# **COM3020J** - Cryptography
# Crypto Basics:

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# Cryptography Basics

MXDXBVTZWVMXNSPBQXLIMSCCSGXSCJXBOVQXCJZMOJZCVC
TVWJCZAAXZBCSSCJXBQCJZCOJZCNSPOXBXSBTVWJC
JZDXGXXMOZQMSCSCJXBOVQXCJZMOJZCNSPJZHGXXMOSPLH
JZDXZAAXZBXHCSCJXTCSGXSCJXBOVQX

— plaintext from Lewis Carroll, *Alice in Wonderland*

The solution is by no means so difficult as you might be led to imagine from the first hasty inspection of the characters. These characters, as any one might readily guess, form a cipher — that is to say, they convey a meaning…

— Edgar Allan Poe, *The Gold Bug*

# What Is Cryptography ?

**Cryptography** — **making "secret codes"**

is the study of mathematical techniques related to aspects of information security.

**Cryptanalysis:** — **breaking "secret codes"**

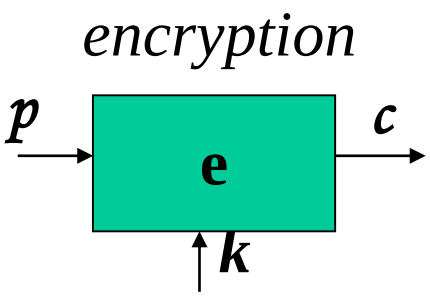
the study of mathematical techniques for attempting to defeat information security services.

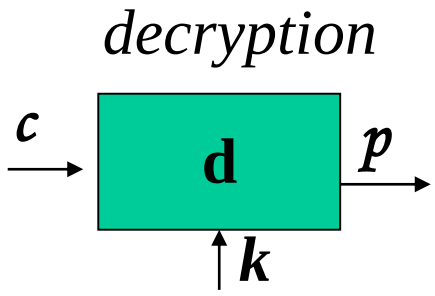
**Cryptology:** — **The art & science of making + breaking "secret codes"**

the study of cryptography and cryptanalysis.

# What is a Cryptosystem?

- A *cipher* or *cryptosystem* is used to *encrypt* (e) the *plaintext* (p)
- The result of encryption is *ciphertext* (c)
- We *decrypt* (d) ciphertext to recover plaintext
- A *key* (k) is used to configure a cryptosystem
- $\mathbf{d_K(e_K(p)) = p}$



# Cryptosystem

- **Basic assumptions**
  - The system is completely known to the attacker
  - Only the key is secret
  - That is, crypto algorithms (ciphers) are not secret
- 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

# Characteristics of a Good Cipher

**A cryptosystem should be secure even**

**if everything about the system, except the key, is public knowledge**

# Examples of Classic Ciphers

- **Reading:**
  - **Chapter 1: Crypto Basics**

    **of "Information Security: Principles and Practice"**, 2nd edition, Mark Stamp, (Wiley, May 2011, ISBN-10: 0470626399, ISBN-13: 978-0470626399).

# 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”

# Ceasar'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

# Not-so-Simple Substitution

- Shift by n for some n $\in$ {0,1,2,…,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

- A simple substitution (shift by n) is used
  - But the key is unknown
- Given ciphertext: CSYEVIXIVQMREXIH
- How to find 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 shift of the alphabet
- 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 |

- Then 26! > $2^{88}$ possible keys

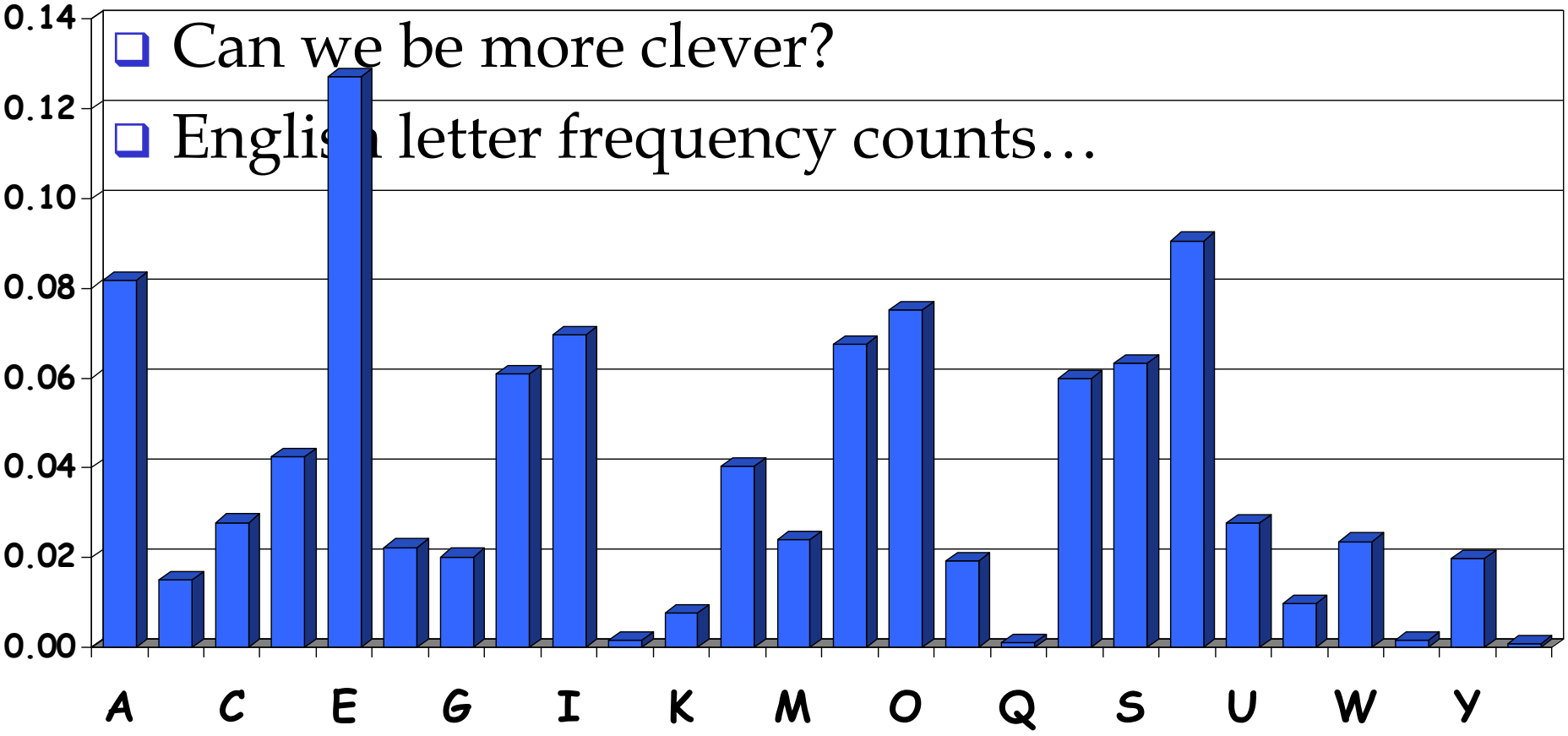
# Cryptanalysis II: Be Clever

- We know that a simple substitution is used
- But not necessarily a shift by n
- 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

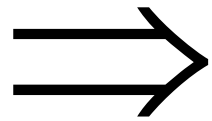
- Cryptosystem is **secure** if best know attack is to try all keys
  - Exhaustive key search, that is
- Cryptosystem is **insecure** if ***any*** shortcut attack is known
- But then insecure cipher might be harder to break than a secure cipher!
  - What the … ?

# 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



| | 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 ⊕ 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 claims 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 provides **no** 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 msg instead of pad?

# Real-World One-Time Pad

- Project VENONA
  - Encrypted spy 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 |
| : | : |

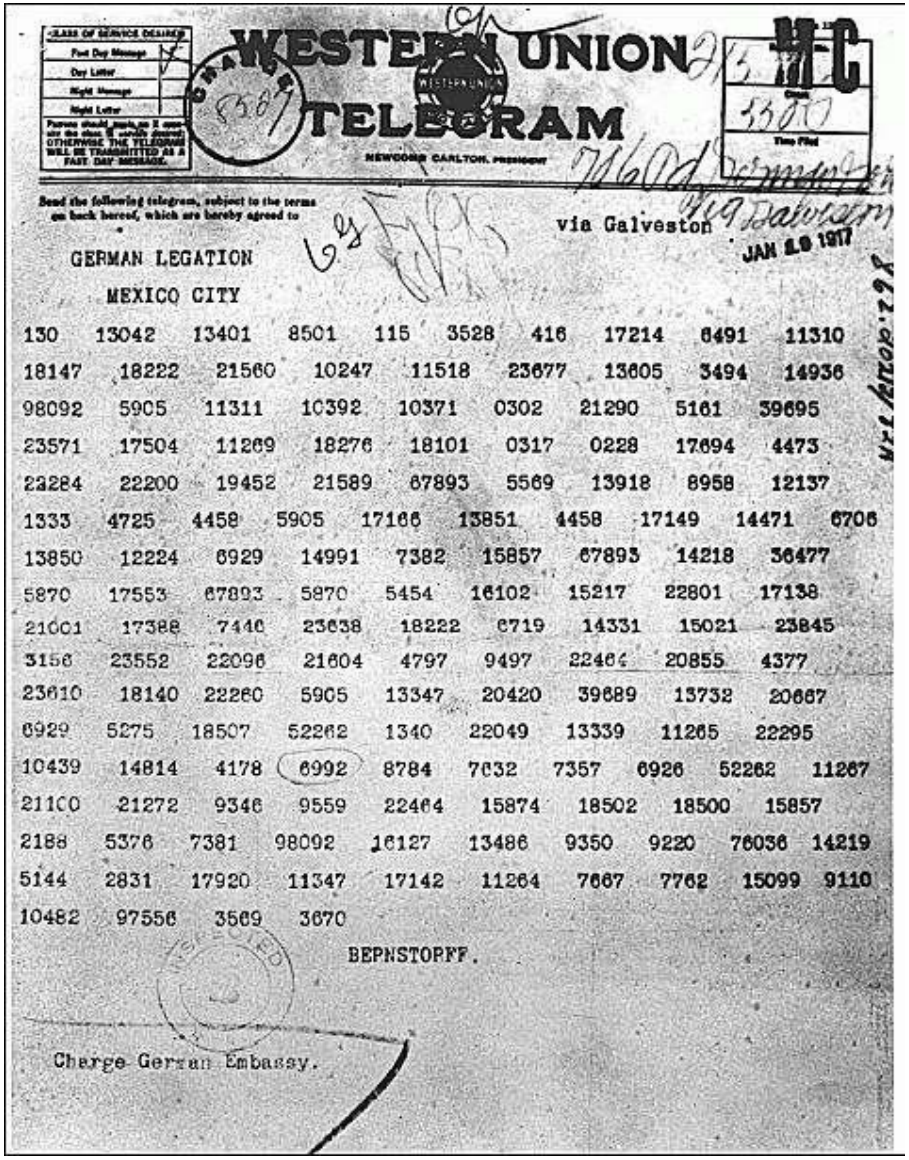
- Modern block ciphers are codebooks!
- More about this later…

# Codebook Cipher: Additive

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

# Zimmerman Telegram

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



WESTERN UNION TELEGRAM

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

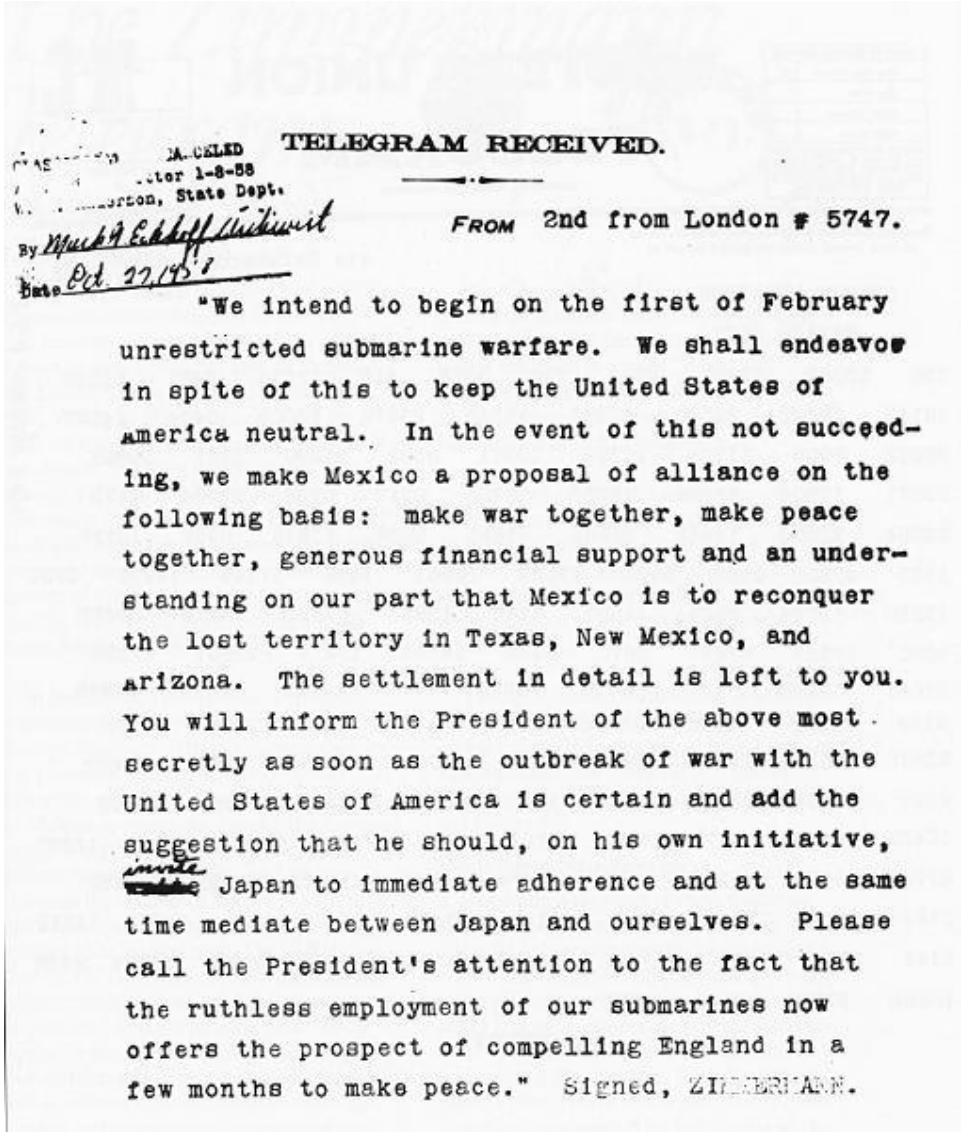
130 13042 13401 8501 115 3528 416 17214 6491 11310
18147 18222 21560 10247 11518 23677 13605 3494 14936
98092 5905 11311 10392 10371 0302 21290 5161 39695
23571 17504 11269 18276 18101 0317 0228 17694 4473
23284 22200 19452 21589 67893 5569 13918 8958 12137
1333 4725 4458 5905 17166 13851 4458 17149 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.

# Zimmerman 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.

# Types 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

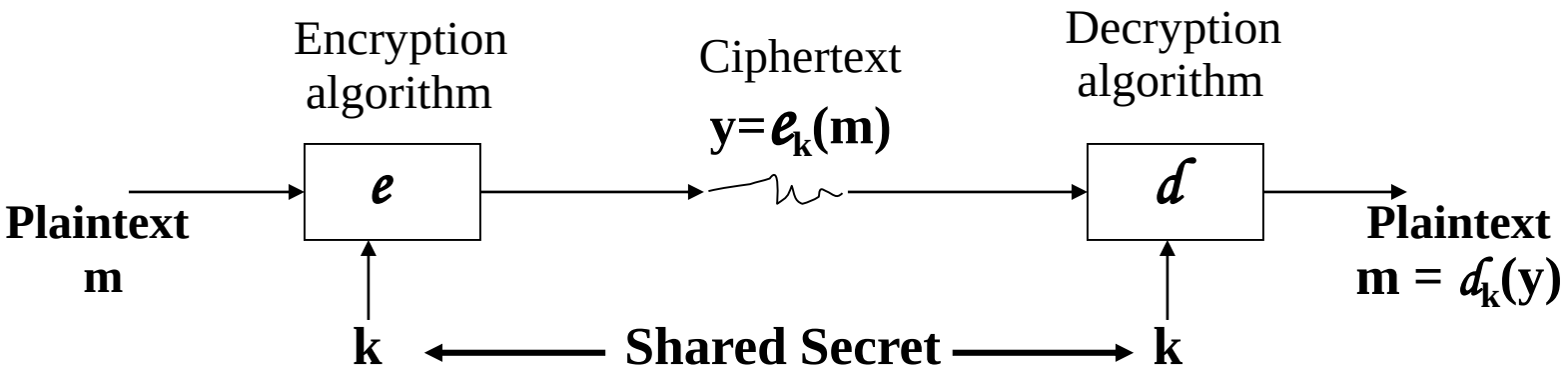
# Types of Cryptanalysis

- 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…

# Symmetric key (Conventional) Crypto

- Unique key (k) for correspondence
- In a network, the transmitter and receiver share a common key
- Keys must be delivered/distributed in a secure manner

# Symmetric key (Conventional) Crypto




- Communicating parties share a secret key (k)
- Encryption followed by decryption, using the same key, causes the original message to be recovered [ $m = d_k(e_k(m))$ ]
- For secrecy/confidentiality between A and B, only A and B must know the shared key (k).