Information security

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About this course

- Materials
  - slides
- Evaluation
  - Project + exercises: (30%)
  - final exam: writing exam (70%)
- Contents
  - Cryptography foundation
    - Ciphers
    - Cryptography protocols
  - Security applications
    - Digital signature
    - Network security

Cryptography I

General concepts and some classical ciphers

Outline

- Basic concepts
- Attack models
- Classic ciphers: mono-alphabetic
- Vigenere cipher
- One-time-pad cipher

Security Goals

- Confidentiality (secrecy, privacy)
  - Assure that data is accessible to only one who are authorized to know
- Integrity
  - Assure that data is only modified by authorized parties and in authorized ways
- Availability
  - Assure that resource is available for authorized users

General tools

- Cryptography
- Software controls
- Hardware controls
- Policies and procedures
- Physical controls

What is Crypto?

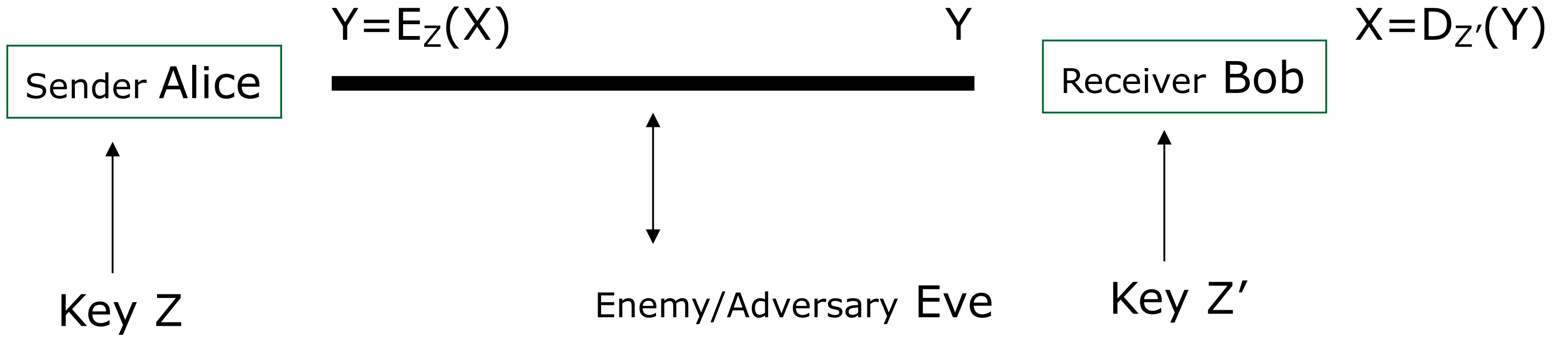
- Constructing and analyzing cryptographic protocols which enable parties to achieve security objectives
  - Under the present of adversaries.
- A protocol (or a scheme) is a suite of procedures that tell each party what to do
  - usually, computer algorithms
- Cryptographers devise and analyze protocols under Attack model
  - assumptions about the resources and actions available to the adversary
    - So, you need to think as an adversary

Terms

- **Cryptography:** the study of mathematical techniques for providing information security services.
- **Cryptanalysis:** the study of mathematical techniques for attempting to get security services breakdown.
- **Cryptology:** the study of cryptography and cryptanalysis.

Terms

- plaintexts
- ciphertexts
- keys
- encryption
- decryption



Secret-key cryptography

- Also called: symmetric cryptography
- Use the same key for both encryption & decryption (Z=Z')
- Key must be kept secret
- Key distribution – how to share a secret between A and B very difficult

Public-key cryptography

- Also called: asymmetric cryptography
- Encryption key different from decryption key and
  - It is not possible to derive decryption key from encryption key
- Higher cost than symmetric cryptography

Breaking ciphers …

- There are different methods of breaking a cipher, depending on:
  - the type of information available to the attacker
  - the interaction with the cipher machine
  - the computational power available to the attacker

Breaking ciphers …

- **Ciphertext-only attack**:
  - The cryptanalyst knows **only the ciphertext**.
  - Goal: to find the plaintext and the key.
  - NOTE: such vulnerable is seen completely insecure
- **Known-plaintext attack**:
  - The cryptanalyst knows **one or several pairs of ciphertext and the corresponding plaintext.**
  - Goal: to find the key used to encrypt these messages
    - or a way to decrypt any new messages that use the same key (although may not know the key).

Breaking ciphers …

- **Chosen-plaintext attack**
  - The cryptanalyst **can choose a number of messages and obtain the ciphertexts for them**
  - Goal: deduce the key used in the other encrypted messages or decrypt any new messages (using that key).
- **Chosen-ciphertext attack**
  - Similar to above, but the cryptanalyst **can choose a number of ciphertexts and obtain the plaintexts.**
- Both can be **adaptive**
  - The choice of ciphertext may depend on the plaintext received from previous requests.

Classic ciphers

Shift cipher (additive cipher)

- Key Space: [1 .. 25]
- Encryption given a key K:
  - each letter in the plaintext P is replaced with the K'th letter following corresponding number (shift right):
  - Another way: $Y = X \oplus K$ ➔ additive cipher
- Decryption given K:
  - shift left

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
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
P = CRYPTOGRAPHYISFUN
K = 11
C = NCJAVZRCLASJTDQFY

Shift Cipher: Cryptanalysis

- Easy, just do exhaustive search
  - key space is small (<= 26 possible keys).
  - once K is found, very easy to decrypt

General Mono-alphabetical Substitution Cipher

- The key space: all permutations of $\Sigma = \{A, B, C, \ldots, Z\}$
- Encryption given a key π:
  - each letter X in the plaintext P is replaced with $\pi(X)$
- Decryption given a key π :
  - each letter Y in the cipherext P is replaced with $\pi^{-1}(Y)$

- **Example:**

  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

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

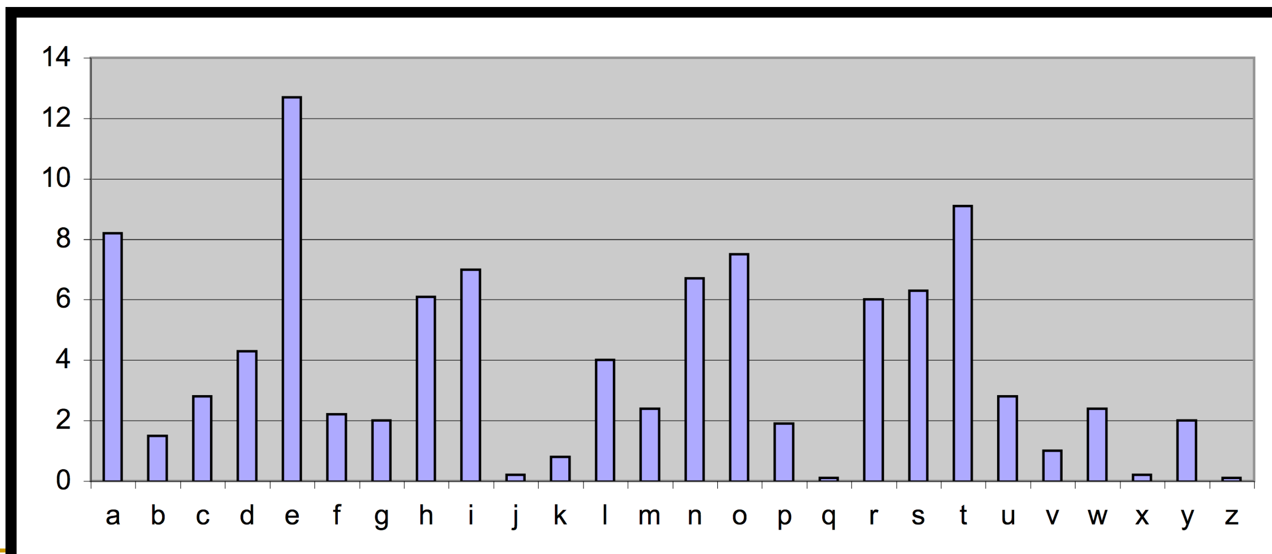
BECAUSE $\rightarrow$ AZDBJSZ

Looks secure, early days

- Exhaustive search is infeasible
  - key space size is $26! \approx 4*10^{26}$
- Dominates the art of secret writing throughout the first millennium A.D.
- Thought to be unbreakable by many back then

Cryptanalysis of Substitution Ciphers: Frequency Analysis

- Each language has certain features:
  - frequency of letters, or of groups of two or more letters.
- Substitution ciphers preserve the mentioned language features ➔ vulnerable to frequency analysis attacks



General Mono-alphabetical Substitution Cipher

- Observations:
  - A cipher system should not allow statistical properties of plaintext to pass to the ciphertext.
  - The ciphertext ginerated by a "good" cipher systim should be satistically indistinguishable form random text.
- Idea for a stronger cipher (1460’s by Alberti)
  - use more than one cipher alphabet, and switch between them when encrypting different letters ➔ Polyalphabetic Substitution Ciphers
  - Developed into a practical cipher by Vigenère (published in 1586)

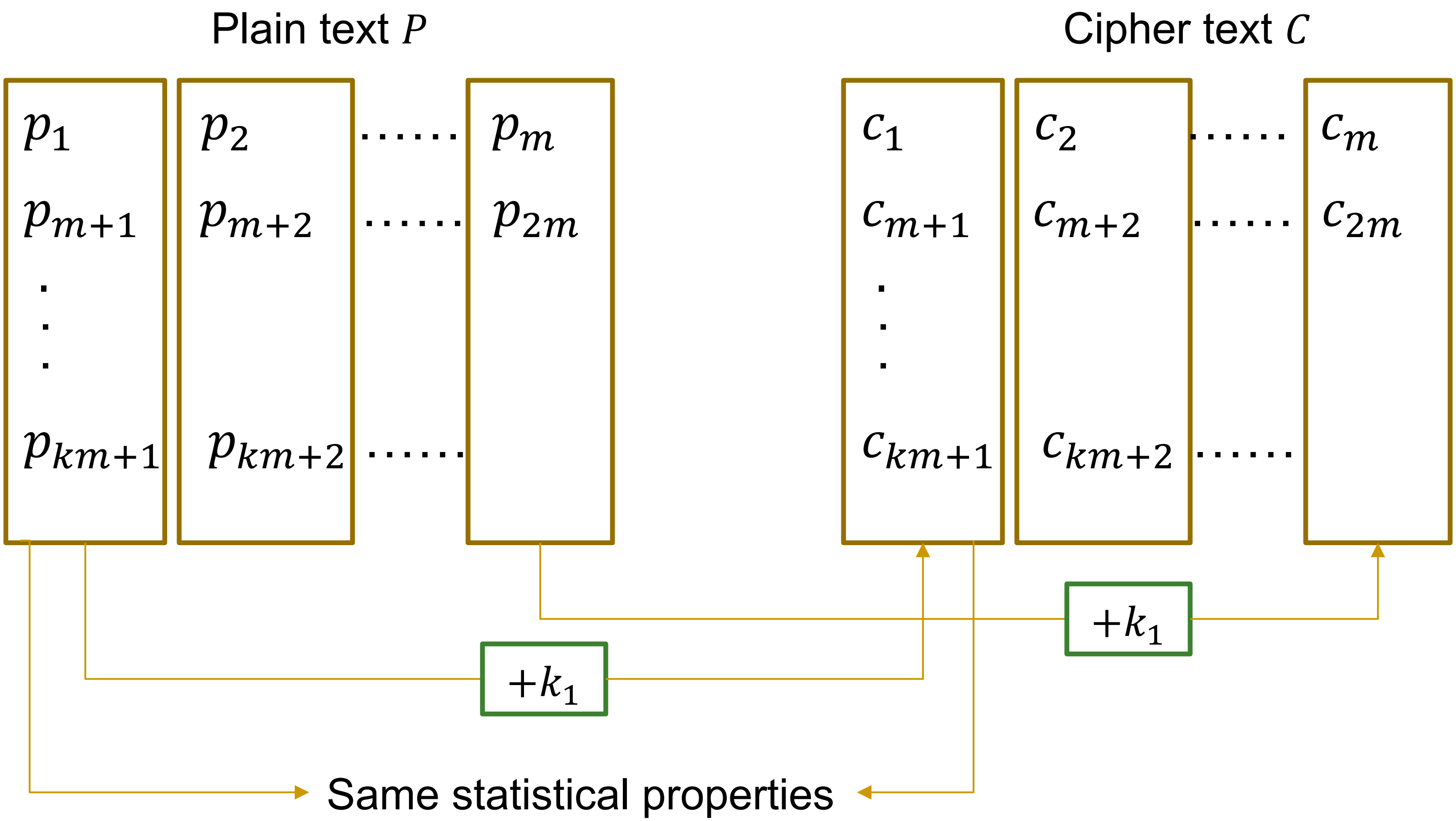
Polyalphabetic Substitution Ciphers

- Polyalphabetic Substitution Ciphers (Vigenère cipher - published in 1586)
  - Definition:
    - Given m, a positive integer, $P = C = (Z_{26})^n$, and $K = (k_1, k_2, \ldots, k_m)$ a key, we define:
  - Encryption:
    - $e_k (p_1, p_2 \ldots p_m) = (p_1+k_1, p_2+k_2 \ldots p_m+k_m) \pmod{26}$
  - Decryption:
    - $d_k (c_1, c_2 \ldots c_m) = (c_1-k_1, c_2-k_2 \ldots c_m- k_m) \pmod{26}$
  - Example:

Plaintext:	C R Y P T O G R A P H Y
Key:	L U C K L U C K L U C K
Ciphertext:	N L A Z E I I B L J J I

Vigenère cipher

- Cryptanalysis



Can be broken by the statistical method once the key length is determined

Vigenère cipher

- How to determine the key length
  - The frequency of letters in $\{p_j, p_{m+j}, \dots, p_{km+j}\}$ is approximately the same as that in the plain text P
  - The frequency of letters in $\{c_j, c_{m+j}, \dots, c_{km+j}\}$ is the same as that in $\{p_j, p_{m+j}, \dots, p_{km+j}\}$
- The index of coincidence (IC)
  - Suppose $x = x_1 x_2 \dots . x_n$ is a string of alphabetic characters → $IC(x)$ is the probability that two random elements of x are identical

Vigenère cipher

- The index of coincidence (IC)
  - Suppose the frequencies of $A, B, \ldots, Z$ in x are $f_0, f_1 \ldots, f_{25}$
  - $IC(x) = \frac{\sum_{i=0}^{25}\binom{f_i}{2}}{\binom{n}{2}} = \sum_{i=0}^{25} \frac{f_i}{n}\frac{f_i - 1}{n-1} \approx \sum_{i=0}^{25}(p_i)^2$

p_i: the frequency of the i-th letter

letter	probability
A	.082
B	.015
C	.028
D	.043
E	.127
F	.022
…	
Z	.001

For an English text

$IC(x) \approx 0.065$

For a totally random string

$$IC(x) \approx \sum_{i=0}^{25} \frac{1}{26} = 0.038$$

Vigenère cipher

- The index of coincidence (IC)
  - Let $P_j = \{p_j, p_{m+j}, \dots, p_{km+j}\}; C_j = \{c_j, c_{m+j}, \dots, c_{km+j}\}$
    - $IC(C_j) = IC(P_j) \approx 0.065$
- Cryptanalysis algorithm
  1. Set $m = 1$
  2. Check if m is indeed the key length
     - Divide the cipher into m letter group and compute the IC of each
     - If they are quite the same and approximately equals to 0.065 then m is the key length
     - If they are quite different and smaller than 0.065, then the key length should be greater
  3. Increase m by 1 and go to step 1

Vigenère cipher

- Kasiski method: a hint to find the key length
  - Observation: two identical segments of plaintext will be encrypted to the same cipher text wherever their occurrence in the plain text is δ position apart, $\delta \equiv 0(mod\ m)$

$$p_1 \ \cdots \boxed{p_j p_{j+1} \cdots p_{j+u}} \cdots\cdots \ p_m$$

$$\vdots$$

$$p_{vm+1} \ \cdots \boxed{p_{vm+j} p_{vm+j+1} \cdots p_{vmj+u}} \cdots\cdots \ p_{vm+m}$$

If these are the same

$$c_1 \ \cdots \boxed{c_j c_{j+1} \cdots c_{j+u}} \cdots\cdots \ c_m$$

$$\vdots$$

$$c_{vm+1} \ \cdots \boxed{c_{vm+j} c_{vm+j+1} \cdots c_{vmj+u}} \cdots\cdots \ c_{vm+m}$$

Then, these will be the same

Vigenère cipher

- Kasiski method
  - Search the cipher text for pairs of identical segments and record the distance between their starting positions
    - Suppose the obtained distances are $\delta_1, \ldots, \delta_k$
  - Then, m should divides the greatest common divisor of $\delta_1, \ldots, \delta_k$

Vigenère cipher

- Example

```
CHREEVOAHMAERATBIAXXWTNXBEEOPHBSBQMQEQERBW
RVXUOAKXAOSXXWEAHBWGJMMQMNKGRFVGXWTRZXWIAK
LXFPSKAUTEMNDCMGTSXMXBTUIADNGMGPSRELXNJELX
VRVPRTULHDNQWTWDTYGBPHXTFALJHASVBFXNGLLCHR
ZBWELEKMSJIKNBHWRJGNMGJSGLXFEYPHAGNRBIEQJT
AMRVLCRREMNDGLXRRIMGNSNRWCHRQHAEYEVTAQEBBI
PEEWEVKAKOEWADREMXMTBHHCHRTKDNVRZCHRCLQOHP
WQAIIWXNRMGWOIIFKEE
```

Vigenère cipher

- Example

```
CHR EEVOAHMAERATBIAXXWTNXBEEOPHBSBQMQEQERBW
RVXUOAKXAOSXXWEAHBWGJMMQMNKGRFVGXWTRZXWIAK
LXFPSKAUTEMNDCMGTSXMXBTUIADNGMGPSRELXNJELX
VRVPRTULHDNQWTWDTYGBPHXTFALJHASVBFXNGLL CHR
ZBWELEKMSJIKNBHWRJGNMGJSGLXFEYPHAGNRBIEQJT
AMRVLCRREMNDGLXRRIMGNSNRW CHR QHAEYEVTAQEBBI
PEEWEVKAKOEWADREMXMTBHH CHR TKDNVRZ CHR CLQOHP
WQAIIWXNRMGWOIIFKEE
```

Kasiski method: CHR's occurrence positions: 1, 166, 236, 276 and 286
→ Distances: 165, 235, 275 and 285
→ Gcd(165, 235, 275, 285) = 5
→ The key length should divides 5

Vigenère cipher

- Example

```
CHREEVOAHMAERATBIAXXWTNXBEEOPHBSBQMQEQERBW
RVXUOAKXAOSXXWEAHBWGJMMQMNKGRFVGXWTRZXWIAK
LXFPSKAUTEMNDCMGTSXMXBTUIADNGMGPSRELXNJELX
VRVPRTULHDNQWTWDTYGBPHXTFALJHASVBFXNGLLCHR
ZBWELEKMSJIKNBHWRJGNMGJSGLXFEYPHAGNRBIEQJT
AMRVLCRREMNDGLXRRIMGNSNRWCHRQHAEYEVTAQEBBI
PEEWEVKAKOEWADREMXMTBHHCHRTKDNVRZCHRCLQOHP
WQAIIWXNRMGWOIIFKEE
```

Confirmation of Kasiski method

M = 1 → IC = 0.045

M = 2 → ICs = 0.046 and 0.041

M = 3 → ICs = 0.043, 0.050, 0.047

M = 4 → ICs = 0.042, 0.039, 0.046, 0.040

M = 5 → ICs = 0.063, 0.068, 0.069, 0.061 and 0.072

Vigenère cipher

i	value of $M_g(\mathbf{y}_i)$								
1	.035	.031	.036	.037	.035	.039	.028	.028	.048
	$\boxed{.061}$	.039	.032	.040	.038	.038	.045	.036	.030
	.042	.043	.036	.033	.049	.043	.042	.036	
2	$\boxed{.069}$	.044	.032	.035	.044	.034	.036	.033	.029
	.031	.042	.045	.040	.045	.046	.042	.037	.032
	.034	.037	.032	.034	.043	.032	.026	.047	
3	.048	.029	.042	.043	.044	.034	.038	.035	.032
	.049	.035	.031	.035	$\boxed{.066}$	.035	.038	.036	.045
	.027	.035	.034	.034	.036	.035	.046	.040	
4	.045	.032	.033	.038	$\boxed{.060}$	.034	.034	.034	.050
	.033	.033	.043	.040	.033	.029	.036	.040	.044
	.037	.050	.034	.034	.039	.044	.038	.035	
5	.034	.031	.035	.044	.047	.037	.043	.038	.042
	.037	.033	.032	.036	.037	.036	.045	.032	.029
	.044	$\boxed{.072}$	.037	.027	.031	.048	.036	.037	

$$M_g = \sum_{i=0}^{25} \frac{p_i f_{i+g}}{n'}$$

If $g \neq k_i$, then $M_g \ll 0.065$

$$K = (9, 0, 13, 4, 19) = JANET$$

The almond tree was in tentative blossom. The days were longer, often ending with magnificent evenings of corrugated pink skies. The hunting season was over, with hounds and guns put away for six months. The vineyards were busy again as the well-organized farmers treated their vines and the more lackadaisical neighbors hurried to do the pruning they should have done in November.

Exercises

- Decode the following cipher texts
  - Encrypted by shift cipher:
    - JBCRCLQRWCRVNBJENBWRWN
  - Encrypted by substitution cipher:
    - Pjmu mu b amtjfo rfsr. Mr jbu cffi fiaowtrfg cw rjf uvcurmrvrmqi amtjfo. Wqv bof xfow nvahw. Rjf amtjfo jbu cffi coqhfi
    - YIFQFMZRWQFYVECFMDZPCVMRZWNMDZVEJBTXCDDUMJ NDIFEFMDZCDMQZKCEYFCJMYRNCWJCSZREXCHZUNMXZ NZUCDRJXYYSMRTMEYIFZWDYVZVYFZUMRZCRWNZDZJJ XZWGCHSMRNMDHNCMFQCHZJMXJZWIEJYUCFWDJNZDIR
    - Hints:
      - The letters in the English alphabet can be divided into 5 groups of similar frequencies
        - e
        - t,a,o,i,n,s,h,r
        - d,l
        - c,u,m,w,f,g,y,p,b
        - v,k,j,x,q,z
      - Some frequently appearing bigrams or trigrams
        - Th, he, in, an, re, ed, on, es, st, en at, to
        - The, ing, and, hex, ent, tha, nth, was eth, for, dth.

Exercises

- Decode the following cipher texts
  - Encrypted by substitution cipher:

YIFQFMZRWQFYVECFMDZPCVMRZWNMDZVEJBTXCDDUMJ
NDIFEFMDZCDMQZKCEYFCJMYRNCWJCSZREXCHZUNMXZ
NZUCDRJXYYSMRTMEYIFZWDYVZVYFZUMRZCRWNZDZJJ
XZWGCHSMRNMDHNCMFQCHZJMXJZWIEJYUCFWDJNZDIR

letter	frequency	letter	frequency
A	0	*N*	9
B	1	*O*	0
C	15	*P*	1
D	13	*Q*	4
E	7	*R*	10
F	11	*S*	3
G	1	*T*	2
H	4	*U*	5
I	5	*V*	5
J	11	*W*	8
K	1	*X*	6
L	0	*Y*	10
M	16	*Z*	20

DZ and *ZW:* four times each
NZ and *ZU:* three times each
RZ, HZ, YZ, FZ, ZR, ZV, ZC, ZD, ZJ: twice each