Lecture 9:

Network Security

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Security properties

- Confidentiality
  - only the sender and the receiver understand the contents of the message
- Authenticity
  - the message is from whom it claims to be
- Integrity
  - the message was not changed along the way

Outline

- Building blocks
- Providing security properties
- Securing Internet protocols
- Operational security

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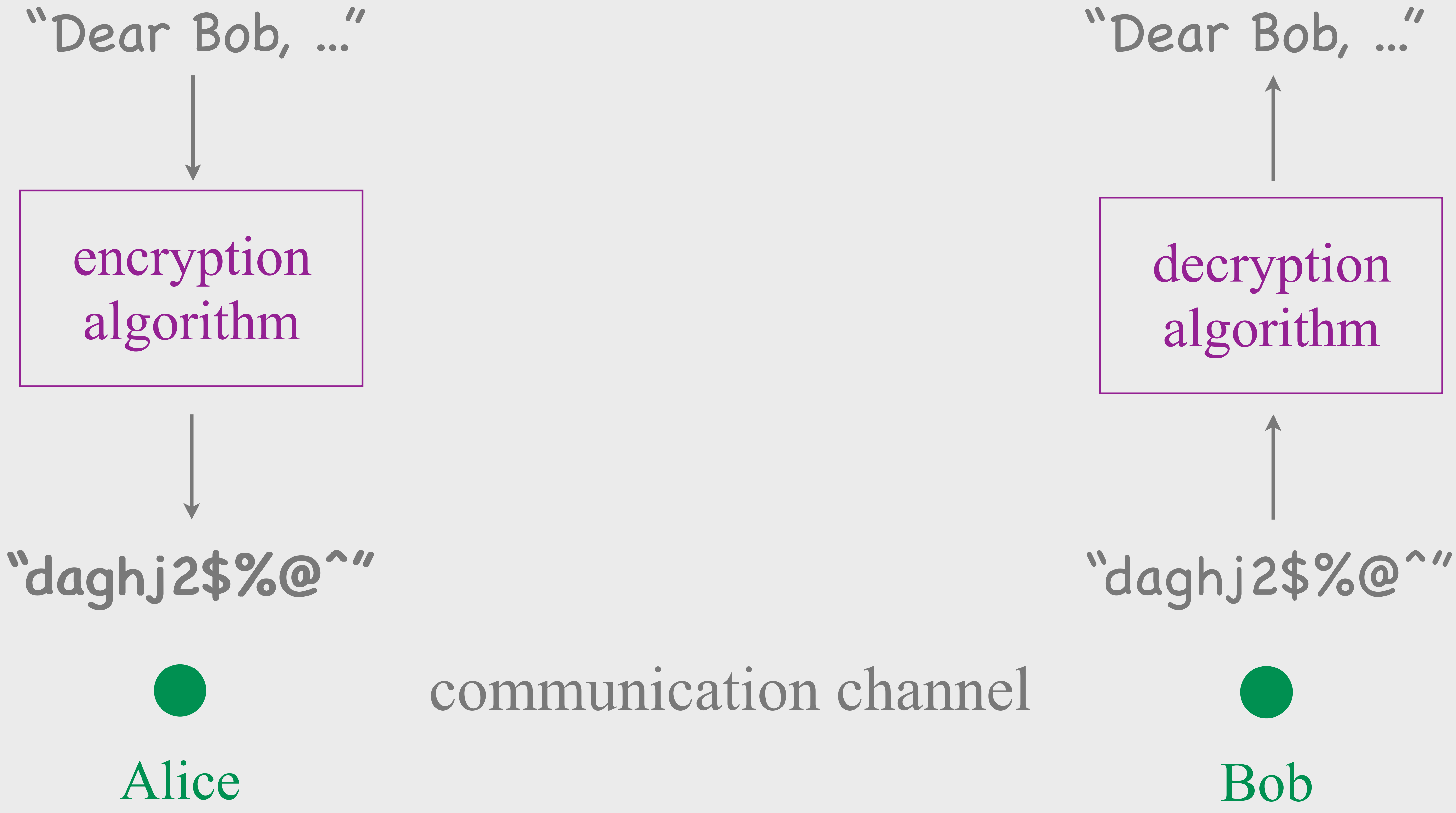


"Dear Bob, …"

encryption algorithm

"daghj2$%@^"

Alice

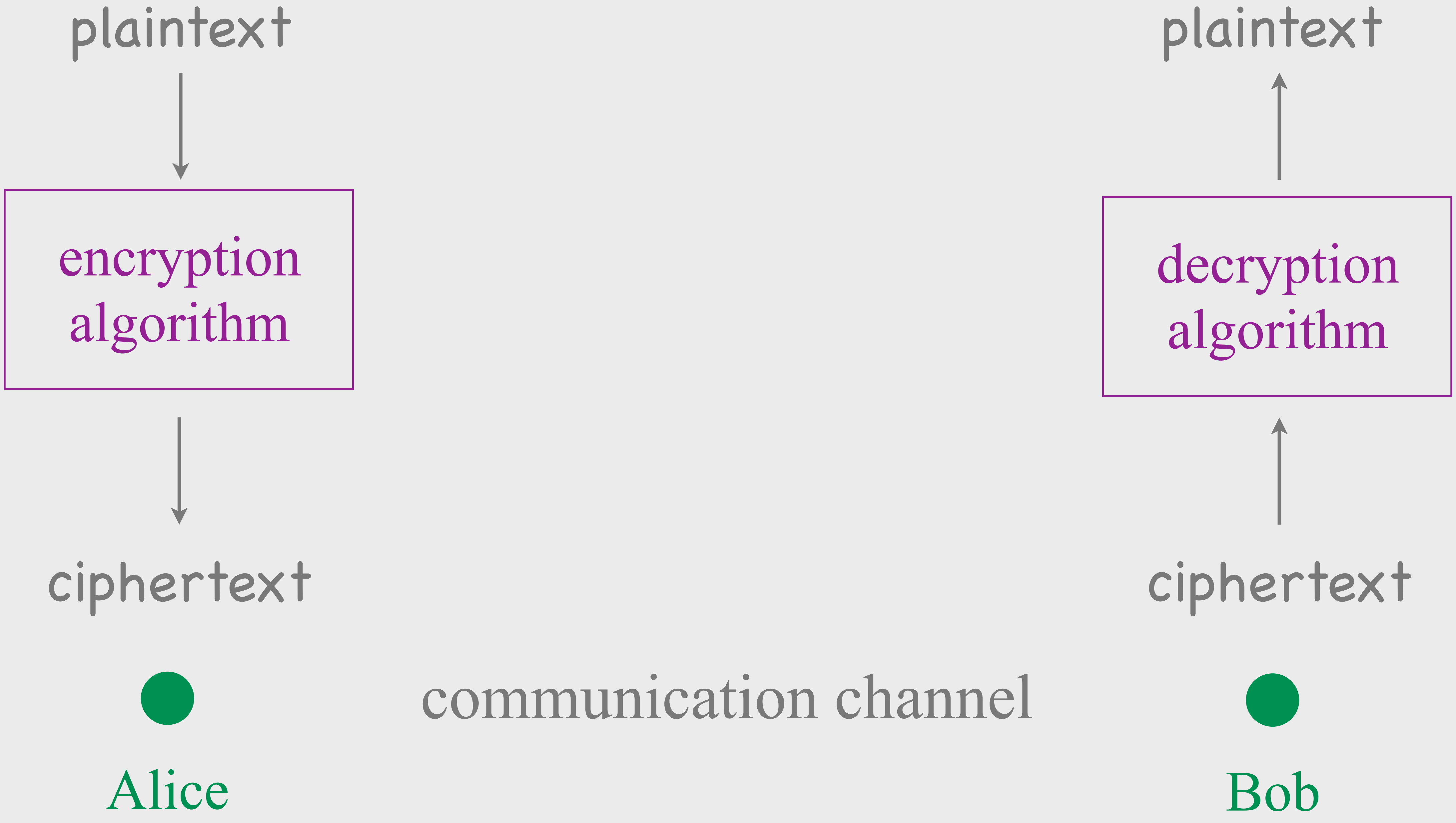
communication channel

"Dear Bob, …"

decryption algorithm

"daghj2$%@^"

Bob



plaintext

encryption algorithm

ciphertext

Alice

communication channel

plaintext

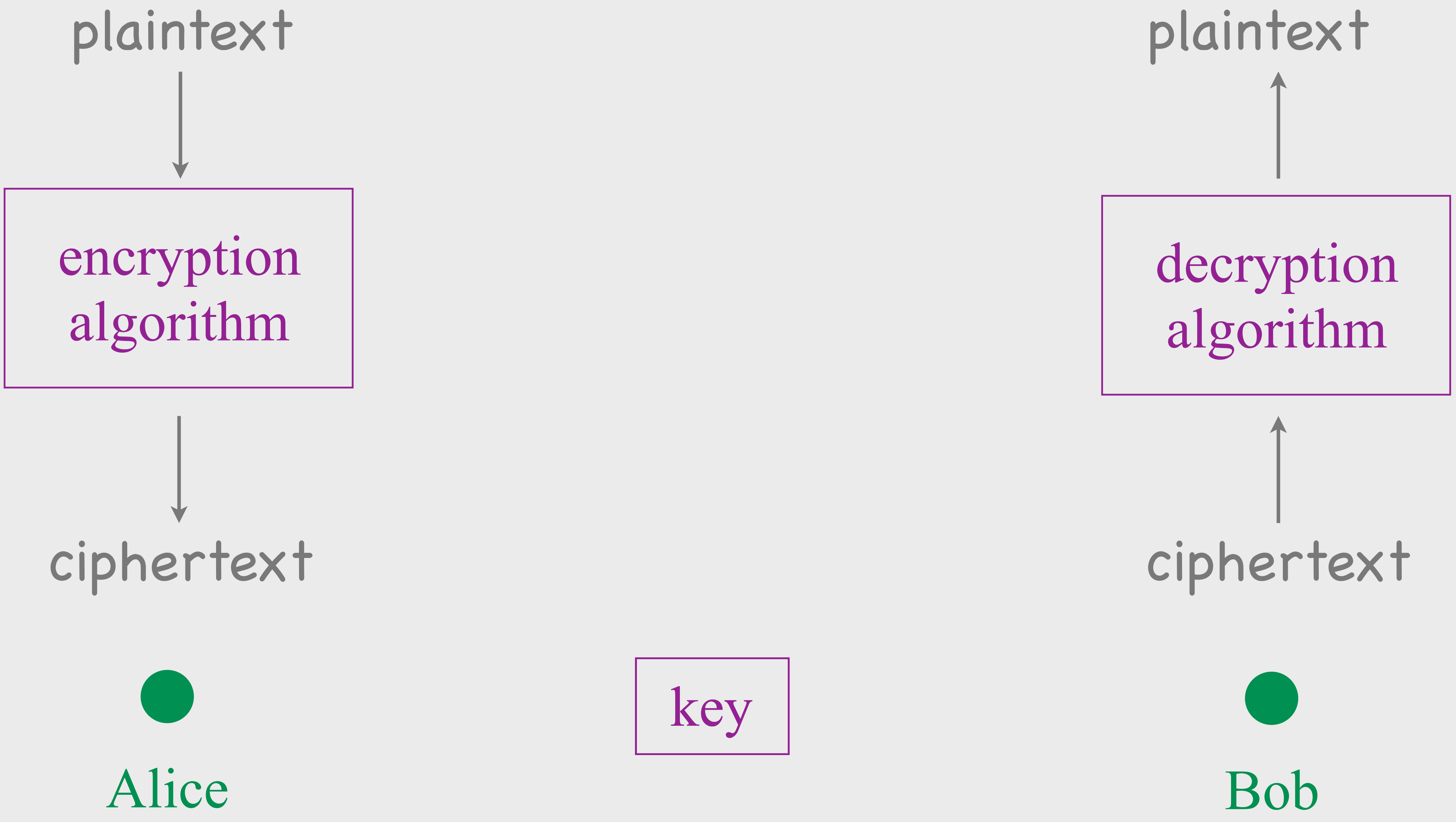
decryption algorithm

ciphertext

Bob

Encryption & decryption

- Encryption: plaintext in, ciphertext out
- Decryption: ciphertext in, plaintext out
- Ciphertext: ideally, should reveal no information about the plaintext



plaintext

encryption algorithm

ciphertext

Alice

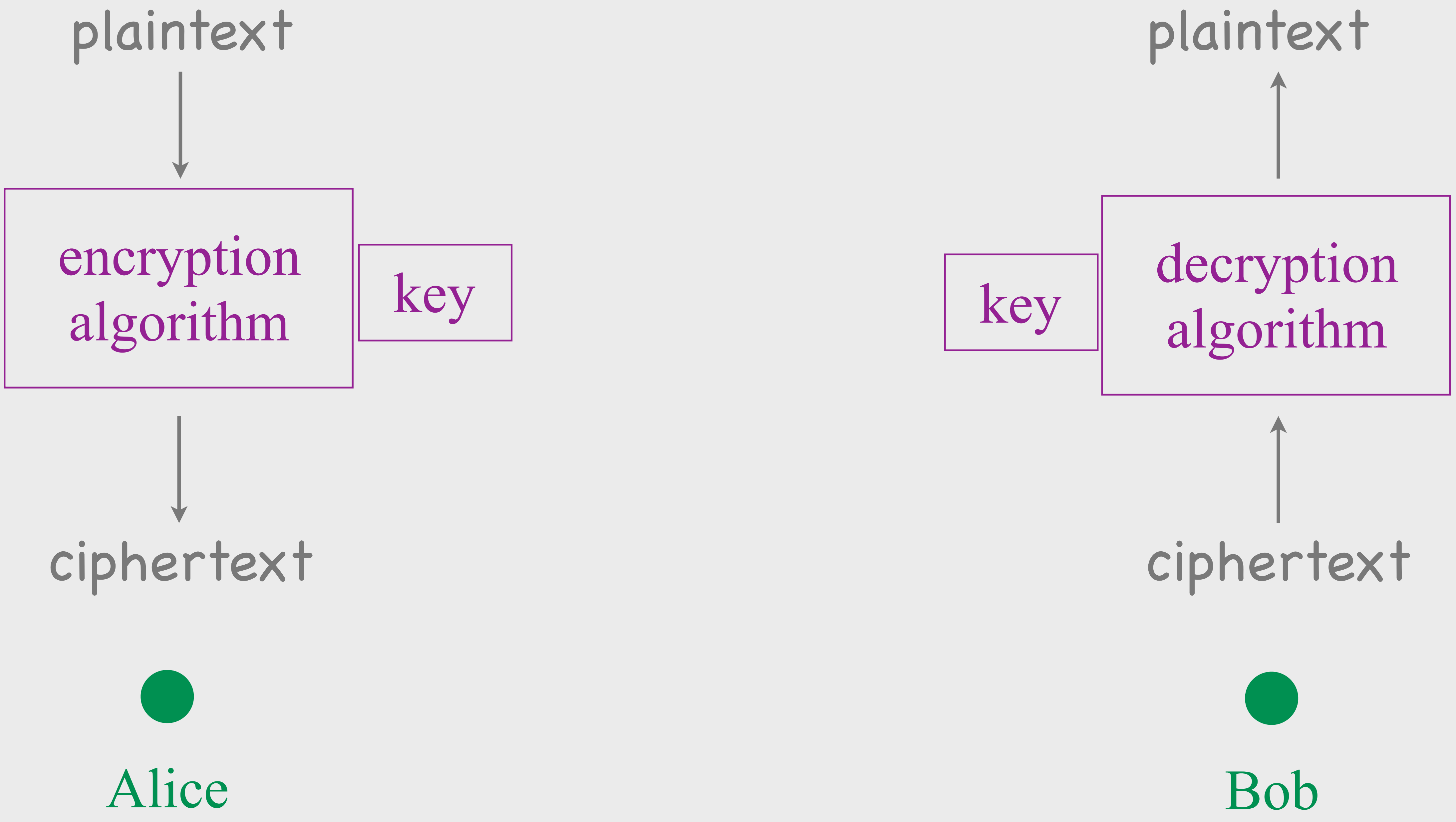
key

plaintext

decryption algorithm

ciphertext

Bob



plaintext

encryption algorithm

key

ciphertext

Alice

plaintext

key

decryption algorithm

ciphertext

Bob

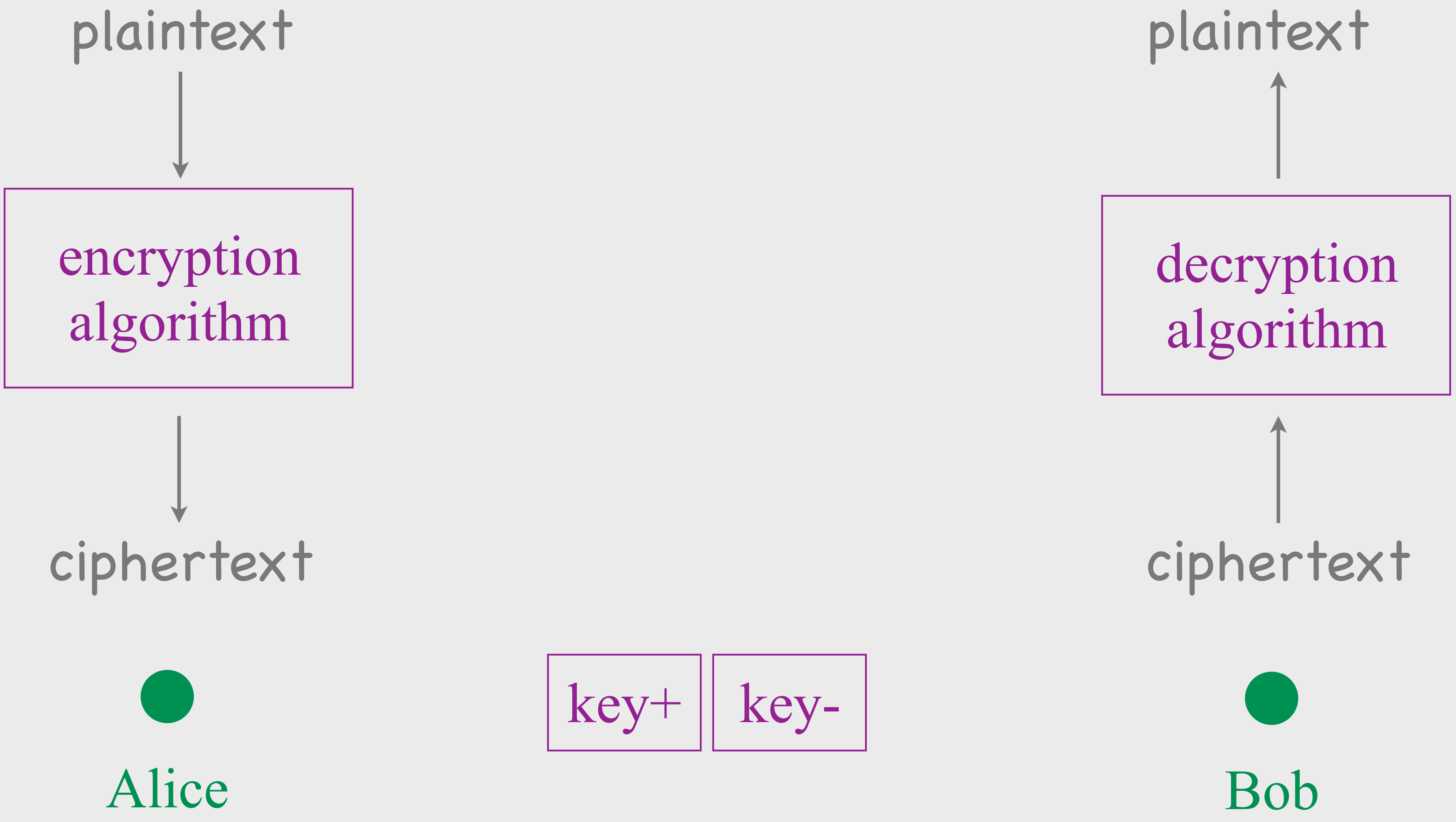
key{ key{ plaintext } } = plaintext

Symmetric key cryptography

- Alice and Bob share the same key
  - used both for the encryption and decryption algorithm
- Use key to “scramble” the plaintext
  - stream ciphers & block ciphers
  - RC4, AES, Blowfish

Symmetric key cryptography

- Challenge: how to share a key?
  - out of band
  - not always an option



plaintext

encryption algorithm

ciphertext

Alice

key+

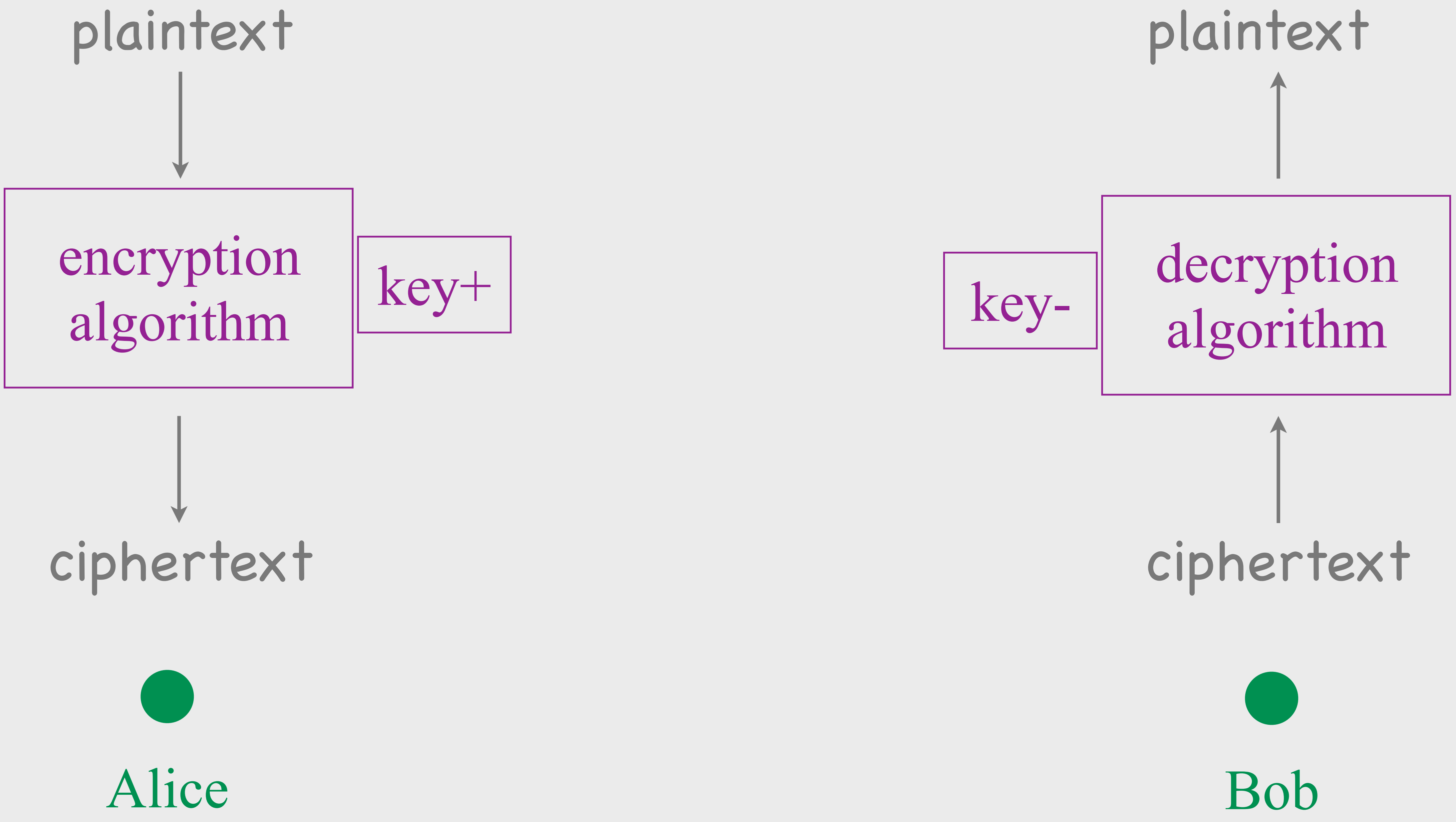
key-

plaintext

decryption algorithm

ciphertext

Bob



plaintext

encryption algorithm

key+

ciphertext

Alice

plaintext

key-

decryption algorithm

ciphertext

Bob

key-{ key+{ plaintext } } = plaintext

Asymmetric key cryptography

- Alice and Bob use different keys
  - public (key+) and private (key-) key
- There is a special relationship between them
  - key-{ key+{ plaintext } } = plaintext
  - key+{ key-{ plaintext } } = plaintext
  - RSA, DSA

Asymmetric key cryptography

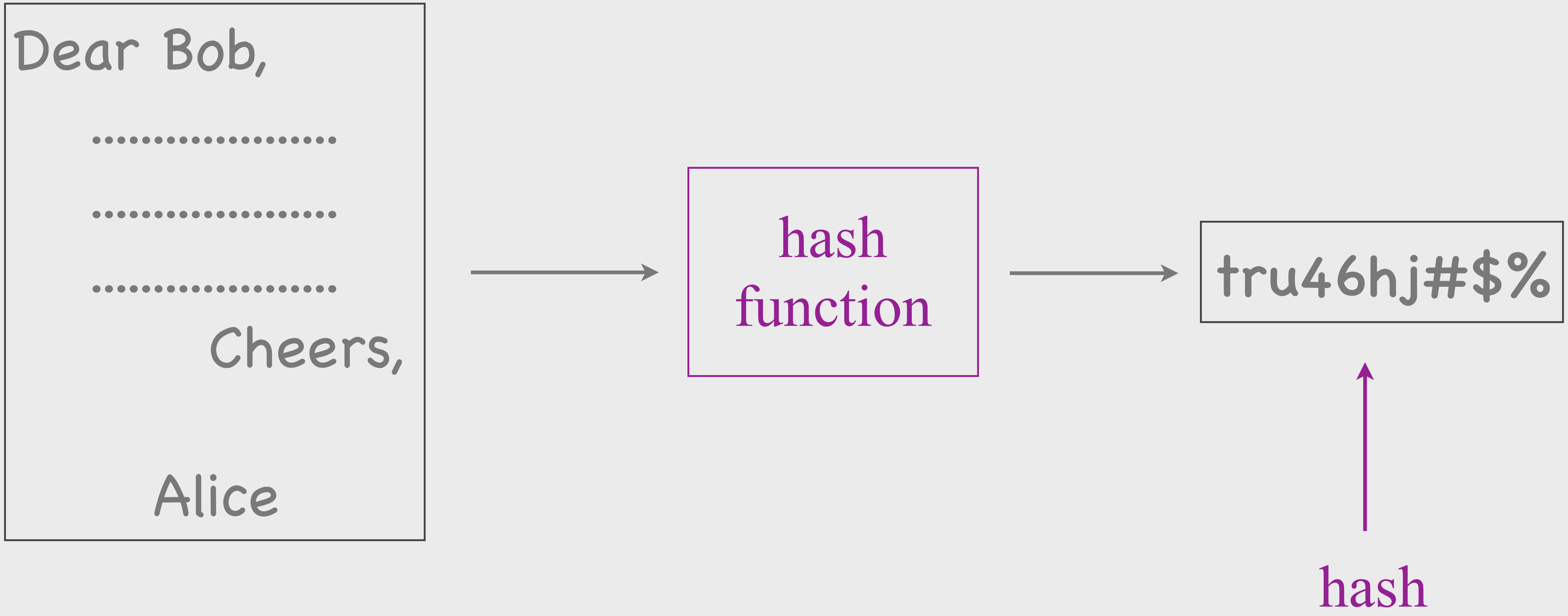
- Public key is not secret
  - only private key is secret
  - enough to guarantee secrecy
- But you can’t guess one from the other
  - Alice/Bob can share key+ with everyone
  - without revealing information about key-

Asymmetric key cryptography

- Challenge: computationally expensive
  - sophisticated encryption/decryption algorithms based on number theory

Two approaches to crypto

- Symmetric: faster but out-of-band key sharing
- Asymmetric: no out-of-band key sharing but slower



Dear Bob,

....

....

....

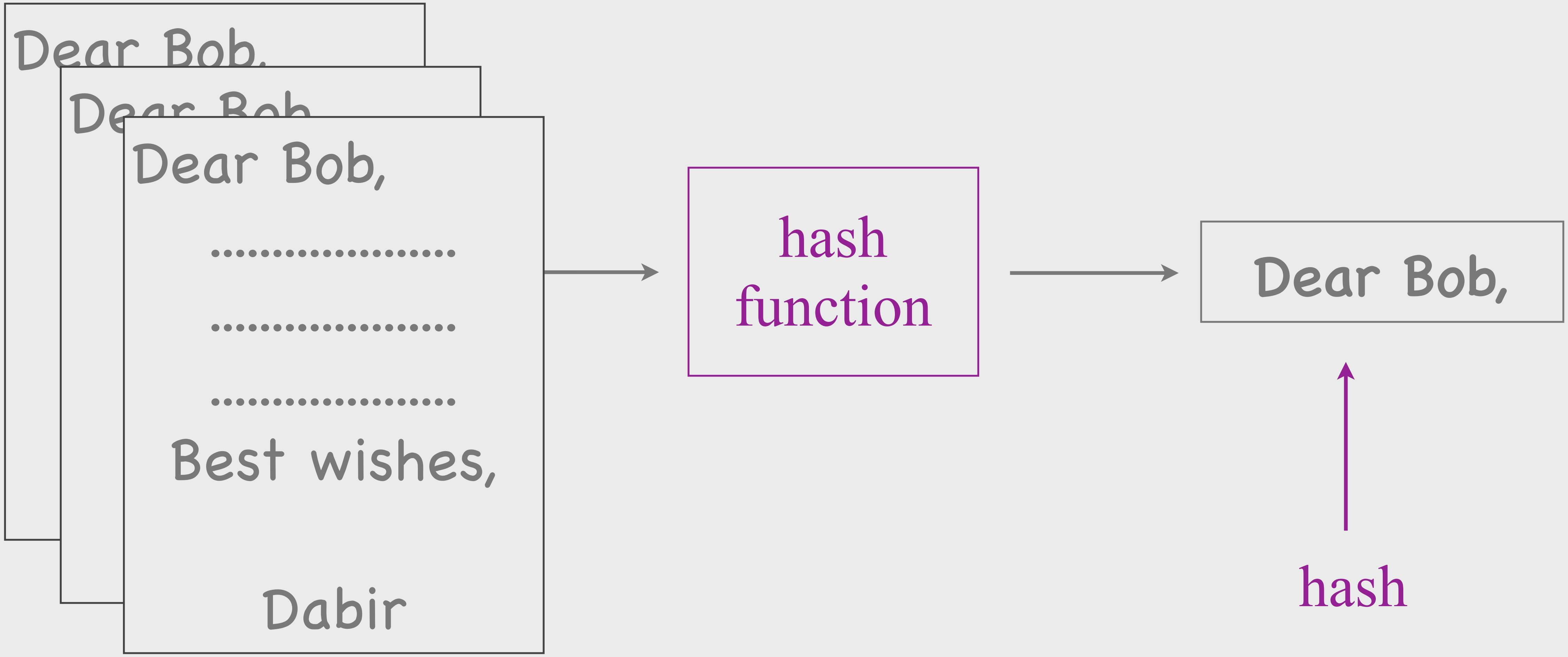
Cheers,

Alice

hash function

tru46hj#$%

hash



Dear Bob,

Dear Bob,

Dear Bob,

....

....

....

Best wishes,

Dabir

hash function

Dear Bob,

hash

Cryptographic hash function

- Maps larger input space to smaller hash space
- Hash ideally reveals no information on input
- Should be hard to identify two inputs that lead to the same hash

How is hashing different from encryption?

Building blocks

- Symmetric key encryption/decryption
  - Alice and Bob share the same secret key
  - challenge: exchanging the secret key
- Asymmetric key encryption/decryption
  - Alice and Bob use different keys
  - challenge: computationally more expensive
- Cryptographic hash function
  - produces a hash of the original message

Outline

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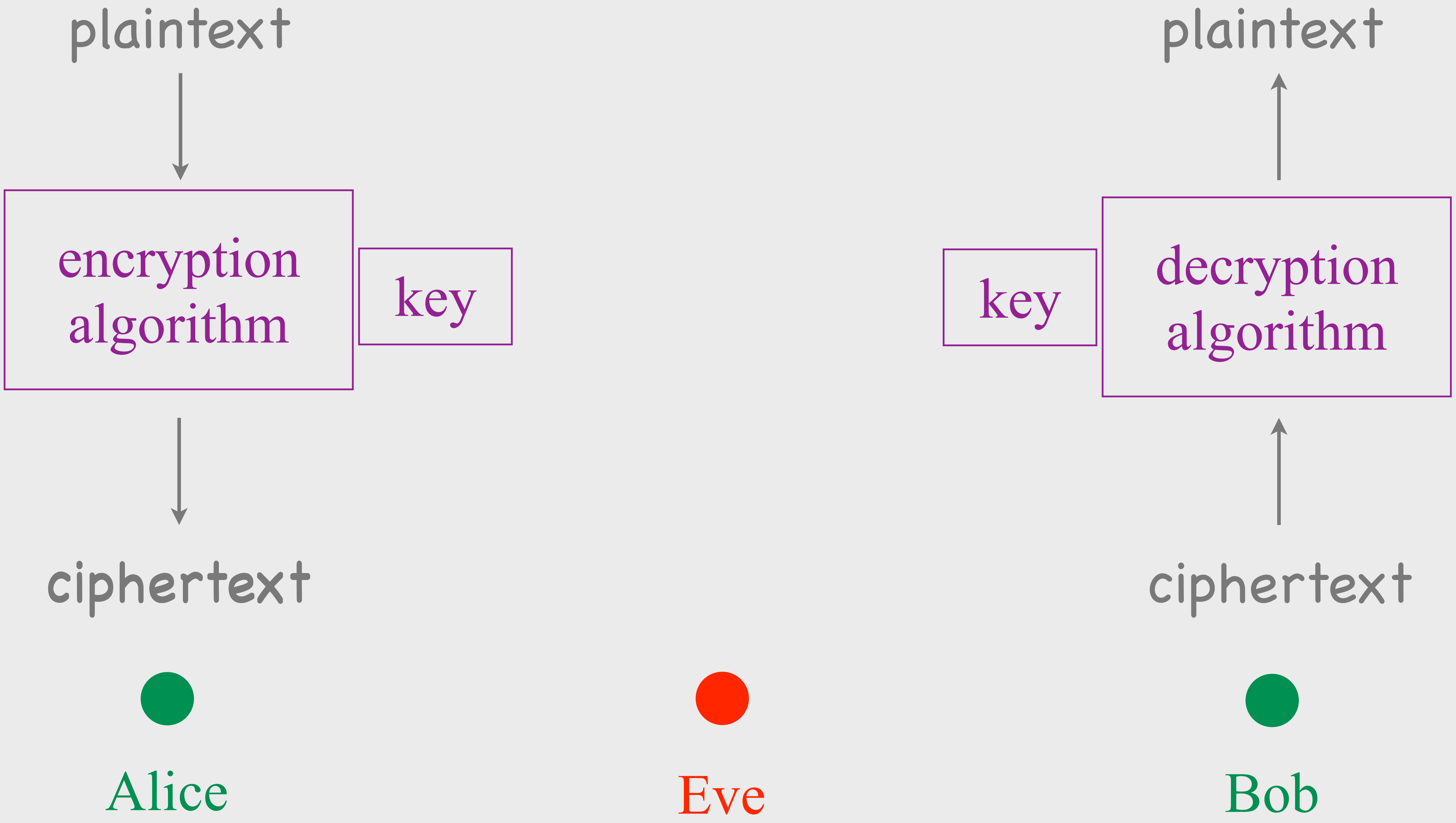
Providing confidentiality



plaintext

encryption algorithm

key

ciphertext

Alice

Eve

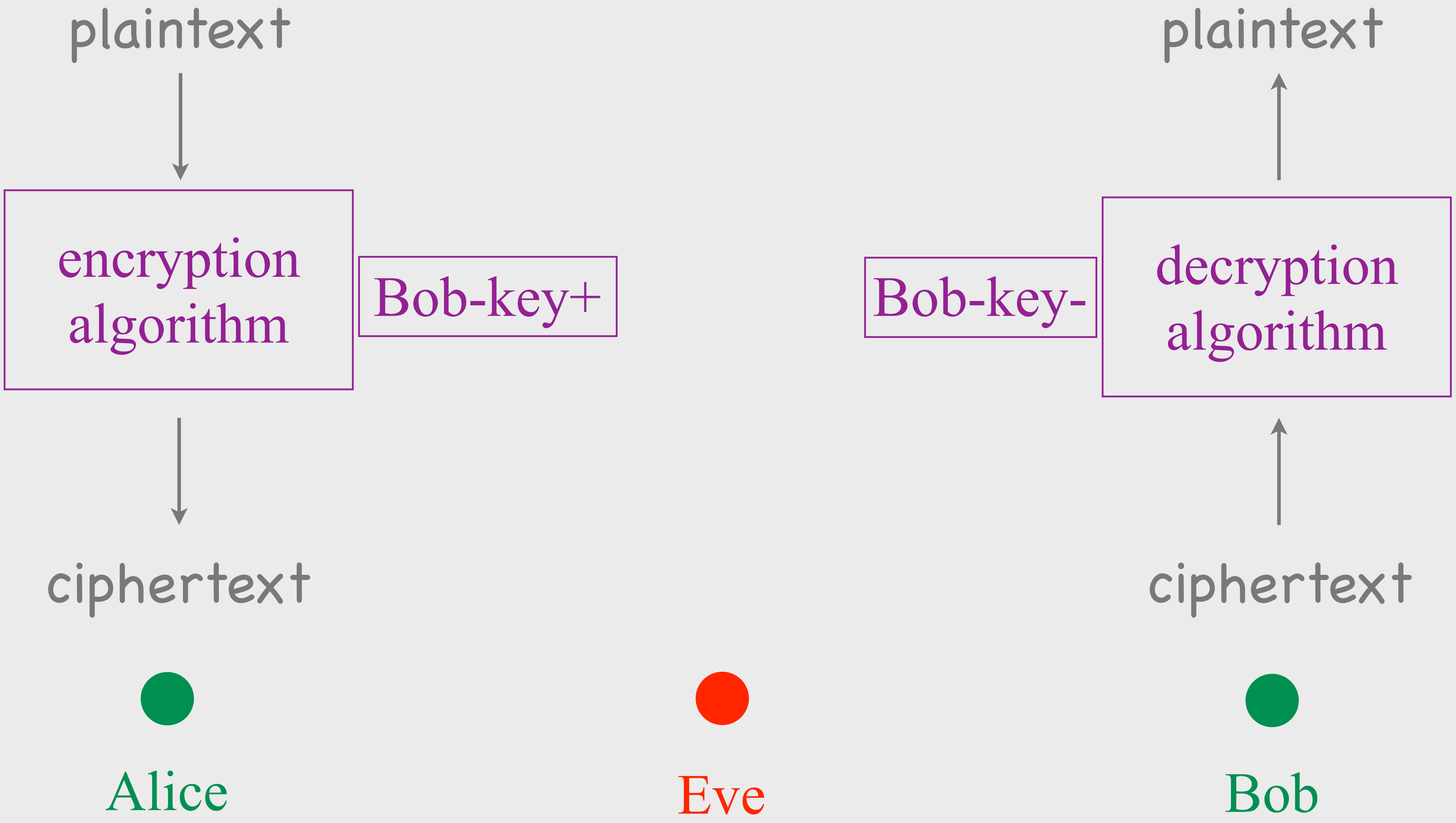
plaintext

key

decryption algorithm

ciphertext

Bob



plaintext

encryption algorithm

Bob-key+

ciphertext

Alice

Eve

plaintext

Bob-key-

decryption algorithm

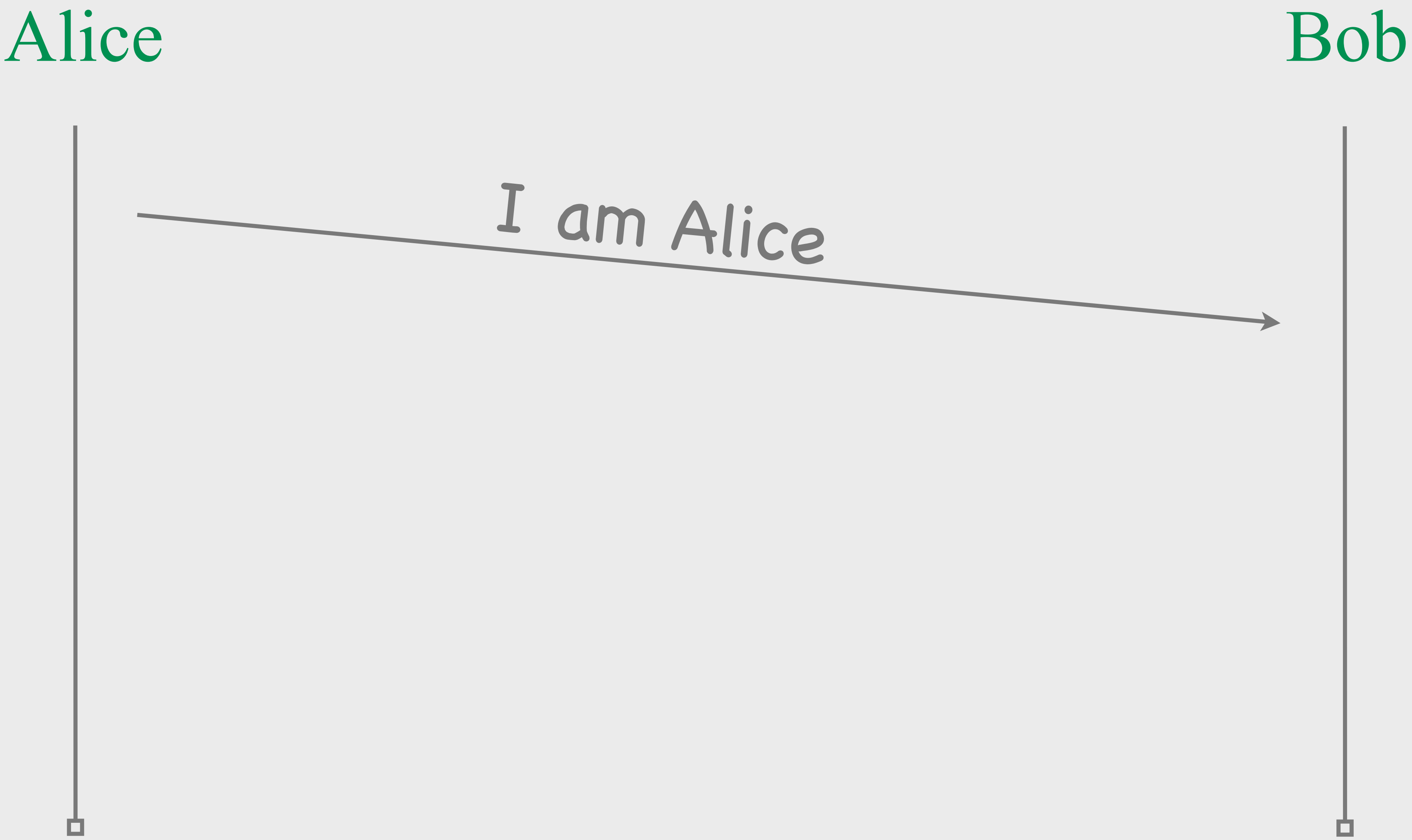
ciphertext

Bob

Providing confidentiality

- With symmetric key crypto
  - Alice encrypts message with shared key
  - only Bob can decrypt it (with shared key)
- With asymmetric key crypto
  - Alice encrypts message with Bob's public key
  - only Bob can decrypt it (with his private key)

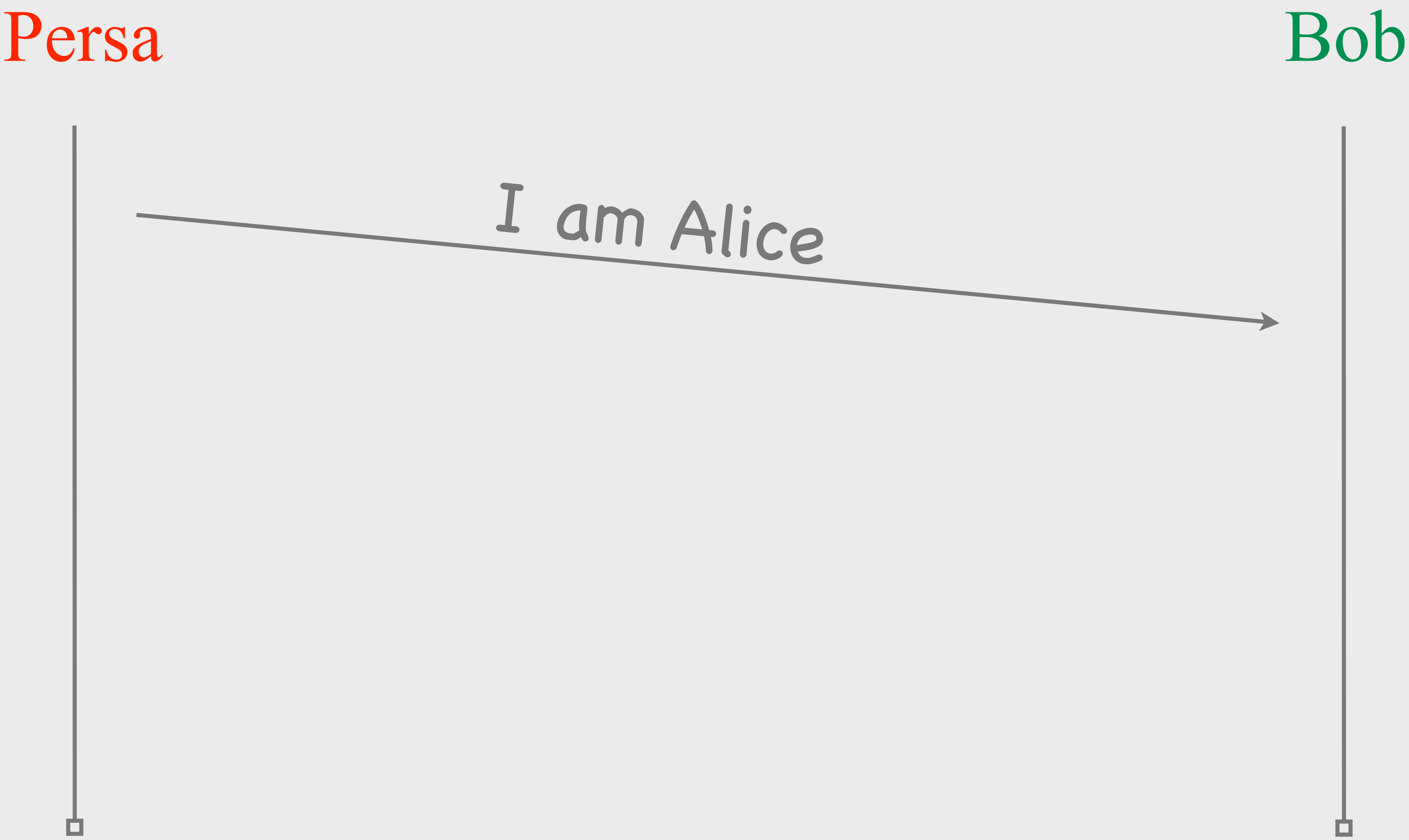
Providing authenticity



Alice

Bob

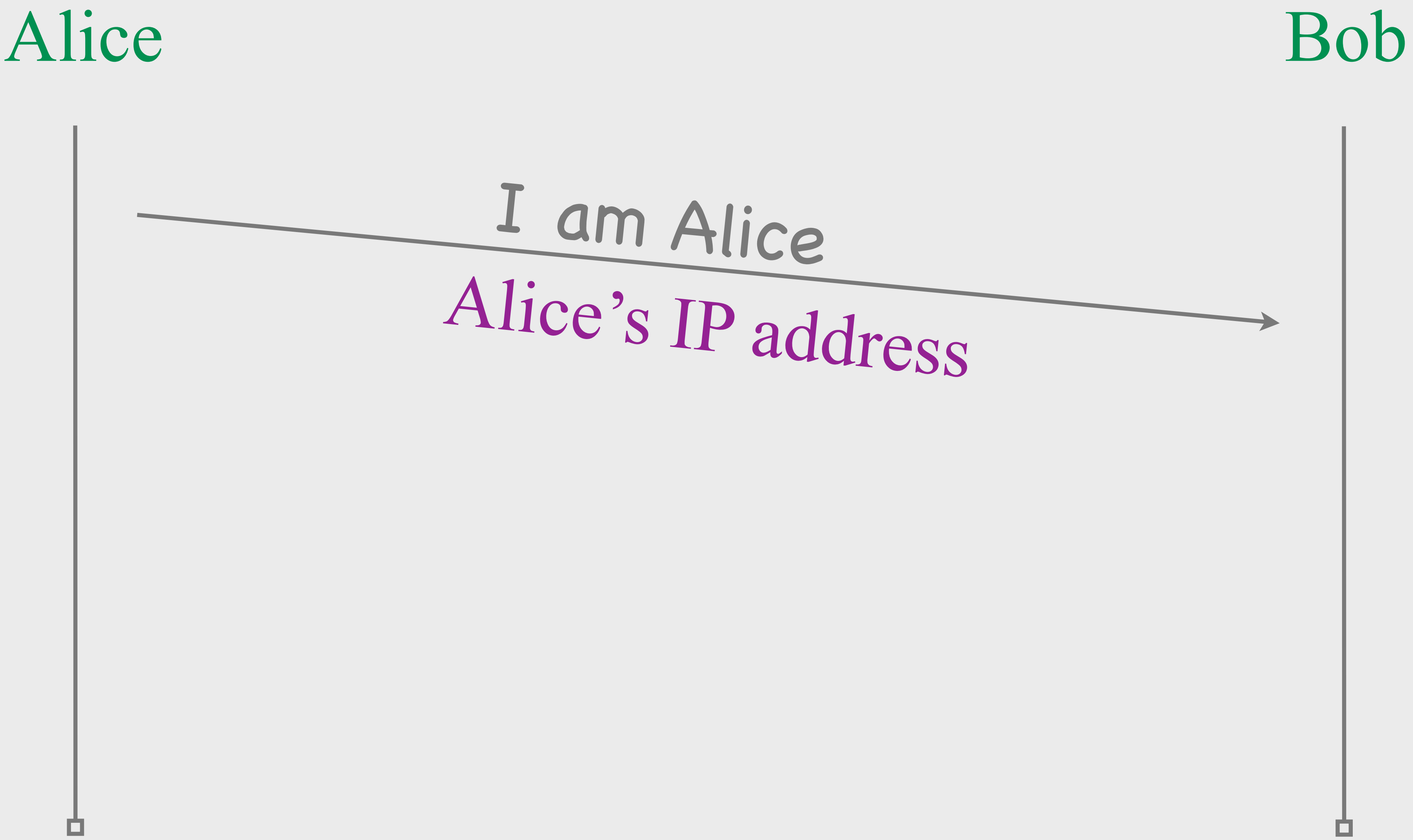
I am Alice



Persa

Bob

I am Alice

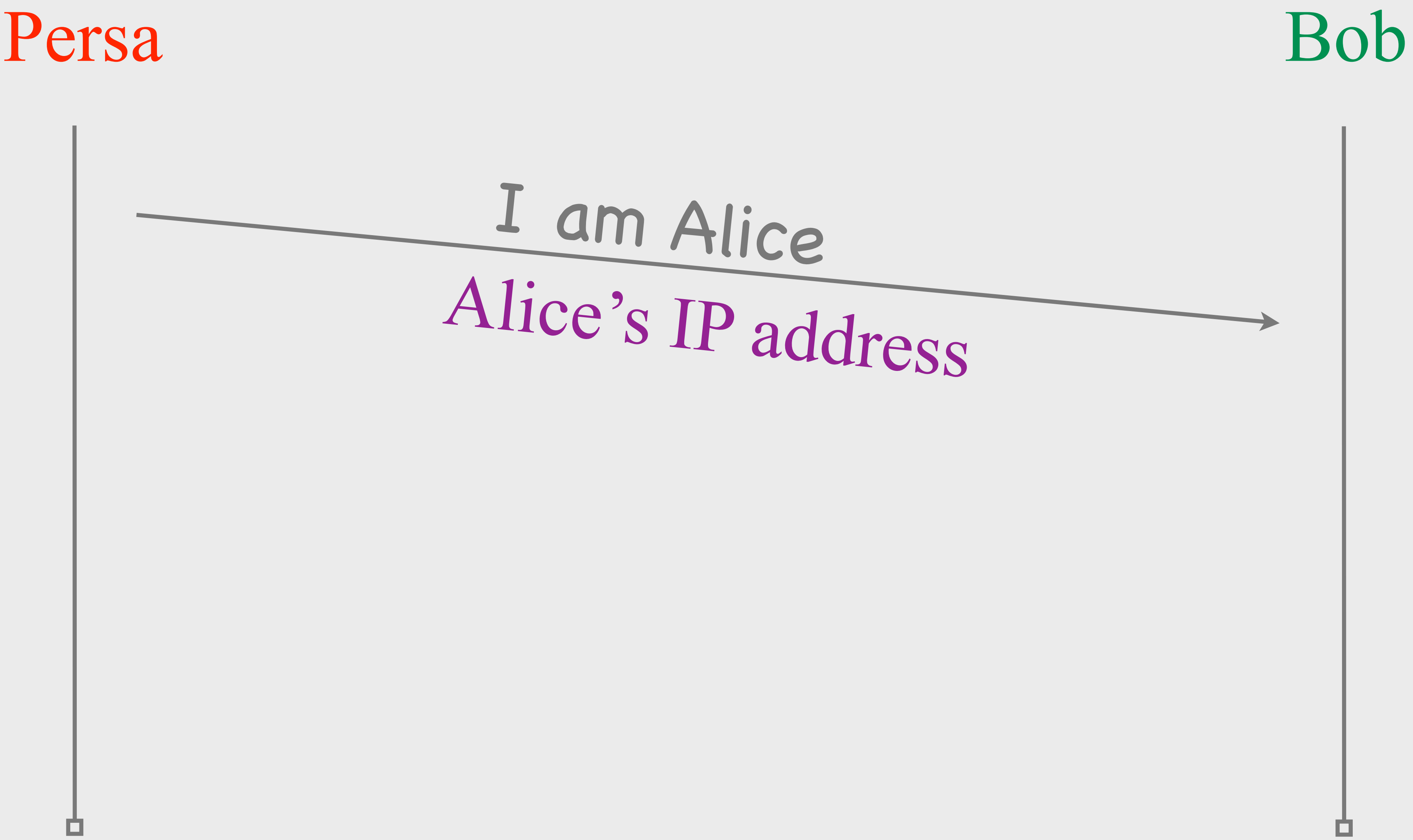


Alice

Bob

I am Alice

Alice’s IP address

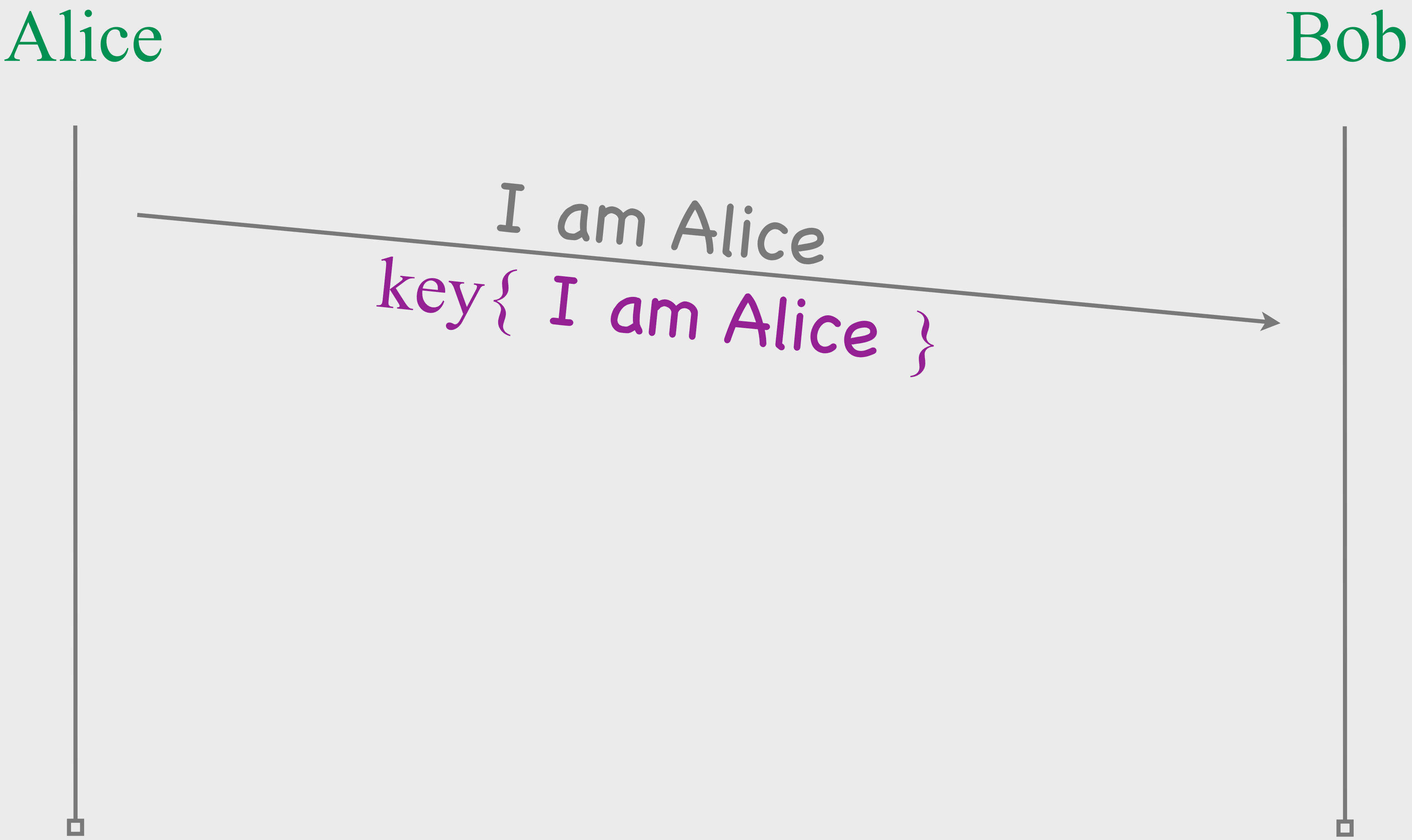


Persa

Bob

I am Alice

Alice’s IP address

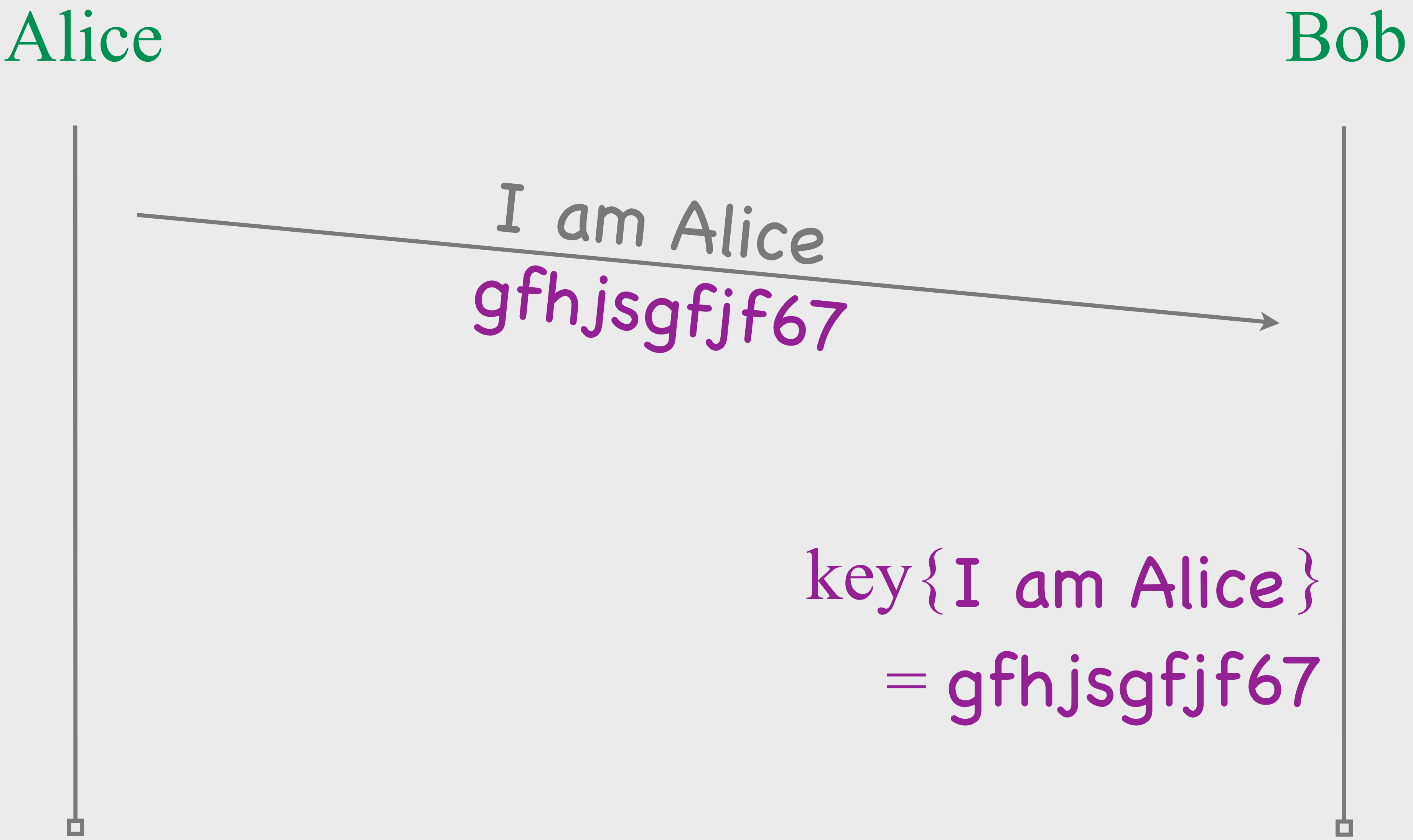


Alice

Bob

I am Alice

key{ I am Alice }



Alice

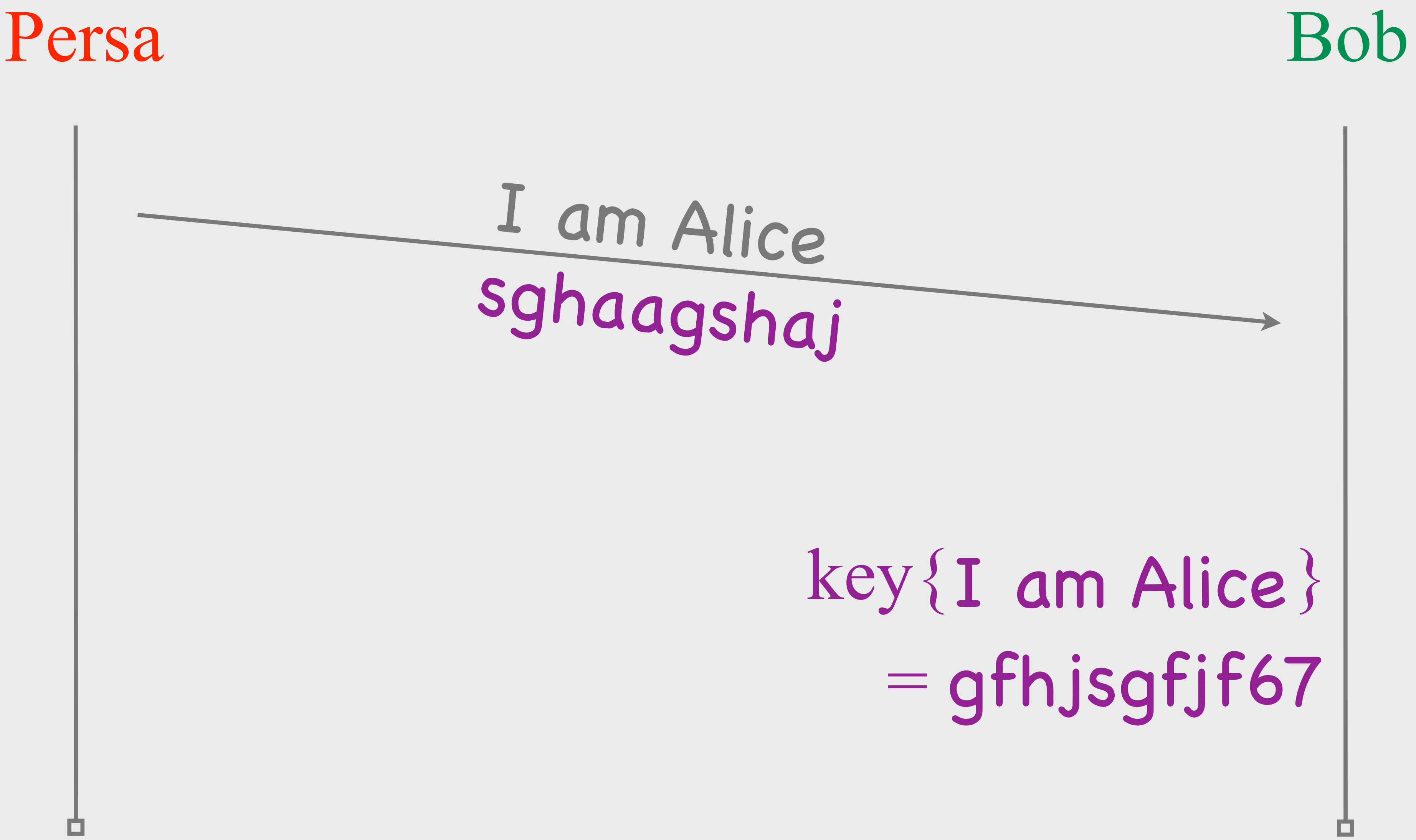
Bob

I am Alice

gfhjsgfjf67

key{I am Alice}

= gfhjsgfjf67



Persa

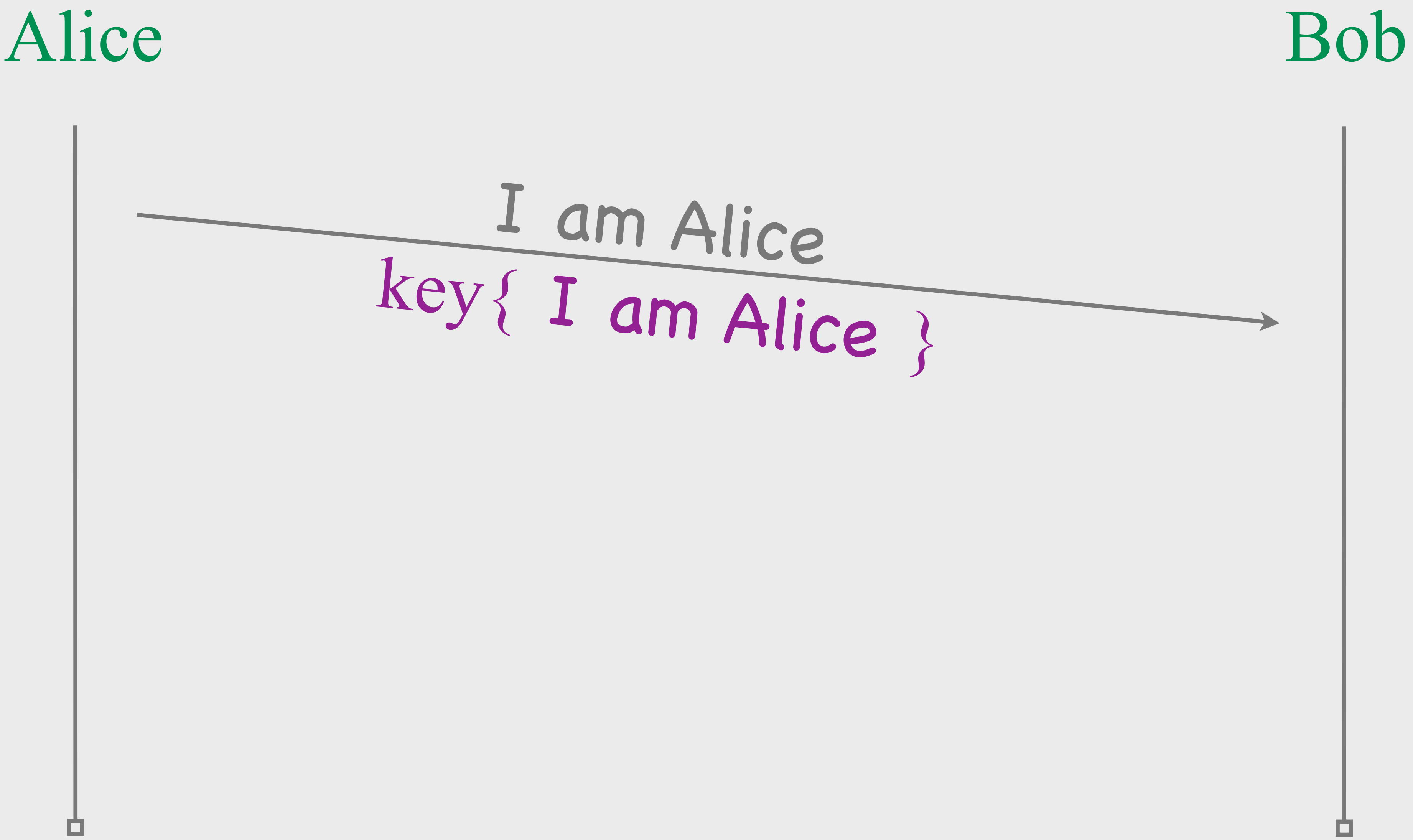
Bob

I am Alice

sghaagshaj

key{I am Alice}

= gfhjsgfjf67

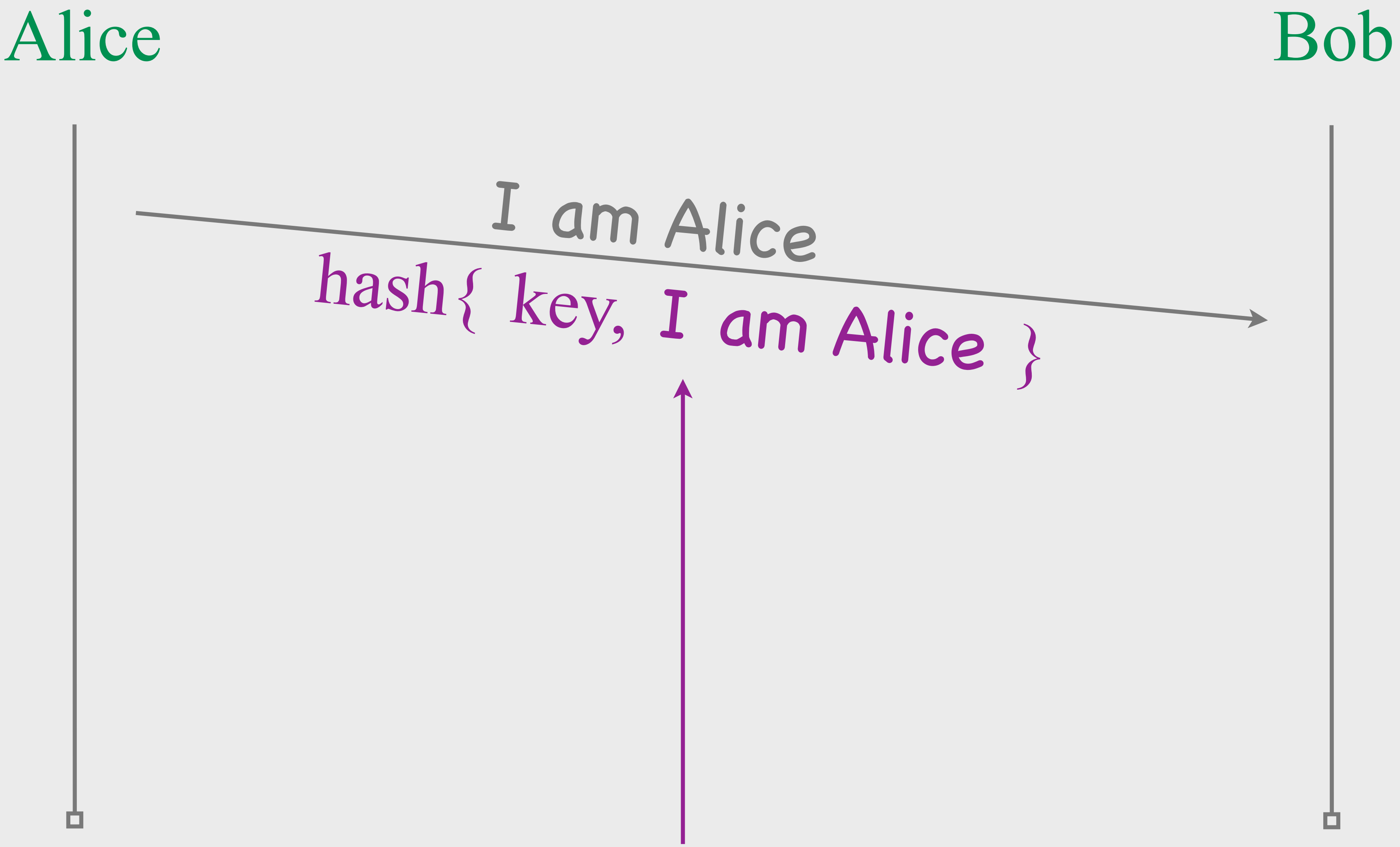


Alice

Bob

I am Alice

key{ I am Alice }



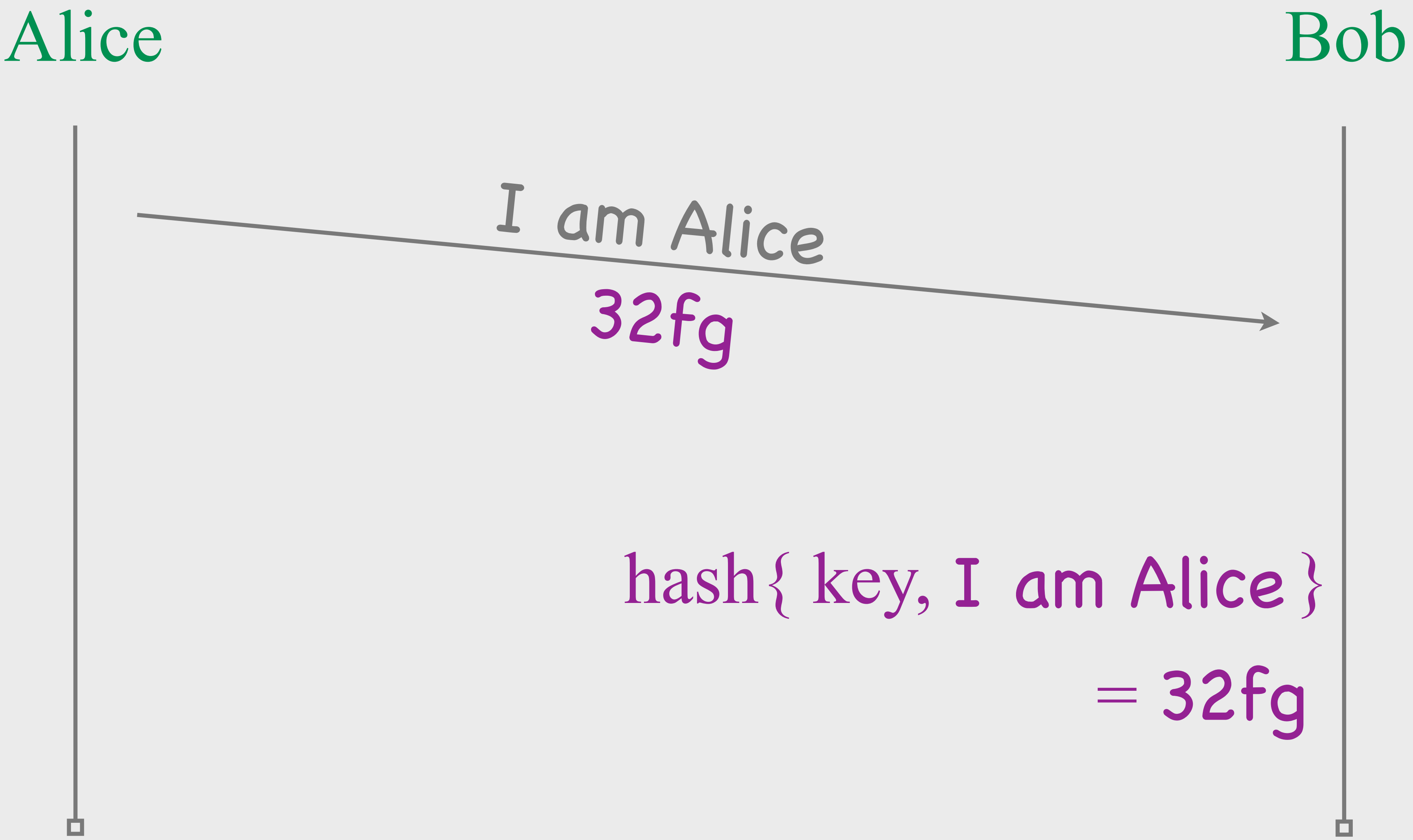
Alice

Bob

I am Alice

hash{ key, I am Alice }

Message Authentication Code (MAC)



Alice

Bob

I am Alice

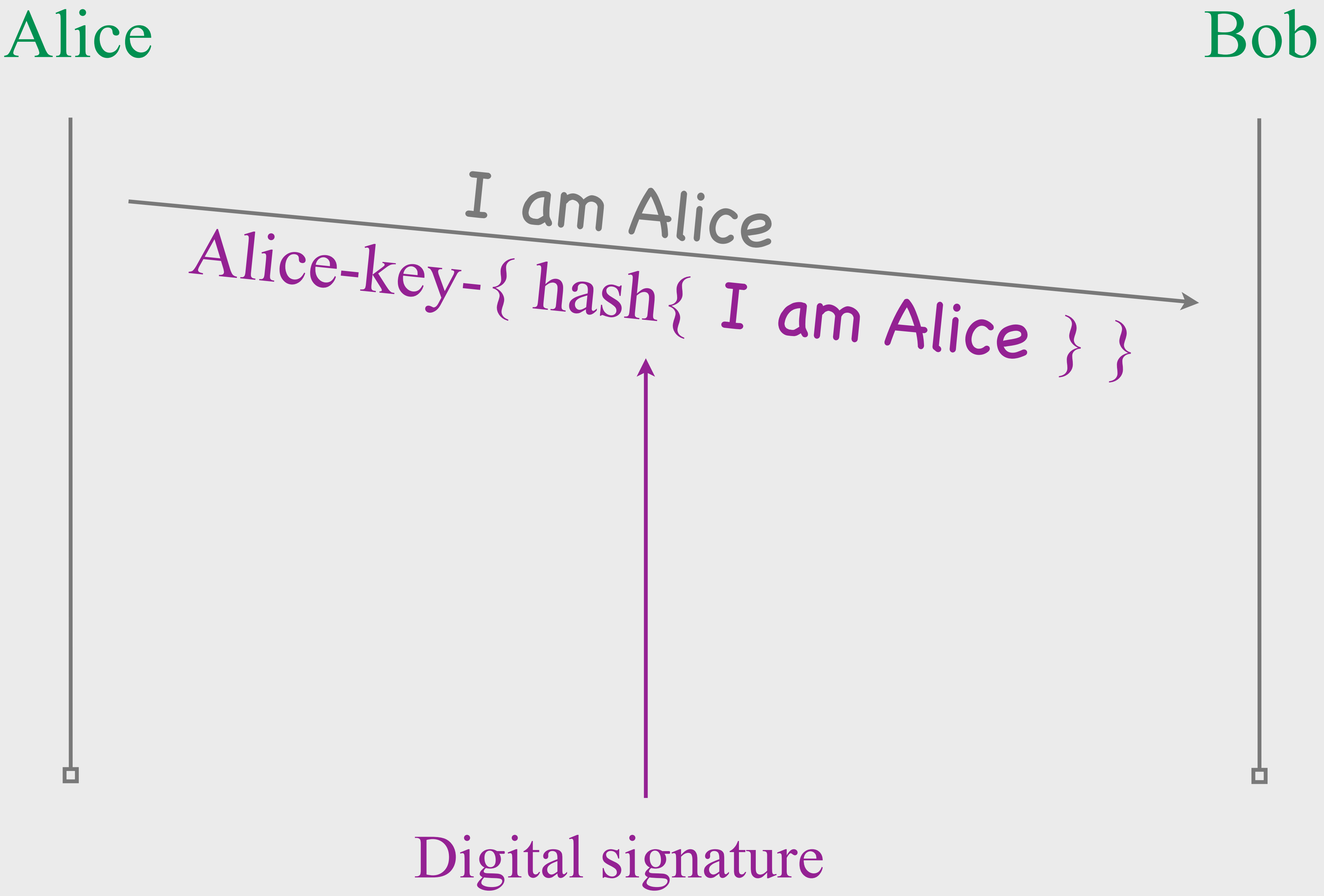
32fg

hash{ key, I am Alice }

= 32fg

Message Authentication Code

- hash{ key, plaintext }
- Proof that this particular plaintext was sent by an entity that knows the key



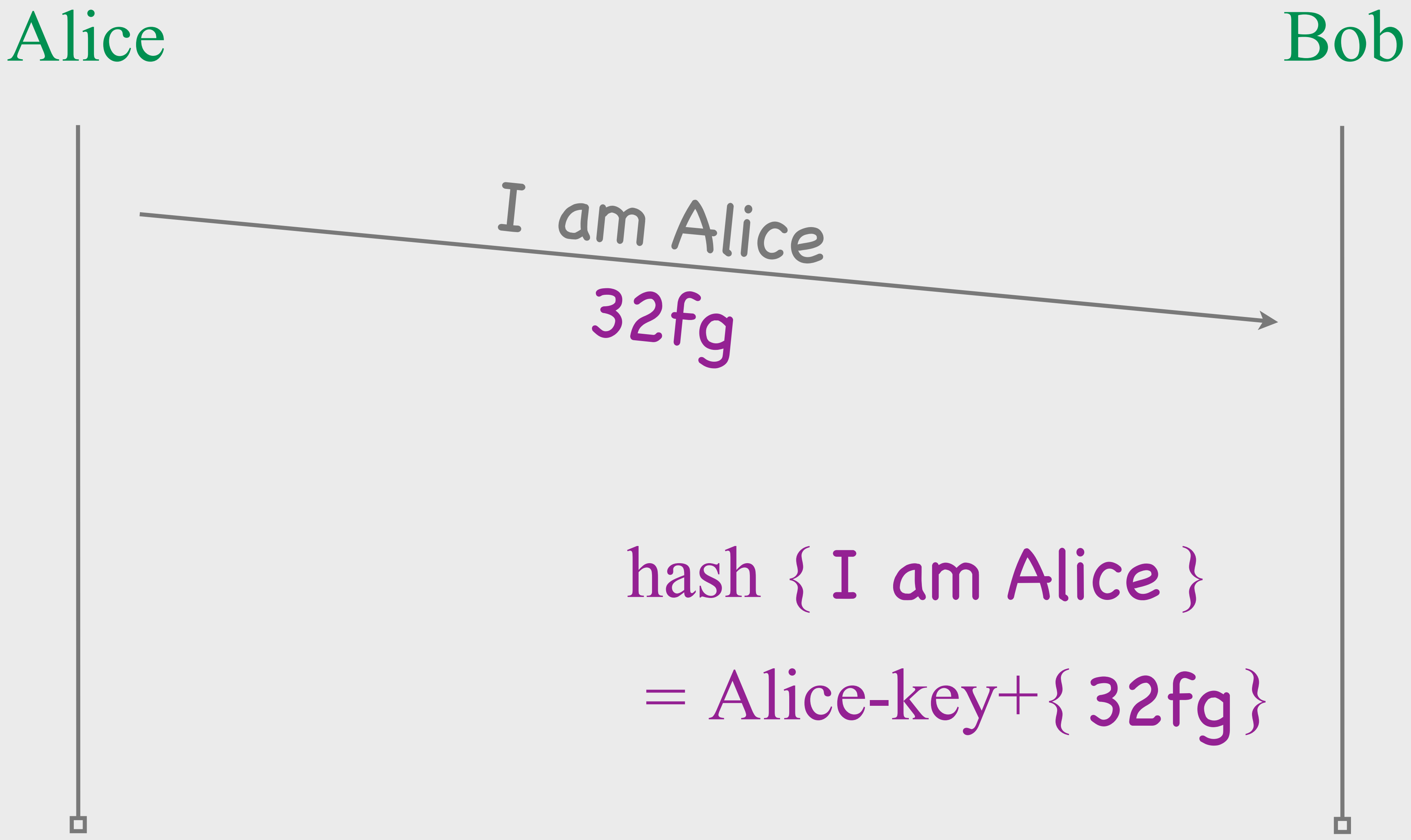
Alice

Bob

I am Alice

Alice-key-{ hash{ I am Alice } }

Digital signature

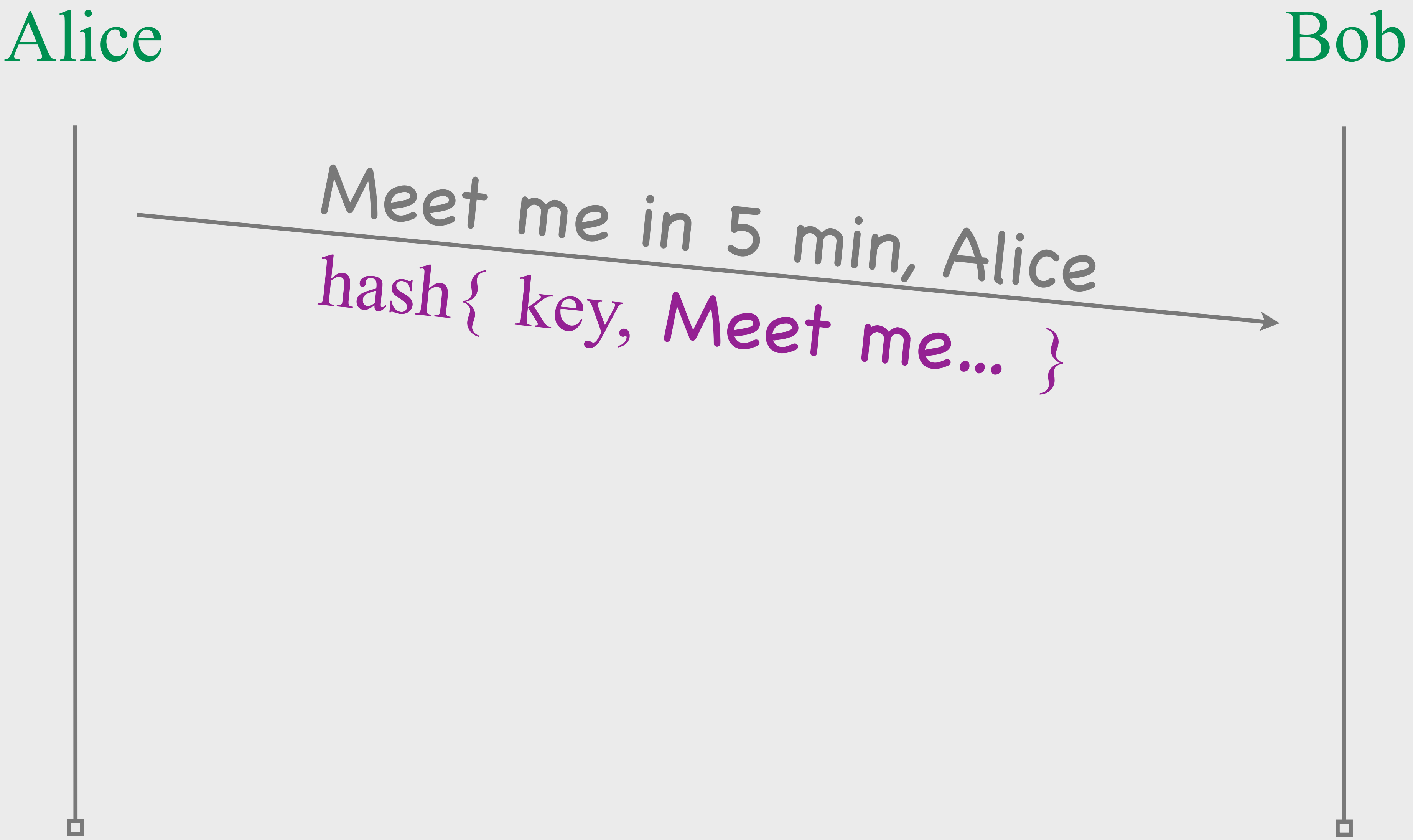


hash { I am Alice }

= Alice-key+{ 32fg }

Digital signature

- Generate: key-{ hash{ message } }
- Verify: key+{…} == hash { message }
- Proof that this particular message was sent by an entity who knows the private key that matches public key key+

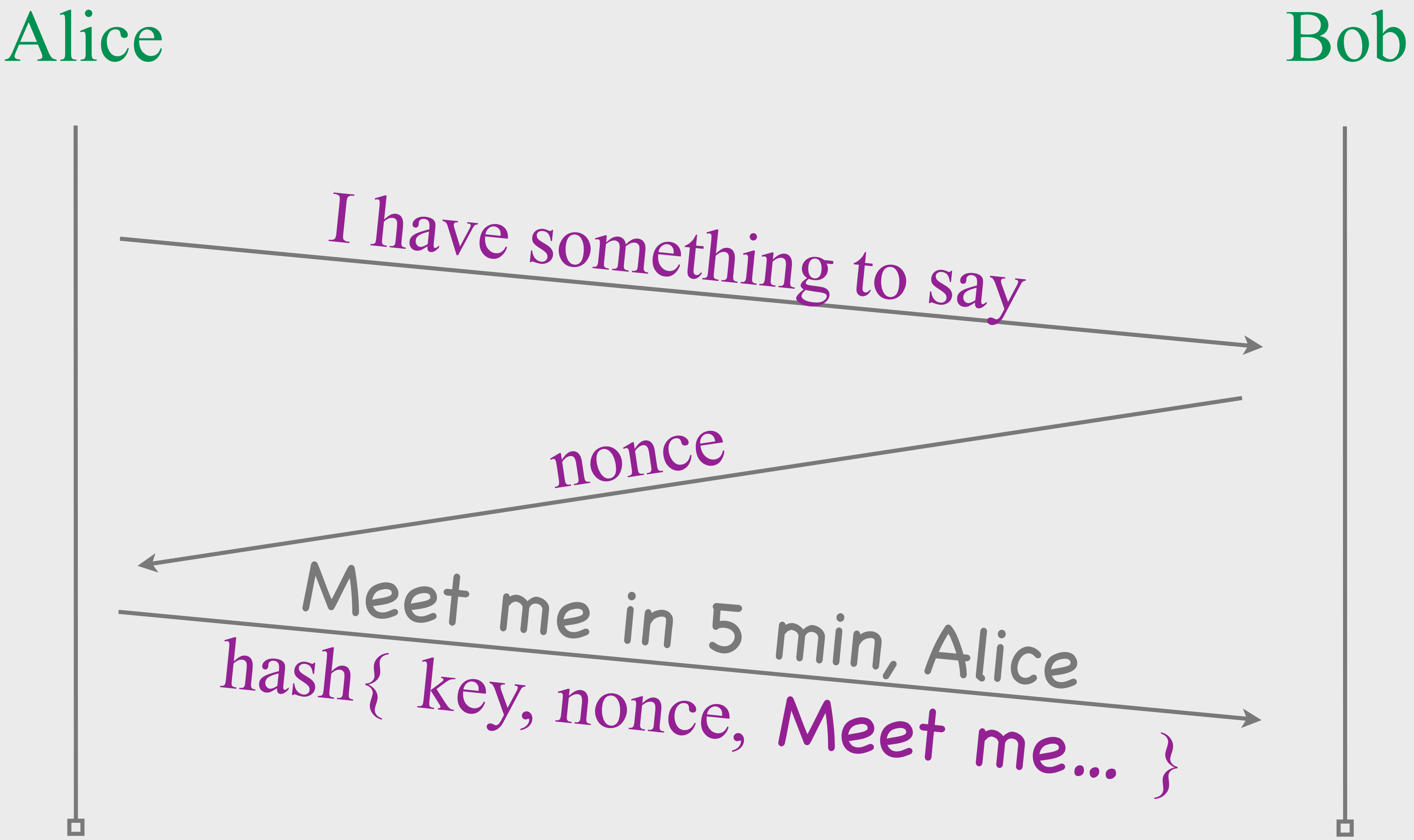


Alice

Bob

Meet me in 5 min, Alice

hash{ key, Meet me... }



Alice

Bob

I have something to say

nonce

Meet me in 5 min, Alice

hash{ key, nonce, Meet me… }

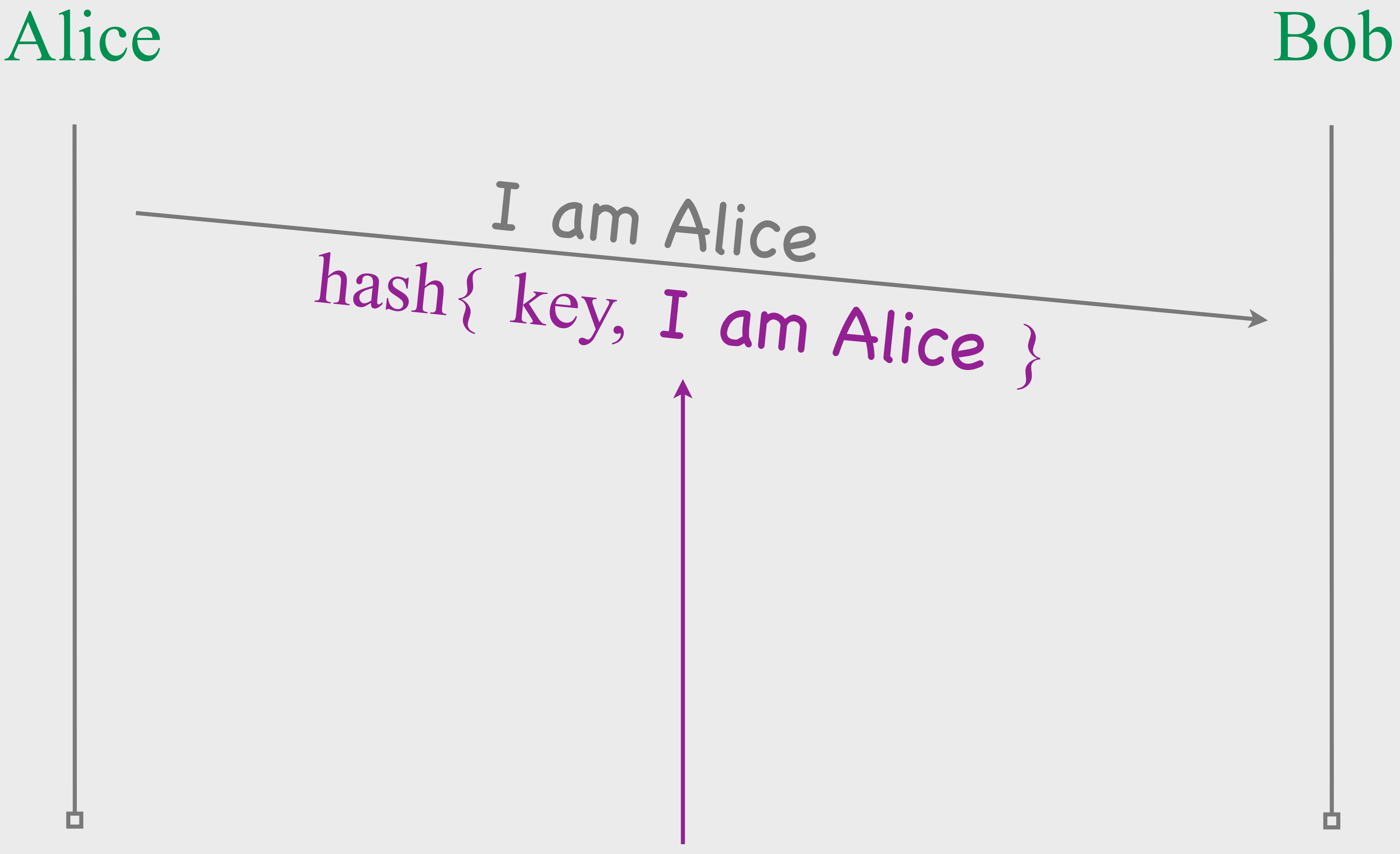
Providing authenticity

- With symmetric key crypto
  - Alice appends MAC
  - Bob checks that it is correct (using shared key)
- With asymmetric key crypto
  - Alice appends digital signature
  - Bob checks that it is correct (using Alice's public key)

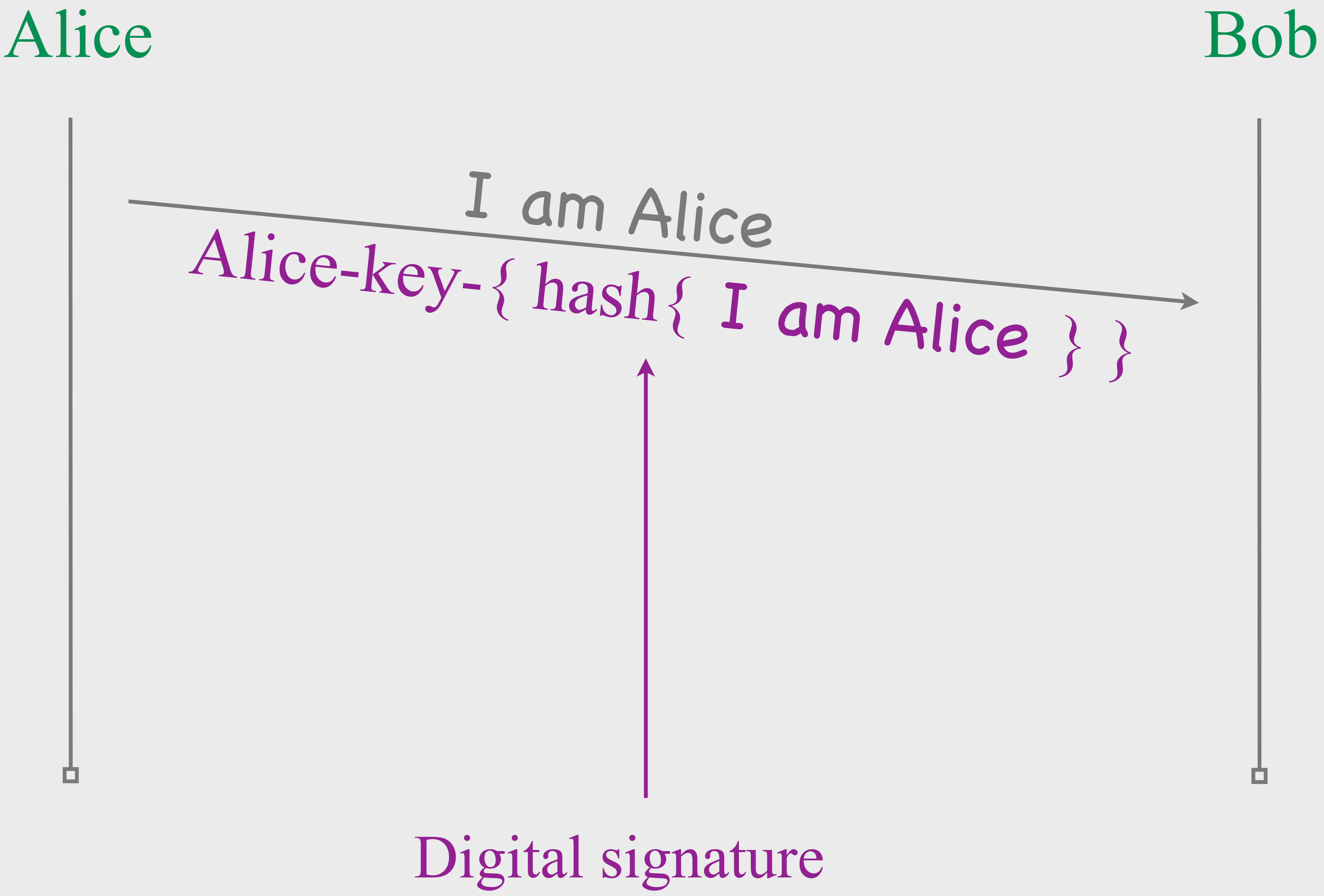
Providing authenticity

- Use nonce to prevent replay attacks
  - Alice appends MAC or digital signature of nonce + message
  - Bob verifies that it is correct

Providing data integrity



Message Authentication Code
(MAC)



Alice

Bob

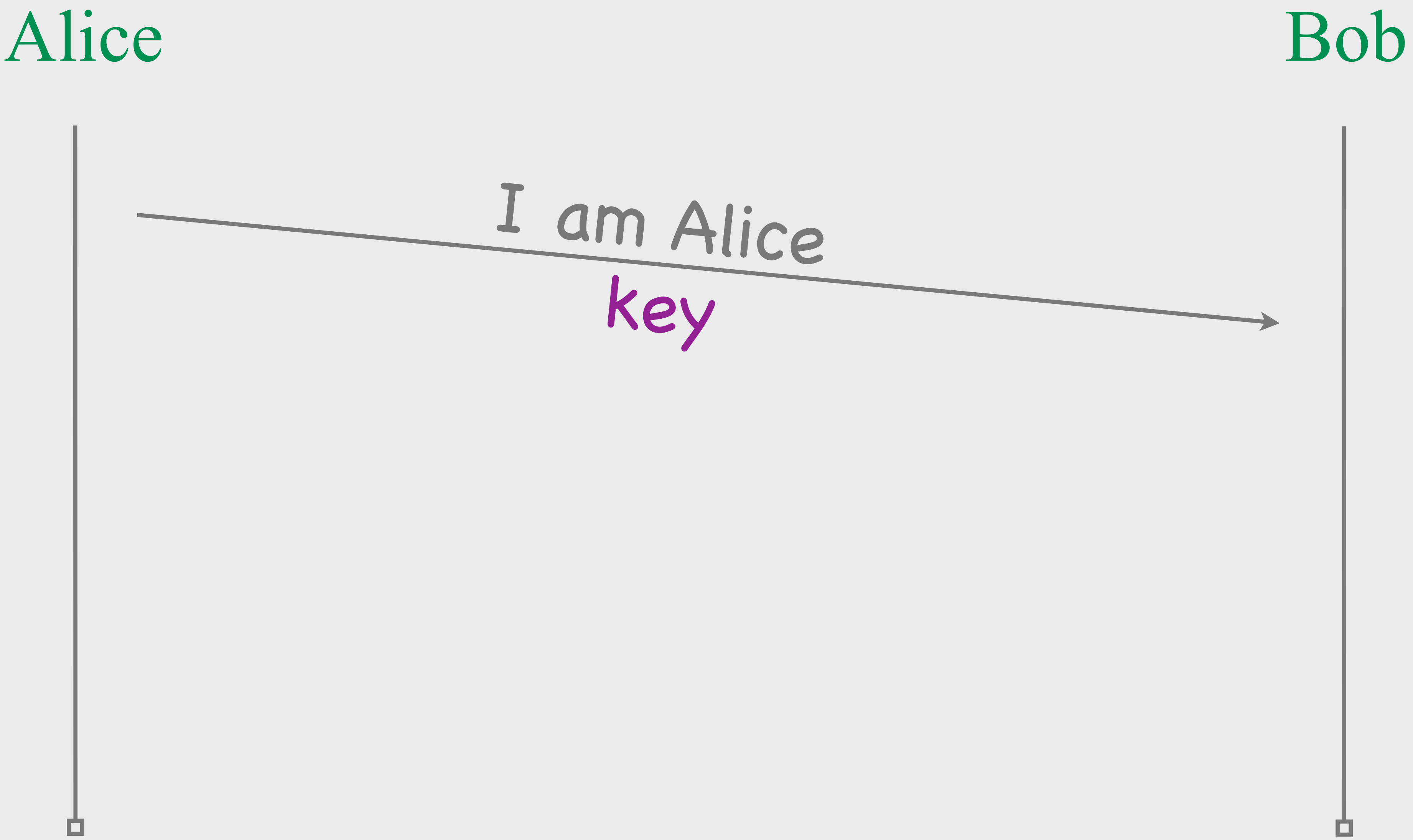
I am Alice

Alice-key-{ hash{ I am Alice } }

Digital signature

Providing integrity

- With exactly the same mechanisms that provide authenticity



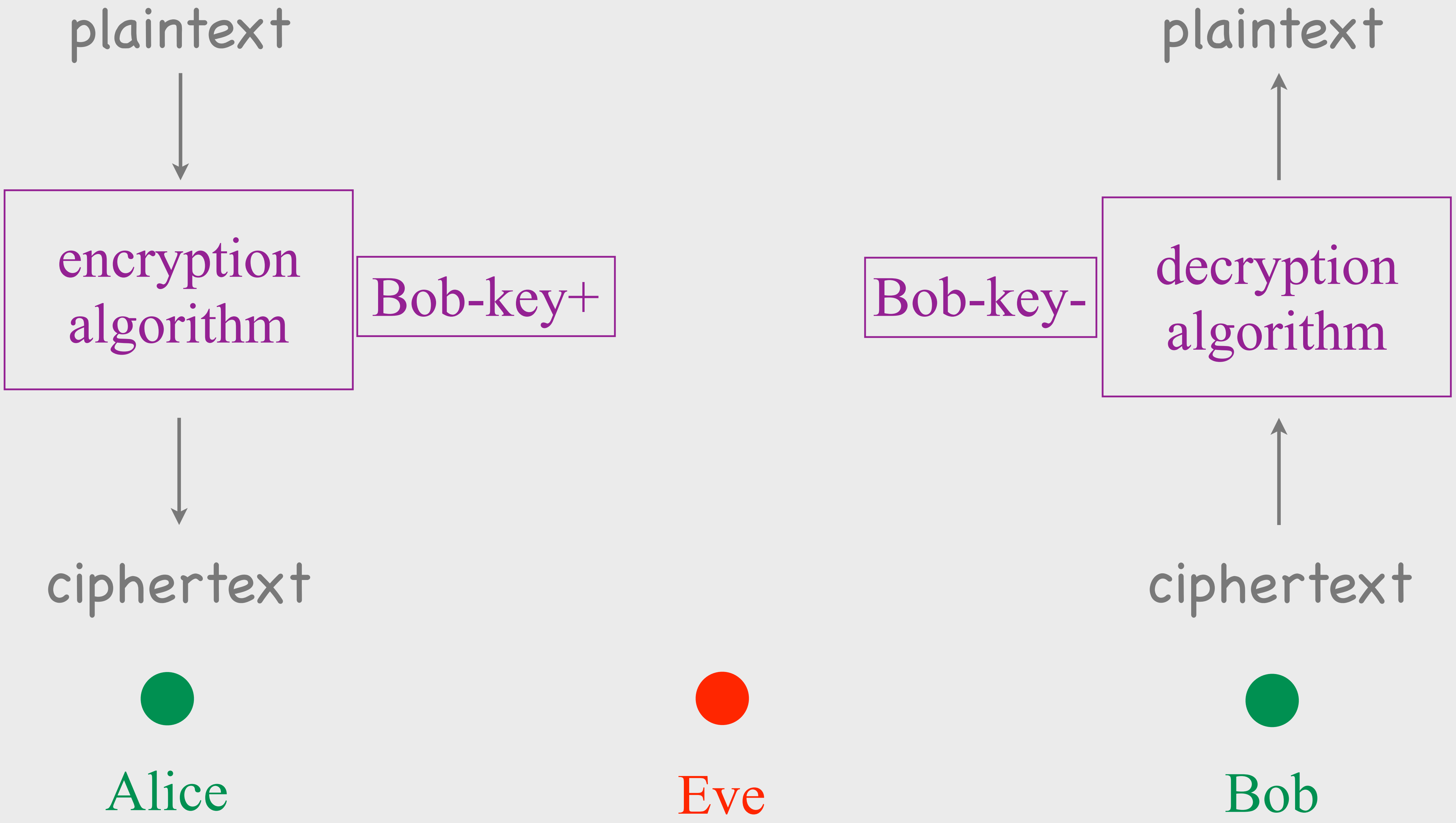
Alice

Bob

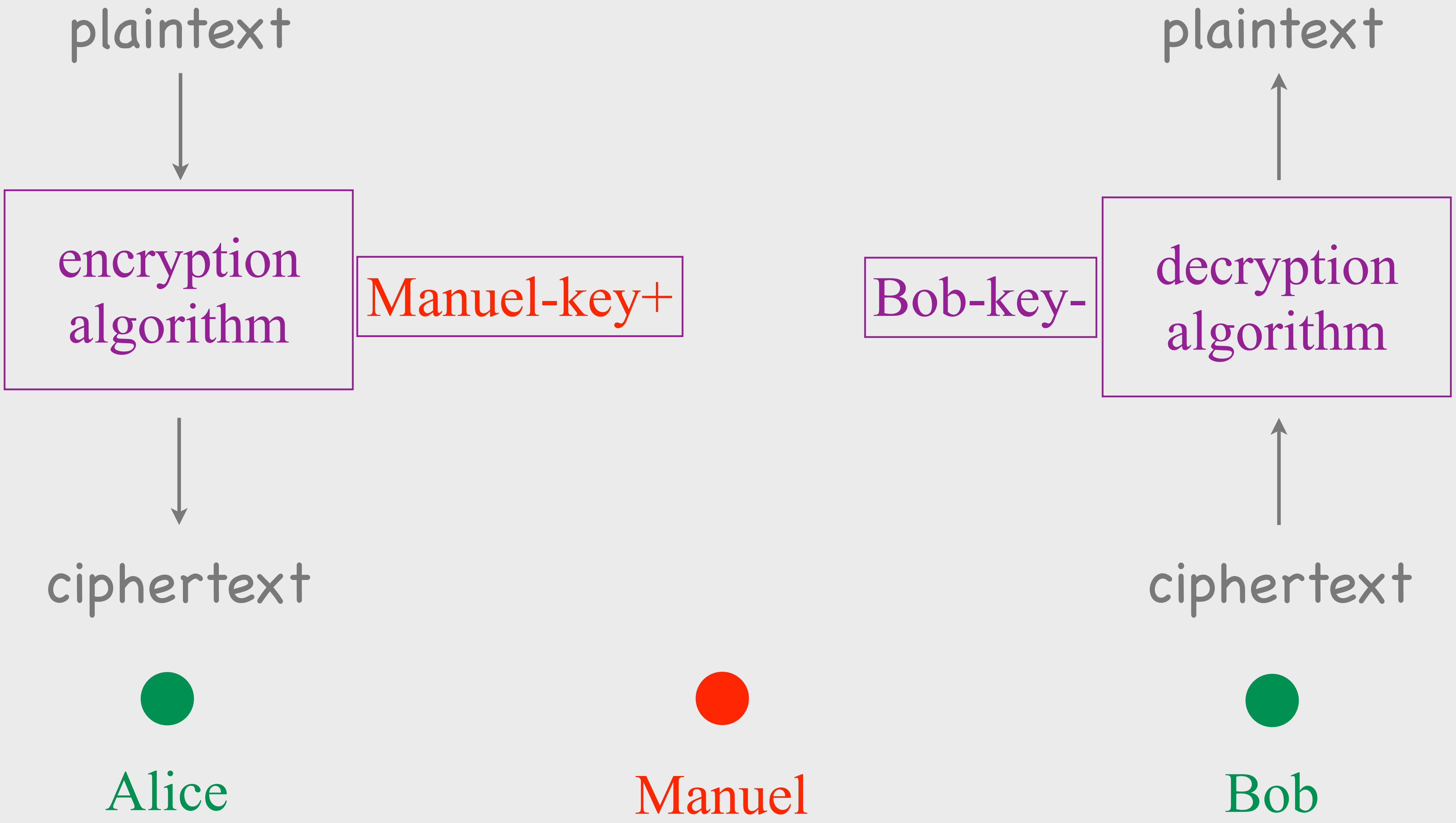
I am Alice

key

Preventing man-in-the-middle attacks



plaintext
encryption algorithm
Bob-key+
ciphertext
Alice
Eve
plaintext
Bob-key-
decryption algorithm
ciphertext
Bob



plaintext

encryption algorithm

Manuel-key+

ciphertext

Alice

Manuel

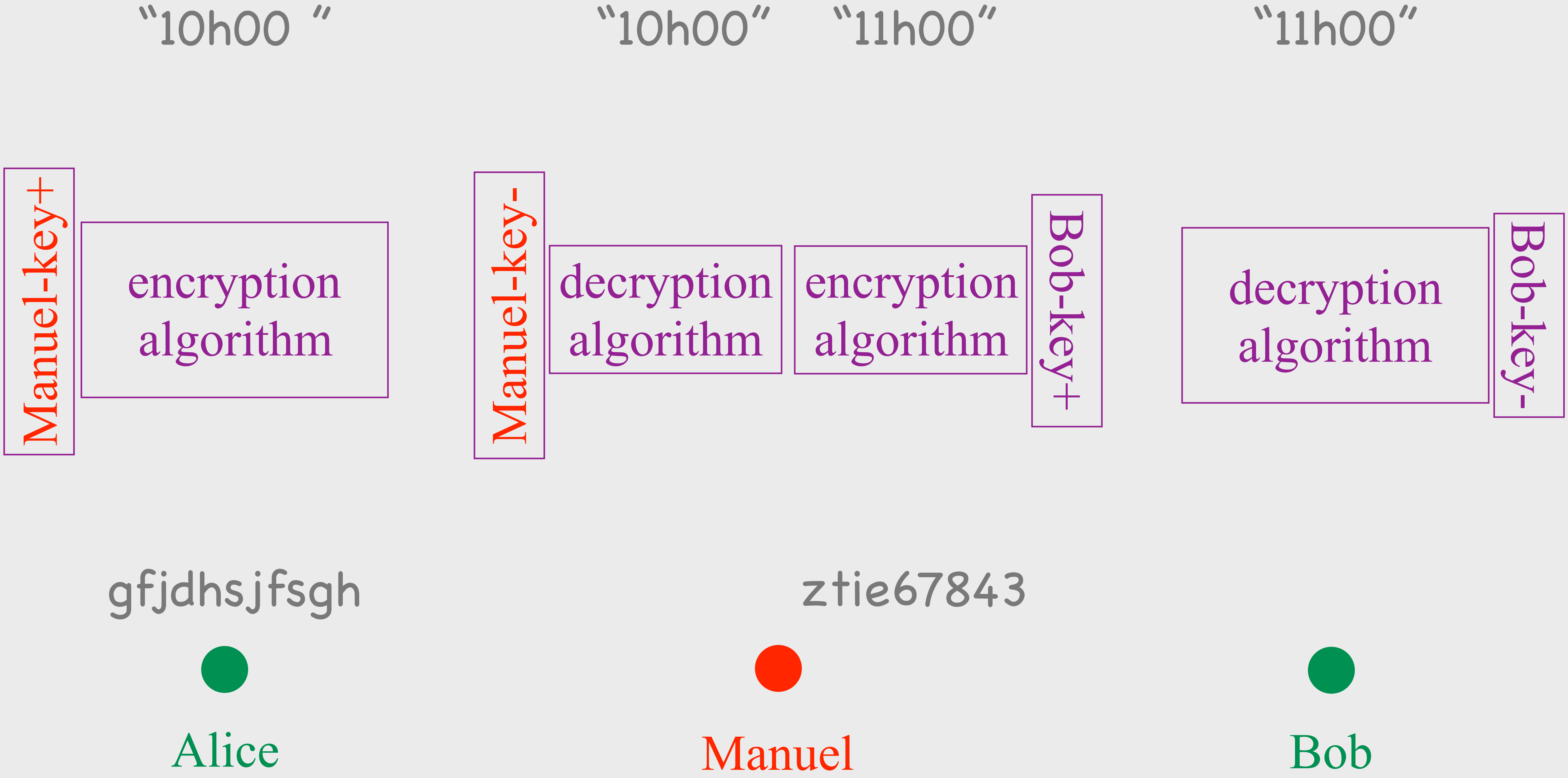
Bob-key-

plaintext

decryption algorithm

ciphertext

Bob



"10h00 "

"10h00" "11h00"

"11h00"

Manuel-key+

encryption algorithm

Manuel-key-

decryption algorithm

encryption algorithm

Bob-key+

decryption algorithm

Bob-key-

gfjdhsjfsgh

ztie67843

Alice

Manuel

Bob

Man in the middle

- Can break confidentiality
  - Manuel convinces Alice to use his public key instead of Bob's
  - decrypts and re-encrypts Alice-Bob messages
- Cause: no way to verify public-keys
  - when Alice learns Bob's public key, she must verify that it is indeed his

Solution: public-key certificates

- Rely on trusted certificate authority (CA)
  - an entity that both Alice & Bob trust
- CA produces certificate of Bob's public key
  - { Bob owns Bob-key+, … }
  - CA-key-{ hash{ Bob owns Bob-key+, … } }

Solution: public-key certificates

- Alice needs Bob’s true public key
  - to produce Bob-key+{ message }
  - to check Bob-key-{ hash{ message } }
- Bob sends public key & certificate
  - CA-key-{ hash{ Bob owns Bob-key+, … } }
  - guarantees this is Bob's public key
- Alice needs CA’s true public key
  - to check CA-key-{ hash{ Bob owns Bob-key+, … } }

Bootstrapping is unavoidable

- Secure communication requires some form of shared state
- Symmetric crypto: secret key
- Asymmetric crypto: CA's public key
  - typically stored in browser

Asymmetric crypto reduces bootstrapping information

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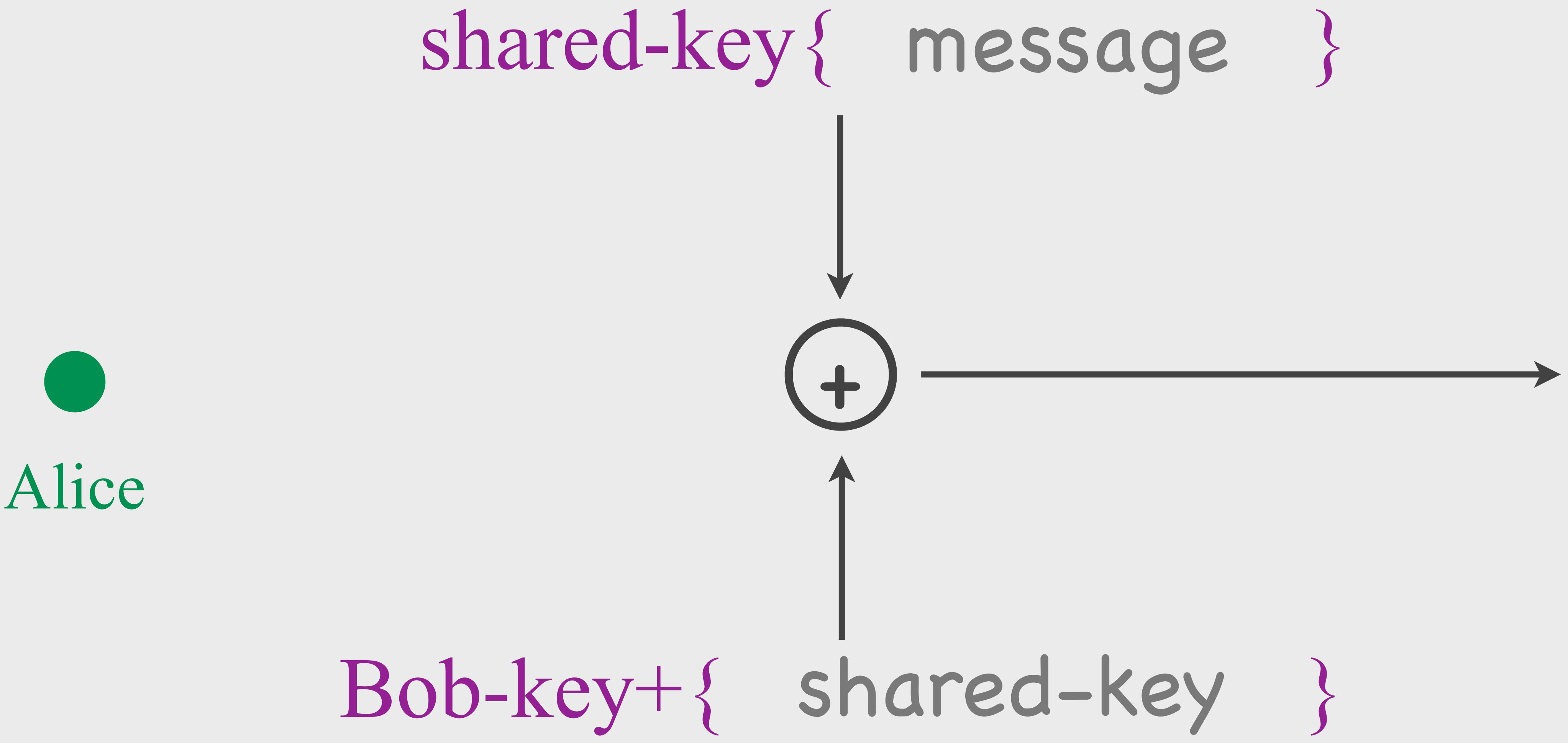
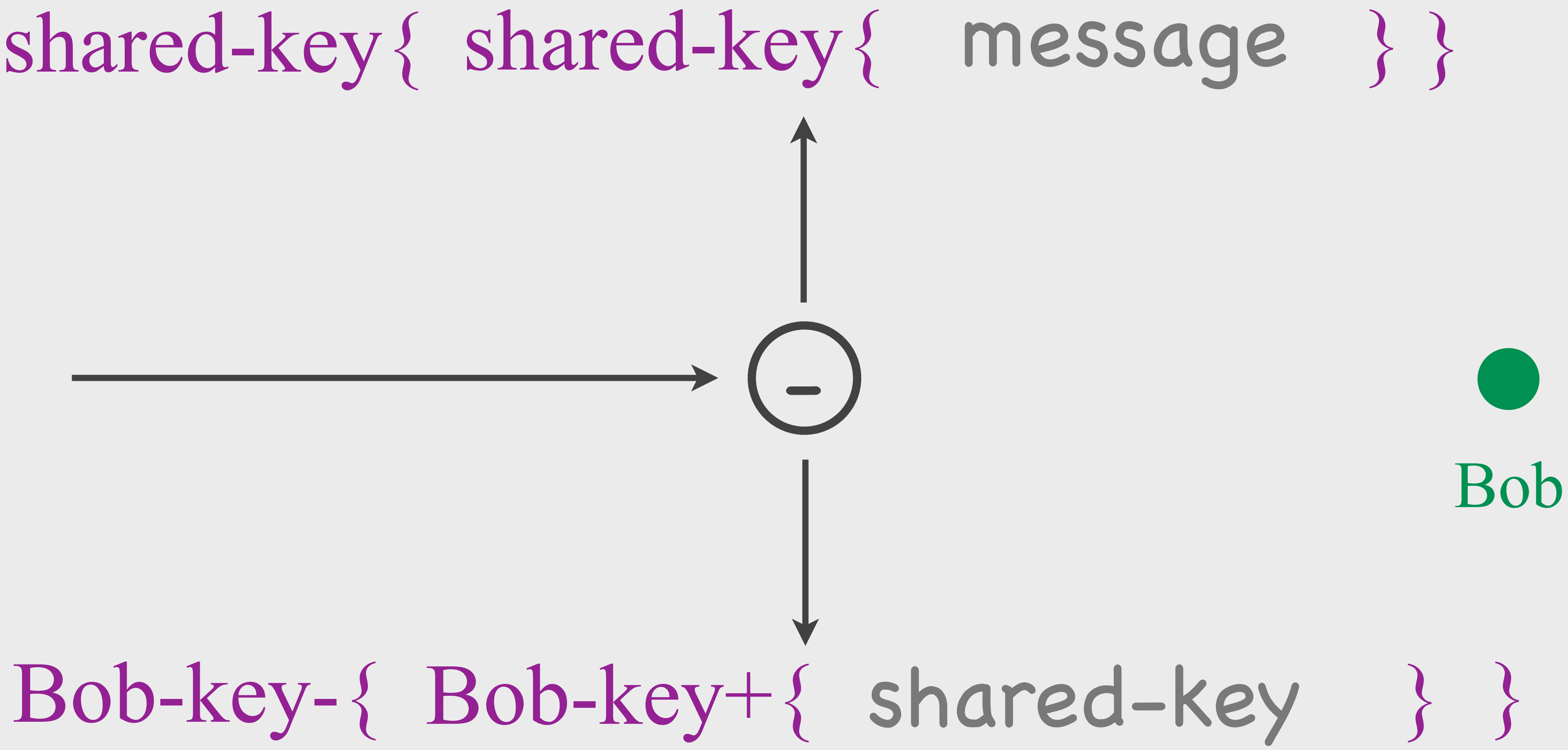


shared-key{ message }

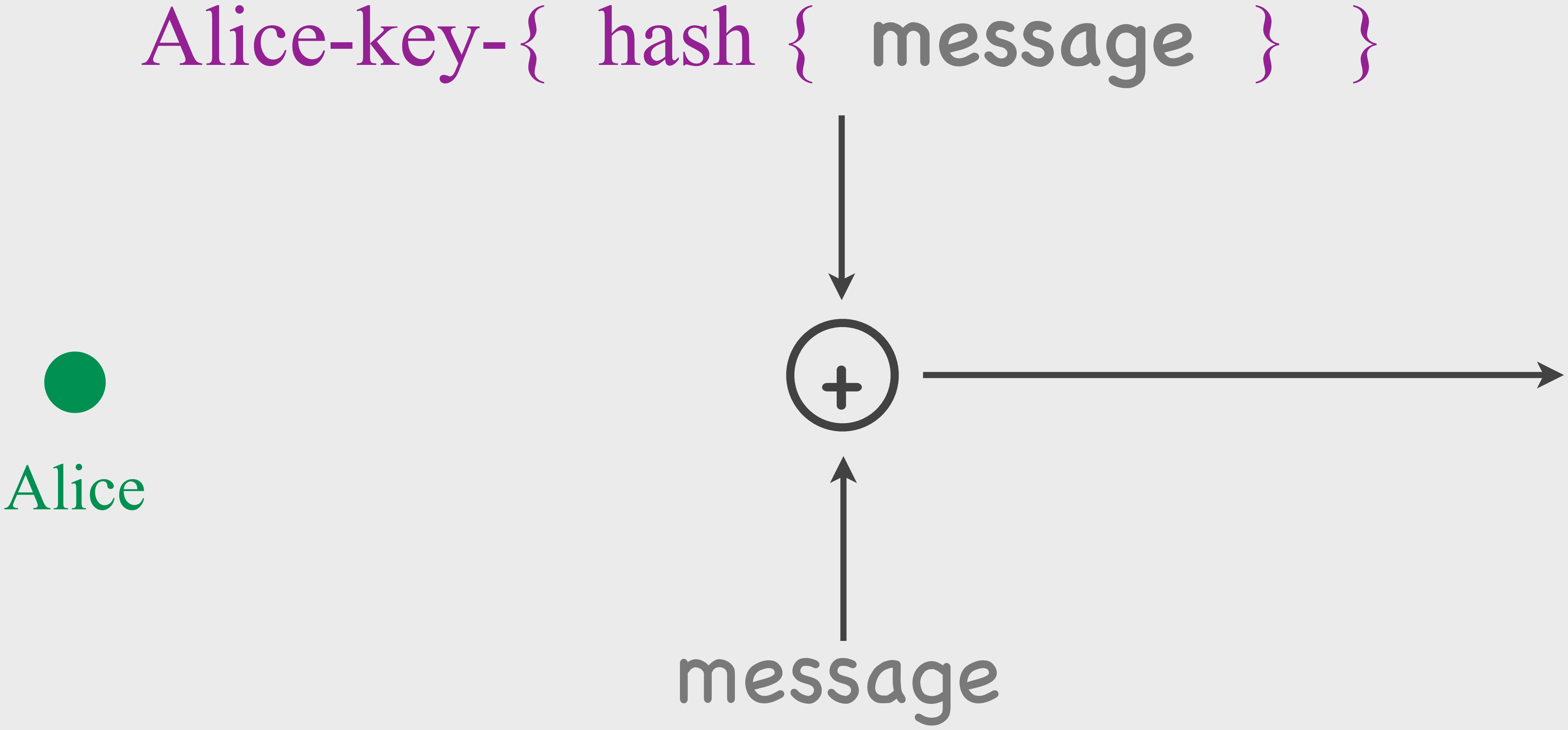
Alice

Bob-key+{ shared-key }



shared-key{ shared-key{ message } }

Bob-key-{ Bob-key+{ shared-key } }

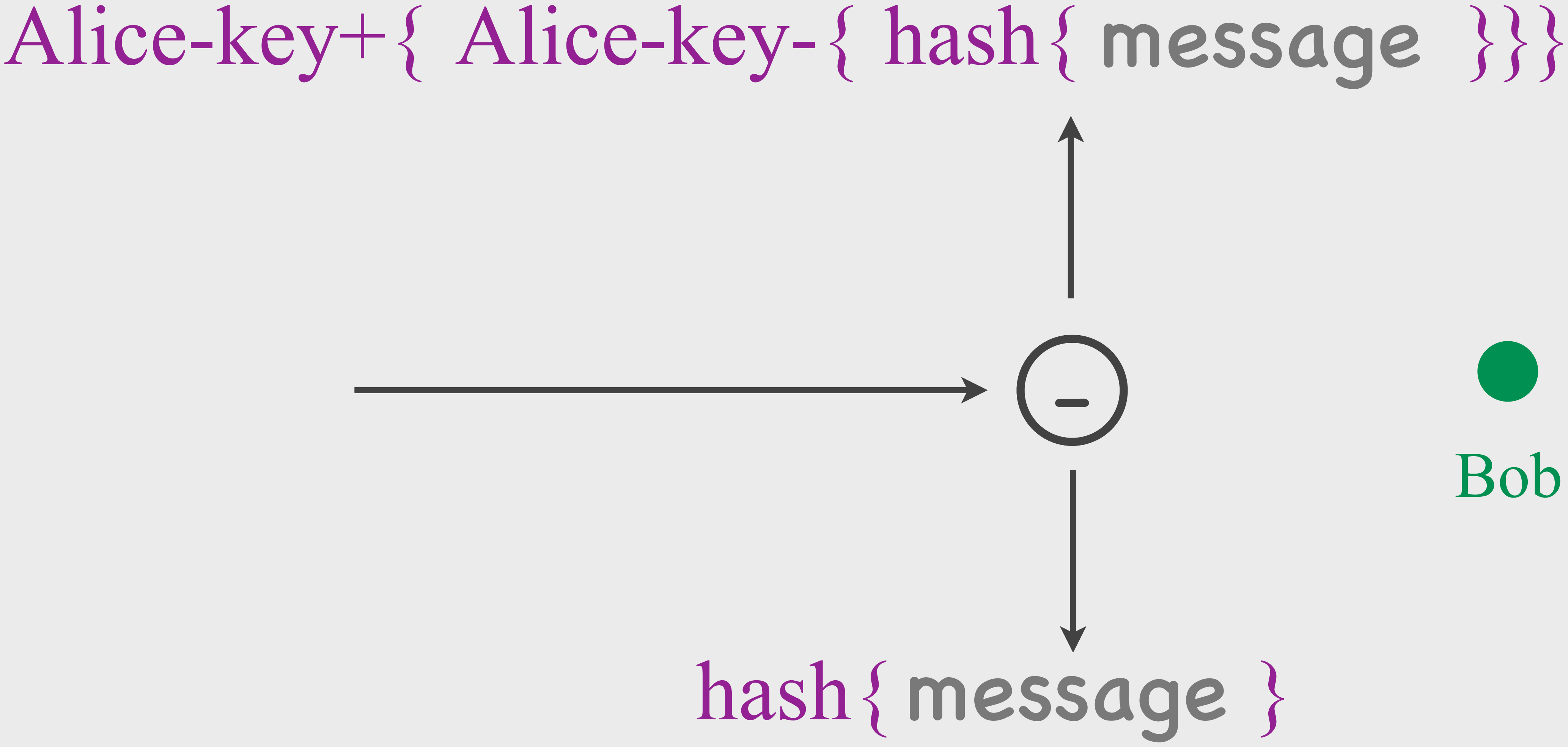


Alice-key-{ hash { message } }

Alice

⊕

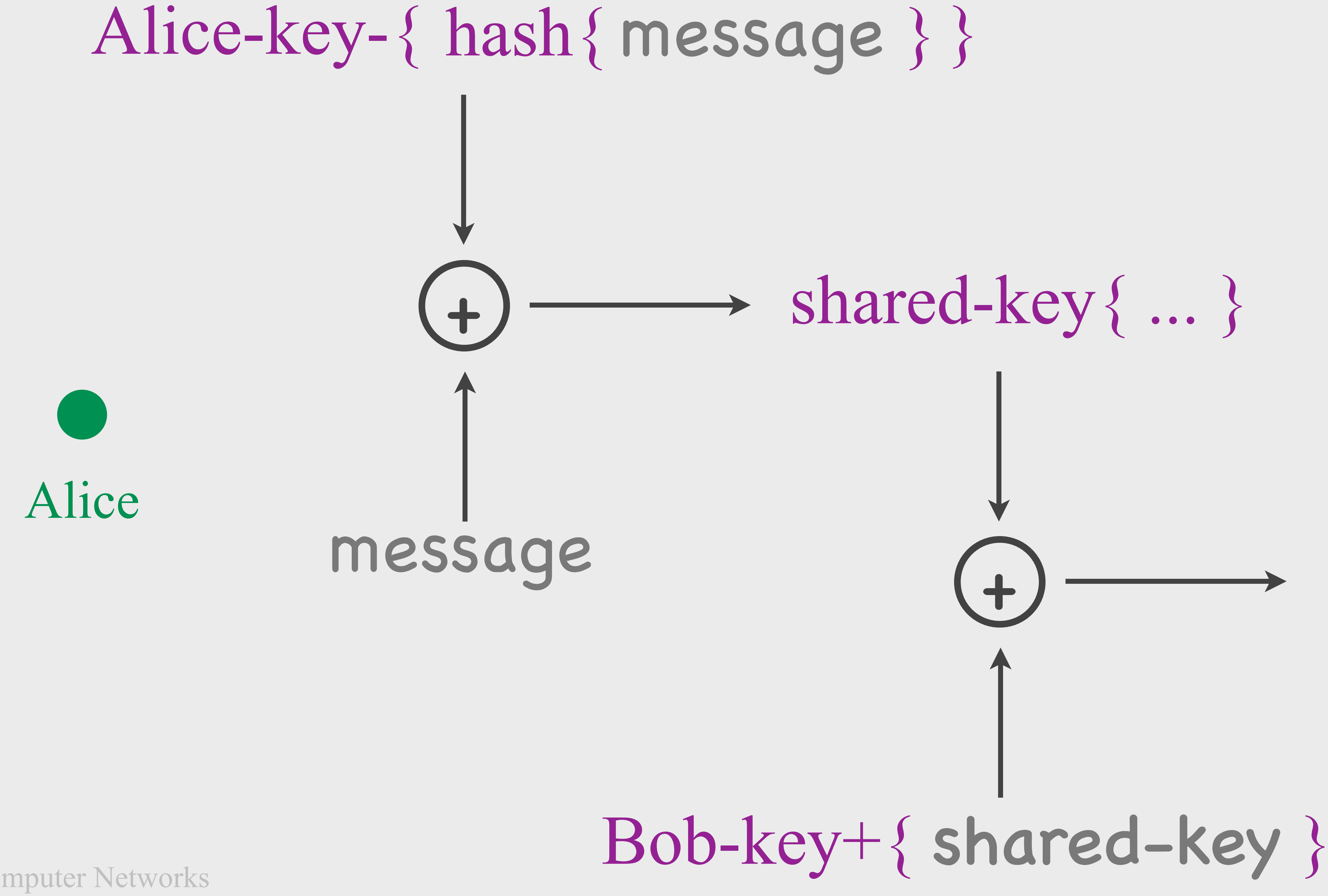
message



Alice-key+{ Alice-key-{ hash{ message }}}

Bob

hash{ message }



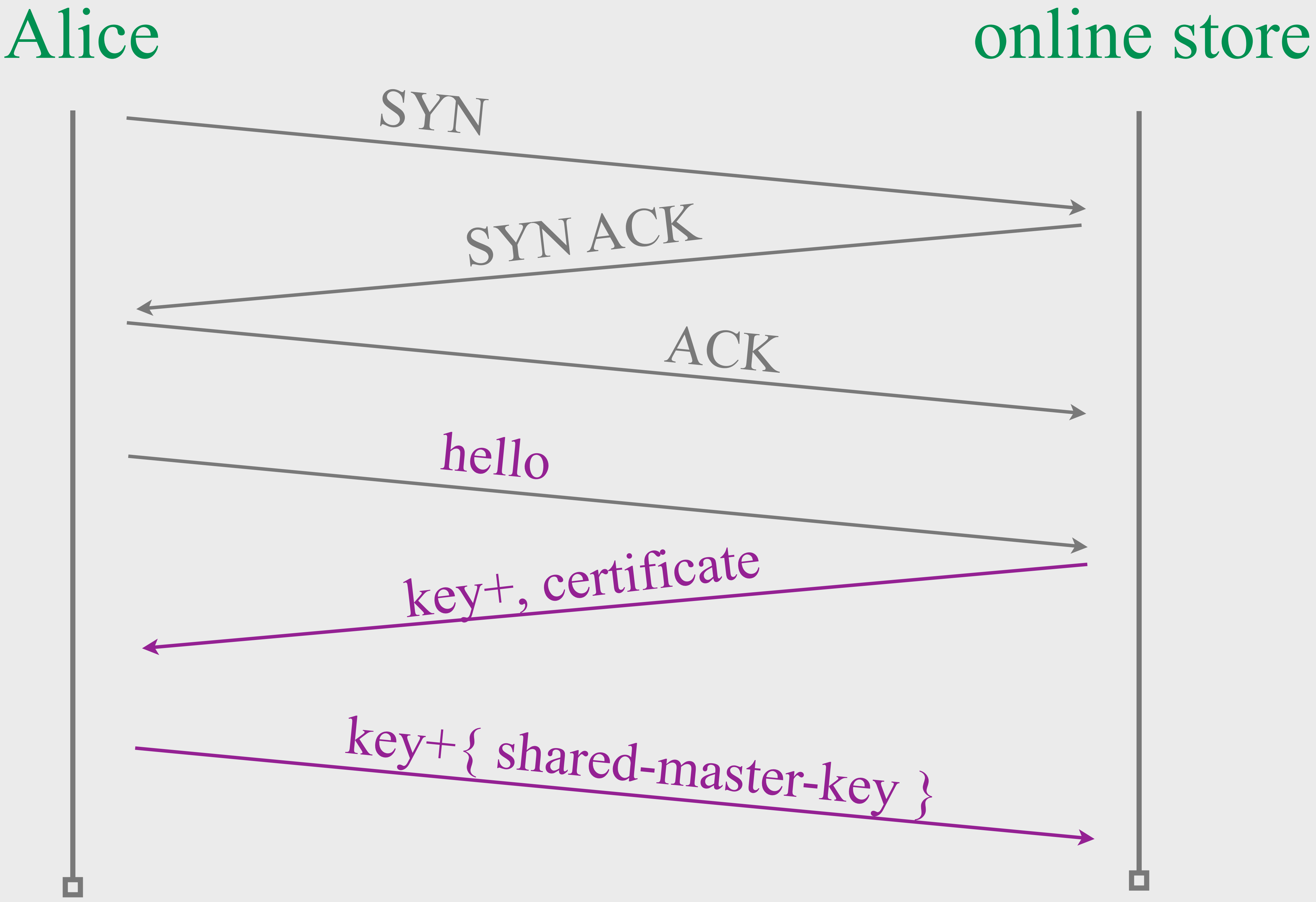
Alice-key-{ hash{ message } }

shared-key{ ... }

Alice

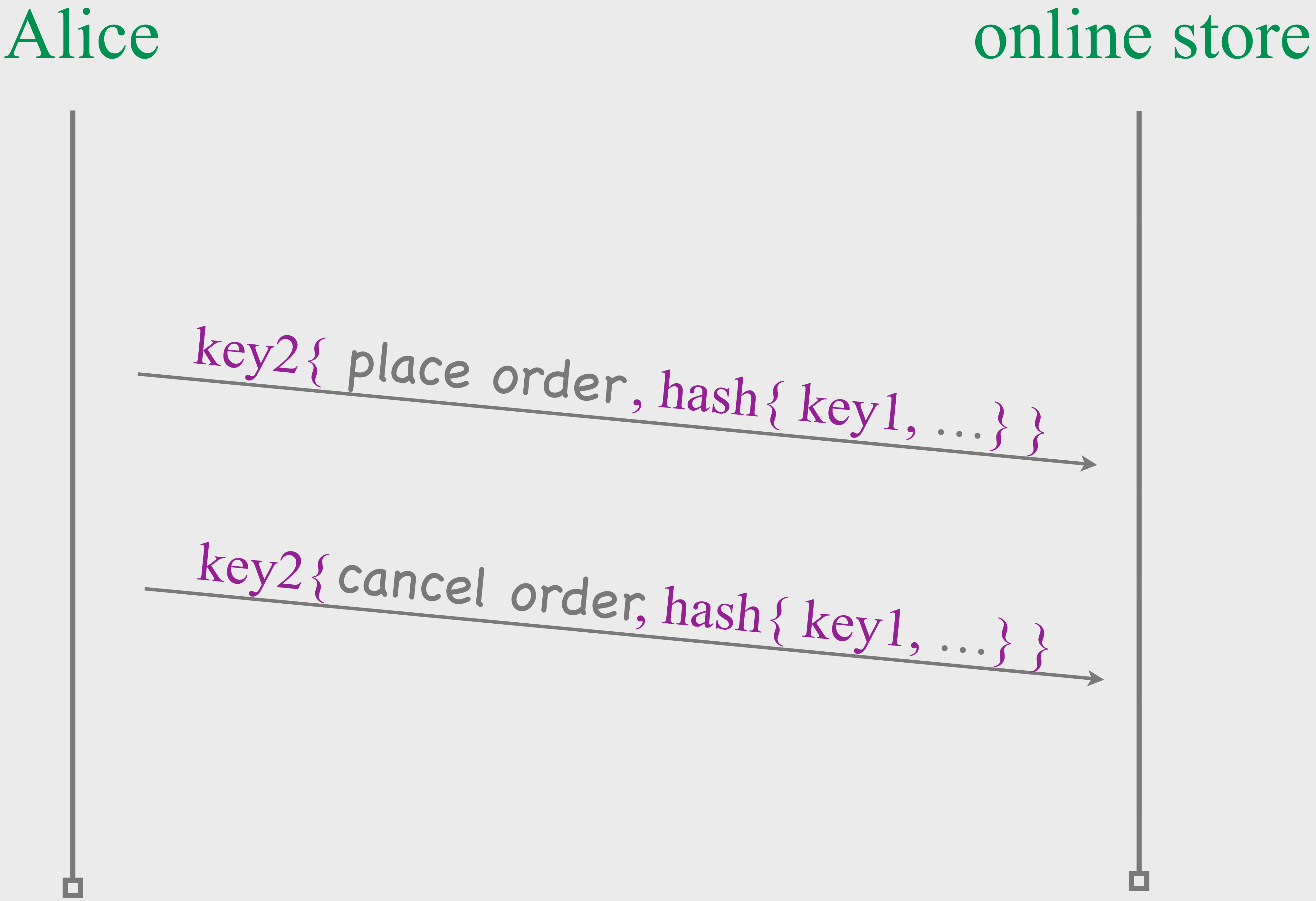
message

Bob-key+{ shared-key }


Alice
online store
SYN
SYN ACK
ACK
hello
key+, certificate
key+{ shared-master-key }

Securing TCP applications

- Server sends its public key & certificate
- Client creates and sends a shared master key
  - encrypts it with server's public key
- Both use master key to create 4 session keys
  - 1 key for encrypting client --> server data
  - 1 key for creating MAC for client --> server data
  - same for server --> client data

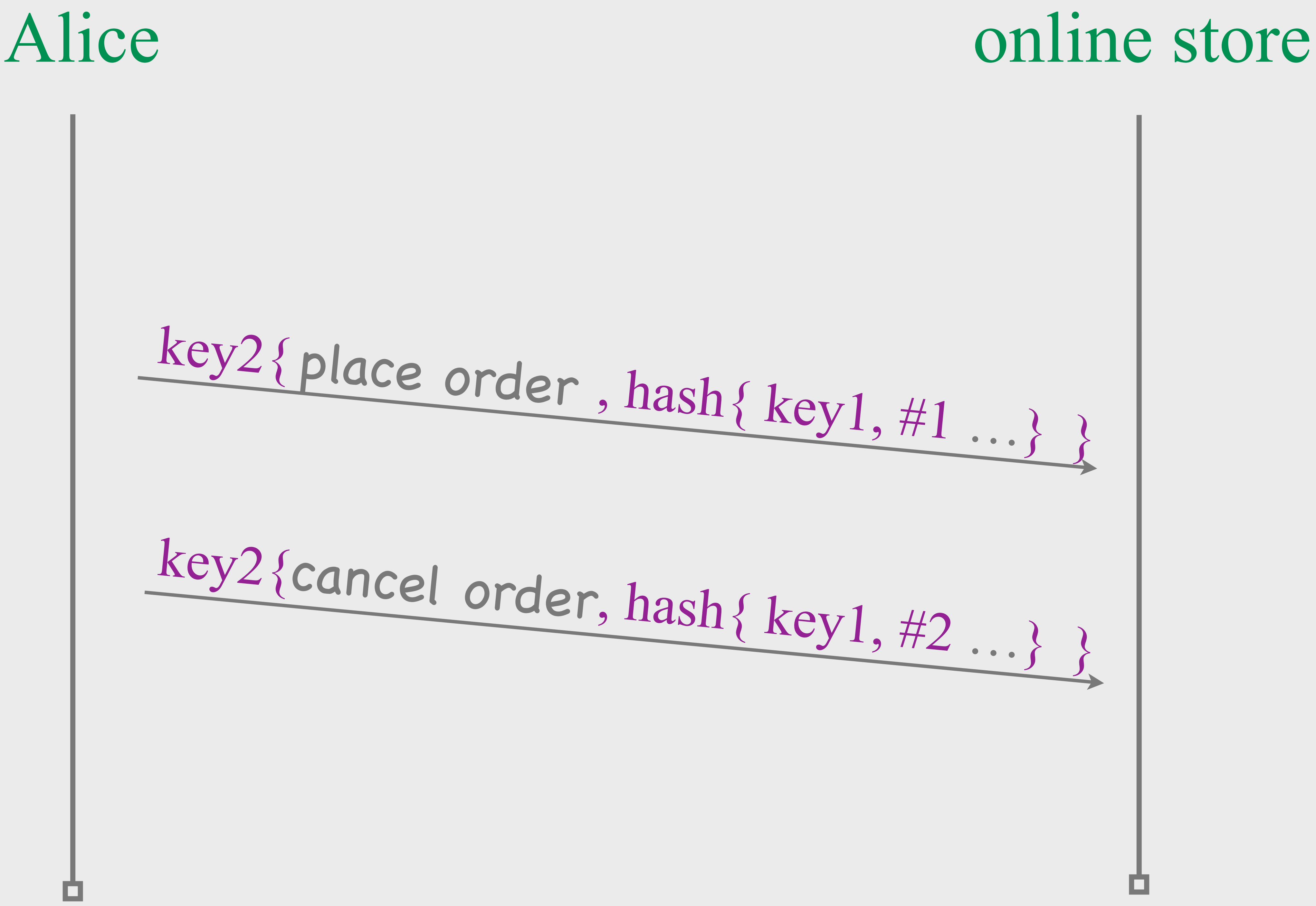


Alice

online store

key2{ place order, hash{ key1, …} }

key2{cancel order, hash{ key1, …} }



Alice

online store

key2{place order , hash{ key1, #1 …} }

key2{cancel order, hash{ key1, #2 …} }

Securing TCP applications

- Client organizes data in records
  - each record has a sequence number
- Creates MAC for each record + sequence #
  - using one of the 4 session keys
- Encrypts the data + MAC for each record
  - using (another) one of the 4 session keys

Key ideas

- Combination of symmetric/asymmetric keys
  - asymmetric key crypto to exchange shared keys
  - symmetric key crypto for confidentiality, authenticity, & integrity
  - symmetric key crypto is faster
- Seq. numbers to avoid reordering attacks
  - organize data in records with seq. numbers
  - compute MAC on record data + seq. number

Outline

- Building blocks
- Providing security properties
- Securing Internet protocols
- Operational security

action	src IP	dst IP	proto	src port	dst port
allow	167.67/16	any	TCP	> 1023	80
allow	any	167.67/16	TCP	80	> 1023
deny	all	all	all	all	all