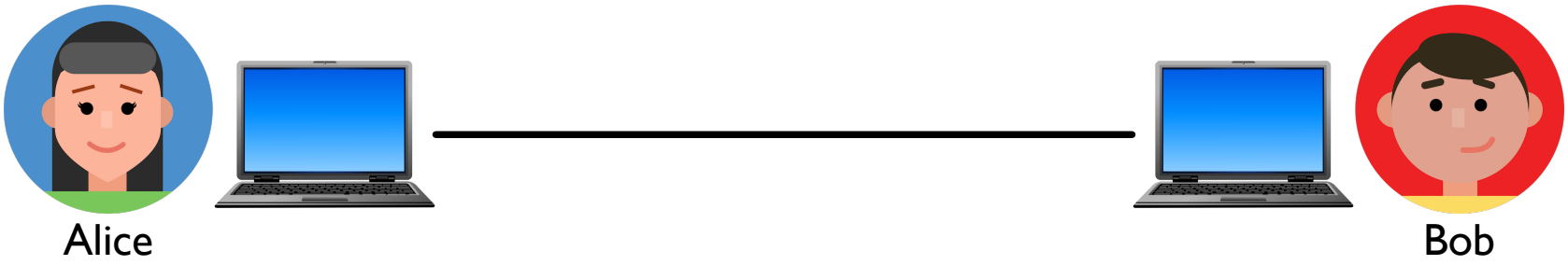
Cryptography

Cryptography: secure communication in the presence of adversaries



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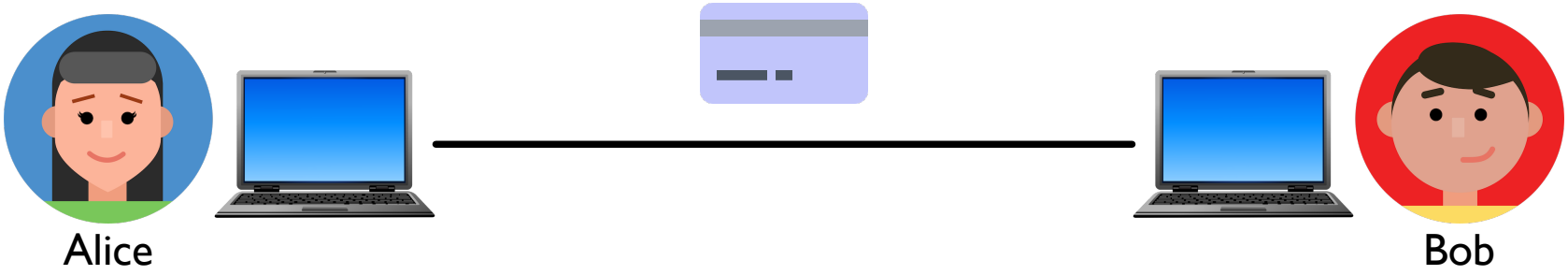

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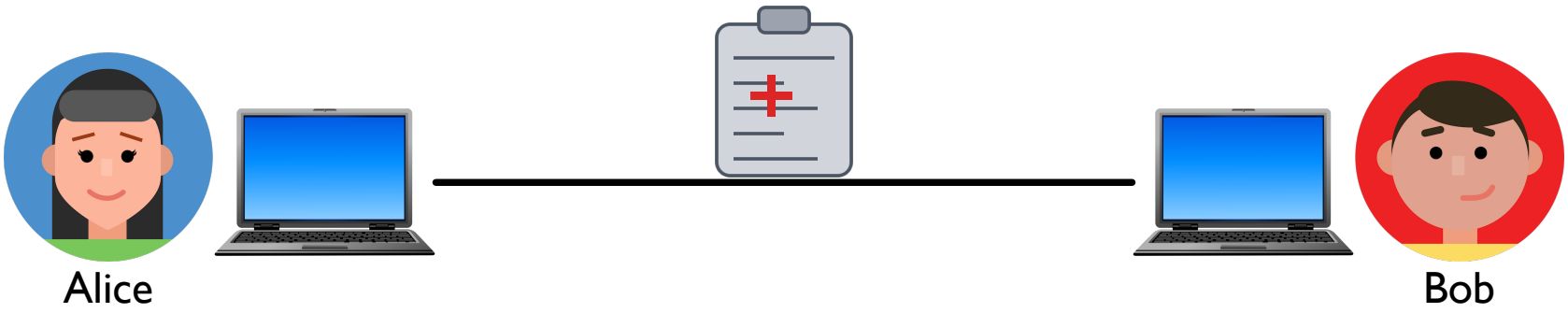

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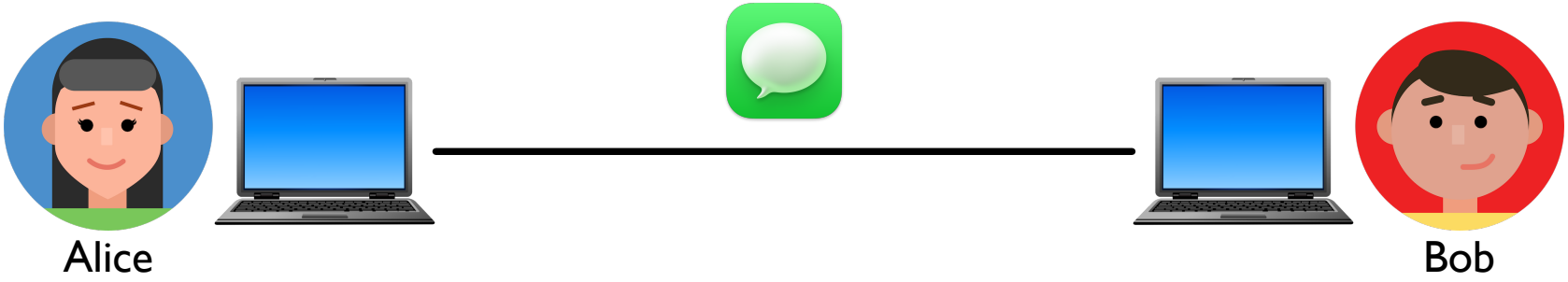

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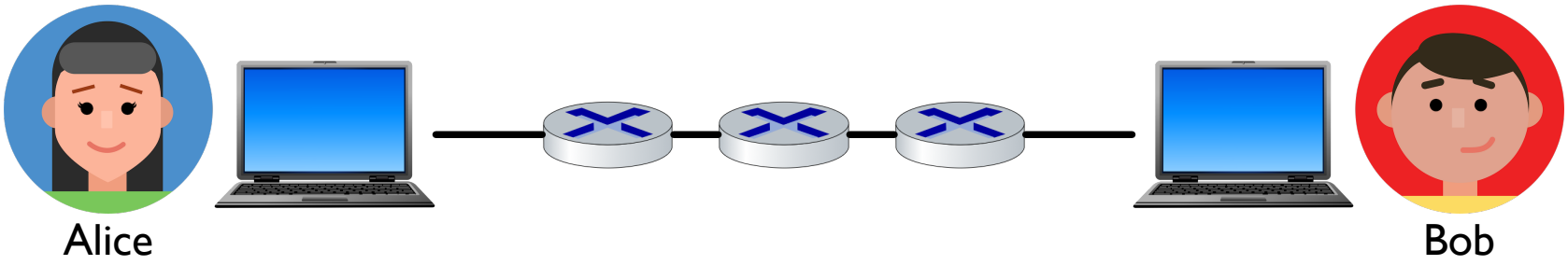

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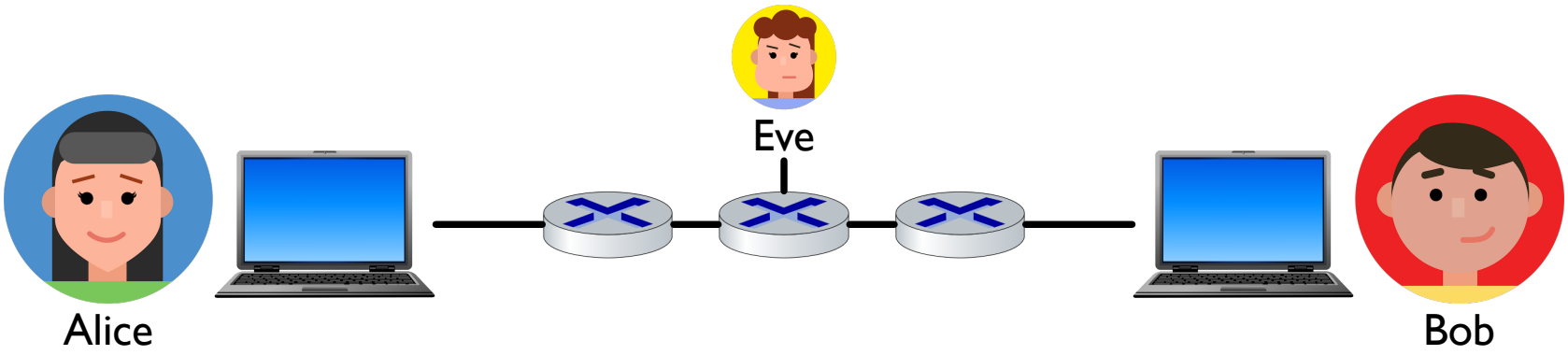

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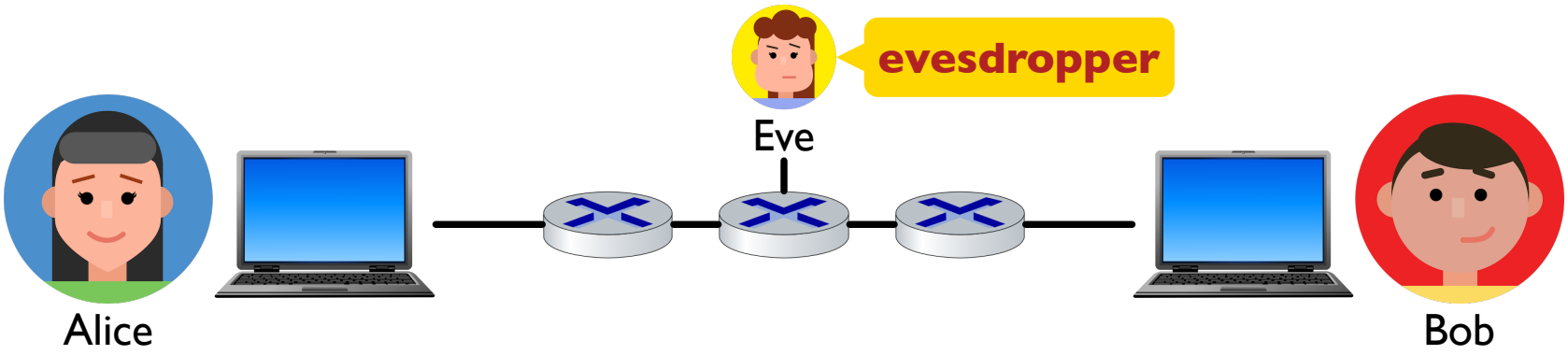

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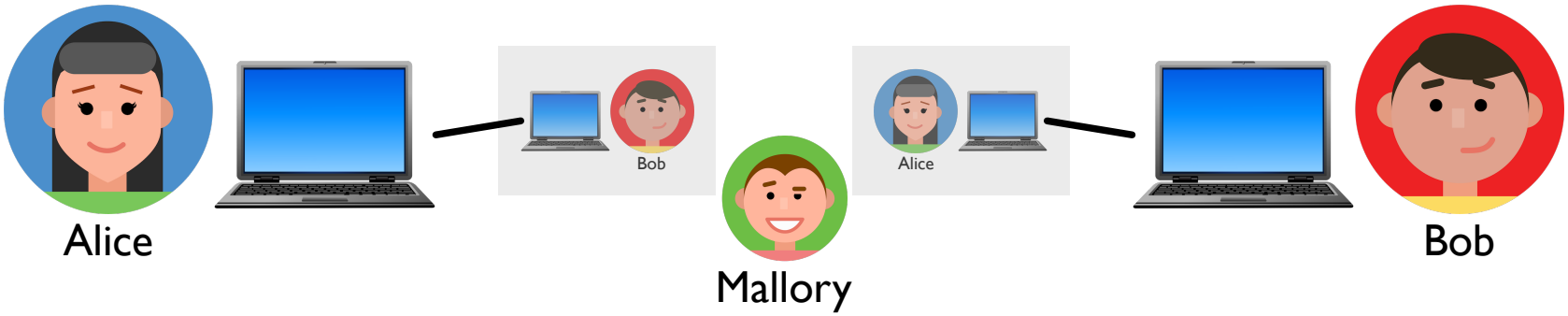

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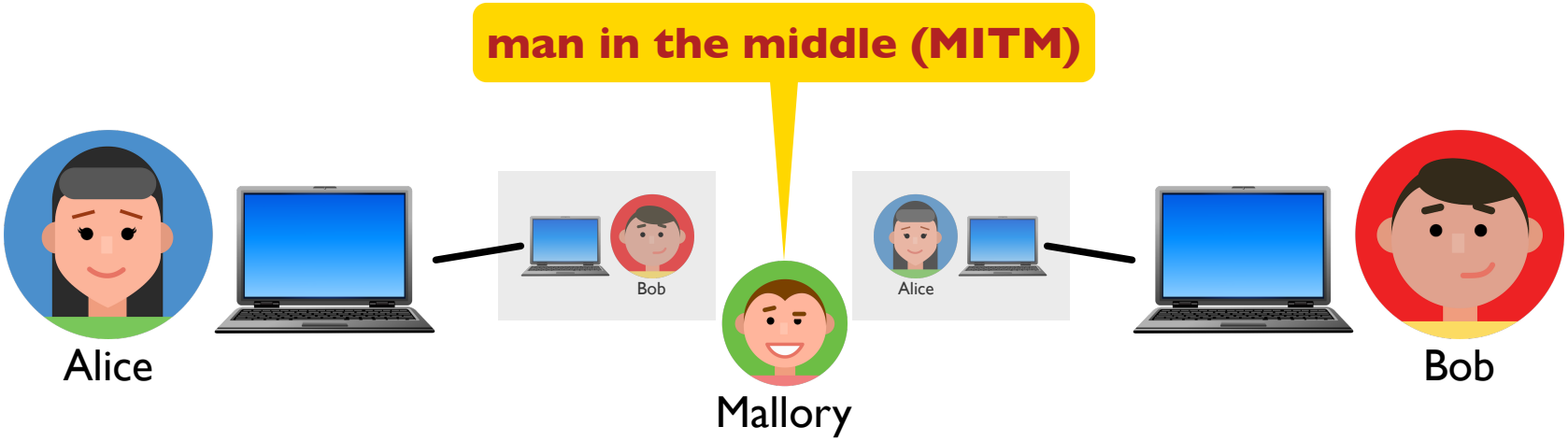

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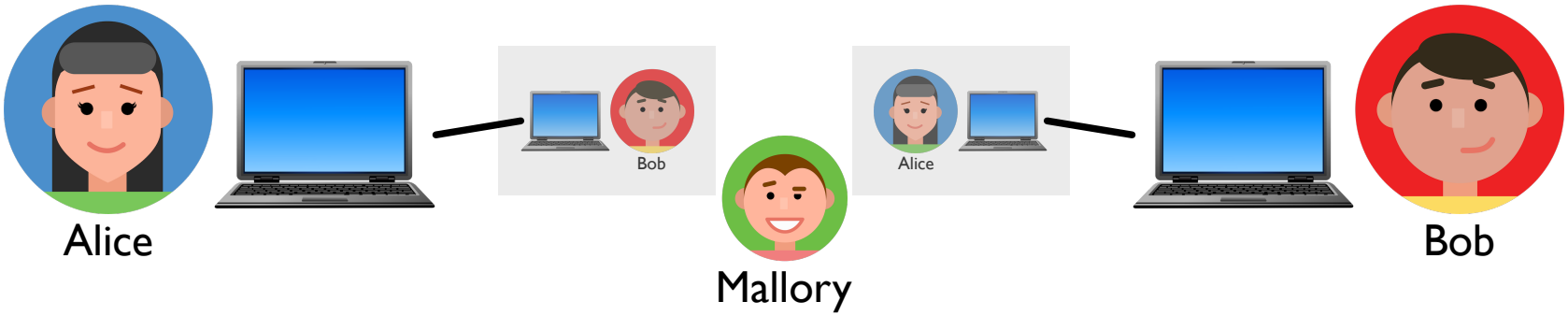
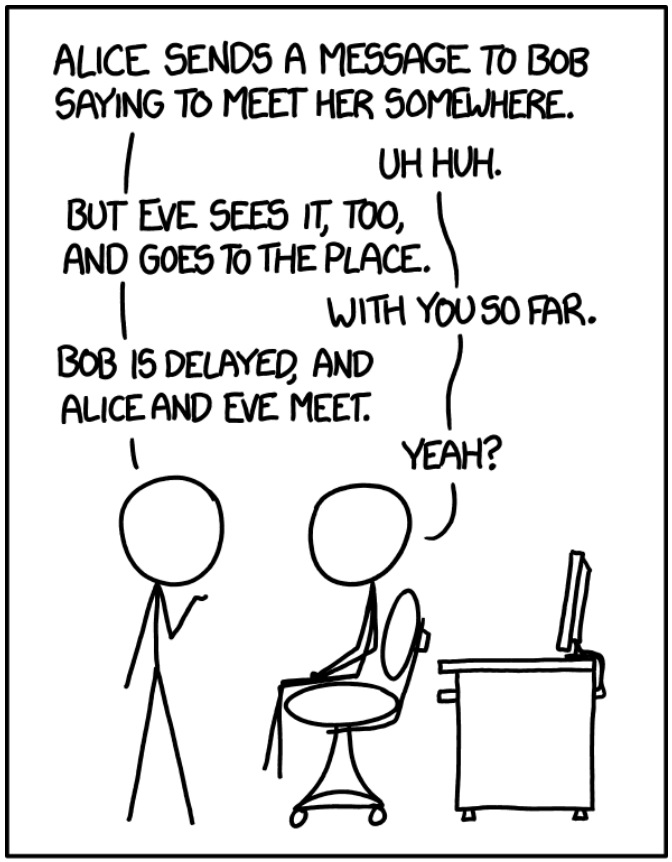


In this class, *crypto* is short for *cryptography*, not *cryptocurrency* or *cryptoanalysis*

Alice and Bob



https://xkcd.com/1323/

Cryptography Application Goals

Confidentiality

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Confidentiality: only intended recipient can read a message

Integrity

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Integrity: received message is unchanged from sender

Authenticity

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Authenticity: identity of each communicating party can be confirmed

and sometimes

Non-repudiation

Cryptography Application Goals

Confidentiality: only intended recipient can read a message

Integrity: received message is unchanged from sender

Authenticity: identity of each communicating party can be confirmed

and sometimes

Non-repudiation: parties cannot deny previous commitments

Assume that attackers are capable of evesdropping,
are capable of MITM,
know your algorithms, and
have NSA-scale compute power

Ciphers, Algorithms, Keys

Alice

Bob

```
MEET ME AT THE CLOCK TOWER
```

Ciphers, Algorithms, Keys

Alice

Bob

MEET ME AT THE CLOCK TOWER → MEET ME AT THE CLOCK TOWER

Ciphers, Algorithms, Keys

Alice

Bob

plaintext

```
MEET ME AT THE CLOCK TOWER
```

→

```
MEET ME AT THE CLOCK TOWER
```

Ciphers, Algorithms, Keys

Alice

Bob

plaintext

```
MEET ME AT THE CLOCK TOWER
```

```
ZRRG ZR NG GUR PYBPX GBJRE
```

```
MEET ME AT THE CLOCK TOWER
```

Ciphers, Algorithms, Keys

Alice

Bob

plaintext

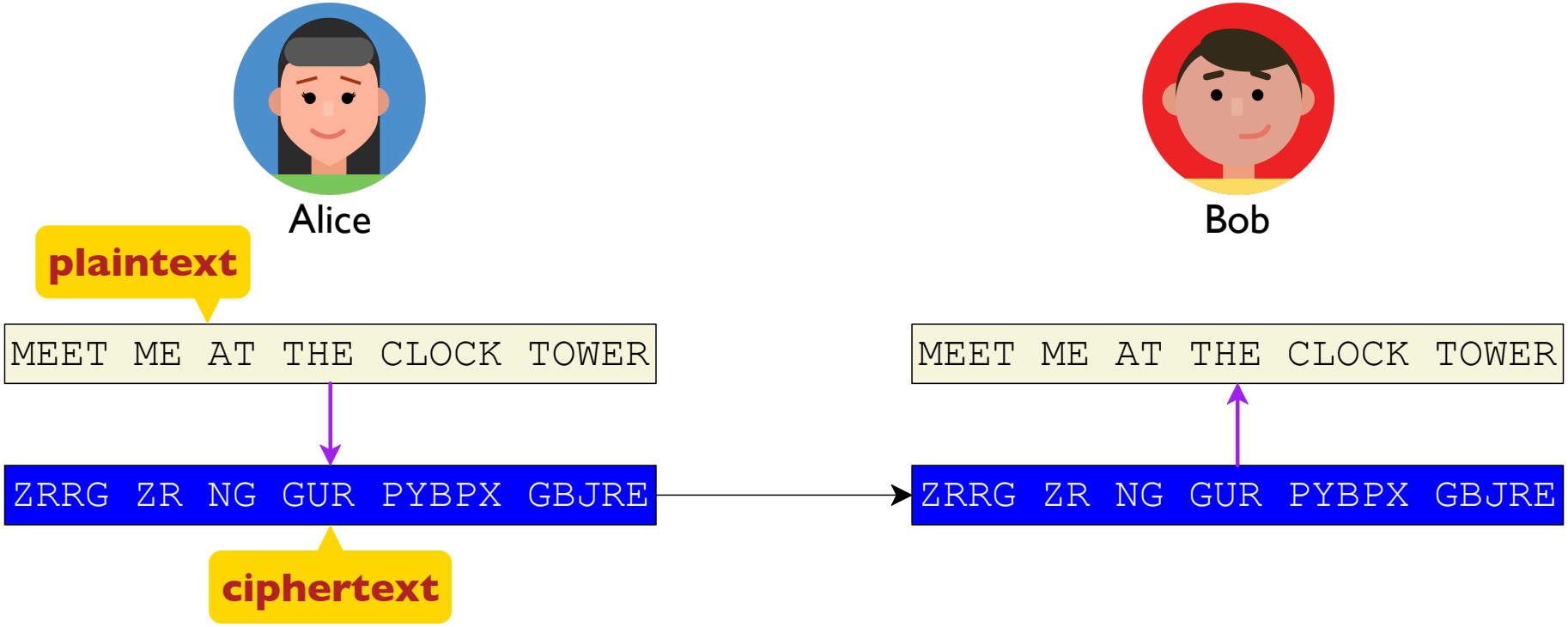
```
MEET ME AT THE CLOCK TOWER
```

```
ZRRG ZR NG GUR PYBPX GBJRE
```

ciphertext

```
MEET ME AT THE CLOCK TOWER
```

Ciphers, Algorithms, Keys



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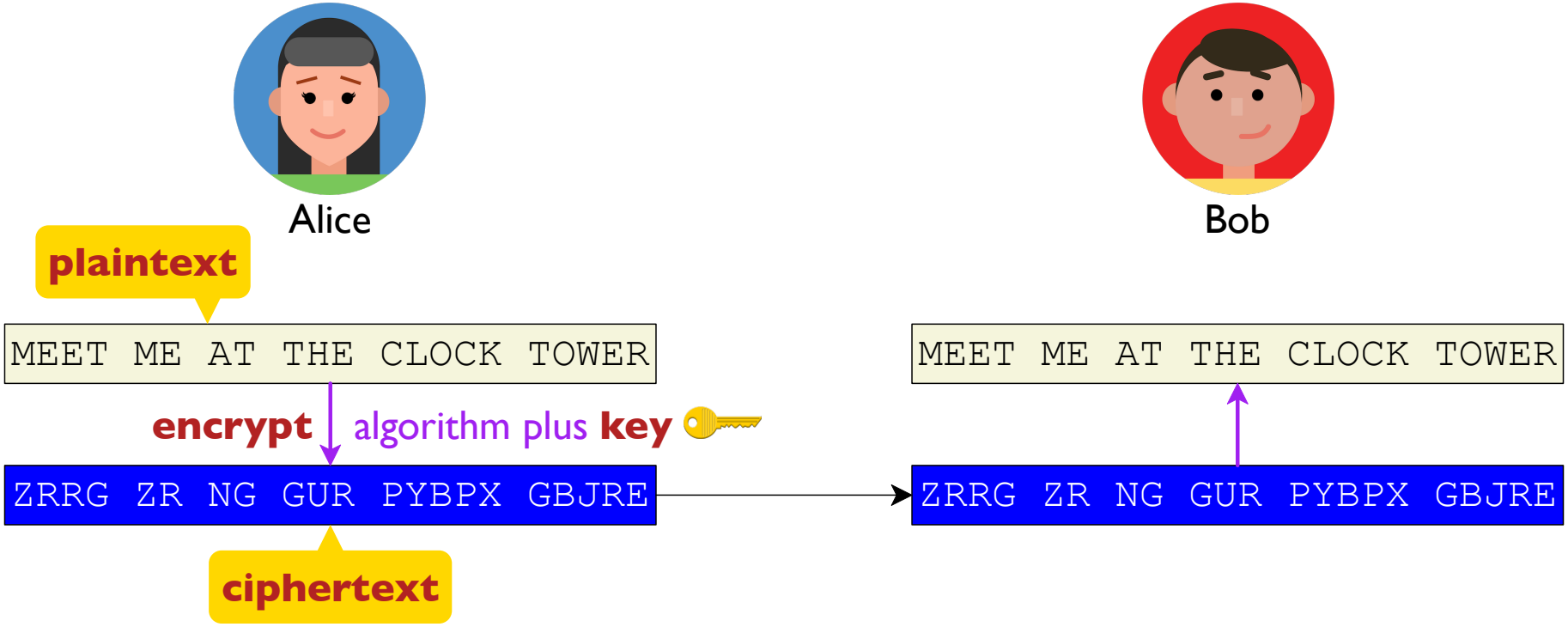

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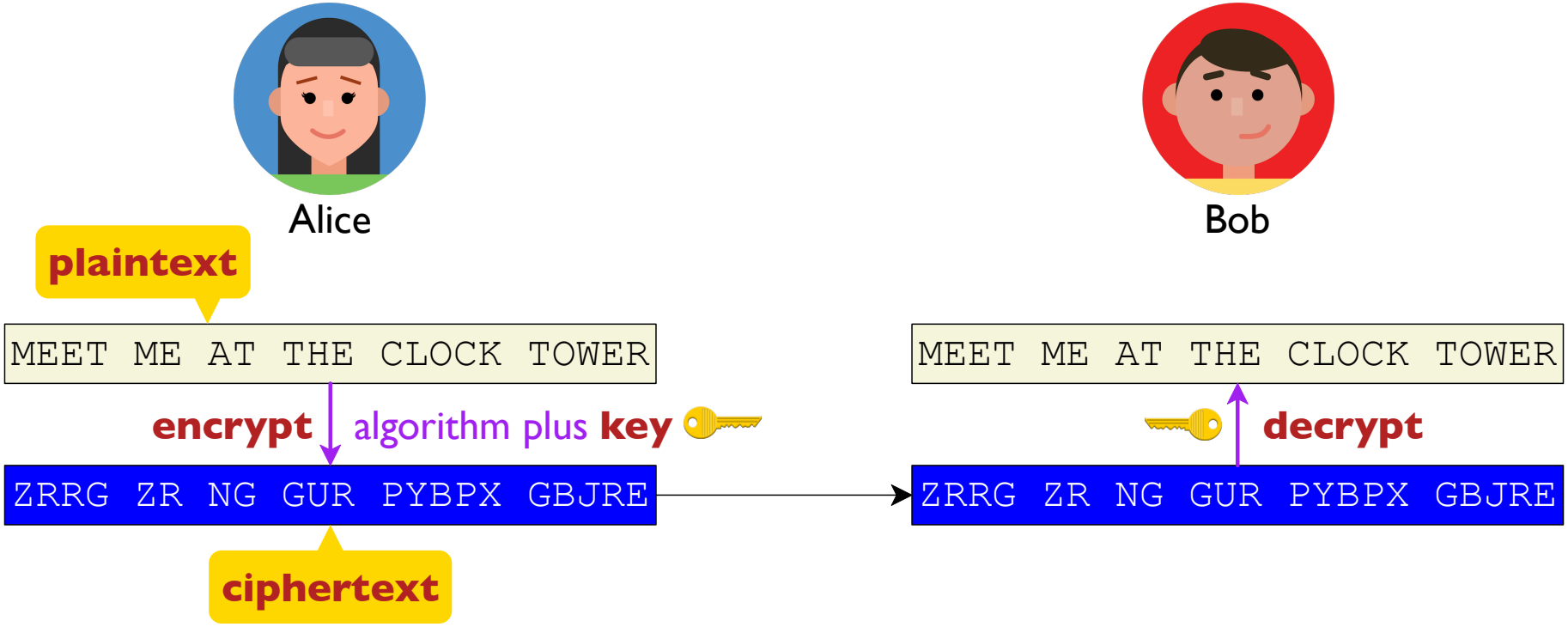
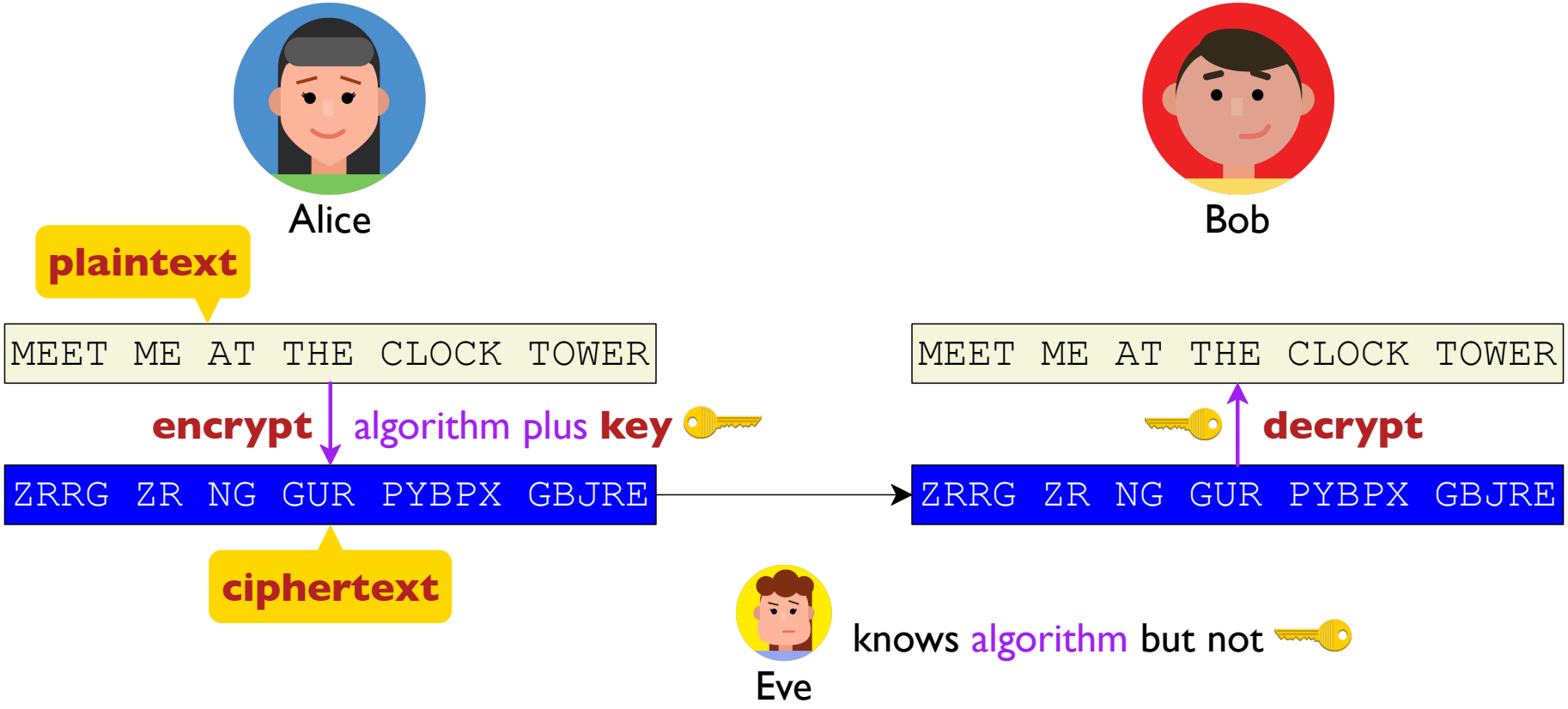


Ciphers, Algorithms, Keys



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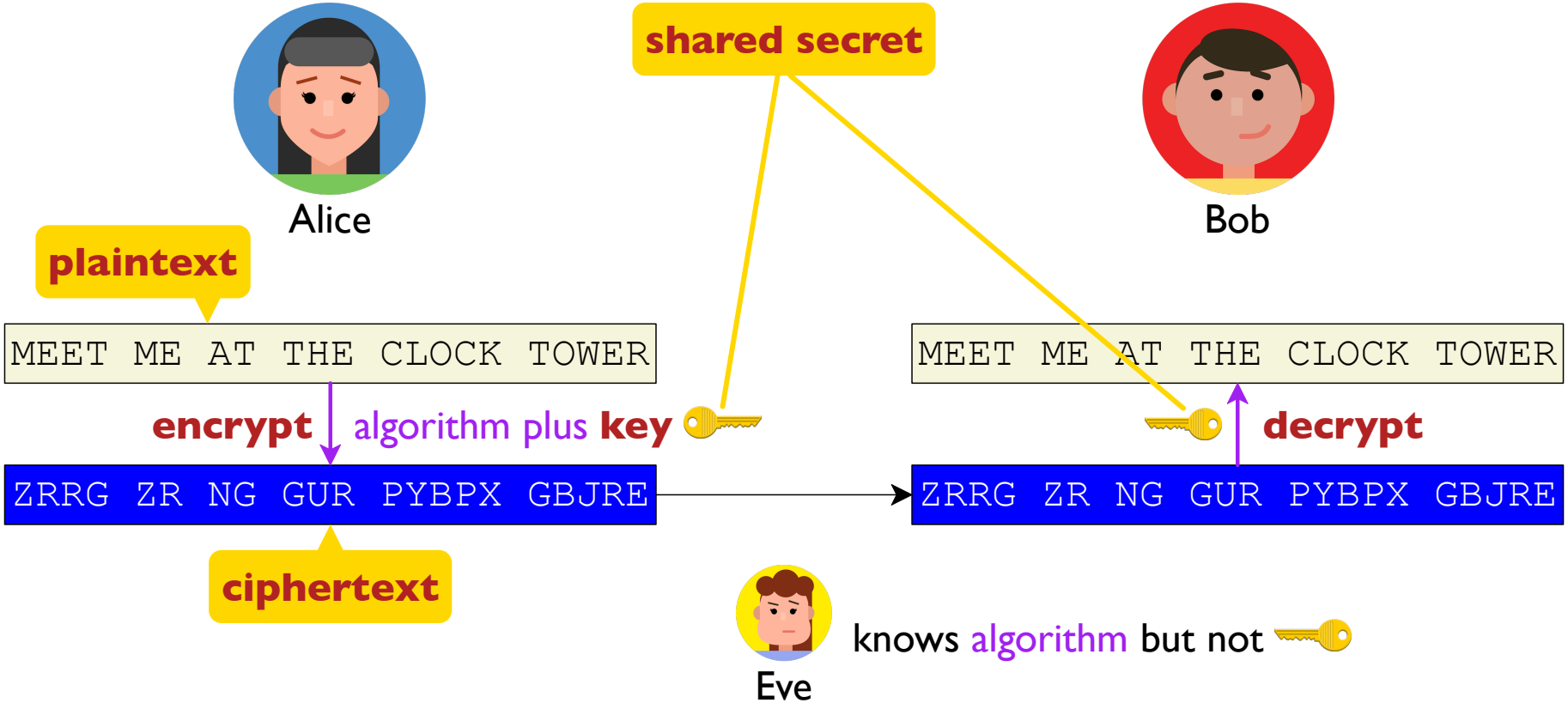

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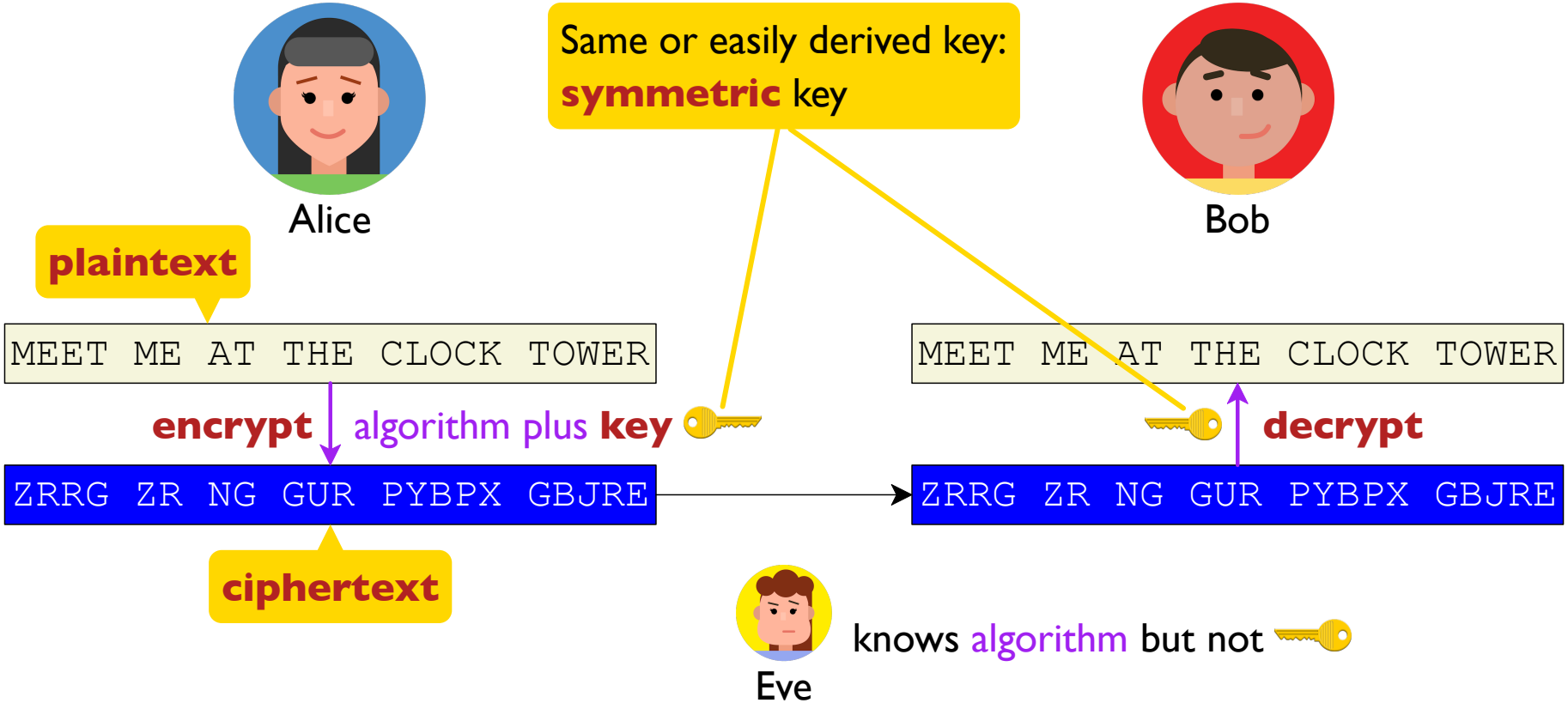
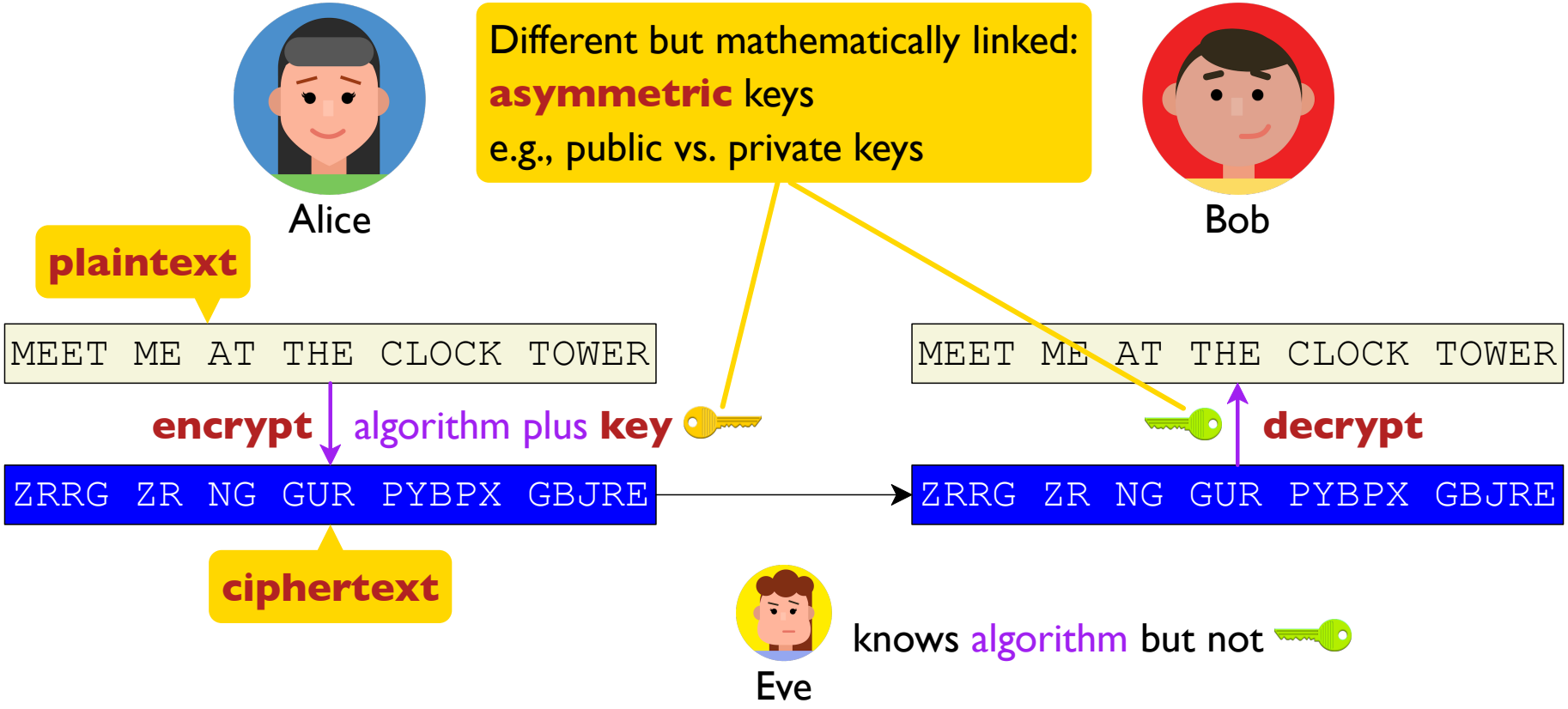


Ciphers, Algorithms, Keys



Encrypt and Decrypt

Encryption can use any function

that can be reversed by a decryption function

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function in the mathematical sense
i.e., deterministic

Enc(plaintext, ) = ciphertext

that can be reversed by a decryption function

Dec(ciphertext, ) = plaintext

Goals:

functions that make ciphertext look random

functions with enough  s to making guessing impractical

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Dec(ciphertext, ) = plaintext

Goals:

functions that make ciphertext look random

functions with enough  s to making guessing impractical

A good algorithm is one where this **brute force** strategy is the only one

Attack Modes

Ciphertext only: attacker has only ciphertext to work from, but maybe many of them

Known plaintext: attacker has an example plaintext and matching ciphertext to work from

Chosen plaintext: attacker can get its own plaintext encoded to its ciphertext

Substitution

IFMMP XPSME

HELLO WORLD

Substitution

IFMMP XPSME

HELLO WORLD

A	B
B	C
C	D
D	E
E	F
F	G
G	H
H	I
…	…
X	Y
Y	Z
Z	A

Substitution

JGNNQ YQTNF

HELLO WORLD

Substitution

JGNNQ YQTNF

HELLO WORLD

A	C
B	D
C	E
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HELLO WORLD

A	C
B	D
C	E
D	F
E	G
F	H
G	I
H	J
...	...
X	Z
Y	A
Z	B

Ceasar cipher

 = 2

 = -2

Substitution

URYYB JBEYQ

HELLO WORLD

A	N
B	O
C	P
D	Q
E	R
F	S
G	T
H	U
…	…
X	K
Y	L
Z	M

Ceasar cipher

 = 13

 = -13

a.k.a. ROT13

Substitution

URYYB JBEYQ

HELLO WORLD

A	N
B	O
C	P
D	Q
E	R
F	S
G	T
H	U
...	...
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Y	L
Z	M

Ceasar cipher

 = 13

 = -13

a.k.a. ROT13

With only 26 possible keys guessing is easy

Substitution

URYYB JBEYQ

HELLO WORLD

A	N
B	O
C	P
D	Q
E	R
F	S
G	T
H	U
...	...
X	K
Y	L
Z	M

Ceasar cipher

 = 13

 = -13

a.k.a. ROT13

Can treat N letters in a row as base-26 digits:

$$\text{HEL} = 8 \times 26^2 + 5 \times 26 + 12$$

That gives us 26^N keys

Substitution

URYYB JBEYQ

Substitution creates **confusion**

But substitution by itself is weak, because it preserves patterns:

- Commonly used letters ⇒ commonly used replacements
- Local patterns like “ll” in “hello” ⇒ local patterns in ciphertext

Permutation

A permutation can create **diffusion** to break up local patterns:

MEET ME AT THE CLOCK TOWER

M	E	E	T
	M	E	
A	T		T
H	E		C
L	O	C	K
	T	O	W
E	R	□	□

M AHL EEMTEOTREE COT TCKW

Permutation

A permutation can create **diffusion** to break up local patterns:

```
MEET ME AT THE CLOCK TOWER
```

M	E	E	T
	M	E	
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M	E	E	T
	M	E	
A	T		T
H	E		C
L	O	C	K
	T	O	W
E	R	□	□

= number of columns

```
M AHL EEMTEOTREE  COT TCKW
```

Other examples of permutations:
- shifting with wraparound
- shuffling deterministically

Substitution plus Permutation

Combining substitution and permutation is even better:

MEET ME AT THE CLOCK TOWER

ZRRG ZR NG GUR PYBPX GBJRE

Z	R	R	G
	Z	R	
N	G		G
U	R		P
Y	B	P	X
	G	B	J
R	E	□	□

Z NUY RRZGRBGERR PBG GPXJ

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```
MEET ME AT THE CLOCK TOWER
```

```
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```

Z	R	R	G
	Z	R	
N	G		G
U	R		P
Y	B	P	X
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R	E	□	□

is ⟨rotation, columns⟩

```
Z NUY RRZGRBGERR  PBG GPXJ
```

Substitution plus Permutation

Combining substitution and permutation is even better:

MEET ME IN THE CLOCK TOWER

ZRRG ZR NG GUR PYBPX GBJRE

Z	R	R	G
	Z	R	
V	A		G
U	R		P
Y	B	P	X
	G	B	J
R	E	□	□

is ⟨rotation, columns⟩

Z VUY RRZARBGERR PBG GPXJ

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Z	R	R	G
	Z	R	
V	A		G
U	R		P
Y	B	P	X
	G	B	J
R	E	□	□

Z VUY RRZARBGERR PBG GPXJ

Still, small changes in plaintext trigger only small changes in ciphertext

is ⟨rotation, columns⟩

Chaining

More **diffusion** via running total mod 27 ⇒ each position affects all later

M	E	E	T		M	E		A	T		T	H	E		C	L	O	C	K		T	O	W	E	R

	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5	13	5	5	20	0	13	5	0	1	20	0	20	8	5	0	3	12	15	3	11	0	20	15	23	5	18
	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
	18	23	1	21	21	7	12	12	13	6	6	26	7	12	12	15	0	15	18	2	2	22	10	6	11	2

R	W	A	U	U	G	L	L	M	F	F	Z	G	L	L	O		O	R	B	B	V	J	F	K	B

Chaining

More **diffusion** via running total mod 27 ⇒ each position affects all later

M	E	E	T		M	E		A	T		T	H	E		C	L	O	C	K		T	O	W	E	R

+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
13	5	5	20	0	13	5	0	1	20	0	20	8	5	0	3	12	15	3	11	0	20	15	23	5	18
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
18	23	1	21	21	7	12	12	13	6	6	26	7	12	12	15	0	15	18	2	2	22	10	6	11	2

R	W	A	U	U	G	L	L	M	F	F	Z	G	L	L	O		O	R	B	B	V	J	F	K	B

Can decrypt because + is reversible
The xor operation has the same property

Chaining

More **diffusion** via running total mod 27 ⇒ each position affects all later

M	E	E	T		M	E		A	T		T	H	E		C	L	O	C	K		T	O	W	E	R

+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
13	5	5	20	0	13	5	0	1	20	0	20	8	5	0	3	12	15	3	11	0	20	15	23	5	18
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
18	23	1	21	21	7	12	12	13	6	6	26	7	12	12	15	0	15	18	2	2	22	10	6	11	2

R	W	A	U	U	G	L	L	M	F	F	Z	G	L	L	O		O	R	B	B	V	J	F	K	B

Can decrypt because + is reversible
The xor operation has the same property

but needs to be combined with other techniques

Chaining

More **diffusion** via running total mod 27 ⇒ each position affects all later

M	E	E	T		M	E		I	N		T	H	E		C	L	O	C	K		T	O	W	E	R

	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5	13	5	5	20	0	13	5	0	1	20	0	20	8	5	0	3	12	15	3	11	0	20	15	23	5	18
	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
	18	23	1	21	21	7	12	12	13	6	6	26	7	12	12	15	0	15	18	2	2	22	10	6	11	2

R	W	A	U	U	G	L	L	U	H	H	A	I	N	N	Q	B	Q	T	D	D	X	L	H	M	D

Chaining

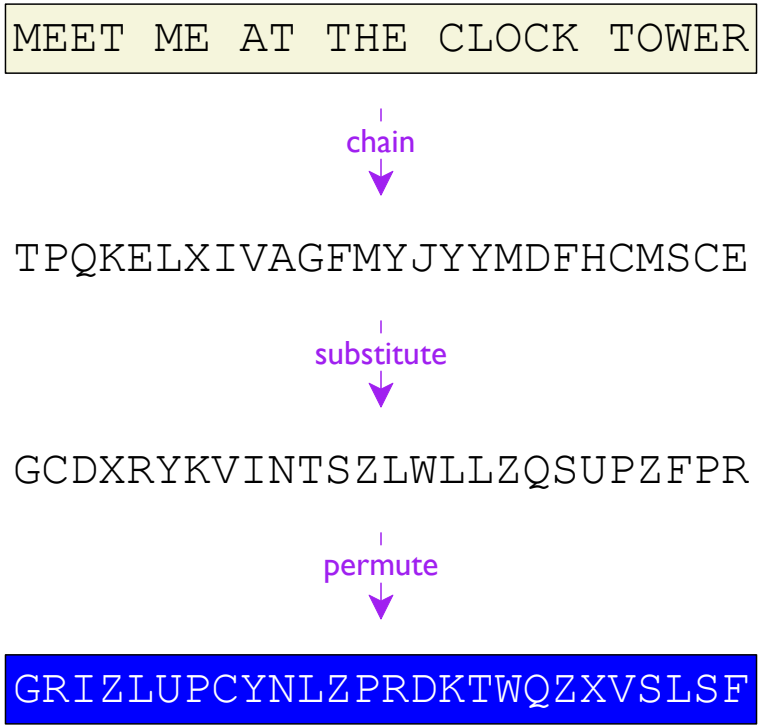
Could run it twice to make every position affect all positions...

M	E	E	T		M	E		I	N		T	H	E		C	L	O	C	K		T	O	W	E	R

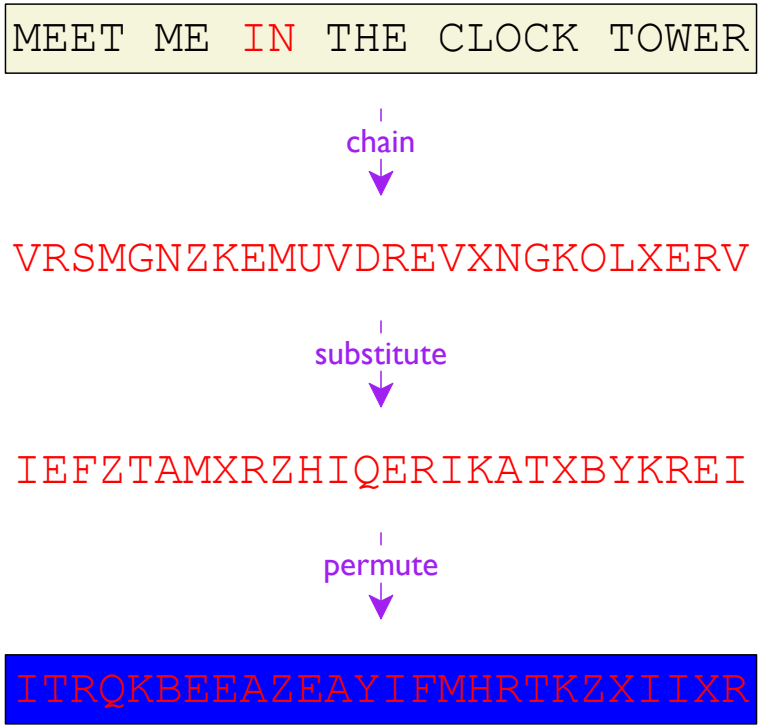
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
13	5	5	20	0	13	5	0	1	20	0	20	8	5	0	3	12	15	3	11	0	20	15	23	5	18
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
18	23	1	21	21	7	12	12	13	6	6	26	7	12	12	15	0	15	18	2	2	22	10	6	11	2
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
20	16	17	11	5	12	24	9	22	1	7	6	13	25	10	25	25	13	4	6	8	3	13	19	3	5

V	R	S	M	G	N	Z	K	E	M	U	V	D	R	E	V	X	N	G	K	O	L	X	E	R	V

Chaining plus Substitution plus Permutation



Chaining plus Substitution plus Permutation



Key Size

Substitution, permutation, and chaining are useful building blocks, and our example combination generates results that *look* random, but there's an easy way to see that it's insecure

 = ⟨rotation, columns, init, times⟩

Assuming that up to 32 columns and 10 iterations make sense:

$$26 \times 32 \times 27 \times 10 \quad = \quad 224{,}640 \text{ possible keys}$$

So, **key size** is going to be an important metric

Block Size

For a long enough message, typically you want to encode only small parts at a time, as opposed to keeping the whole message in memory to rearrange all the bytes

As our permutation example shows, though, it's useful to be able to mix large chunks to create confusion

So, **block size** is going to be an important metric

Summary

Goals are

- **Confidentiality**
- **Integrity**
- **Authenticity**
- **Non-repudiation** (sometimes)

Some building blocks:

- Substitution to create **confusion**
- Permutation to create **diffusion**
- Chaining to increase **diffusion**

Results depend on **key size** and **block size**