A History of Cryptography and Cryptanalysis

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Transposition Ciphers

- Rearrange text
- Common example Columnar Cipher

[6, pg. 12]

Columnar Transposition Cipher

Plaintext: THIS IS A SECRET MESSAGE

T	H	I	S	I
S	A	S	E	C
R	E	T	M	E
S	S	A	G	E

Ciphertext: TSRS HAES ISTA SEMG ICEE

Monoalphabetic Substitution Ciphers

Monoalphabetic substitution ciphers replace each character in the plaintext with another character

- Shift Cipher

$$E(p_i, k) = p_i + k \pmod{n}$$

$$D(c_i, k) = c_i - k \pmod{n}$$

- Substitution Cipher
  - Each character from the plaintext is mapped to a character from a table to obtain the plaintext

Polyalphabetic Substitution Ciphers

- Vigenère Cipher
  - 26 alphabets
  - encrypt plaintext character p and key character k by finding character in p column and k row

$$E(p_i, k_j) = p_i + k_j \pmod{26} = c_i$$

$$D(c_i, k_j) = c_i - k_j \pmod{26} = p_i$$

Vigenère Square

	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

Vigenère Cipher Example

Plaintext: SEND SUPPLIES AT ONCE
Key: CODE

S	E	N	D	S	U	P	P	L	I	E	S	A	T	O	N	C	E
C	O	D	E	C	O	D	E	C	O	D	E	C	O	D	E	C	O
U	S	Q	H	U	I	S	T	N	W	H	W	C	H	R	R	E	S

Ciphertext: USQHUISTNWHWCHRRES

Frequency Analysis

Substitution ciphers can be broken by using a a statistical technique called frequency analysis

- Shift cipher
  - Compare character frequency chart or graph to sample of english
- Vigenère cipher
  - Fist find length of key using frequency analysis
  - find each character in key using frequency analysis

Character Frequency Chart for English

Letter	Percentage	Letter	Percentage	Letter	Percentage
a	8.2	j	0.2	s	6.3
b	1.5	k	0.8	t	9.1
c	2.8	l	4.0	u	2.8
d	4.3	m	2.4	v	1.0
e	12.7	n	6.7	w	2.4
f	2.2	o	7.5	x	0.2
g	2.0	p	1.9	y	2.0
h	6.1	q	0.1	z	0.1
i	7.0	r	6.0		

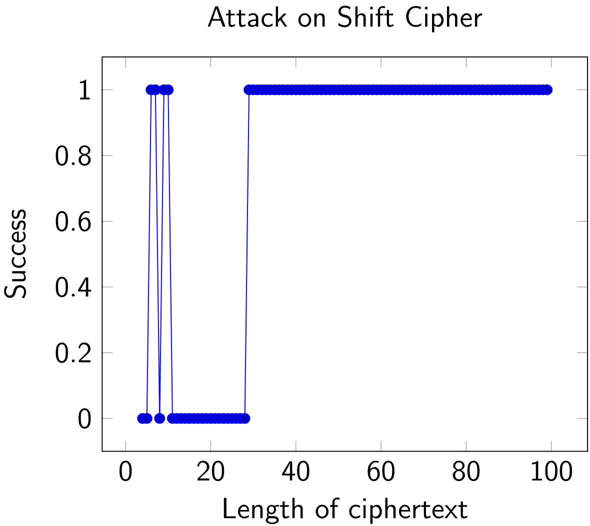
[7, pg. 19]

Character Frequency Chart for Ciphertext

The sample text was encoded using a shift cipher

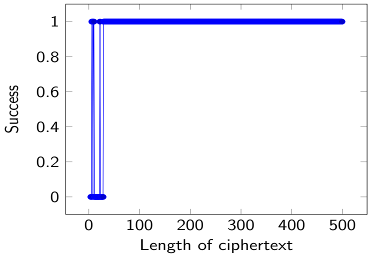
Letter	Percentage	Letter	Percentage	Letter	Percentage
a	8.4	j	0.1	s	2.5
b	1.4	k	2.3	t	6.0
c	0.0	l	0.0	u	6.5
d	4.6	m	8.3	v	0.3
e	5.8	n	1.7	w	1.3
f	9.7	o	1.9	x	4.0
g	3.2	p	5.4	y	2.4
h	0.7	q	11.2	z	7.5
i	3.0	r	1.8		

Attack on Shift Cipher

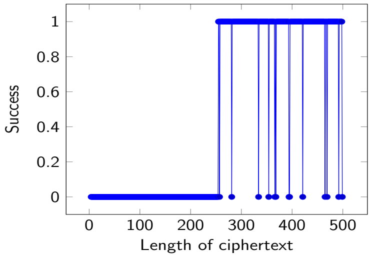


Attack on Vigenère Cipher

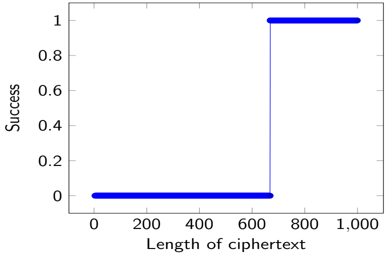
Attack on Vigenère Cipher With Key Length 1



Attack on Vigenère Cipher With Key Length 2



Attack on Vigenère Cipher With Key Length 5



One Time Pad

The one time pad cipher is a version of the Vigenère cipher where

- The key is the same length as the plaintext
- The key is random, and
- The key is not reused for multiple encryptions

There is no statistical analysis that can be applied to the ciphertext to break the one time pad [4, pg. 393]

One Way Hashes

A one way hash is an algorithm or function H that takes a plaintext p and converts it to ciphertext c, where computing $H^{-1}(c) = p$ is much more computationally difficult than computing $H(p) = c$

Attacks

- Brute Force
- Birthday
- Statistical
- Man in the Middle
- Side-Channel

Brute Force Attack

- Try every possible key
- Not efficient or practical against most ciphers

A brute force attack tries every possible key

Birthday Attack

Given a ciphertext c where $H(p) = c$, a birthday attack on a one way hash is to find p' where $H(p) = H(p')$ [6]

Man in the Middle Attack

Attack on public key cryptography. An attacker can control all communications if there is no authentication.

Side-Channel Attack

Using information available from other sources than the ciphertext and plaintext, an attacker could determine information about the key to a cipher

- Timing
- Power consumption
- Fault

Future Research

- Differential cryptanalysis
- Attacks on recently broken ciphers and hashing algorithms
- Man in the middle and side-channel attacks

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