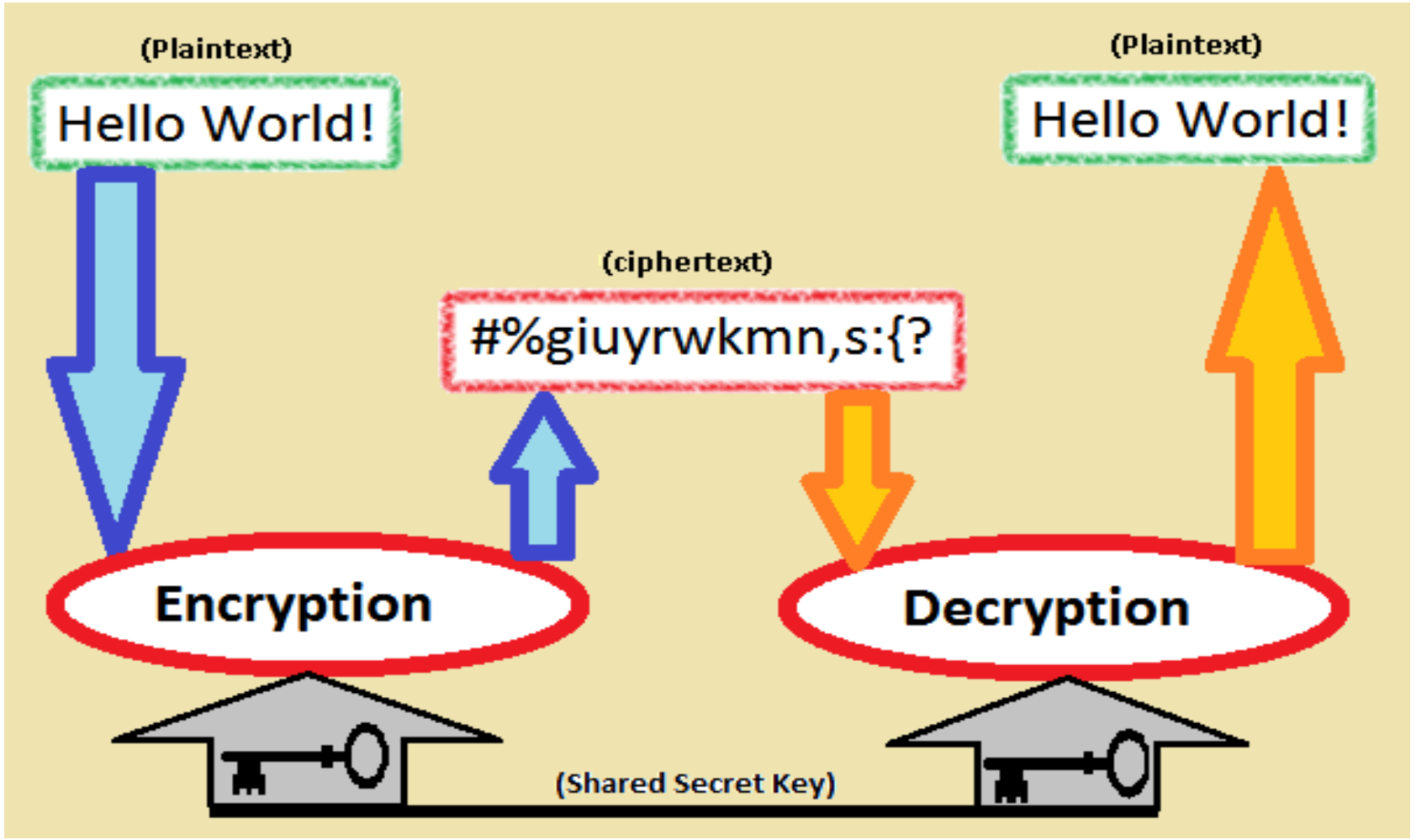
Basics of crypto...

- Symmetric encryption
  - Assumes two parties wishing to communicate already have a shared secret
- Asymmetric encryption
  - Makes different assumptions (*e.g.*, that everybody knows the public key or that the eavesdropper is passive)
  - Quantum computers break current algorithms that are used in practice
- Secure hash functions and message authentication

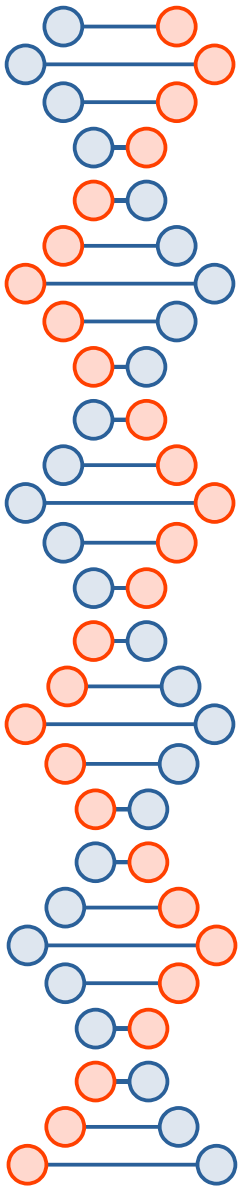


Symmetric Crypto

- Confidentiality
- Integrity
- ~~Availability~~
- Authentication
- ~~Non-repudiation~~
- ~~A way to distribute the shared secret keys~~

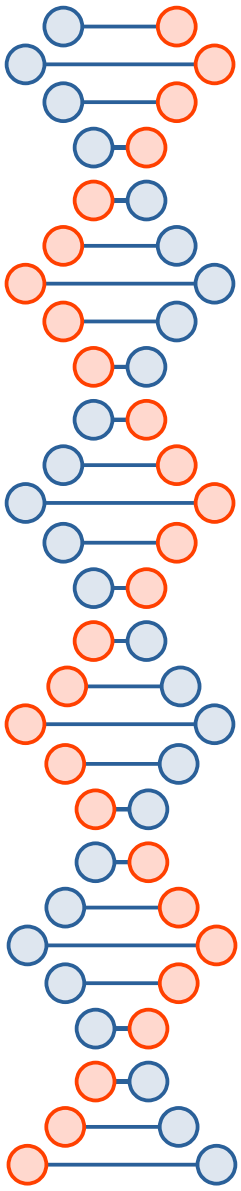


Source: Wikipedia



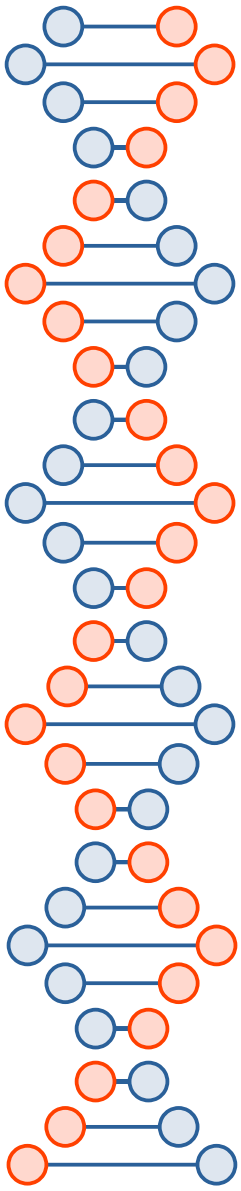
Terminology

- Plaintext – before encryption, easy to read
- Ciphertext – after encryption, hopefully indecipherable without the key
- Key – the shared secret, typically just bits that were generated with a high entropy process



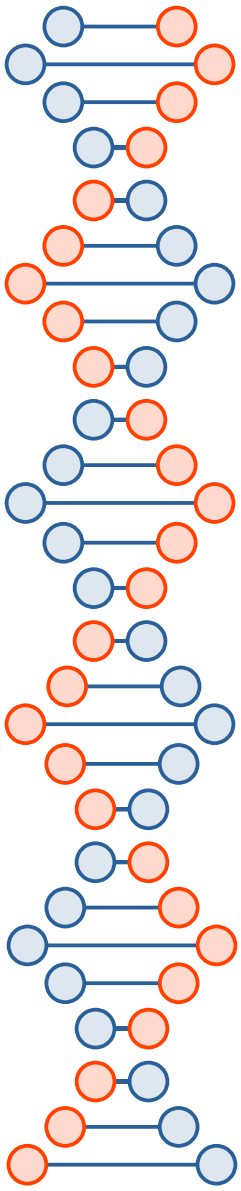
Review on your own...

- Caesar Cipher
- Vigenere Cipher and related attacks



Modern symmetric crypto

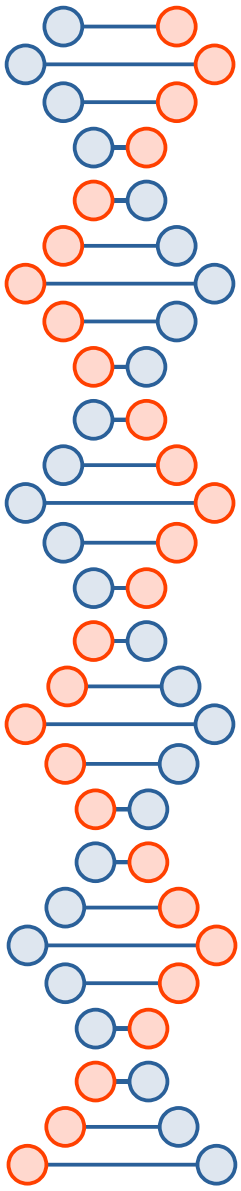
- Mostly:
  - Substitution
  - Permutation (or transposition)
  - XOR



Substitution

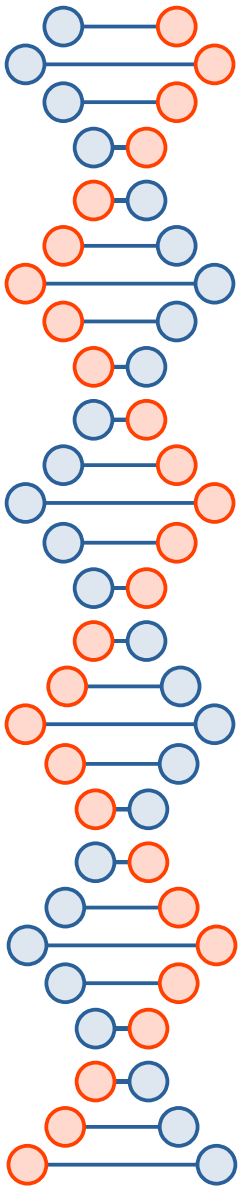
HELLO WORLD

TNWWX DXPWE



Permutation

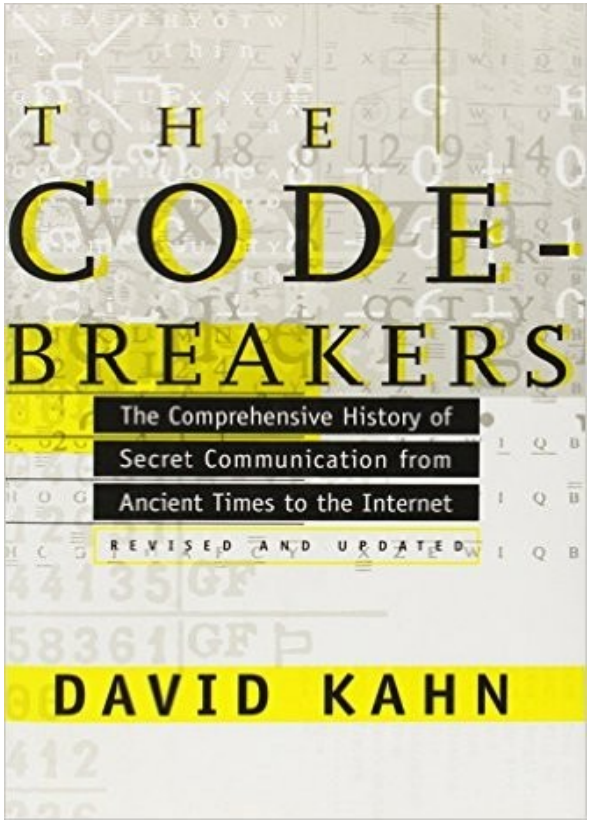
ABCD	ABDC	ACBD	ACDB	ADBC	ADCB
BACD	BADC	BCAD	BCDA	BDAC	BDCA
CABD	CADB	CBAD	CBDA	CDAB	CDBA
DABC	DACB	DBAC	DBCA	DCAB	DCBA

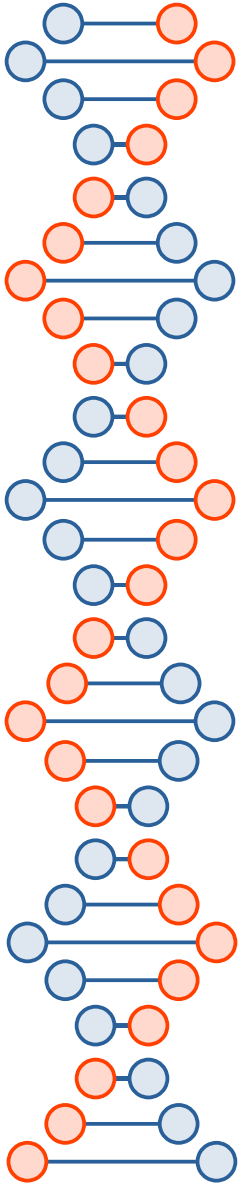


Bitwise XOR

$$
\begin{aligned}
&00101010_{\mathrm{b}} \\
\oplus\,&10000110_{\mathrm{b}} \\
=\,&10101100_{\mathrm{b}}
\end{aligned}
$$

2000+ years of history...



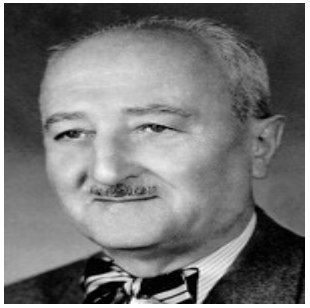


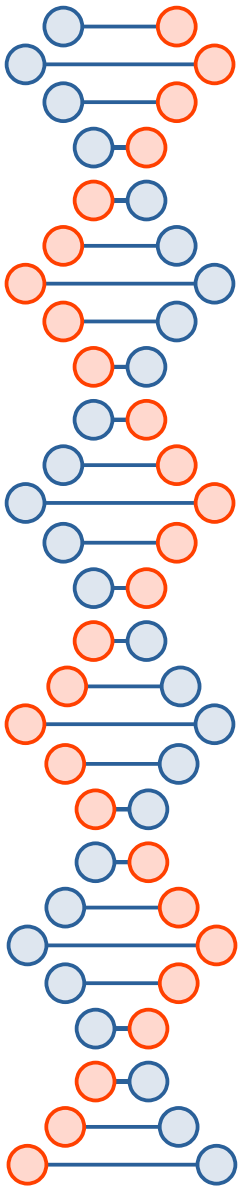
Symmetric encryption over time

- Handwritten notes, *etc.* for centuries
  - Typically the algorithm was secret
- 1883 … Kerckhoff's rules
  - Now we know the key should be the only secret
- 1975 … DES
  - Efficient in hardware, not in software
- 2001 … AES
  - Efficient in software, and lots of different kinds of hardware

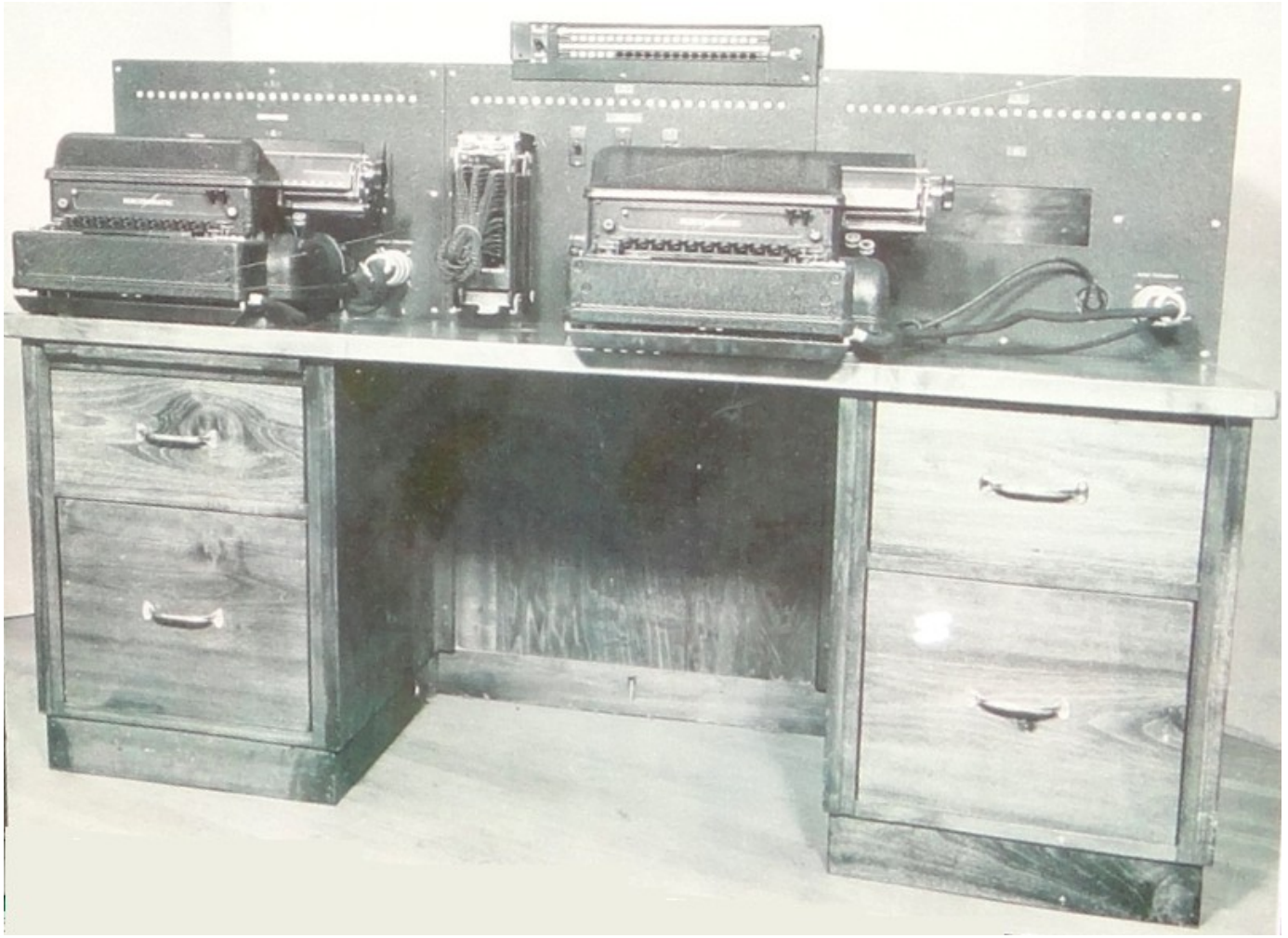
William and Elizabeth Friedman

- Met while analyzing Shakespeare ciphers at Riverbank Laboratories (“William Friedman wrote Shakespeare's plays”)
- Elizabeth solved ciphers of alcohol and drug smugglers, then German ambassadors in South America (three enigma machines)
- William led a team that solved PURPLE, conceived CryptoAG scheme





Substitution and/or permutation...

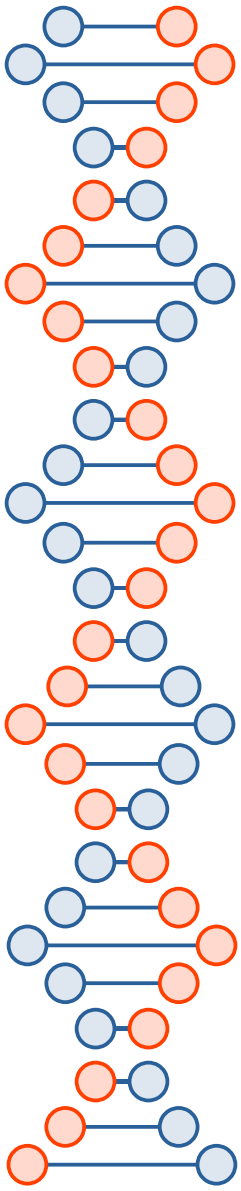


https://en.wikipedia.org/wiki/Type_B_Cipher_Machine#/media/File:Purple_cipher_machine_analog_bw_photo_NCM.jpg

https://en.wikipedia.org/wiki/Enigma_machine#/media/File:Enigma_(crittografia)_-_Museo_scienza_e_tecnologia_Milano.jpg

Zodiac cipher

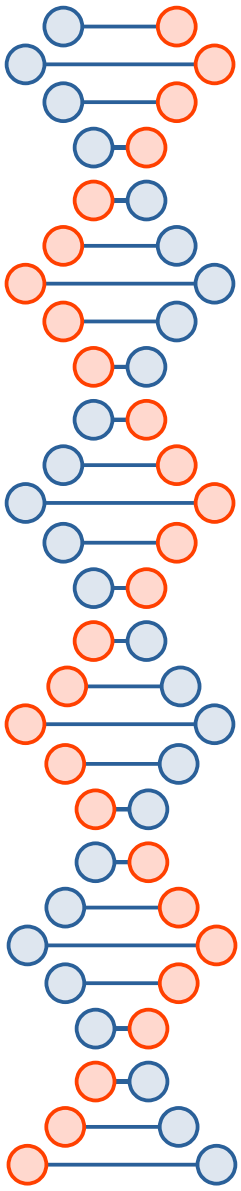
Image from wikia



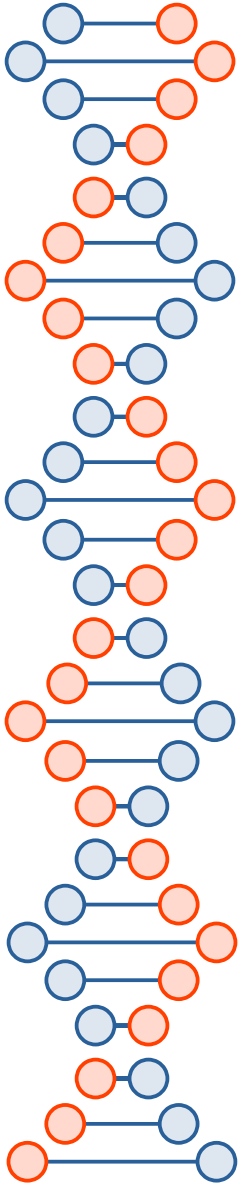
How to crack?

- Frequency analysis
- “The most common letter in the english language is e”
- “Gsv nlhg xlnnlm ovggvi rm gsv vmtorhs ozmtfztv rh v”
  - 7 v’s, 4 g’s, 4 m’s, 3 s’s, 3 n’s, 3 l’s …

- Guess what quantum computers are good at?

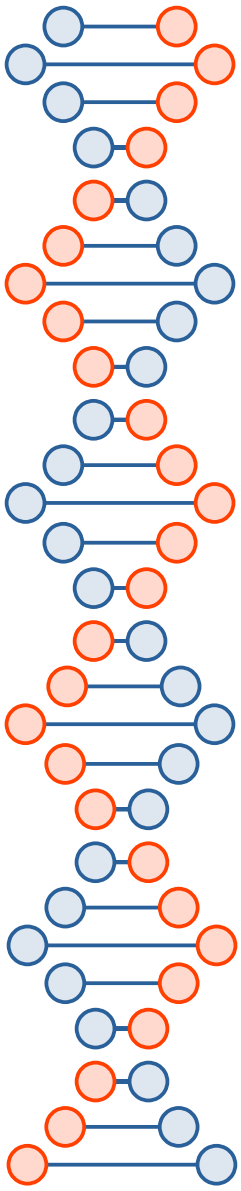


XOR...



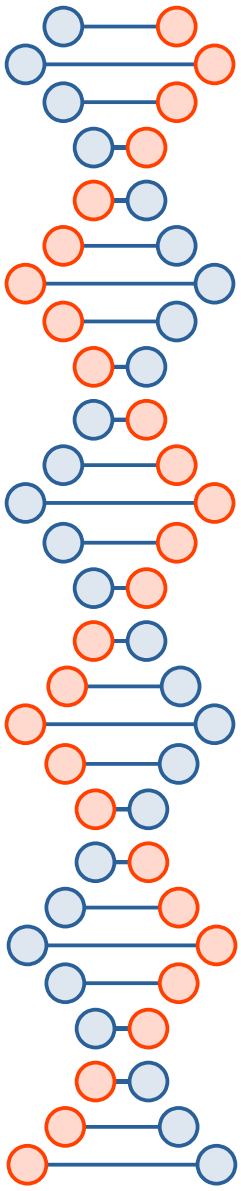
Bitwise XOR as a cipher itself

- Typically used by malware, 8 or 32 bits
  - WEP attack uses these properties
- (B xor K) xor K = B
- (A xor K) xor (B xor K) = A xor B
- (0 xor K) = K
- (K xor K) = 0
- Frequency analysis or brute force



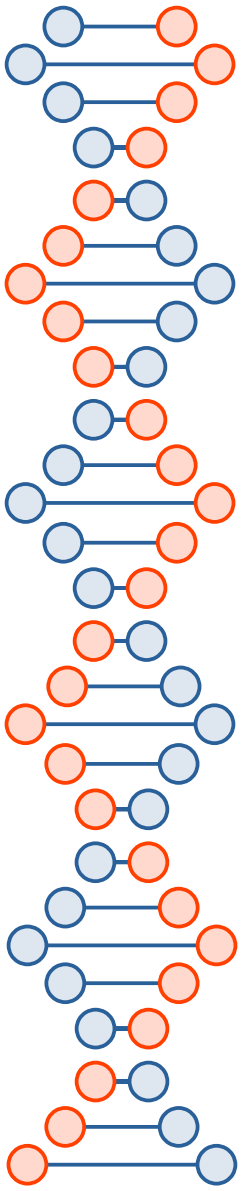
One-time pad

- *E.g.*, an XOR cipher or Caesar cipher where the key has good randomness and is as long as the plaintext
  - And never gets reused
- Most codes made by the NSA through the 1980s were one-time pads
  - What if it's not practical to share enough key material beforehand, *e.g.*, on the Internet?



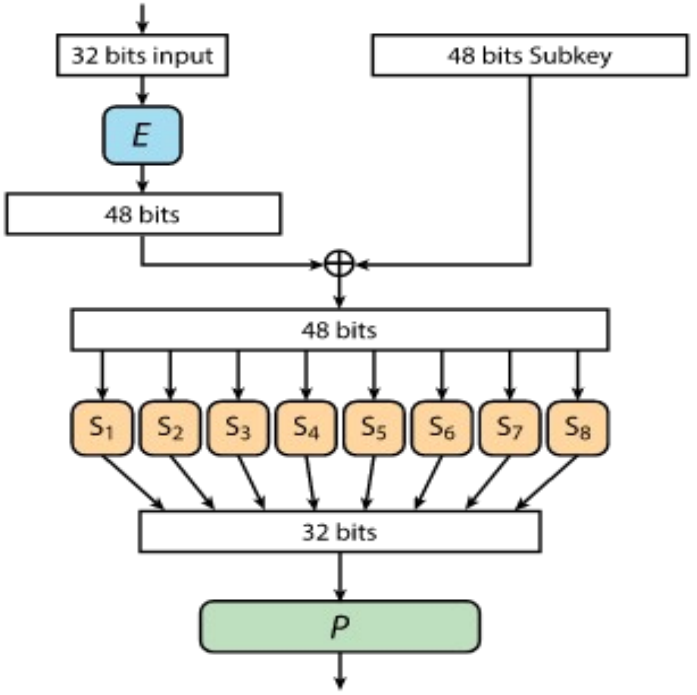
Preview:

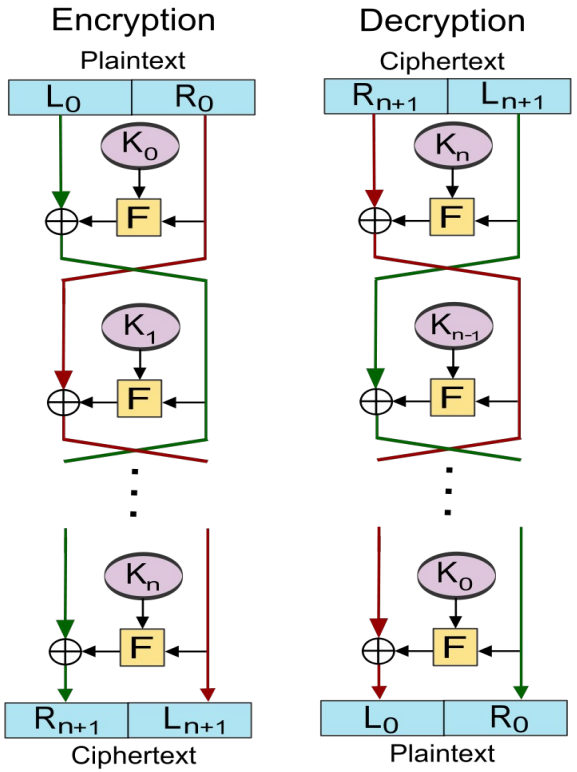
CNOT, the quantum version of XOR, will defy your concept of time and causality and we'll see that the outputs sometimes affect the inputs.

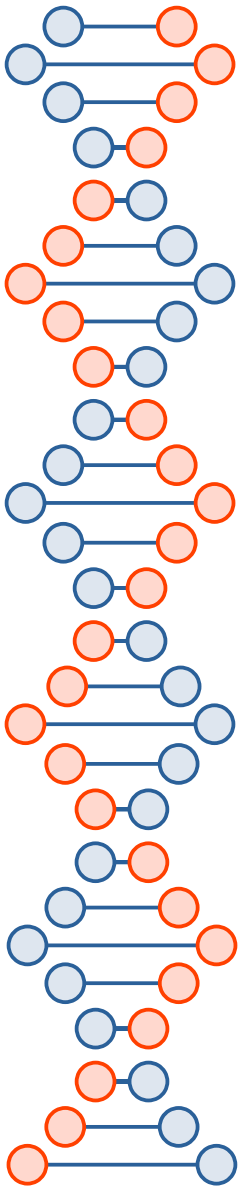


Now, let’s look at the first really good (in Jed’s opinion) symmetric cipher...

1977 - DES (16 rounds, 64-bit blocks, 56-bit key)



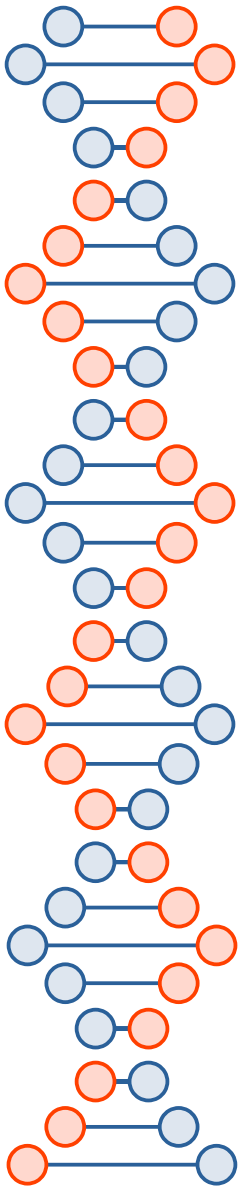




DES S-boxes

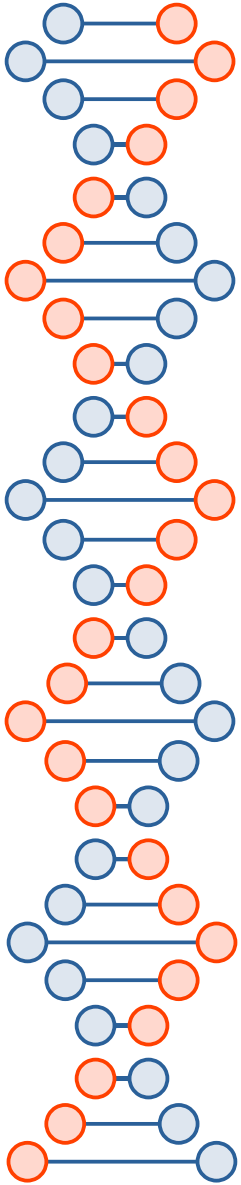
- 6 bits becomes 4 bits
- Values somewhat arbitrary
  - IBM proposed some, NSA replaced with others
    - Linear and differential cryptanalysis (unknown in the open literature at the time) were probably the reasons

שורה	מס' עמודה															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	S_1															
0	14	4	13	1	2	15	11	8	3	10	6	12	5	9	0	7
1	0	15	7	3	14	2	13	1	10	6	12	11	9	5	3	8
2	4	1	14	8	13	6	2	11	15	12	9	7	13	10	5	0
3	15	12	8	2	4	9	1	7	5	11	3	14	10	0	6	13
	S_2															
0	15	1	8	14	6	11	3	4	9	7	2	13	12	0	5	10
1	3	13	4	7	15	2	8	14	12	0	1	10	6	9	11	5
2	0	14	7	11	10	4	13	1	5	8	12	6	9	3	2	15
3	13	8	10	1	3	15	4	2	11	6	7	12	0	5	14	9
	S_3															
0	10	0	9	14	6	3	15	5	1	13	12	7	11	4	2	8
1	13	7	0	9	3	4	6	10	2	8	5	14	12	11	15	1
2	13	6	4	9	8	15	3	0	11	1	2	12	5	10	14	7
3	1	10	13	0	6	9	8	7	4	15	14	3	11	5	2	12
	S_4															
0	7	13	14	3	0	6	9	10	1	2	8	5	11	12	4	15
1	13	8	11	5	6	15	0	3	4	7	2	12	1	10	14	9
2	10	6	9	0	12	11	7	13	15	1	3	14	5	2	8	4
3	3	15	0	6	10	1	13	8	9	4	5	11	12	7	2	14
	S_5															
0	2	12	4	1	7	10	11	6	8	5	3	15	13	0	14	9
1	14	11	2	12	4	7	13	1	5	0	15	10	3	9	8	6
2	4	2	1	11	10	13	7	8	15	9	12	5	6	3	0	14
3	11	8	12	7	1	14	2	13	6	15	0	9	10	4	5	3
	S_6															
0	12	1	10	15	9	2	6	8	0	13	3	4	14	7	5	11
1	10	15	4	2	7	12	9	5	6	1	13	14	0	11	3	8
2	9	14	15	5	2	8	12	3	7	0	4	10	1	13	11	6
3	4	3	2	12	9	5	15	10	11	14	1	7	6	0	8	13
	S_7															
0	4	11	2	14	15	0	8	13	3	12	9	7	5	10	6	1
1	13	0	11	7	4	9	1	10	14	3	5	12	2	15	8	6
2	1	4	11	13	12	3	7	14	10	15	6	8	0	5	9	2
3	6	11	13	8	1	4	10	7	9	5	0	15	14	2	3	12
	S_8															
0	13	2	8	4	6	15	11	1	10	9	3	14	5	0	12	7
1	1	15	13	8	10	3	7	4	12	5	6	11	0	14	9	2
2	7	11	4	1	9	12	14	2	0	6	10	13	15	3	5	8
3	2	1	14	7	4	10	8	13	15	12	9	0	3	5	6	11



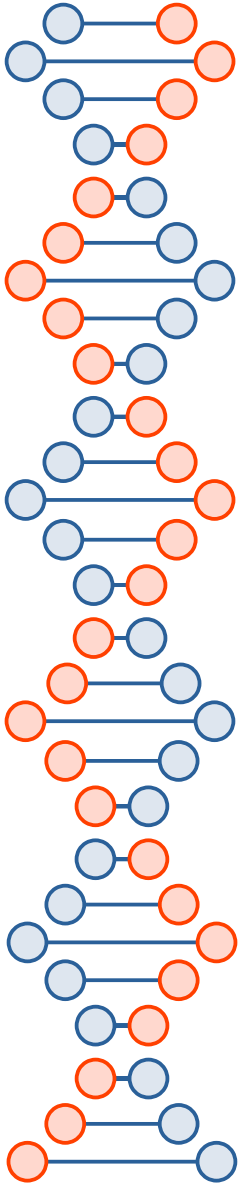
Importance of substitution

- XOR and permutation are linear functions
  - Solve for the key given plaintext and ciphertext?
- Bit differences in inputs are not changed at all by permuting bits
- XOR also preserves differences in bits

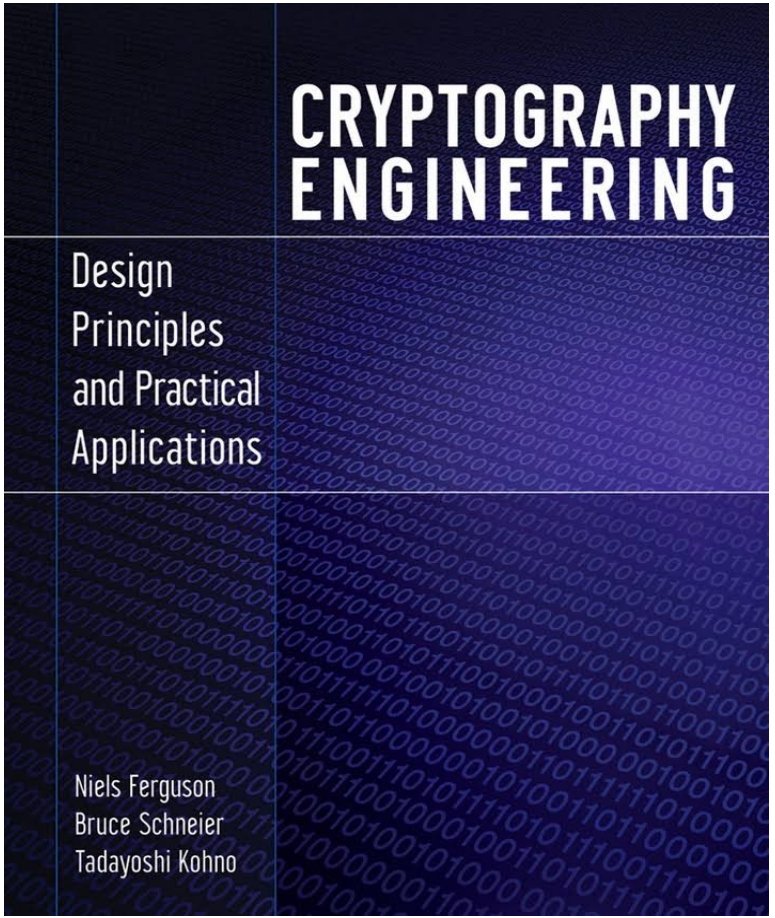


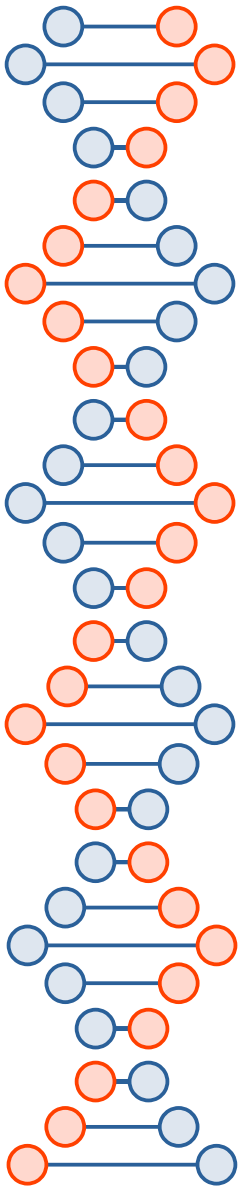
Different approaches (preview)

- DES simply tried to thwart these two specific types of attack (linear and differential) by carefully choosing the S boxes and letting them destroy information about the input (okay because of Feistel structure)
- Blowfish used π as the S boxes
- *Preview:* AES is going to do something very clever, that is invertible (no need for the Feistel structure, so fewer rounds) but still thwarts linear and differential cryptanalysis.



Cryptography Engineering by Ferguson *et al.*





Acknowledgments and resources

- Many of the above images are from Wikipedia
- https://www.youtube.com/watch?v=5mB_FUyfuZE&list=PLmh4YIWteoGgh0E2EuS4ZpzIi7ZhIW9Xp