PMSCS 694
Information Security

Crypto Basics

Lecture 3

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Crypto

- **Cryptology** — The art and science of making and breaking "secret codes"
- **Cryptography** — making "secret codes"
- **Cryptanalysis** — breaking "secret codes"
- **Crypto** — all of the above (and more)

How to Speak Crypto

- A *cipher* or *cryptosystem* is used to *encrypt* the *plaintext*
- The result of encryption is *ciphertext*
- We *decrypt* ciphertext to recover plaintext
- A *key* is used to configure a cryptosystem
- A *symmetric key* cryptosystem uses the same key to encrypt as to decrypt
- A *public key* cryptosystem uses a *public key* to encrypt and a *private key* to decrypt

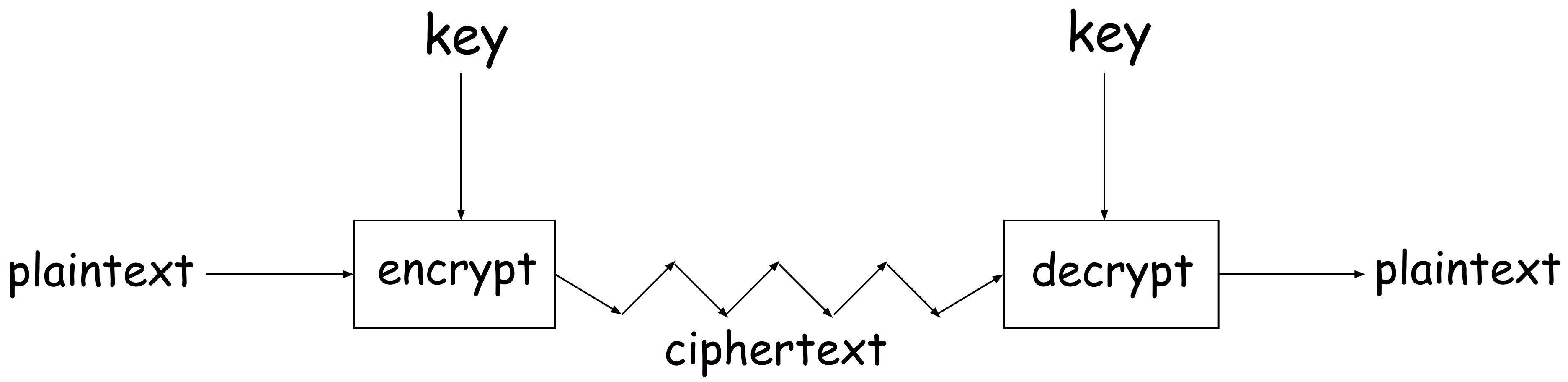
Crypto

- Basic assumptions
  - The system is completely known to the attacker
  - Only the key is secret
  - That is, crypto algorithms are not secret
- **"A cryptographic system should remain secure even if everything about the system, except the key, is public knowledge."**
- This is known as **Kerckhoffs' Principle.**
- Why do we make such an assumption?
  - Experience has shown that secret algorithms tend to be weak when exposed
  - Secret algorithms never remain secret
  - Better to find weaknesses beforehand

Broader Interpretation of Kerckhoffs' Principle

- Generalized Definition:"A secure system should not rely on the secrecy of its design, but rather on the secrecy of small, easily changeable elements—such as passwords, keys, or credentials."
- This broader interpretation is often applied in software engineering, network design, and security system architecture, where the focus is on:
  - Open design: Encouraging peer review and testing
  - Rapid key rotation: Instead of redesigning entire systems
  - Defense in depth: Assuming attackers may understand the system layout
- Example: OpenSSL is a public, open-source cryptographic library. Despite its code being freely accessible, it remains secure because its strength lies in key secrecy, not in hidden implementation.

Crypto as Black Box



A generic view of symmetric key crypto

Simple Substitution

- Plaintext: fourscoreandsevenyearsago
- Key:

Plaintext	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
Ciphertext	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

- Ciphertext:
  IRXUVFRUHDQGVHYHQBHDUVDJR
- Shift by 3 is "Caesar's cipher"

Caesar's Cipher Decryption

- Suppose we know a Caesar's cipher is being used:

Plaintext	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
Ciphertext	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

- Given ciphertext:
  VSRQJHEREVTXDUHSDQWV
- Plaintext: spongebobsquarepants

Caesar's Cipher

- Shift by n for some $n \in \{0,1,2,\ldots,25\}$
- Then key is n
- Example: key $n = 7$

Plaintext	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
Ciphertext	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

Cryptanalysis I: Try Them All

- We know Caesar's cipher and shift by n used
  - But the specific key is unknown
- Given ciphertext: CSYEVIXIVQMREXIH
- How to determine the key?
- Only 26 possible keys — try them all!
- **Exhaustive key search**
- Solution: key is $n = 4$

Simple Substitution: General Case

- In general, simple substitution key can be any **permutation** of letters
  - Not necessarily a Caeser's cipher (shift)
- For example

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

- In general, $26! > 2^{88}$ possible keys

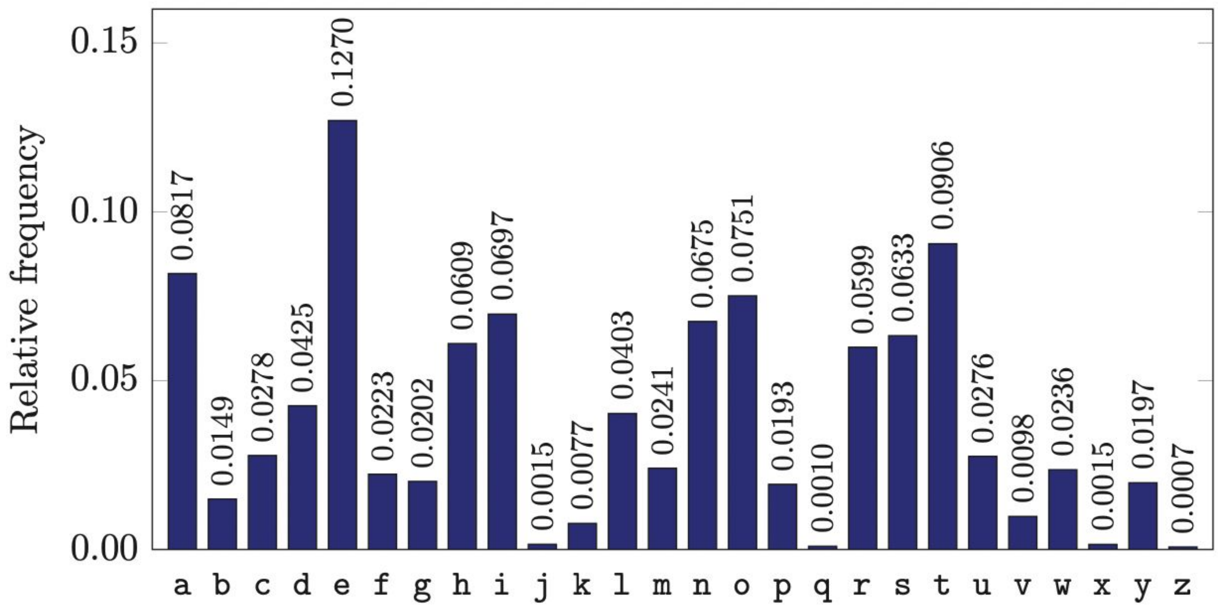
Cryptanalysis II: Be Clever

- We know that a simple substitution used
- But ***not*** necessarily a Ceasar's cipher (shift)
- Find the key given the ciphertext:

PBFPVYFBQXZTYFPBFEQJHDXXQVAPTPQJKTOYQWIPBVWLXTOX
BTFXQWAXBVCXQWAXFQJVWLEQNTOZQGGQLFXQWAKVWLXQ
WAEBIPBFXFQVXGTVJVWLBTPQWAEBFPBFHCVLXBQUFEVWLXGD
PEQVPQGVPPBFTIXPFHXZHVFAGFOTHFEFBQUFTDHZBQPOTHXTY
FTODXQHFTDPTOGHFQPBQWAQJJTODXQHFOQPWTBDHHIXQV
APBFZQHCFWPFHPBFIPBQWKFABVYYDZBOTHPBQPQJTQOTOGHF
QAPBFEQJHDXXQVAVXEBQPEFZBVFOJIWFFACFCCFHQWAUVWF
LQHGFXVAFXQHFUFHILTTAVWAFFAWTEVOITDHFHFQAITIXPFH
XAFQHEFZQWGFLVWPTOFFA

Cryptanalysis II

- Cannot try all 2^{88} simple substitution keys
- Can we be more clever?
- English letter frequency counts…



Cryptanalysis II

- Ciphertext:

PBFPVYFBQXZTYFPBFEQJHDXXQVAPTPQJKTOYQWIPBVWLXTOXBTFXQ
WAXBVCXQWAXFQJVWLEQNTOZQGGQLFXQWAKVWLXQWAEBIPBFXFQ
VXGTVJVWLBTPQWAEBFPBFHCVLXBQUFEVWLXGDPEQVPQGVPPBFTIXPFH
XZHVFAGFOTHFEFBQUFTDHZBQPOTHXTYFTODXQHFTDPTOGHFQPBQW
AQJJTODXQHFOQPWTBDHHIXQVAPBFZQHCFWPFHPBFIPBQWKFABVYY
DZBOTHPBQPQJTQOTOGHFQAPBFEQJHDXXQVAVXEBQPEFZBVFOJIWFF
ACFCCFHQWAUVWFLQHGFXVAFXQHFUFHILTTAVWAFFAWTEVOITDHFH
FQAITIXPFHXAFQHEFZQWGFLVWPTOFFA

- Analyze this message using statistics below

Ciphertext frequency counts:

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
21	26	6	10	12	51	10	25	10	9	3	10	0	1	15	28	42	0	0	27	4	24	22	28	6	8

Cryptanalysis: Terminology

- Cryptosystem is **secure** if best know attack is to try all keys
  - Exhaustive key search, that is
- Cryptosystem is **insecure** if ***any*** shortcut attack is known
- But then insecure cipher might be harder to break than a secure cipher!
  - What the … ?

Vigenere Cipher

- Simple substitution is ***monoalphabetic***
- Vigenere cipher is simple example of a ***polyalphabetic*** substitution
  - Caesars ciphers, based on a keyword
- For example, keyword CAT indicates shift by 2, shift by 0, shift by 19
  - Then repeat as needed

Vigenere Example

- Suppose that we want to encrypt attackatdawn
- Encryption:

keyword:	CATCATCATCAT
plaintext:	attackatdawn
ciphertext:	ctmccdctwcwg

- Ciphertext is ctmccdctwcwg
- How to decrypt? How to attack?

Double Transposition

- Plaintext: attackxatxdawn

	col 1	col 2	col 3
row 1	a	t	t
row 2	a	c	k
row 3	x	a	t
row 4	x	d	a
row 5	w	n	x

Permute rows and columns

$\Rightarrow$

	col 1	col 3	col 2
row 3	x	t	a
row 5	w	x	n
row 1	a	t	t
row 4	x	a	d
row 2	a	k	c

- Ciphertext: xtawxnattxadakc
- Key is matrix size and permutations: (3,5,1,4,2) and (1,3,2)

One-Time Pad: Encryption

e=000 h=001 i=010 k=011 l=100 r=101 s=110 t=111

Encryption: Plaintext $\oplus$ Key = Ciphertext

	h	e	i	l	h	i	t	l	e	r
Plaintext:	001	000	010	100	001	010	111	100	000	101
Key:	111	101	110	101	111	100	000	101	110	000
Ciphertext:	110	101	100	001	110	110	111	001	110	101
	s	r	l	h	s	s	t	h	s	r

One-Time Pad: Decryption

e=000 h=001 i=010 k=011 l=100 r=101 s=110 t=111

Decryption: Ciphertext ⊕ Key = Plaintext

	s	r	l	h	s	s	t	h	s	r
Ciphertext:	110	101	100	001	110	110	111	001	110	101
Key:	111	101	110	101	111	100	000	101	110	000
Plaintext:	001	000	010	100	001	010	111	100	000	101
	h	e	i	l	h	i	t	l	e	r

One-Time Pad

Double agent claims following "**key**" was used:

	s	r	l	h	s	s	t	h	s	r
Ciphertext:	110	101	100	001	110	110	111	001	110	101
"**key**":	101	111	000	101	111	100	000	101	110	000
"Plaintext":	011	010	100	100	001	010	111	100	000	101
	k	i	l	l	h	i	t	l	e	r

e=000 h=001 i=010 k=011 l=100 r=101 s=110 t=111

One-Time Pad

Or, might claim the key is…

	s	r	l	h	s	s	t	h	s	r
Ciphertext:	110	101	100	001	110	110	111	001	110	101
"key":	111	101	000	011	101	110	001	011	101	101
"Plaintext":	001	000	100	010	011	000	110	010	011	000
	h	e	l	i	k	e	s	i	k	e

e=000 h=001 i=010 k=011 l=100 r=101 s=110 t=111

One-Time Pad Summary

- **Provably** secure
  - Ciphertext gives **no** useful info about plaintext
  - All plaintexts are ***equally likely***
- BUT, only when be used correctly
  - Pad must be random, used only once
  - Pad is known only to sender and receiver
- Note: pad (key) is same size as message
- So, why not distribute message itself, instead of the pad?

Real-World One-Time Pad

- Project VENONA
  - Soviet spies encrypted messages from U.S. to Moscow in 30's, 40's, and 50's
  - Nuclear espionage, etc.
  - Thousands of messages
- Spy carried one-time pad into U.S.
- Spy used pad to encrypt secret messages
- Repeats within the "one-time" pads made cryptanalysis possible

VENONA Decrypt (1944)

[C% Ruth] learned that her husband [v] was called up by the army but he was not sent to the front. He is a mechanical engineer and is now working at the ENORMOUS [ENORMOZ] [vi] plant in SANTA FE, New Mexico. [45 groups unrecoverable]

detain VOLOK [vii] who is working in a plant on ENORMOUS. He is a FELLOWCOUNTRYMAN [ZEMLYaK] [viii]. Yesterday he learned that they had dismissed him from his work. His active work in progressive organizations in the past was cause of his dismissal. In the FELLOWCOUNTRYMAN line LIBERAL is in touch with CHESTER [ix]. They meet once a month for the payment of dues. CHESTER is interested in whether we are satisfied with the collaboration and whether there are not any misunderstandings. He does not inquire about specific items of work [KONKRETNAYa RABOTA]. In as much as CHESTER knows about the role of LIBERAL's group we beg consent to ask C. through LIBERAL about leads from among people who are working on ENOURMOUS and in other technical fields.

- "Ruth" == Ruth Greenglass
- "Liberal" == Julius Rosenberg
- "Enormous" == the atomic bomb

Codebook Cipher

- Literally, a book filled with “codewords”
- Zimmerman Telegram encrypted via codebook

Februar	13605
fest	13732
finanzielle	13850
folgender	13918
Frieden	17142
Friedenschluss	17149
:	:

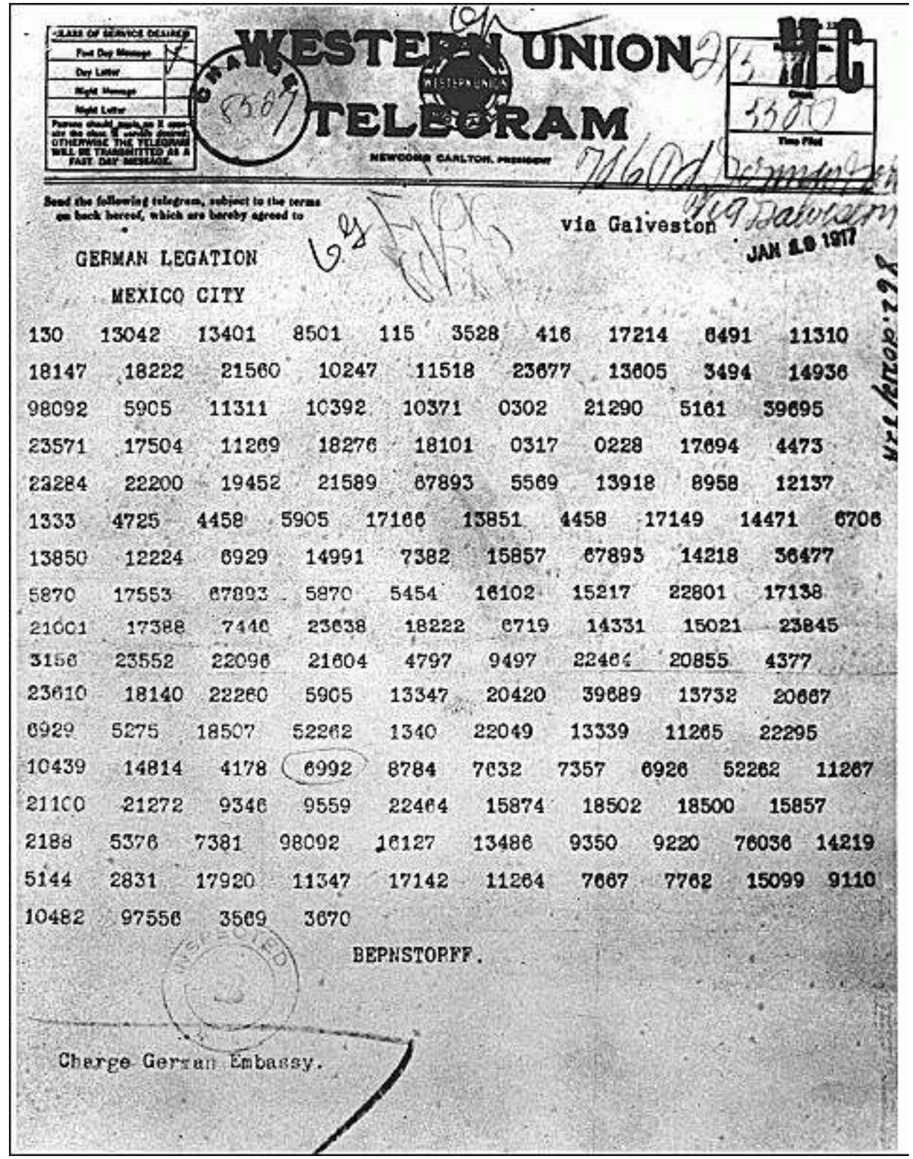
- Modern block ciphers are codebooks!
- More about this later…

Codebook Cipher: Additive

- Codebooks also (usually) use **additive**
- Additive —book of "random" numbers
  - Encrypt message with codebook
  - Then choose position in additive book
  - Add additive sequence to get ciphertext
  - Send ciphertext and additive position (MI)
  - Recipient subtracts additives before decrypting
- Why use an additive sequence?

Zimmermann Telegram

- Perhaps most famous codebook ciphertext ever
- A major factor in U.S. entry into World War I


WESTERN UNION TELEGRAM

NEWCOMB CARLTON, PRESIDENT

Send the following telegram, subject to the terms on back hereof, which are hereby agreed to

via Galveston

JAN 19 1917

GERMAN LEGATION

MEXICO CITY

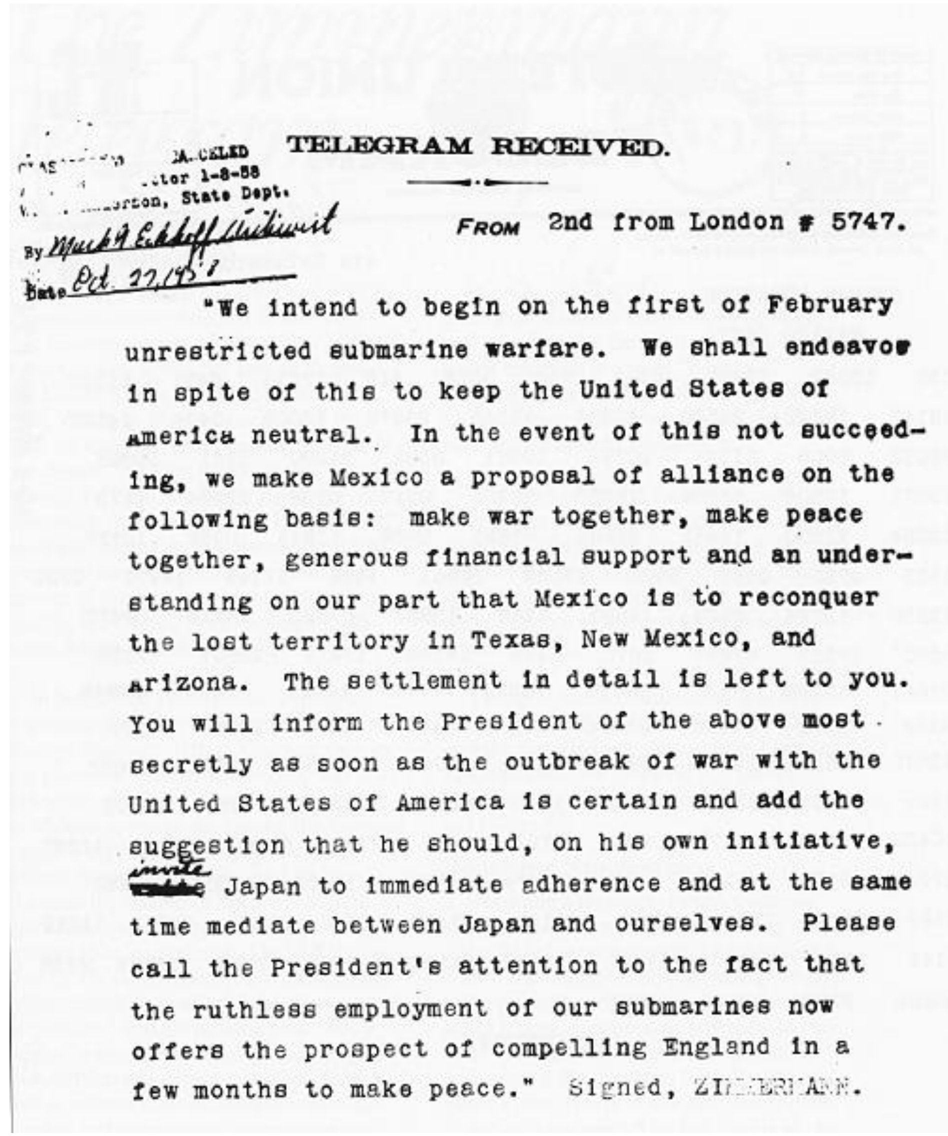
130 13042 13401 8501 115 3528 416 17214 6491 11310
18147 18222 21560 10247 11518 23677 13605 3494 14936
98092 5905 11311 10392 10371 0302 21290 5161 39695
23571 17504 11269 18276 18101 0317 0228 17694 4473
23284 22200 19452 21589 67893 5569 13918 8958 12137
1333 4725 4458 5905 17166 13851 4458 17149 14471 6706
13850 12224 6929 14991 7382 15857 67893 14218 36477
5870 17553 67893 5870 5454 16102 15217 22801 17138
21001 17388 7446 23638 18222 6719 14331 15021 23845
3156 23552 22096 21604 4797 9497 22464 20855 4377
23610 18140 22260 5905 13347 20420 39689 13732 20667
6929 5275 18507 52262 1340 22049 13339 11265 22295
10439 14814 4178 6992 8784 7632 7357 6926 52262 11267
21100 21272 9346 9559 22464 15874 18502 18500 15857
2188 5376 7381 98092 16127 13486 9350 9220 76036 14219
5144 2831 17920 11347 17142 11264 7667 7762 15099 9110
10482 97556 3569 3670

BEPNSTORFF.

Charge German Embassy.

Zimmermann Telegram Decrypted

- British had recovered partial codebook
- Then able to fill in missing parts



TELEGRAM RECEIVED.

FROM 2nd from London # 5747.

"We intend to begin on the first of February unrestricted submarine warfare. We shall endeavor in spite of this to keep the United States of America neutral. In the event of this not succeeding, we make Mexico a proposal of alliance on the following basis: make war together, make peace together, generous financial support and an understanding on our part that Mexico is to reconquer the lost territory in Texas, New Mexico, and Arizona. The settlement in detail is left to you. You will inform the President of the above most secretly as soon as the outbreak of war with the United States of America is certain and add the suggestion that he should, on his own initiative, invite Japan to immediate adherence and at the same time mediate between Japan and ourselves. Please call the President's attention to the fact that the ruthless employment of our submarines now offers the prospect of compelling England in a few months to make peace." Signed, ZIMMERMANN.

Random Historical Items

- Crypto timeline
- Spartan Scytale — transposition cipher
- Caesar's cipher
- Poe's short story: ***The Gold Bug***
- Election of 1876

Election of 1876

- "Rutherfraud" Hayes vs "Swindling" Tilden
  - Popular vote was virtual tie
- Electoral college delegations for 4 states (including Florida) in dispute
- Commission gave all 4 states to Hayes
  - Voted on straight party lines
- Tilden accused Hayes of bribery
  - Was it true?

Election of 1876

- Encrypted messages by Tilden supporters later emerged
- Cipher: Partial codebook, plus transposition
- Codebook substitution for important words

ciphertext	**plaintext**
Copenhagen	Greenbacks
Greece	Hayes
Rochester	votes
Russia	Tilden
Warsaw	telegram
:	:

Election of 1876

- Apply codebook to original message
- Pad message to multiple of 5 words (total length, 10,15,20,25 or 30 words)
- For each length, a fixed permutation applied to resulting message
- Permutations found by comparing several messages of same length
- Note that the **same key** is applied to all messages of a given length

Election of 1876

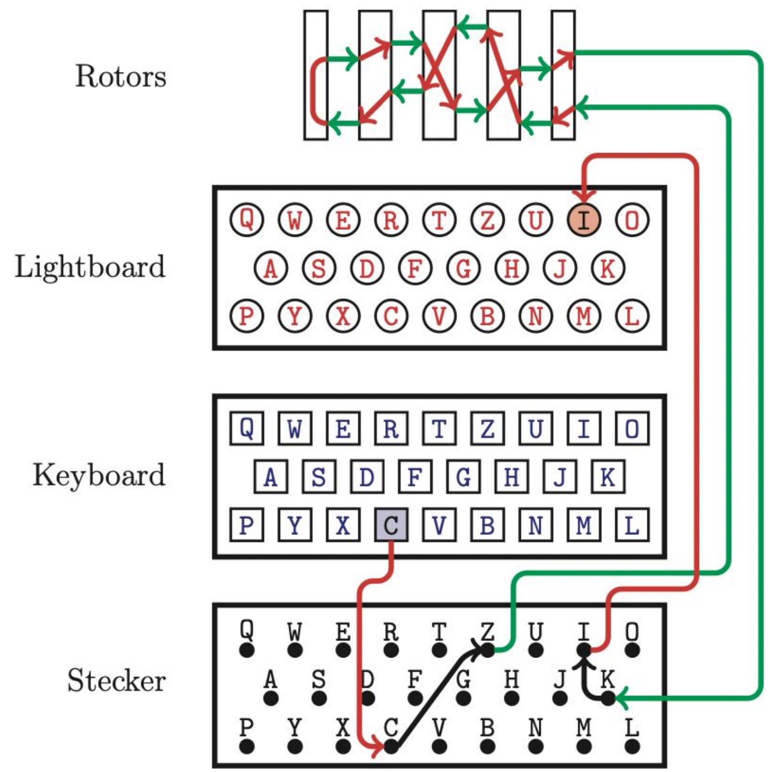
- Ciphertext: **Warsaw they read all unchanged last are idiots can't situation**
- Codebook: Warsaw == telegram
- Transposition: 9,3,6,1,10,5,2,7,4,8
- Plaintext: **Can't read last telegram. Situation unchanged. They are all idiots.**
- A weak cipher made worse by reuse of key
- Lesson? Don't overuse keys!

Early 20th Century

- WWI — Zimmermann Telegram
- "Gentlemen do not read each other's mail"
  - Henry L. Stimson, Secretary of State, 1929
- WWII — **golden** age of cryptanalysis
  - Midway/Coral Sea
  - Japanese **Purple** (codename **MAGIC**)
  - German **Enigma** (codename **ULTRA**)

Enigma Cipher Machine

- Most famous cipher of WWII
  - Electro-mechanical device
  - Very rugged, used in the field



Post-WWII History

- Claude Shannon — father of the science of information theory
- Computer revolution — lots of data to protect
- Data Encryption Standard (DES), 70's
- Public Key cryptography, 70's
- CRYPTO conferences, 80's
- Advanced Encryption Standard (AES), 90's
- The crypto genie is out of the bottle…

Claude Shannon

- Founded field of information theory
- His 1949 paper: *Comm. Thy. of Secrecy Systems*
- Fundamental concepts
  - **Confusion** — obscure relationship between plaintext and ciphertext
  - **Diffusion** — spread plaintext statistics through the ciphertext
- Proved one-time pad is secure
- One-time pad is confusion-only, while double transposition is diffusion-only

Taxonomy of Cryptography

- **Symmetric Key**
  - Same key for encryption and decryption
  - Modern types: Stream ciphers, Block ciphers
- **Public Key** (or "asymmetric" crypto)
  - Two keys, one for encryption (public), and one for decryption (private)
  - And digital signatures — nothing comparable in symmetric key crypto
- **Hash algorithms**
  - Can be viewed as "one way" crypto

Taxonomy of Cryptanalysis

- From perspective of info available to Trudy…
  - Ciphertext only — Trudy's worst-case scenario
  - Known plaintext
  - Chosen plaintext
    - "Lunchtime attack"
    - Some protocols will encrypt chosen data
  - Adaptively chosen plaintext
  - Related key
  - Forward search (public key crypto)
  - And others…