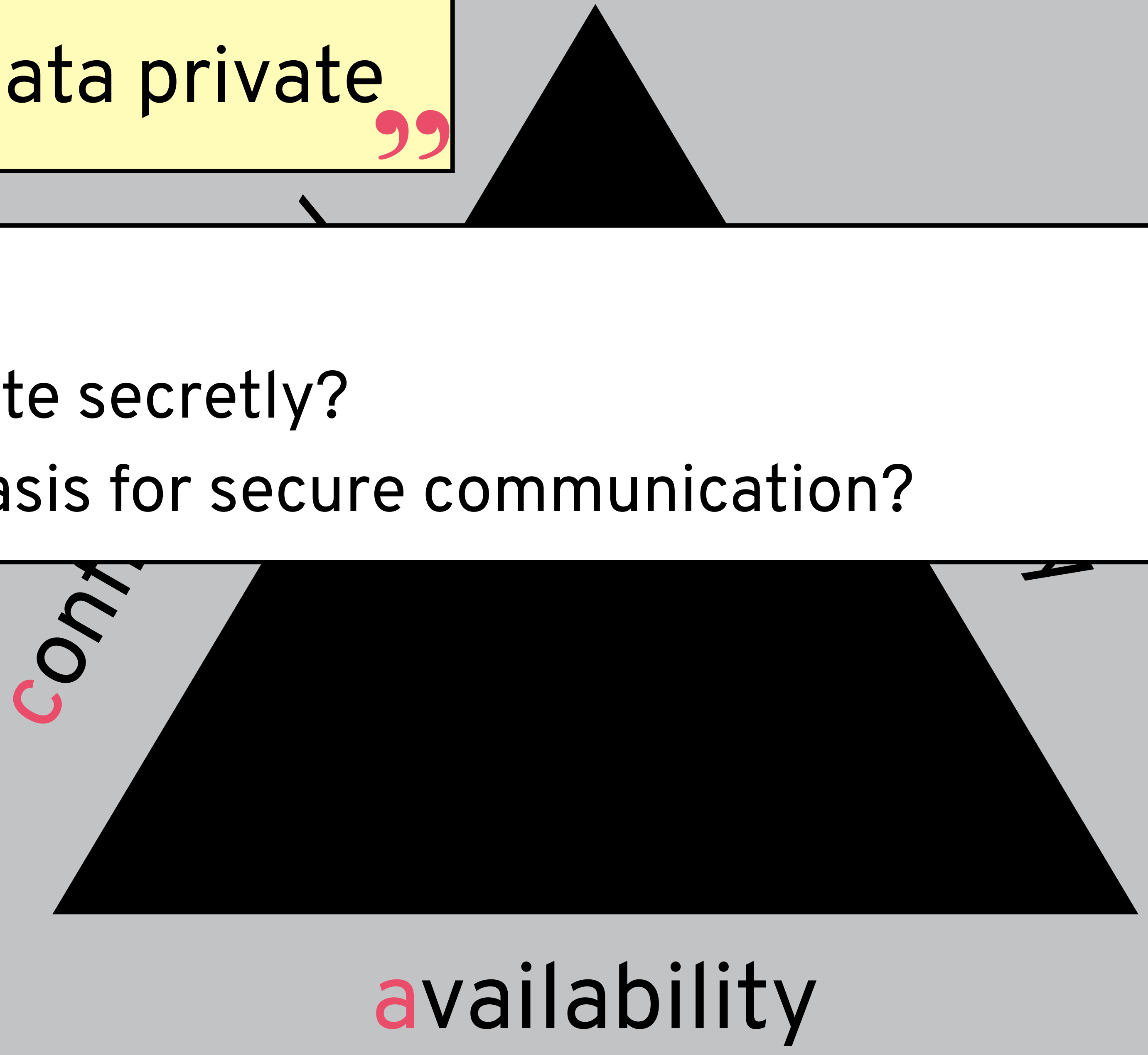
SECURITY (COMP0141): CONFIDENTIALITY

CONFIDENTIALITY

> “keeping data private”

how to:

- communicate secretly?
- establish basis for secure communication?



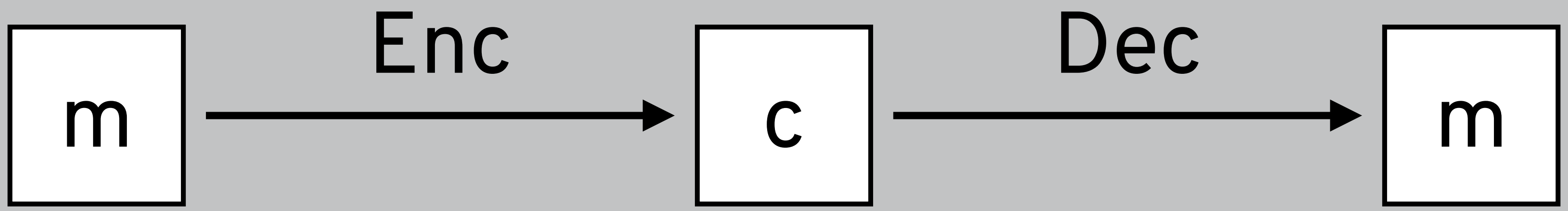
TERMINOLOGY

Cryptographer: person who makes cryptography

Cryptanalyst: person who breaks cryptography

Code: semantic translation (A means B)

Ciphertext: encryption of underlying plaintext



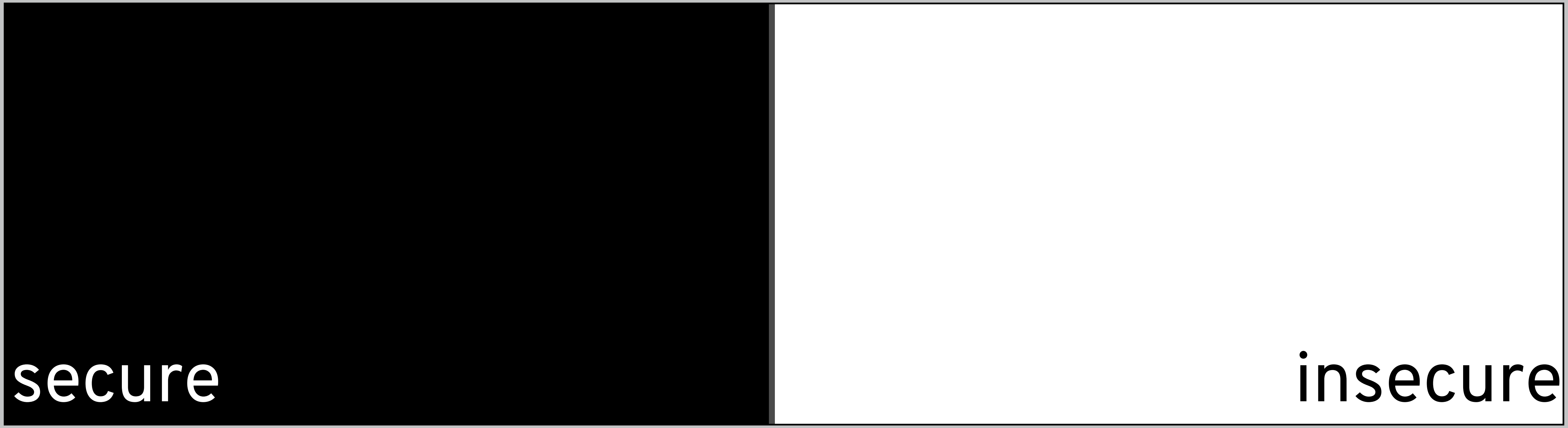
WARNING

You should never design your own cryptography!

This lecture on cryptography does not in any way qualify you to design cryptographic algorithms or protocols

Instead it’s an introduction to what you can expect from cryptography and a feeling for how these algorithms work

WARNING



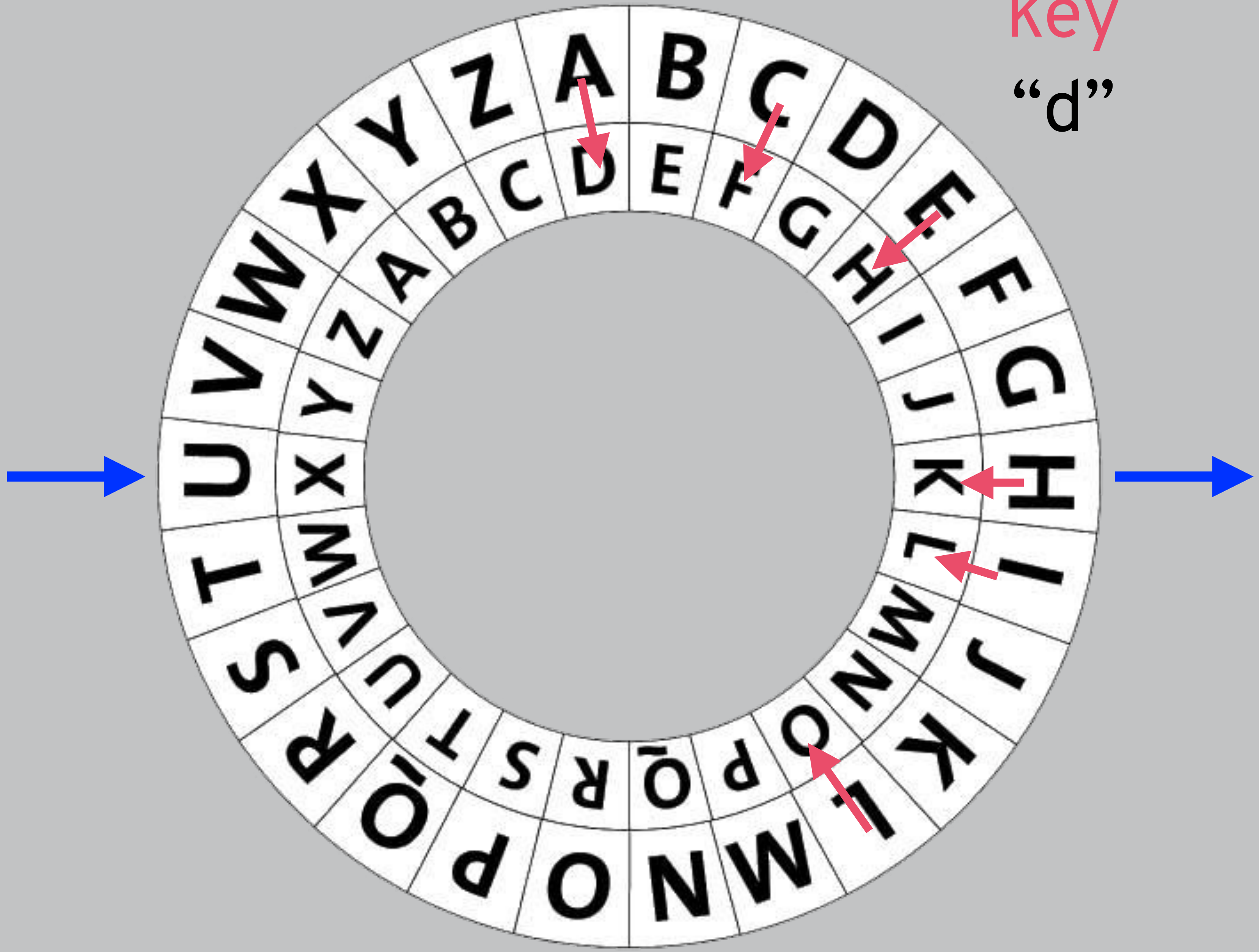
secure

insecure

Cryptography

- If you get it right, could be secure for decades
- If you get it wrong, you get no security at all

CAESAR SHIFT CIPHER


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
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

key

“d”

plaintext

“Hi Alice”

ciphertext

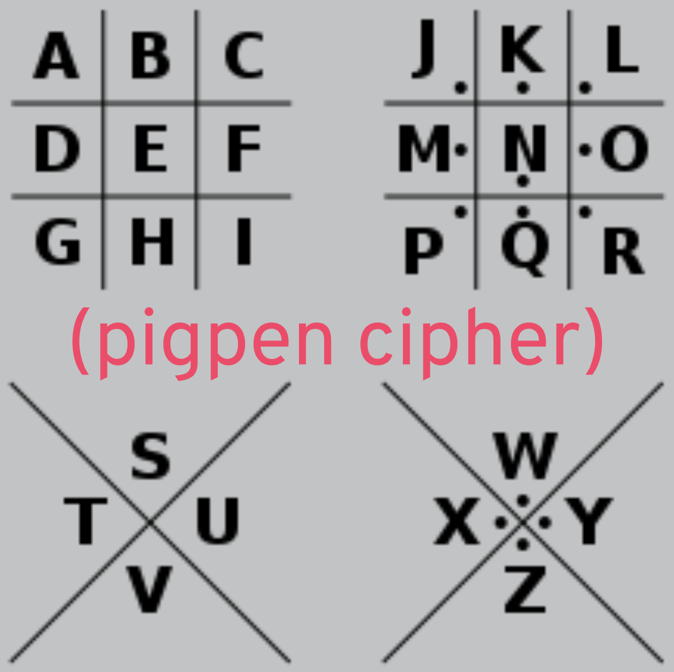
“Kl Dolfh”

MONOALPHABETIC SUBSTITUTION

Monoalphabetic substitution cipher applies permutation $\pi : \Sigma \to \Sigma'$

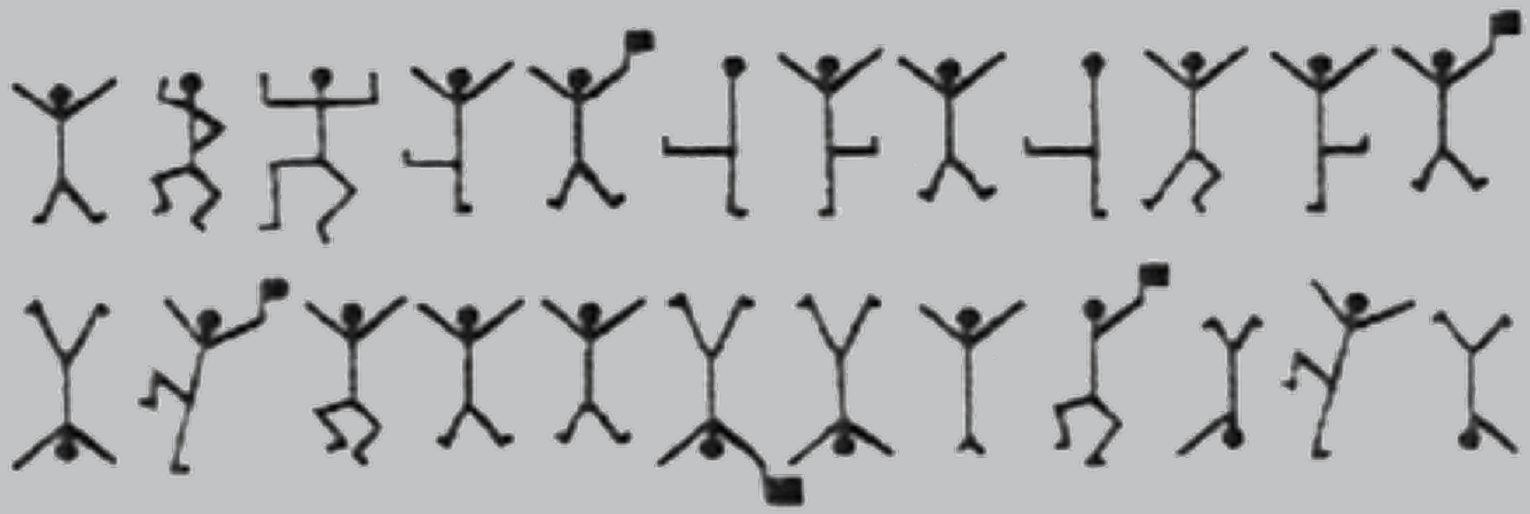
In Caesar shift, π is rotation: $\beta \to \beta$ + key mod 26

More generally, might have $\pi(a) = o$, $\pi(b) = m$, etc., or Σ' might not be same language as Σ



(pigpen cipher)

(adventure of the dancing men)



THREAT MODEL

Motivation:

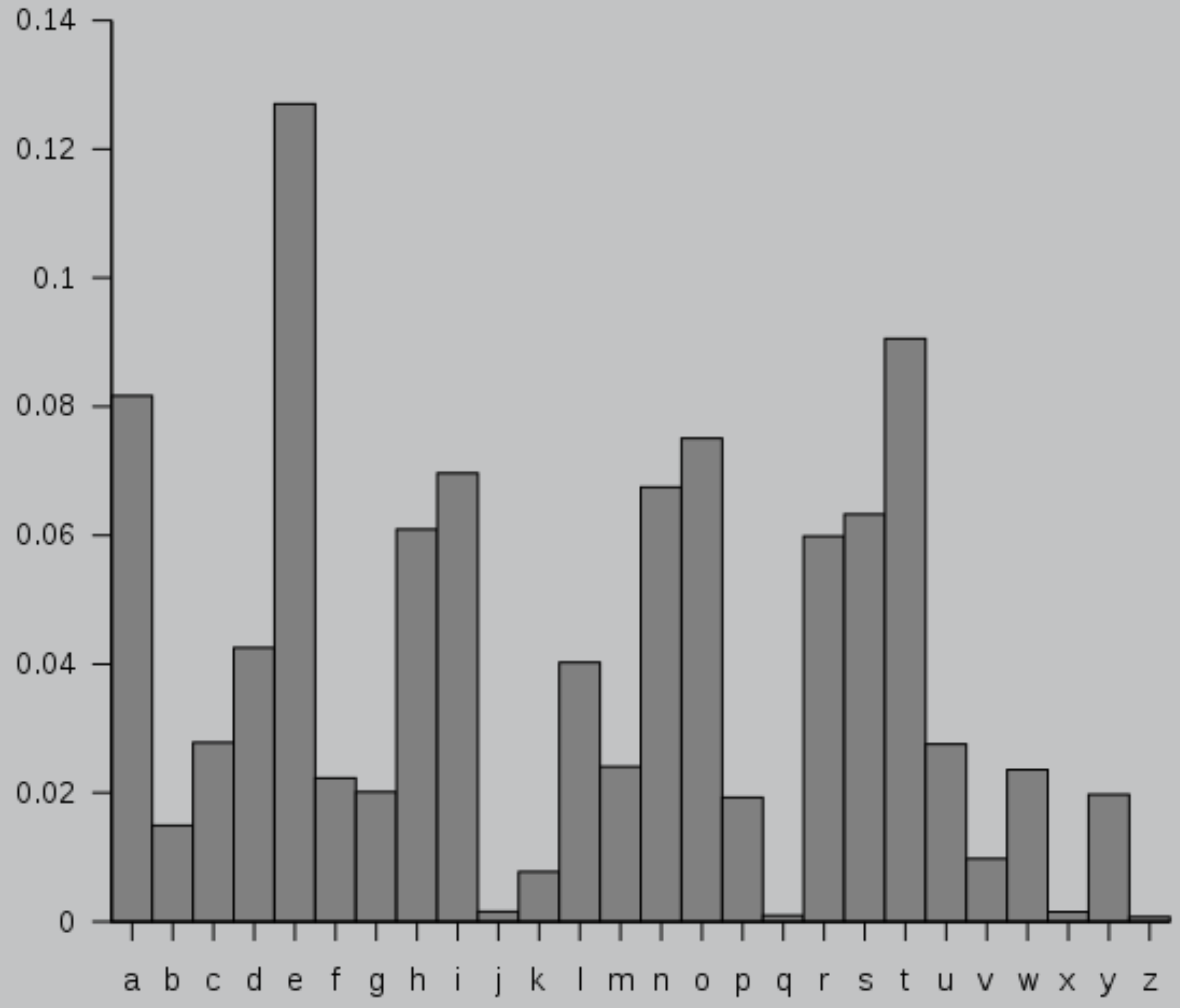
- **Recover key:** learn all future plaintexts
- → **Recover plaintext:** learn this specific plaintext
- **Distinguish plaintext:** learn a single bit about plaintext

Capabilities:

- → **Known ciphertext:** know ciphertext
- **Known algorithm:** know scheme used to encrypt
- **Known plaintext:** (partial) information about plaintext
- **Chosen plaintext:** adversary picked plaintext
- **Chosen ciphertext:** adversary picked ciphertext

Strongest security statement: the adversary with the strongest capabilities can’t achieve even the weakest goal

FREQUENCY ANALYSIS



most common English letters: etnorias (or senorita)

Lw zdv wkh ehvw ri wlphv, lw zdv wkh zruvw ri
wlphv, lw zdv wkh djh ri zlvgrp, lw zdv wkh
djh ri irrolvkqhvv, lw zdv wkh hsrfk ri
eholhi, lw zdv wkh hsrfk ri lqfuhgxolwb, lw
zdv wkh vhdvrq ri Oljkw, lw zdv wkh vhdvrq ri
Gdunqhvv, lw zdv wkh vsulqj ri krsh, lw zdv
wkh zlqw hubwklqj
ehiruh xv, v, zh zhuh
doo jrlqj gluhfw wr khdyhq, zh zhuh doo jrlqj
gluhfw wkh rwkhu zdb – lq vkruw, wkh shulrg
zdv vr idu olnh wkh suhvhqw shulrg, wkdw vrph
ri lwv qrlvlhvw dxwkrulwlhv lqvlvwhg rq lwv
ehlqj uhfhlyhg, iru jrrg ru iru hylo, lq wkh
vxshuodwlyh ghjuhh ri frpsdulvrq rqob.

most common letter is h

Lw zdv wke eevw ri wlpev, lw zdv wke zruvw ri
wlpev, lw zdv wke dje ri zlvgrp, lw zdv wke
dje ri irrolvkqevv, lw zdv wke esrfk ri
eeolei, lw zdv wke esrfk ri lqfuegxolwb, lw
zdv wke vedvrq ri Oljkw, lw zdv wke vedvrq ri
Gdunqe … w zdv
wke … klqj
eeirue … e zeue
doo jri … jrlqj
gluefw wke rwkeu zdb – lq vkruw, wke seulrg
zdv vr idu olne wke sueveqw seulrg, wkdw vrpe
ri lwv qrlvlevw dxwkrulwlev lqvlvweg rq lwv
eelqj uefelyeg, iru jrrg ru iru eylo, lq wke
vxseuodwlye gejuee ri frpsdulvrq rqob.

Caesar shift?

Then h→e ⇒ key is x (23) and we're done!

Lt zdv the eevt ri tlpev, lt zdv the zruvt ri tlpev, lt zdv the dje ri zlvgrp, lt zdv the dje ri irrolvhqevv, lt zdv the esrfh ri eeolei, lt zdv the esrfh ri lqfuegxoltb, lt zdv the vedvrq ri Oljht, lt zdv the vedvrq ri Gdunqevv, lt zdv the vsulqj ri hrse, lt zdv the zlqteu ri gevsdlu, ze hdg eyeubthlqj eeirue xv, ze hdg qrthlqj eeirue xv, ze zeue doo jrlqj glueft tr hedyeq, ze zeue doo jrlqj glueft the rtheu zdb – lq vhrut, the seulrg zdv vr idu olne the sueveqt seulrg, thdt vrpe ri ltv qrlvlevt dxthrultlev lqvlvteg rq ltv eelqj uefelyeg, iru jrrg ru iru eylo, lq the vxseuodtlye gejuee ri frpsdulvrq rqob.

Lt zav the eevt ri tlpev, lt zav the zruvt ri tlpev, lt zav the aje ri zlvgrp, lt zav the aje ri irrolvhqevv, lt zav the esrfh ri eeolei, lt zav the esrfh ri lqfuegxoltb, lt zav the veavrq ri Oljht, lt zav the veavrq ri Gaunqevv, lt zav the vsulqj ri hrse, lt zav the zlqteu ri gevsalu, ze hag eyeubthlqj eeirue xv, ze hag qrthlqj eeirue xv, ze zeue aoo jrlqj glueft tr heayeq, ze zeue aoo jrlqj glueft the rtheu zab – lq vhrut, the seulrg zav vr iau olne the sueveqt seulrg, that vrpe ri ltv qrlvlevt axthrultlev lqvlvteg rq ltv eelqj uefelyeg, iru jrrg ru iru eylo, lq the vxseuoatlye gejuee ri frpsaulvrq rqob.

It zav the eevt ri tipev, it zav the zruvt ri tipev, it zav the aje ri zivgrp, it zav the aje ri irroivhqevv, it zav the esrfh ri eeoiei, it zav the esrfh ri iqfuegxoitb, it zav the veavrq ri Oijht, it zav the veavrq ri Gaunqevv, it zav the vsuiqj ri hrse, it zav the ziqteu ri gevsaiu, ze hag eyeubthiqj eeirue xv, ze hag qrthiqj eeirue xv, ze zeue aoo jriqj giueft tr heayeq, ze zeue aoo jriqj giueft the rtheu zab - iq vhrut, the seuirg zav vr iau oine the sueveqt seuirg, that vrpe ri itv qrivievt axthruitiev iqvivteg rq itv eeiqj uefeiyeg, iru jrrg ru iru eyio, iq the vxseuoatiye gejuee ri frpsauivrq rqob.

It zas the eest ri tipes, it zas the zrust ri tipes, it zas the aje ri zisgrp, it zas the aje ri irroishqess, it zas the esrfh ri eeoiei, it zas the esrfh ri iqfuegxoitb, it zas the seasrq ri Oijht, it zas the seasrq ri Gaunqess, it zas the ssuiqj ri hrse, it zas the ziqteu ri gessaiu, ze hag eyeubthiqj eeirue xs, ze hag qrthiqj eeirue xs, ze zeue aoo jriqj giueft tr heayeq, ze zeue aoo jriqj giueft the rtheu zab - iq shrut, the seuirg zas sr iau oine the sueseqt seuirg, that srpe ri its qrisiest axthruities iqsisteg rq its eeiqj uefeiyeg, iru jrrg ru iru eyio, iq the sxseuoatiye gejuee ri frpsauisrq rqob.

It zas the eest of tipes, it zas the zoust of tipes, it zas the aje of zisgop, it zas the aje of foooishqess, it zas the esofh of eeoief, it zas the esofh of iqfuegxoitb, it zas the seasoq of Oijht, it zas the seasoq of Gaunqess, it zas the ssuiqj of hose, it zas the ziqteu of gessaiu, ze hag eyeubthiqj eefoue xs, ze hag qothiqj eefoue xs, ze zeue aoo joiqj giueft to heayeq, ze zeue aoo joiqj giueft the otheu zab - iq shout, the seuiog zas so fau oine the suseeqt seuiog, that sope of its qoisiest axthouities iqsisteg oq its eeiqj uefeiyeg, fou joog ou fou eyio, iq the sxseuoatiye gejuee of fopsauisoq oqob.

It zas the eest of tipes, it zas the zoust of tipes, it zas the aje of zisgop, it zas the aje of foooishness, it zas the esofh of eeoief, it zas the esofh of infuegxoitb, it zas the season of Oijht, it zas the season of Gaunness, it zas the ssuinj of hose, it zas the zinteu of gessaiu, ze hag eyeubthinj eefoue xs, ze hag nothinj eefoue xs, ze zeue aoo joinj giueft to heayen, ze zeue aoo joinj giueft the otheu zab – in shout, the seuiog zas so fau oine the suesent seuiog, that sope of its noisiest axthouities insisteg on its eeinj uefeiyeg, fou joog ou fou eyio, in the sxseuoatiye gejuee of fopsauison onob.

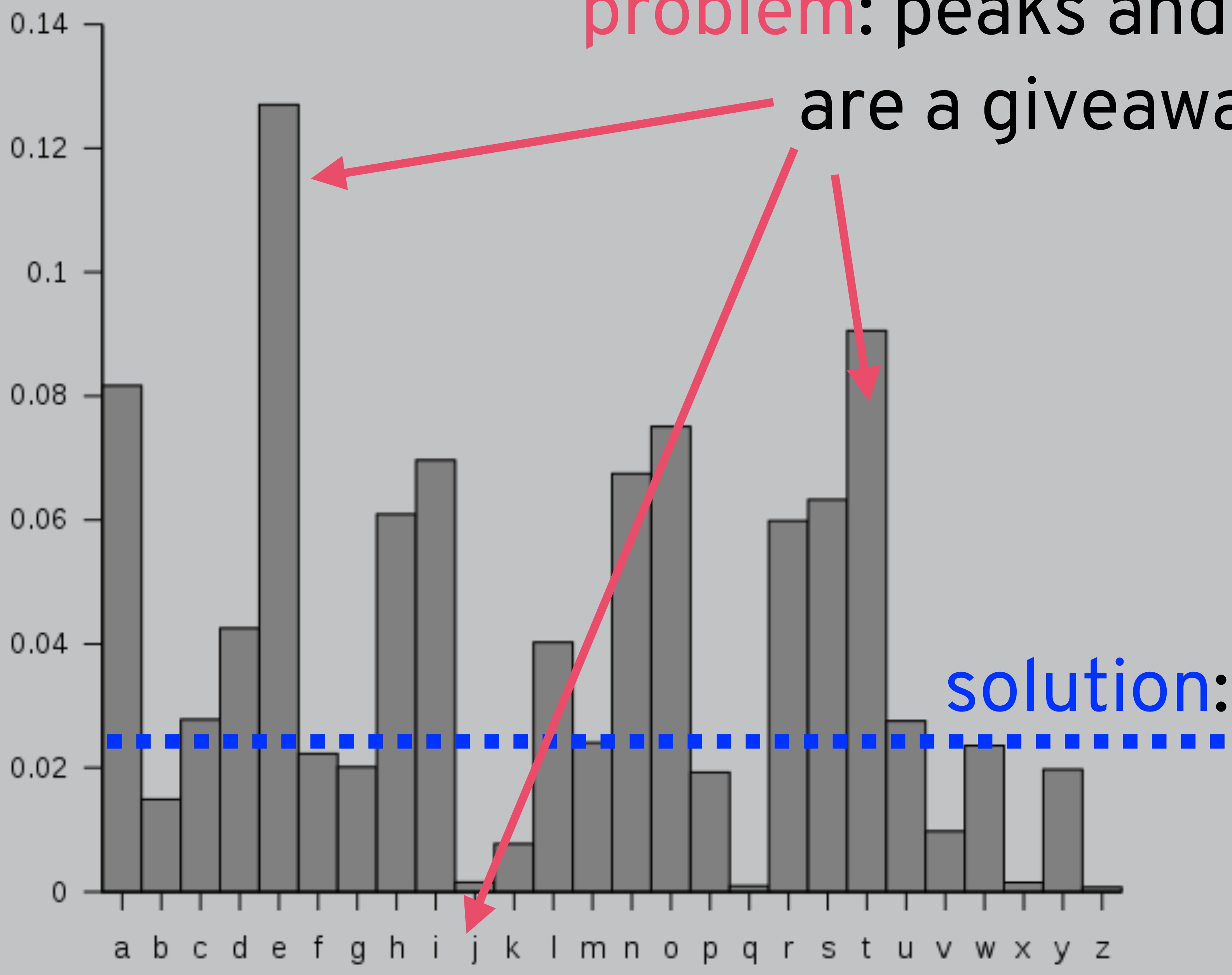
It zas the eest of tipes, it zas the zoust of tipes, it zas the age of zisgop, it zas the age of foooishness, it zas the esofh of eeoief, it zas the esofh of infuegxoitb, it zas the season of Oight, it zas the season of Gaunness, it zas the ssuing of hose, it zas the zinteu of gessaiu, ze hag eyeubthing eefoue xs, ze hag nothing eefoue xs, ze zeue aoo going giueft to heayen, ze zeue aoo going giueft the otheu zab – in shout, the seuiog zas so fau oine the suesent seuiog, that sope of its noisiest axthouities insisteg on its eeing uefeiyeg, fou goog ou fou eyio, in the sxseuoatiye geguee of fopsauison onob.

It zas the eest of tipes, it zas the zorst of tipes, it zas the age of zisgop, it zas the age of foooishness, it zas the esofh of eeoief, it zas the esofh of infregxoitb, it zas the season of Oight, it zas the season of Garnness, it zas the ssring of hose, it zas the zinter of gessair, ze hag eyerbthing eefore xs, ze hag nothing eefore xs, ze zere aoo going gireft to heayen, ze zere aoo going gireft the other zab – in short, the seriog zas so far oine the sresent seriog, that sope of its noisiest axthorities insisteg on its eeing refeiyeg, for goog or for eyio, in the sxseroatiye gegree of fopsarison onob.

It was the eest of tipes, it was the worst of tipes, it was the age of wisgop, it was the age of foooishness, it was the esofh of eeoief, it was the esofh of infregxoitb, it was the season of Oight, it was the season of Garnness, it was the ssring of hose, it was the winter of gessair, we hag eyerbthing eefore xs, we hag nothing eefore xs, we were aoo going gireft to heayen, we were aoo going gireft the other wab - in short, the seriog was so far oine the sresent seriog, that sope of its noisiest axthorities insisteg on its eeing refeiyeg, for goog or for eyio, in the sxseroatiye gegree of fopsarison onob.

It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, we were all going direct to heaven, we were all going direct the other way - in short, the period was so far like the present period, that some of its noisiest authorities insisted on its being received, for good or for evil, in the superlative degree of comparison only.

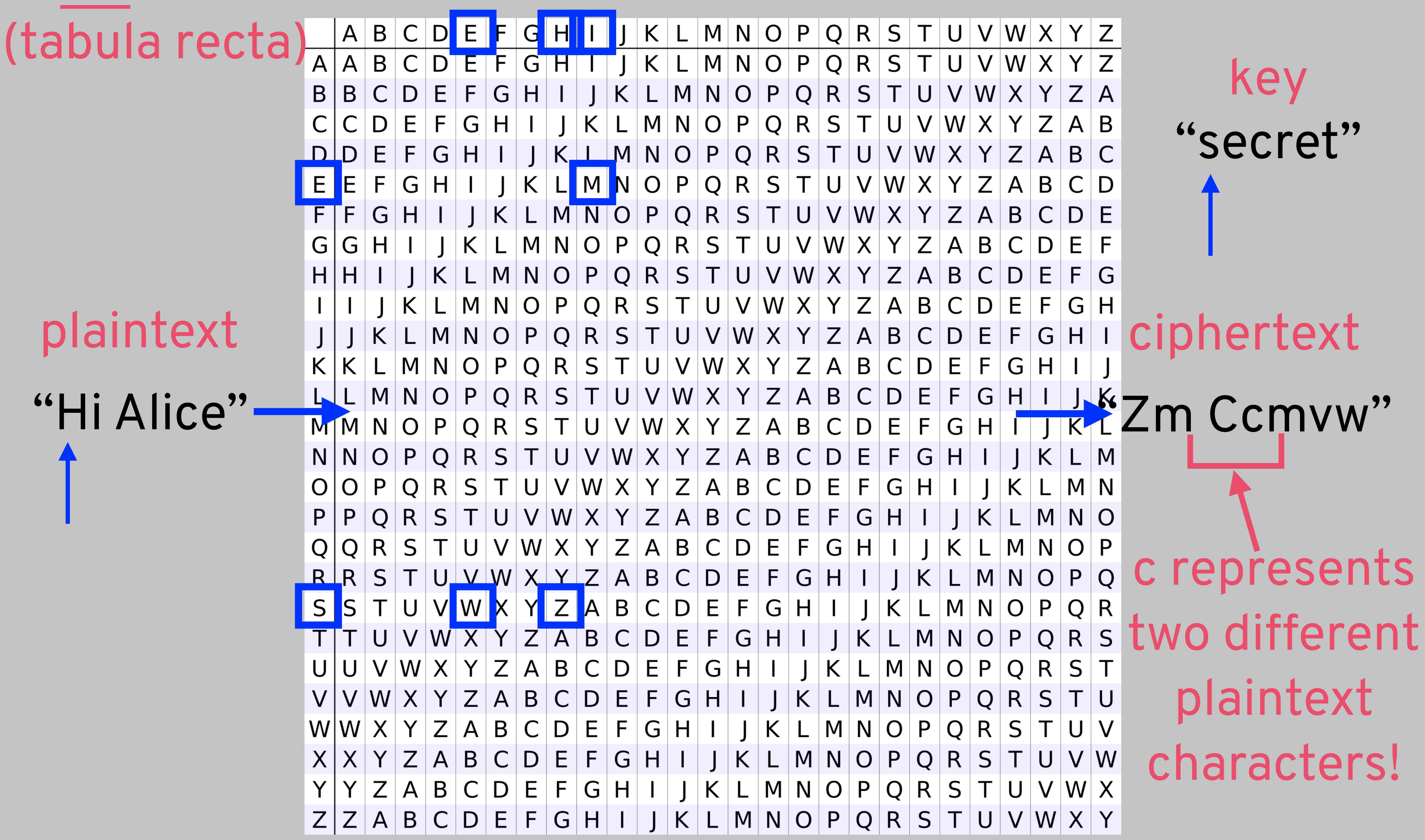
FREQUENCY ANALYSIS



problem: peaks and troughs are a giveaway

solution: diffusion

VIGENERE CIPHER



(tabula recta)

	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

key

“secret”

plaintext

“Hi Alice”

ciphertext

“Zm Ccmvw”

c represents two different plaintext characters!

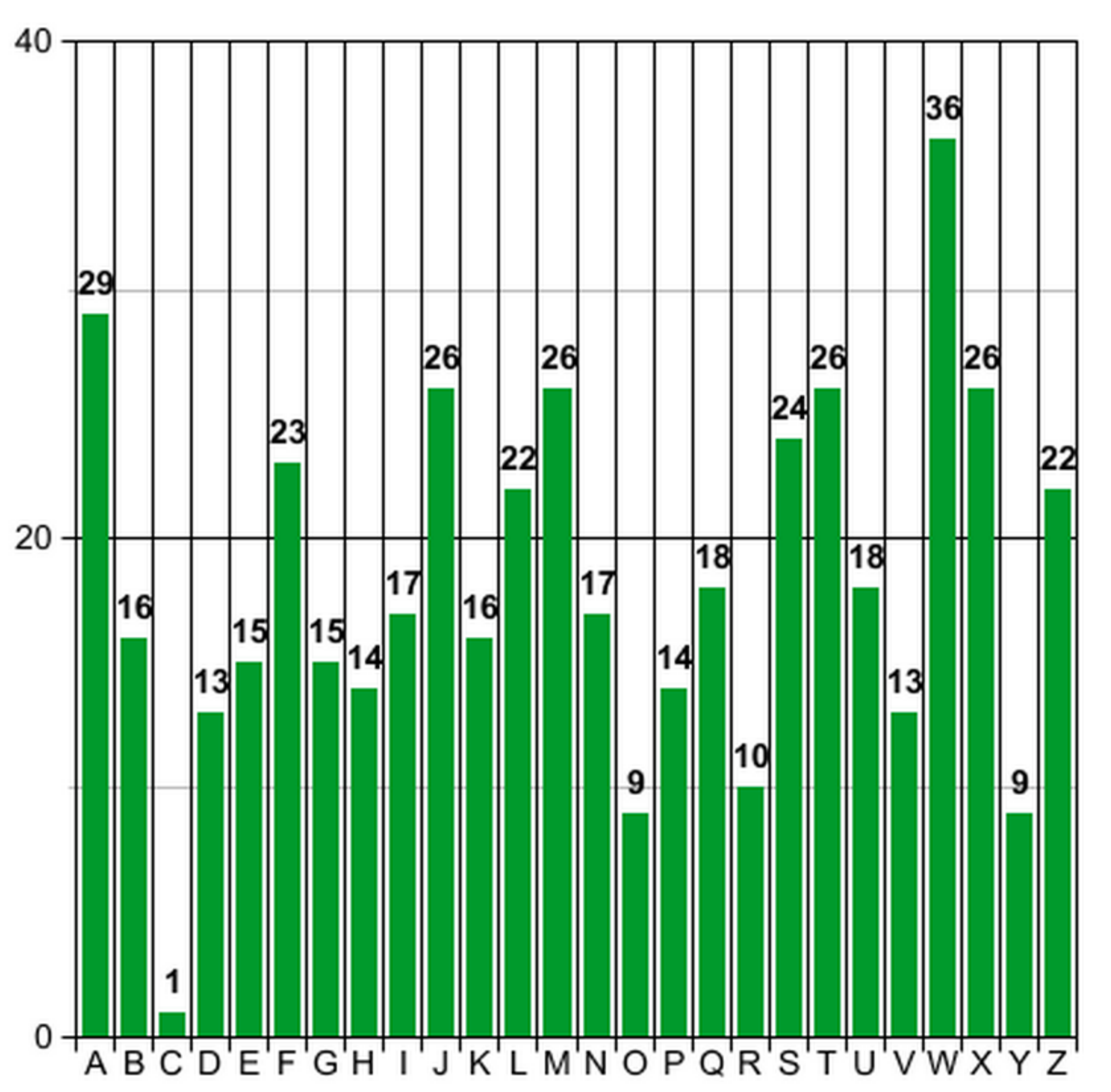
POLYALPHABETIC SUBSTITUTION

Polyalphabetic substitution cipher rotates through permutations $\pi : \Sigma \to \Sigma'$

Example: rotor machines like Enigma

Lb xse yah jfkf ty wqnwe, nm zit ltj prztl ak mlufk, uy pda uzq fzh wg ouxwru, jl ifl wpf ssj hi npgxnlkvfke, nm zit ltj xswdz ak uhtjwr, nm zit ltj xswdz ak bqkswpzelbz, af btv biw ejtvwo gr Qbjpu, af btv biw ejtvwo gr Itusowex, bw ebk fmx vxsazl hi pphq, nm zit ltj plvuwd ty gmthmnk, zm isp johzzltngj jfxawx xa, xw tfw qwuzusz emggdj nv, ef oqwx dtm yangj ljjqhm ww iwmaxq, ef oqwx dtm yangj ljjqhm wpf gfmxu ebq - us lkwsl, fmx smsaai pda tg rfk oqow fmx szfkqsm smsaai, mkiu karx rn jle shlajwey txbigdnmlmt azxbvbfv as bwa cwusz umdwuaxg, npj sthg ws xaw xyqm, az yah avhqwedbjnq ixjzfw ak vruqsdnlrv pfxd.

VIGENERE FREQUENCIES



Lb xse yah jfkf ty wqnwe, nm zit ltj prztl ak mlufk, uy pda uzq fzh wg ouxwru, jl ifl wpf ssj hi npgxnlkvfke, nm zit ltj xswdz ak uhtjwr, nm zit ltj xswdz ak bqkswpzelbz, af btv biw ejtvwo gr Qbjpu, af btv biw ejtvwo gr Itusowex, bw ebk fmx vxsazl hi pphq, nm zit ltj plvuwd ty gmthmnk, zm isp johzzltngj jfxawx xa, xw tfw qwuzusz emggdj nv, ef oqwx dtm yangj ljjqhm ww iwmaxq, ef oqwx dtm yangj ljjqhm wpf gfmxu ebq – us lkwsl, fmx smsaai pda tg rfk oqow fmx szfkqsm smsaai, mkiu karx rn jle shlajwey txbigdnmlmt azxbvbfv as bwa cwusz umdwuaxg, npj sthg ws xaw xyqm, az yah avhqwedbjnq ixjzfw ak vruqsdnlrv pfxd.

VIGENERE CRYPTANALYSIS

nm zit ltj

nm zit ltj

nm zit ltj

same key letters encrypt same plaintext letters!

```
itwasthe
escharle
   ↓
nmzitltj
```

repeated **n-grams** reveal length of key

(because distances between = multiple of key length, so key length = lcd(distances))

problem: key length reduces to monoalphabetic

solution: use a really long key!

RUNNING KEY CIPHER

hialice|hibob|howsitgoing|okayyou

itwasthebestoftimesitwastheworstoftimesitwasthe

↓

qcxmbwm|jnuiq|bxjxbcaljga|thpqrij

split ciphertext into blocks of five characters

use **indicator block** to say where in key to begin

page 63, line 1 ⇒ 06301

agdab ← gets inserted as second-to-last block

RUNNING KEY CIPHER

```
hialice|hibob|howsitgoing|okayyou|howsitgoing
itwasthebestoftimesitwastheworstoftimesitwasthe
   ↓
qcxmbwm|jnuiq|bxjxbcaljga|thpqrij|bxjxbcaljga
```

problem: repetition in key yields patterns

solution: use a long random key!

ONE-TIME PAD (OTP)

```
hialice|hibob|howsitgoing|okayyou|howsitgoing
ujakjywibavnscknkveoldxhinrovngdytlwkhyinncrhih
    ↓
bravraa|iiwbt|rbgnmhrrfuo|fyvlers|skgzgbtbken
```

also called a **perfect substitution cipher**

ONE-TIME PAD

```
hialice|hibob|howsitgoing|ijustki lledsomeone
ujakjywibavnscknkveoldxhirxpbtlhkahzcwonhxwrjih
    ↓
bravraa|iiwbt|rbgnmhrrfuo|fyvlers|skgzgbtbken
```

any ciphertext could decrypt to any plaintext

(if you use key once; otherwise reduces to running key)

KEY MATERIAL

```
hialice|hibob|howsitgoing|okayyou|howsitgoing
ujakjywibavnscknkveoldxhinrovngdytlwkhyinncrhih
   ↓
bravraa|iiwbt|rbgnmhrrfuo|fyvlers|skgzgbtbken
```

problem: how to share keys?

used in WWII and Cold War; → pages destroyed after use

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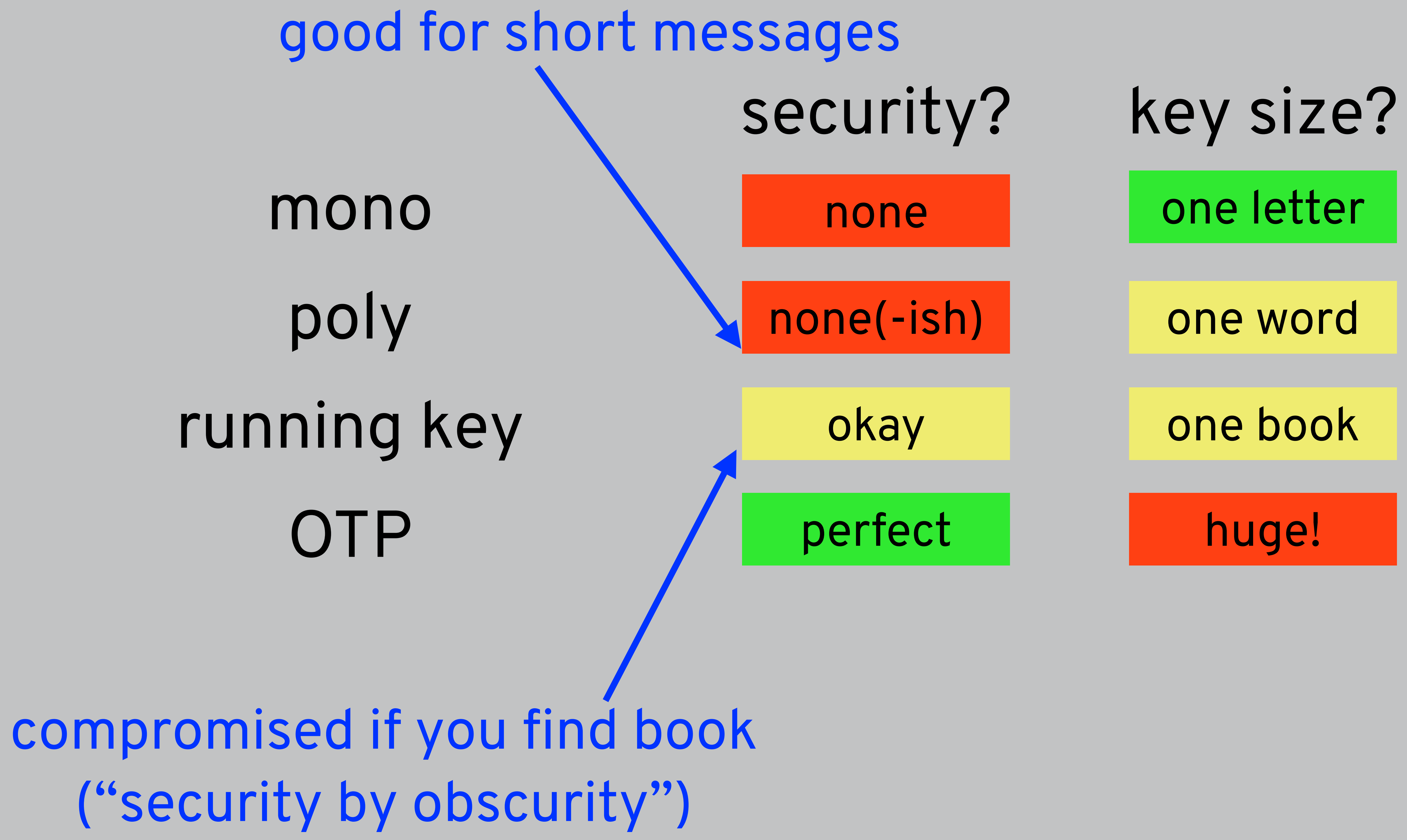
TRADEOFFS OF HISTORICAL CIPHERS



good for short messages

	security?	key size?
mono	none	one letter
poly	none(-ish)	one word
running key	okay	one book
OTP	perfect	huge!

compromised if you find book
("security by obscurity")