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Nature-Inspired Cryptoanalysis Methods for Breaking Vigenère Cipher

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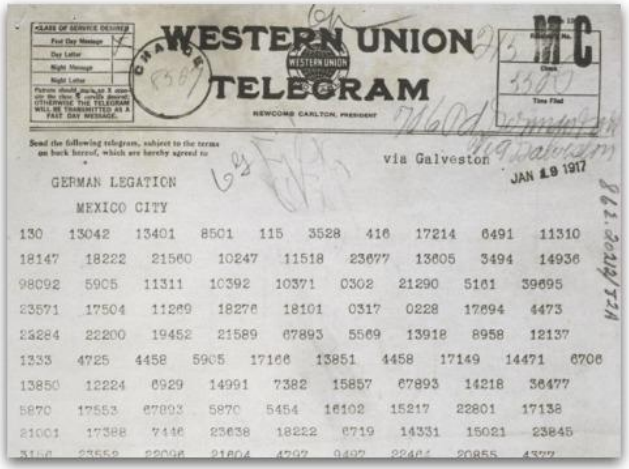
Cryptology

- Classical ciphers
  - transposition
  - substitution
    - monoalphabetic (e.g. Caesar cipher, Affine cipher)
    - polyalphabetic (e.g. Vigenère cipher, Gronsfeld cipher)
    - polygraphic (e.g. Hill cipher)

The Zimmermann Telegram



cryptoanalysis

Vigenère cipher

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
B	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A
C	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B
D	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C
E	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D
F	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E
G	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F
H	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G
I	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H
J	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I
K	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J
L	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K
M	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L
N	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M
O	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N
P	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Q	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
R	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
S	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
T	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
U	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
V	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
W	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
X	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Y	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Z	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y

Plain text	N	E	W	T	E	C	H	N	O	L	O	G	I	E	S
Key	K	E	Y	K	E	Y	K	E	Y	K	E	Y	K	E	Y
Ciphertext	X	I	U	D	I	A	R	R	M	V	S	E	S	I	Q

Vigenère cipher

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- Definition of plaintext (P), key (K), and ciphertext (C):

$$P=(P_1,P_2,\ldots,P_m);\quad K=(K_1,K_2,\ldots,K_n);\quad C=(C_1,C_2,\ldots,C_m)$$

- Encryption E using key K:

$$C_i=E_K(P_i)=(P_i+K_i)\ \ mod\ \ 26$$

- Decryption D using key K:

$$D_K(C_i)=(E_i+K_i)\ \ mod\ \ 26$$

Natural-Inspired algorithms

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- Differential Evolution: Storn and Price (1997)
- Particle Swarm Optimization: Kennedy and Eberhart (1995)
- Firefly Algorithm: Yang (2008)
- Artificial Bee Colony Algorithm: Karaboga (2005)
- Cuckoo Search: Yang and Deb (2009)

N-I cryptanalysis methods

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- Identification of the period of the cipher
  - Friedman attack based on the Index of Coincidence (I_c)

$$I_c = \frac{\sum_{i=1}^{j} f_i(f_i - 1)}{n(n-1)}$$

$$key\_length = \frac{0.027n}{I_c(n-1) - 0.038n + 0.065}$$

- Fitness function

$$f(K) = \sum_{i=1}^{j} |FE_i - FD_i|$$

Results

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- Number of correctly recovered key characters per algorithm

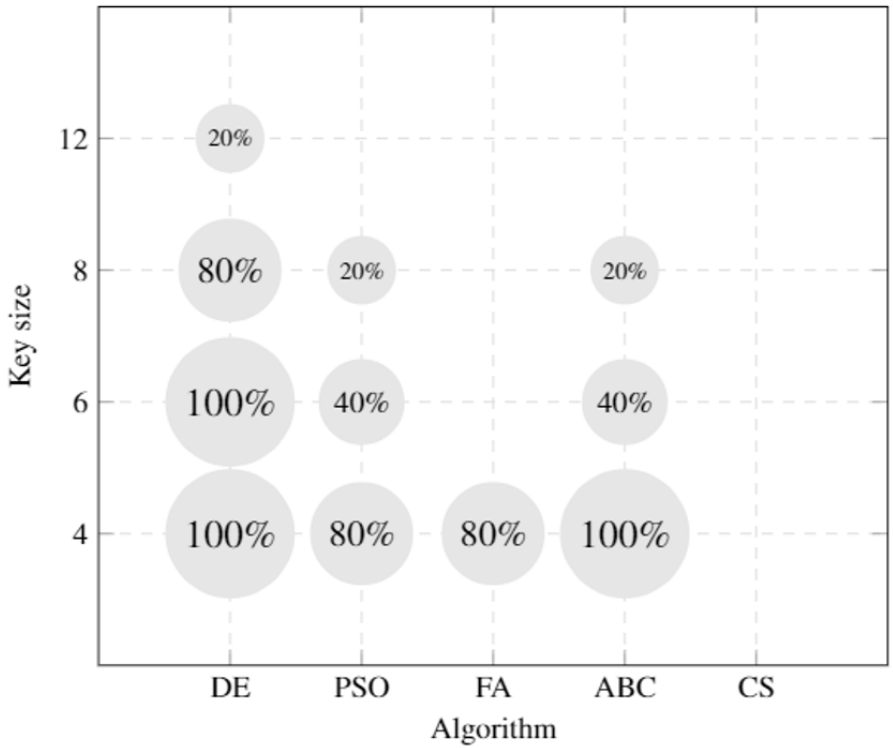
Key size	MAX_KC					MIN_KC					AVG_KC				
	DE	PSO	FA	ABC	CS	DE	PSO	FA	ABC	CS	DE	PSO	FA	ABC	CS
4	4	4	4	4	3	4	3	3	4	2	4	3.8	3.8	4	2.6
6	6	6	5	6	3	6	5	5	4	3	6	5.4	5	5.2	3
8	8	8	6	8	5	6	5	4	5	2	7.6	6	5	6.4	3.8
12	12	9	8	8	5	11	6	5	6	3	11.2	7.8	6.6	7	4

- Time analysis of obtaining the max number of correctly recovered key characters

Key size	DE	PSO	FA	ABC	CS
4	**35.7**	**178.8**	**349.7**	**180.2**	181.7
6	**38.3**	**184.9**	232.8	**187.3**	185.4
8	**40.2**	**214.9**	426.4	**246.6**	205.3
12	**52.8**	216.4	312.1	200.3	229.5

Results

- percentage of all correctly obtained key characters in five independent run



Conclusion

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- Proposed method for breaking the Vigenère cipher
  - Tested with four different key sizes
  - One plaintext
- Best performance: Differential Evolution algorithm
  - Recovered the highest amount of key characters
  - Took the least amount of time
- Future work
  - Utilization of other nature-inspired algorithms
  - Utilization of nature-inspired algorithms to modern cryptography