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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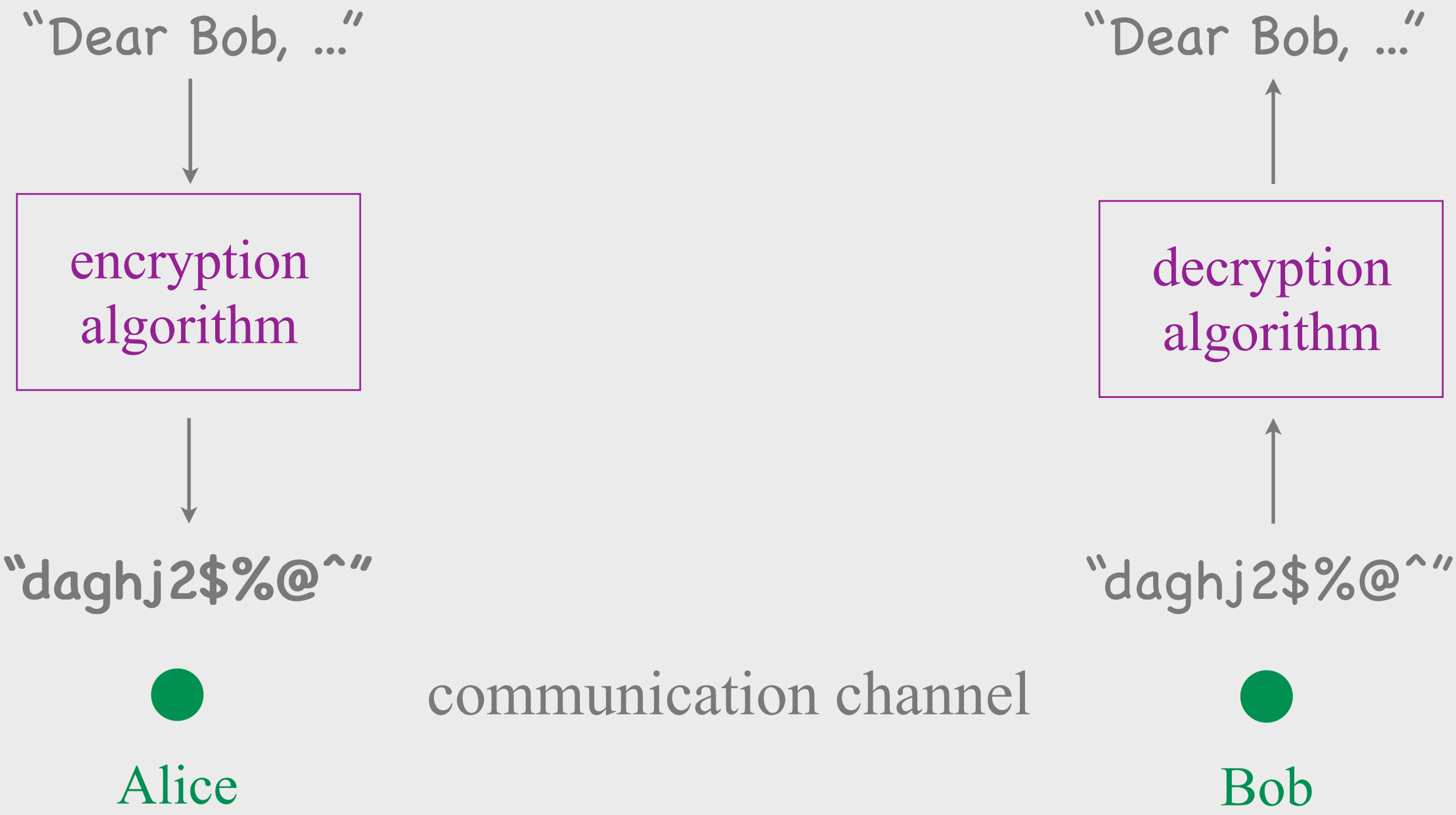
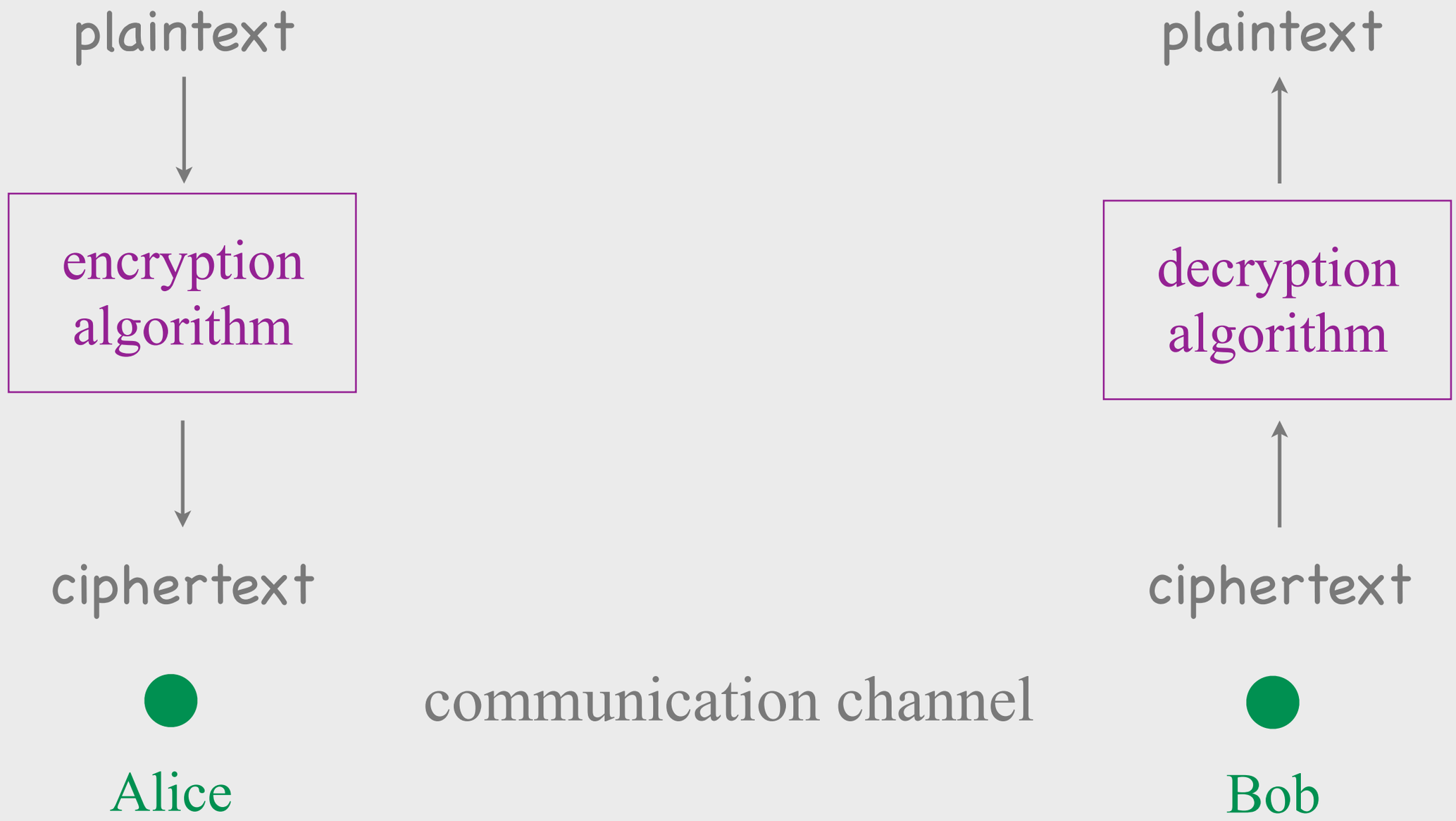
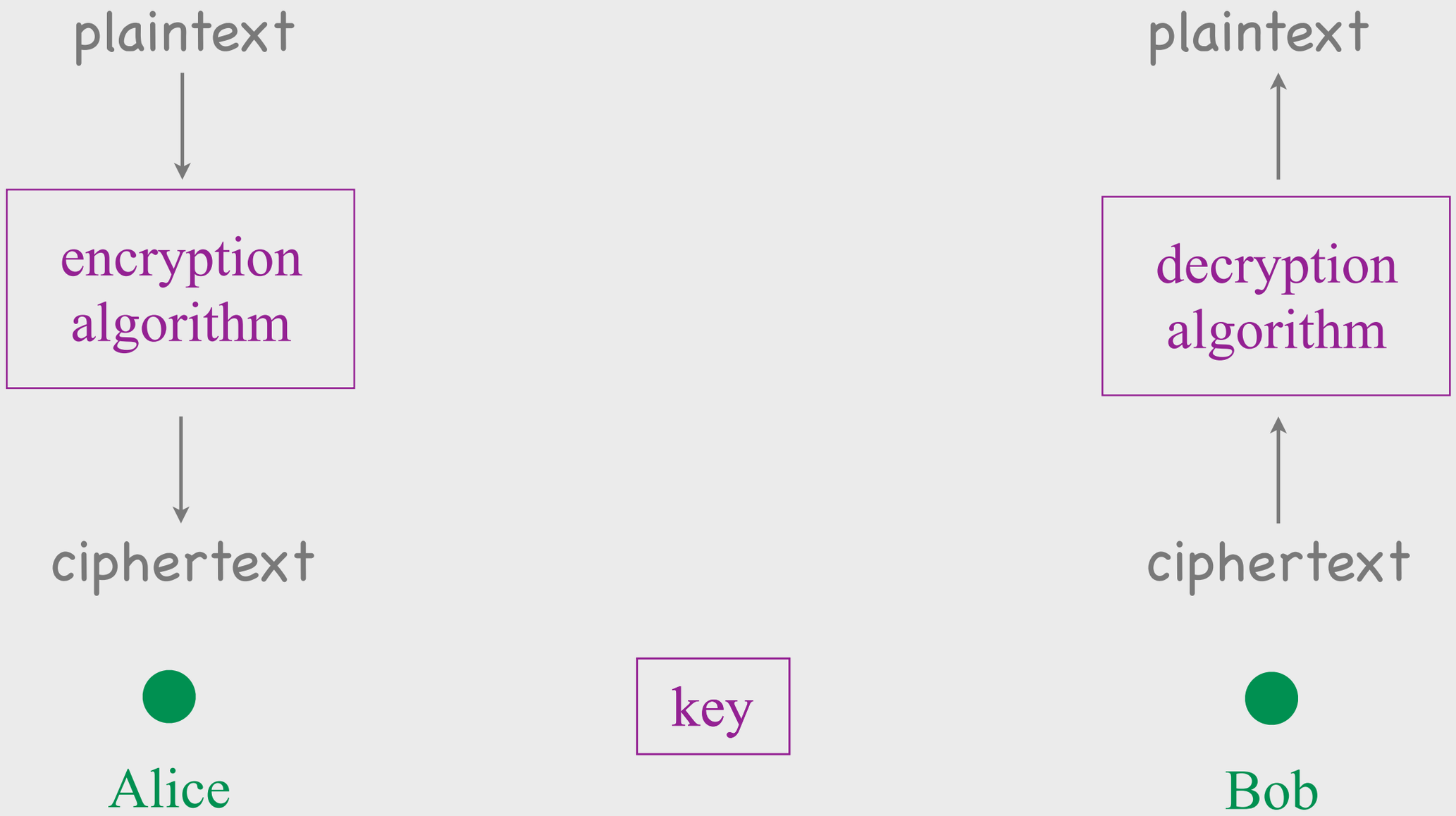
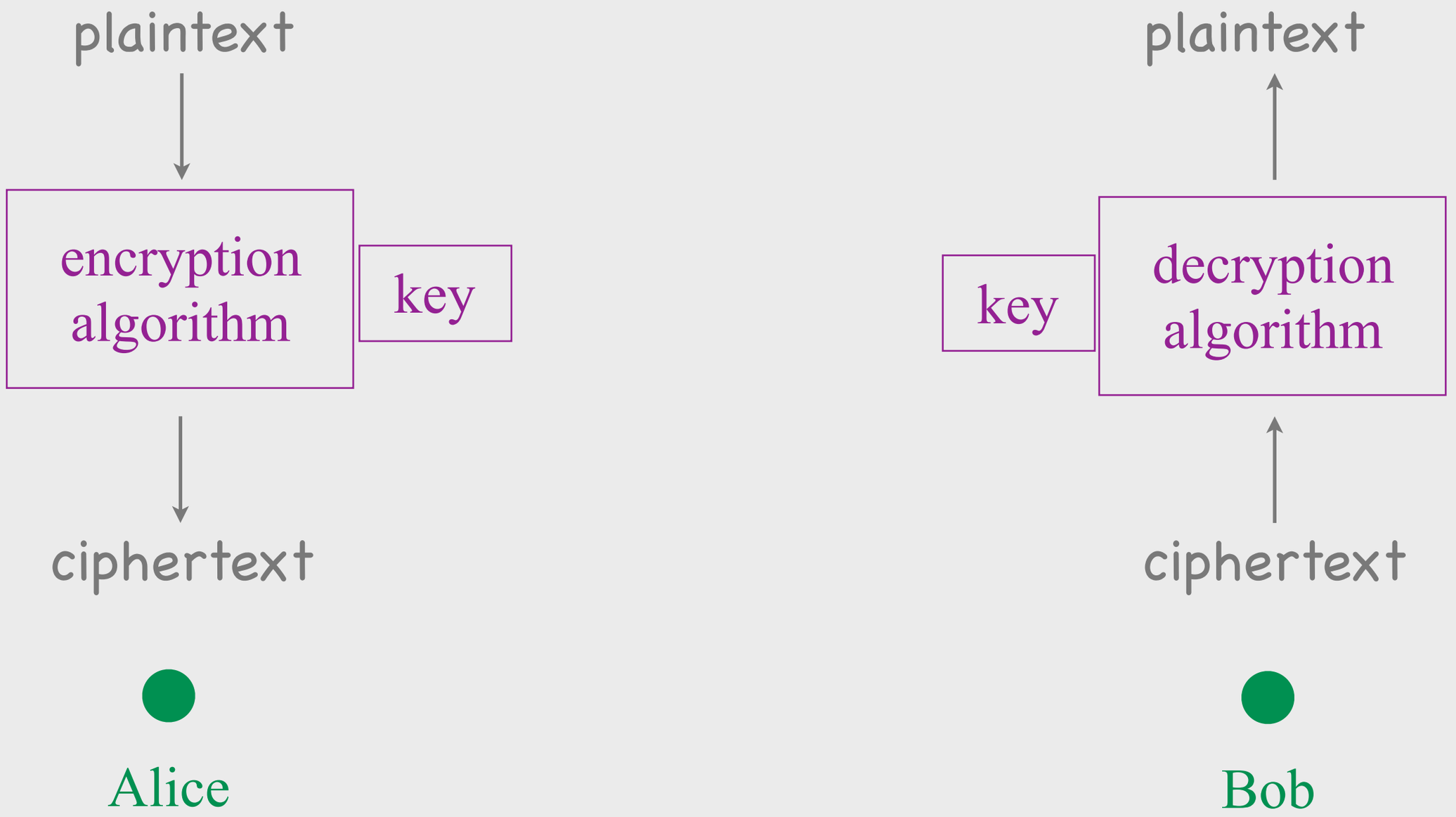

"Dear Bob, ..."
encryption algorithm
"daghj2$%@^"
Alice
communication channel
"Dear Bob, ..."
decryption algorithm
"daghj2$%@^"
Bob


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



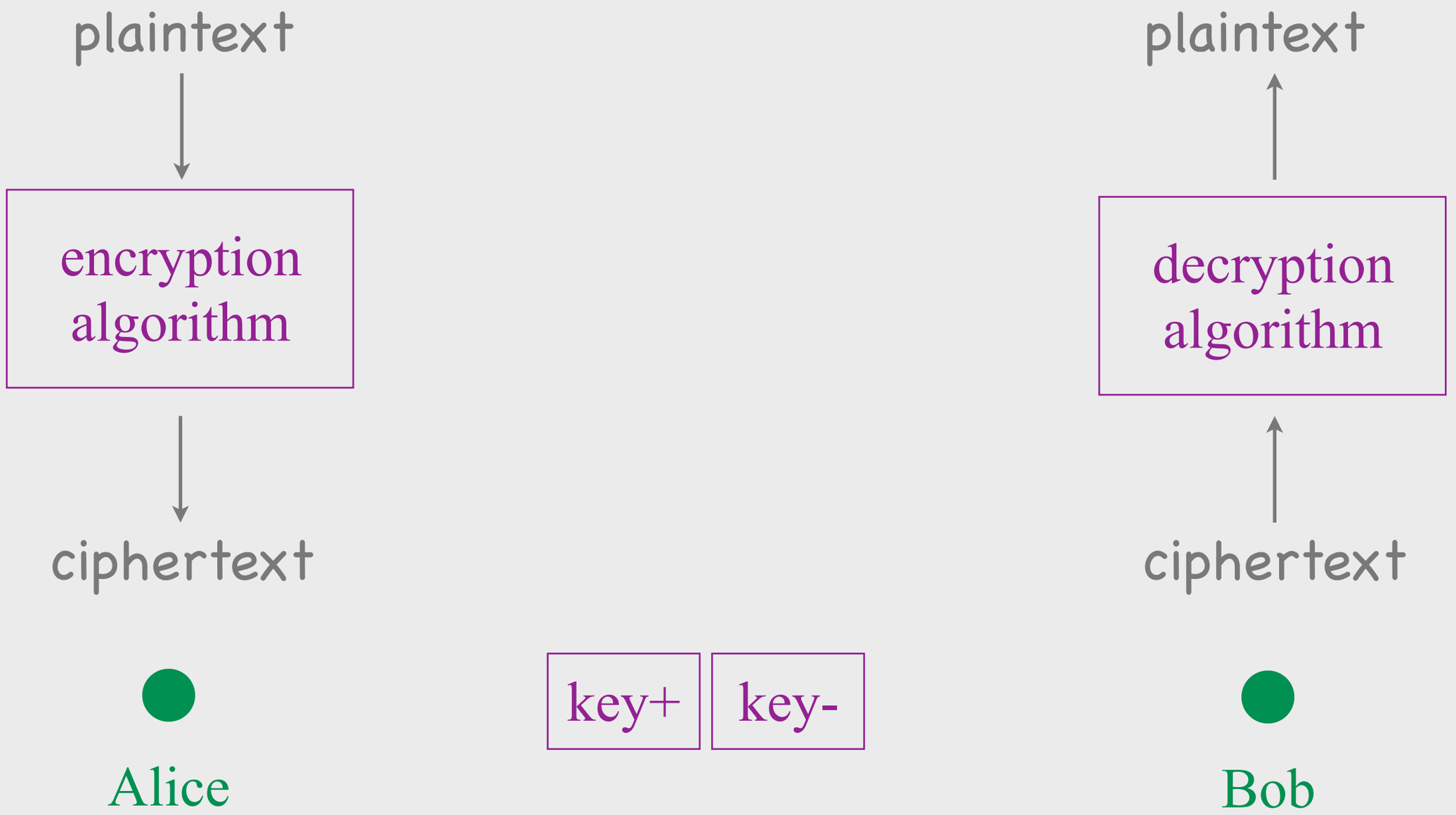
$$key\{\ key\{\ plaintext\ \}\ \} = plaintext$$

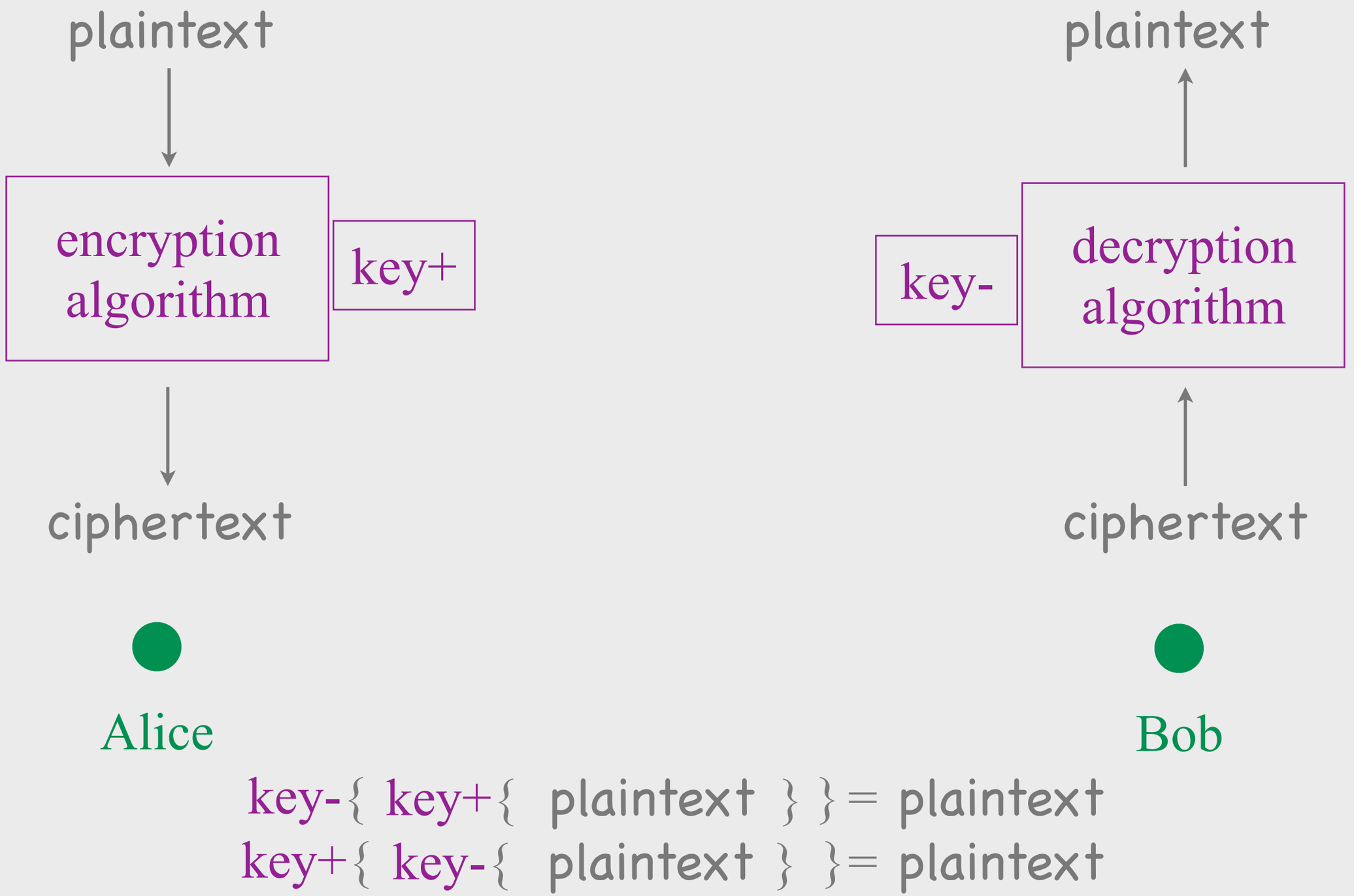
Symmetric key cryptography

- 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
plaintext
decryption algorithm
ciphertext
key+
key-
Alice
Bob



key-{ key+{ plaintext } } = plaintext

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 secret sharing
- Asymmetric: no out-of-band secret sharing but slower

Dear Bob,

.....

.....

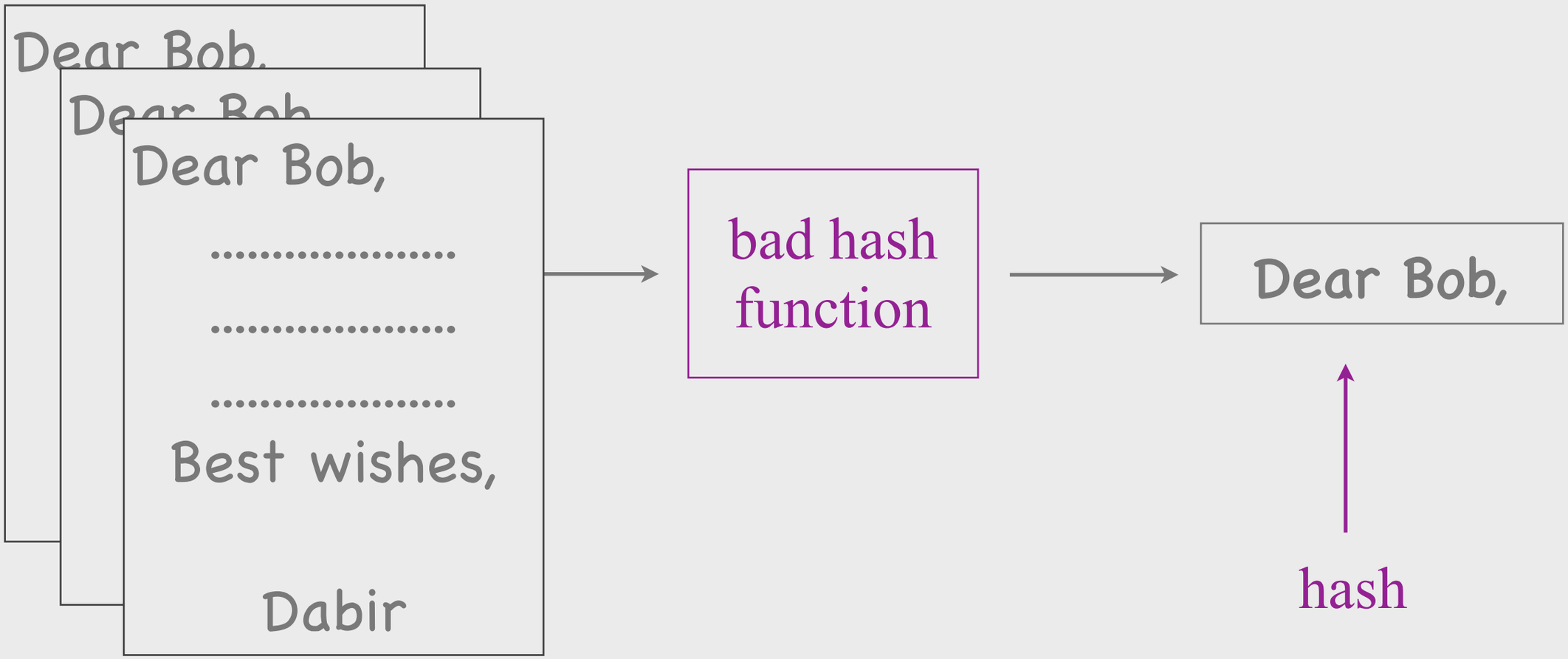
Cheers,

Alice

hash function

tru46hj#$%

hash


Dear Bob,
Dear Bob,
Dear Bob,
.....
.....
.....
Best wishes,
Dabir
bad 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

- Building blocks
- Providing security properties
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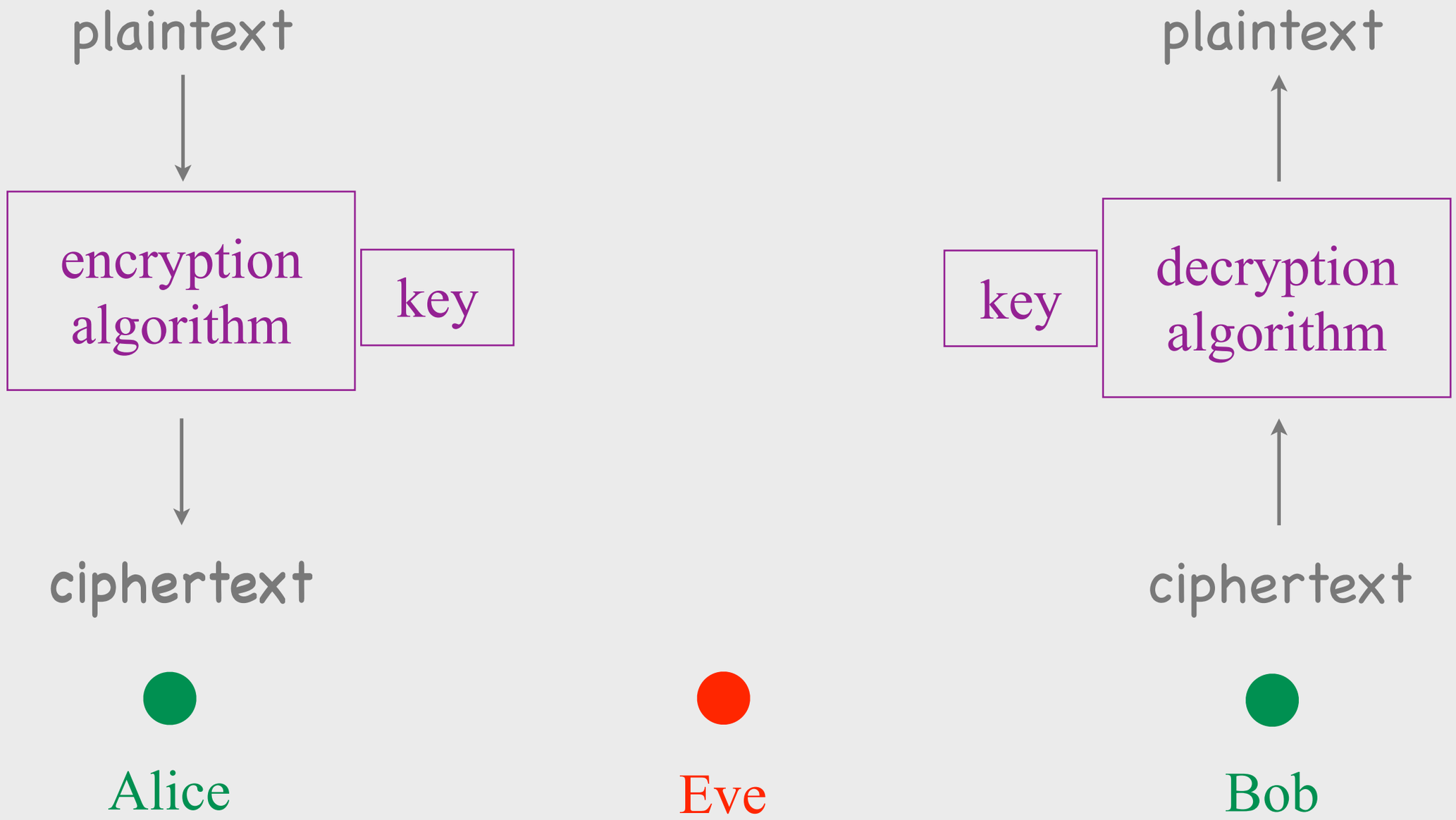
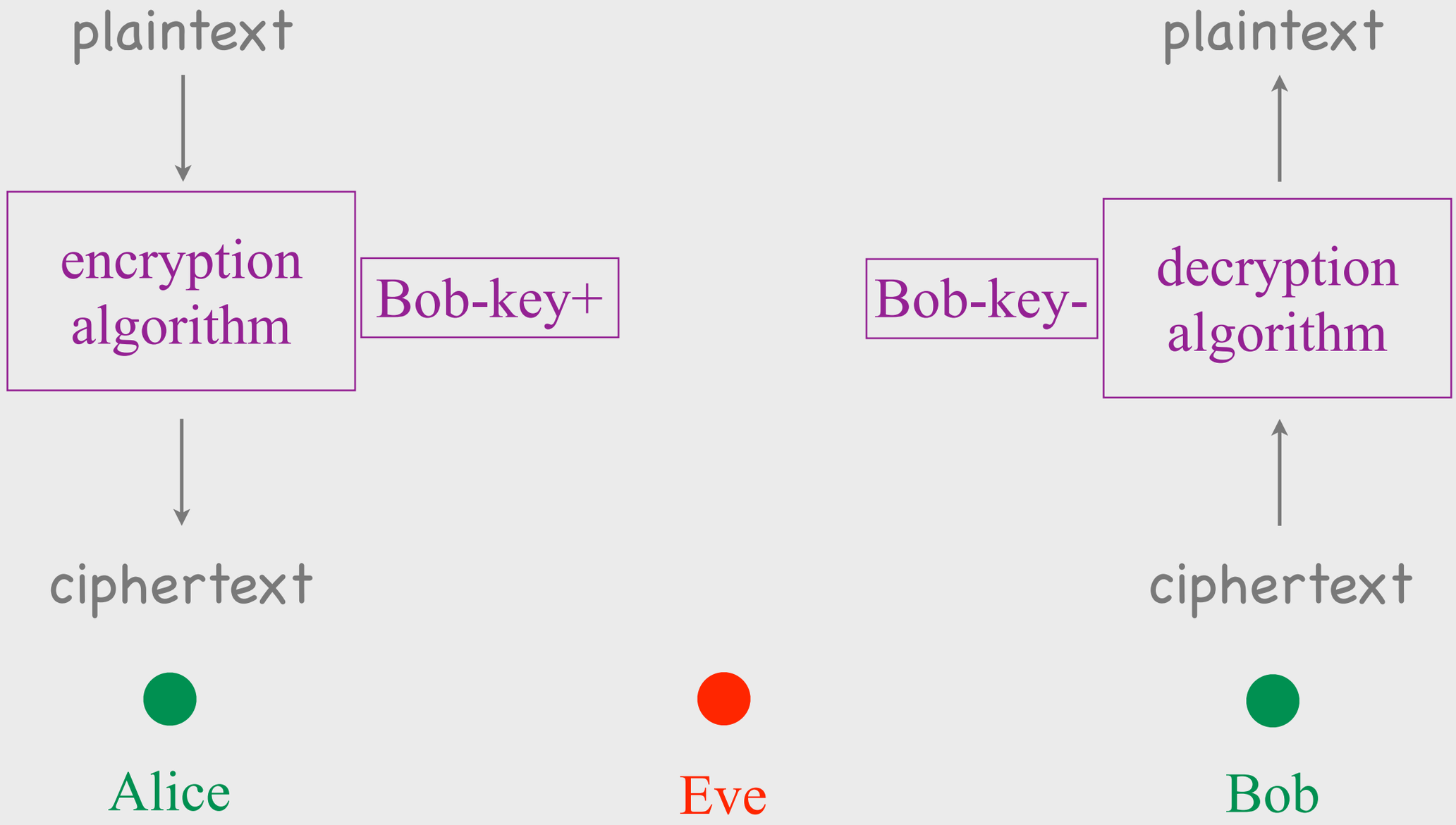
Providing confidentiality


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


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

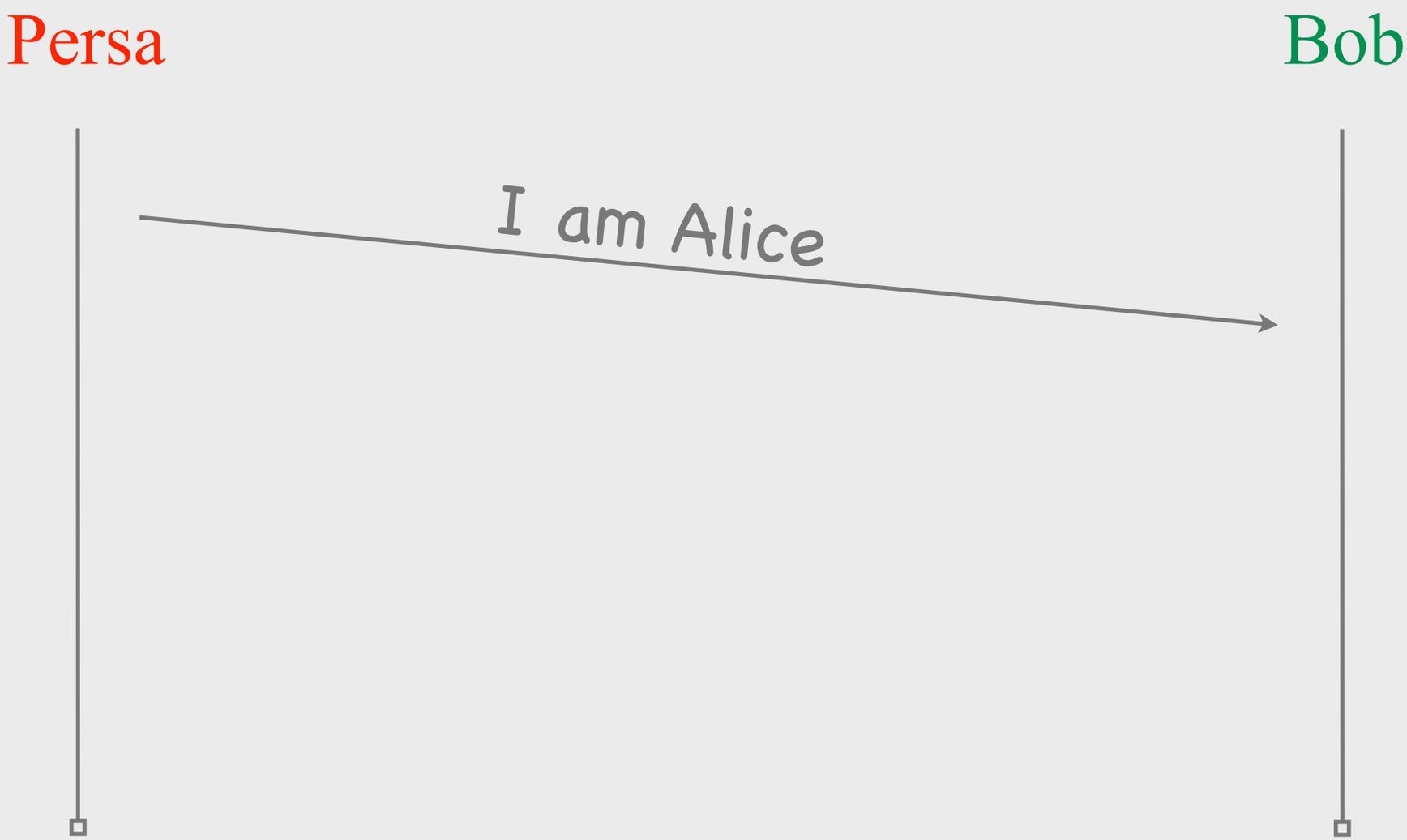
Providing confidentiality

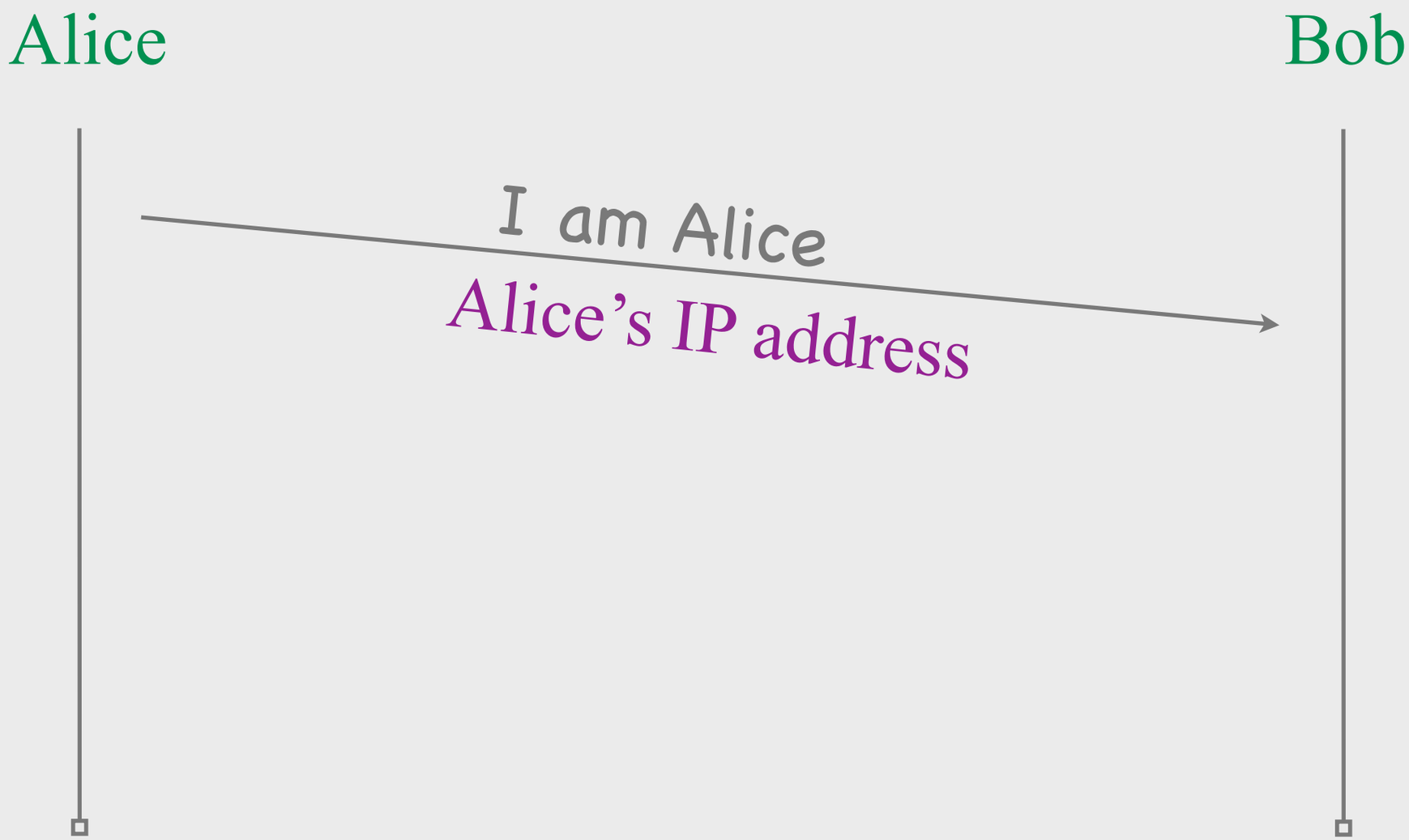
- With symmetric key crypto
  - Alice encrypts message with shared key
  - only Bob can decrypt it (with shared key)

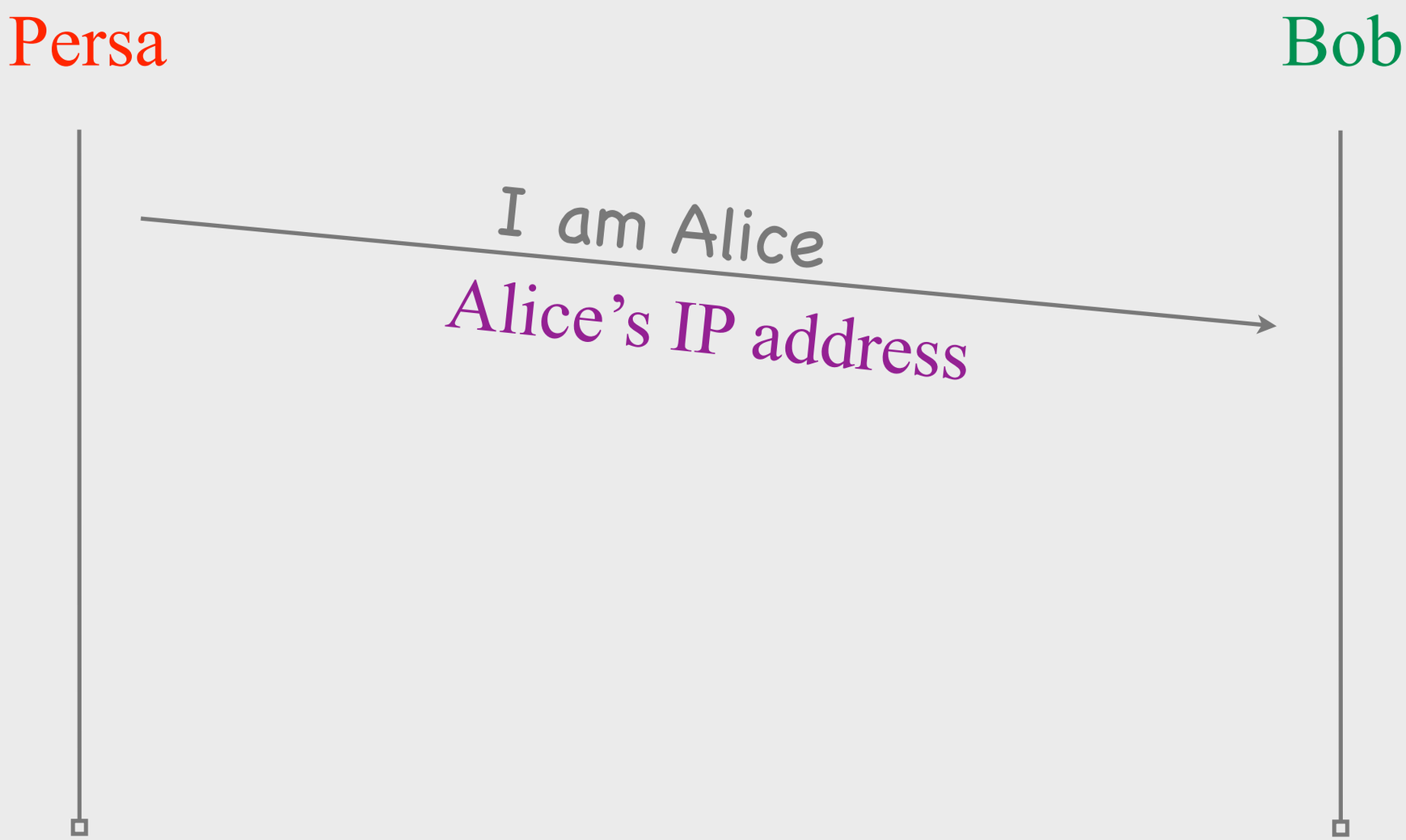
- With asymmetric key crypto
  - Alice encrypts message with Bob's public key
  - only Bob can decrypt it (with his private key)

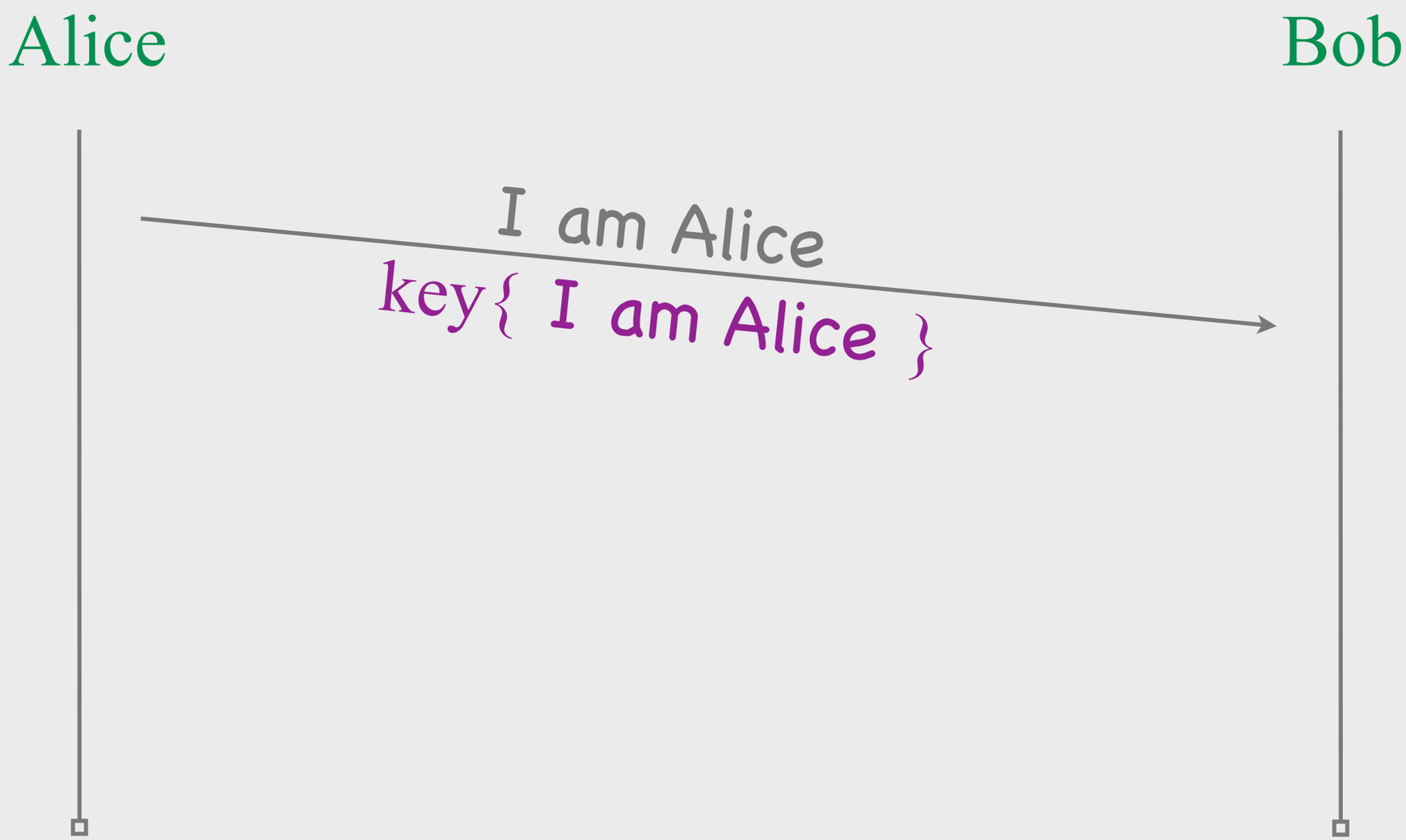
Providing authenticity


Alice
Bob
I am Alice

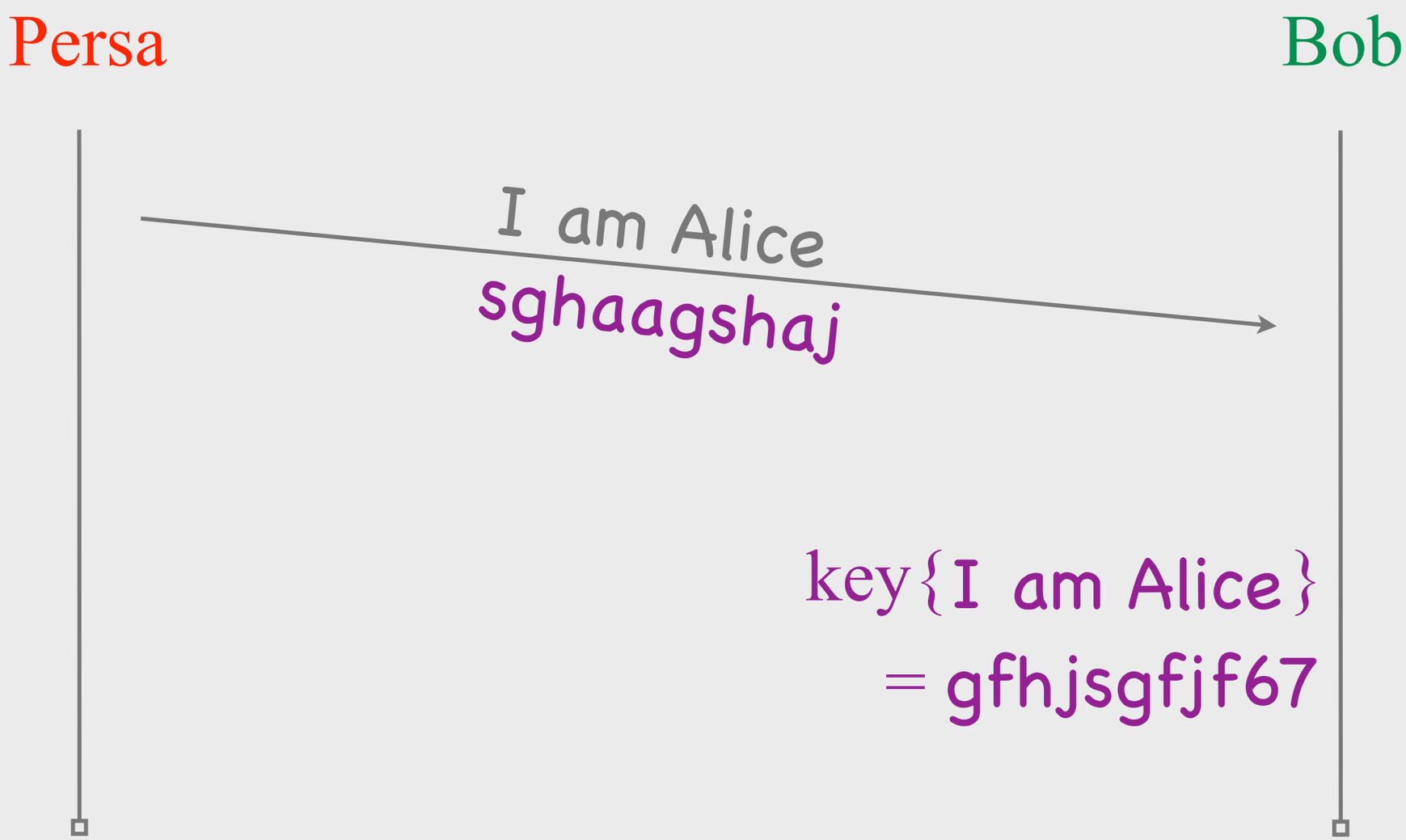

Persa
Bob
I am Alice

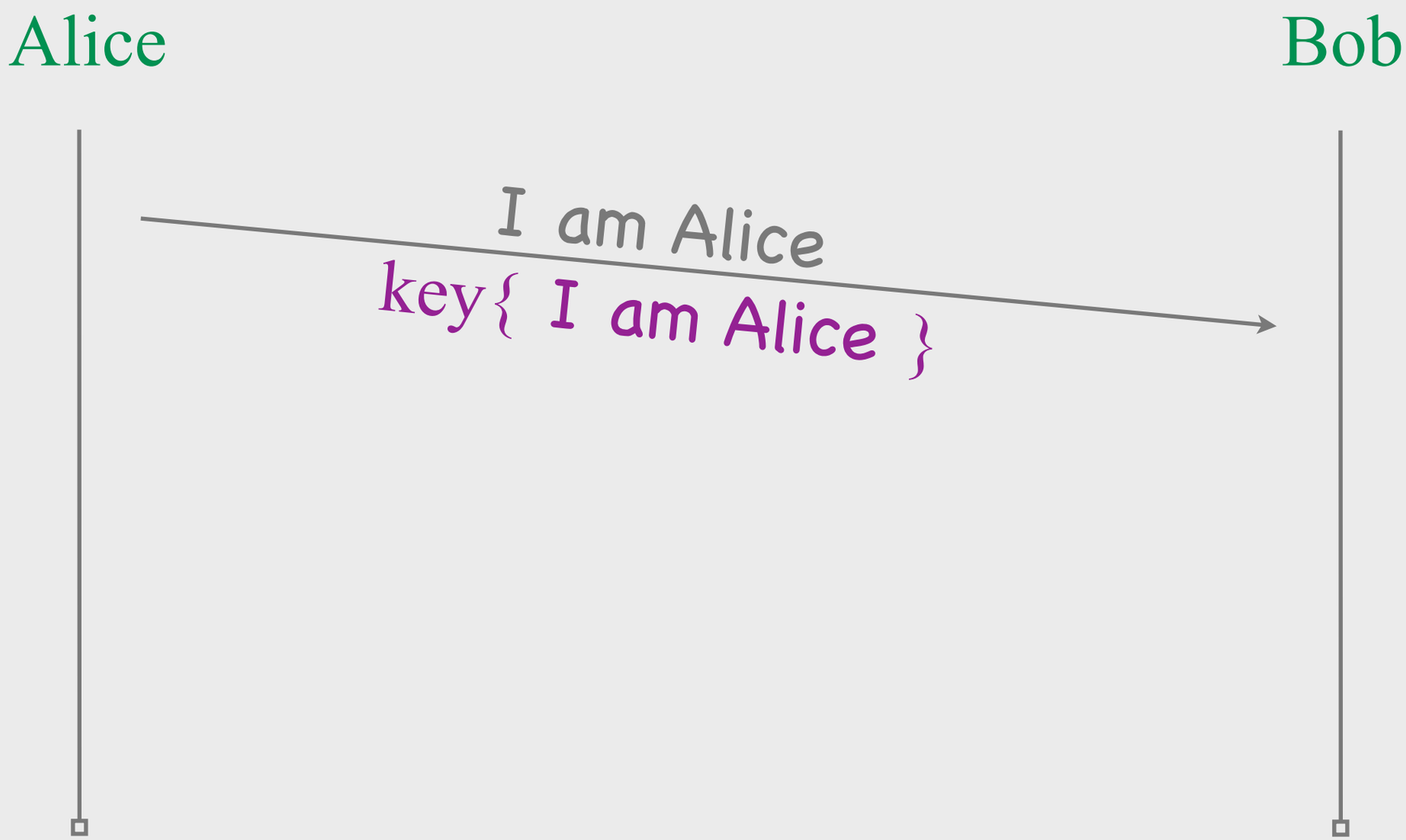

Alice
Bob
I am Alice
Alice's IP address

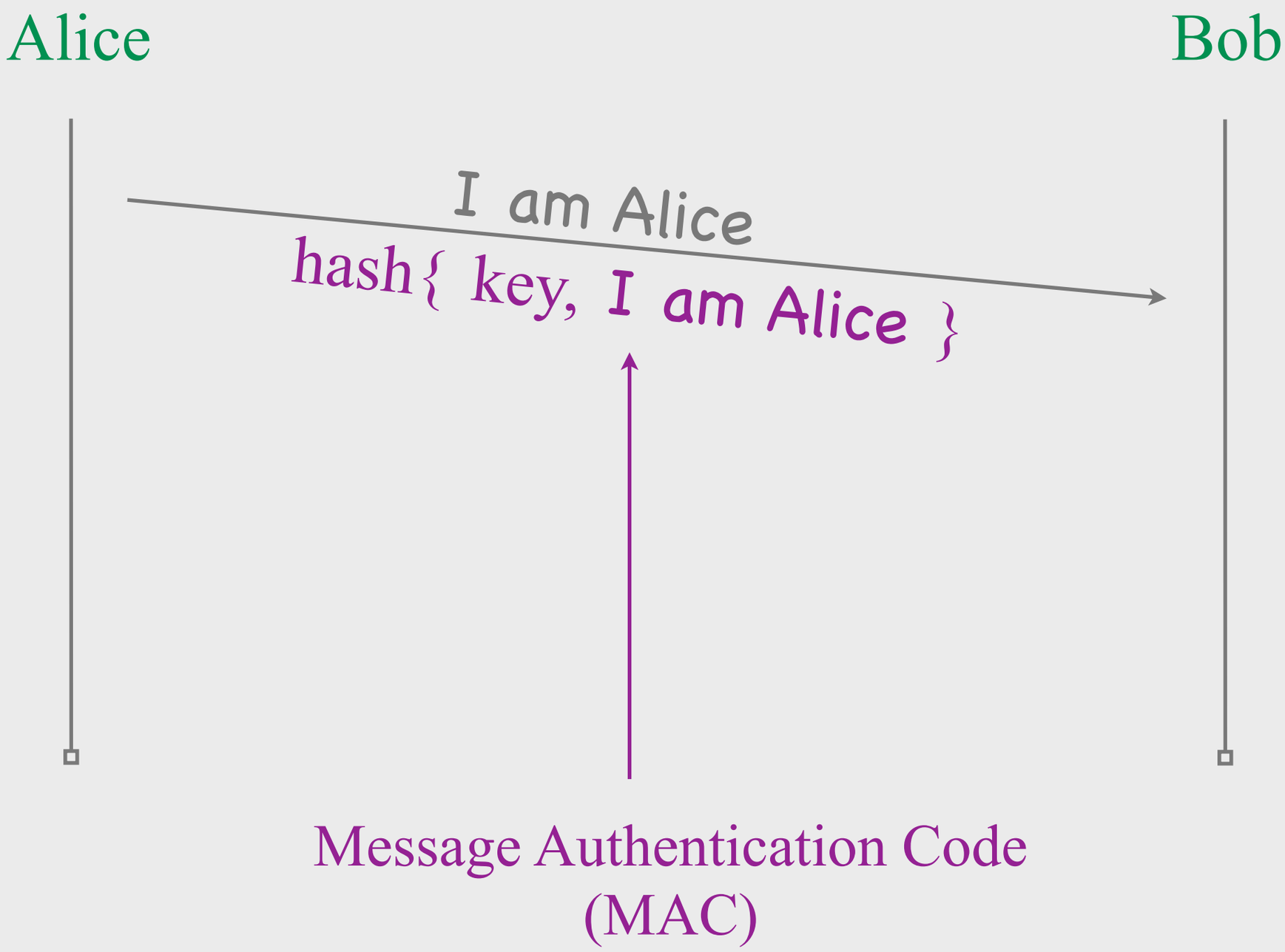

Persa
Bob
I am Alice
Alice's IP address

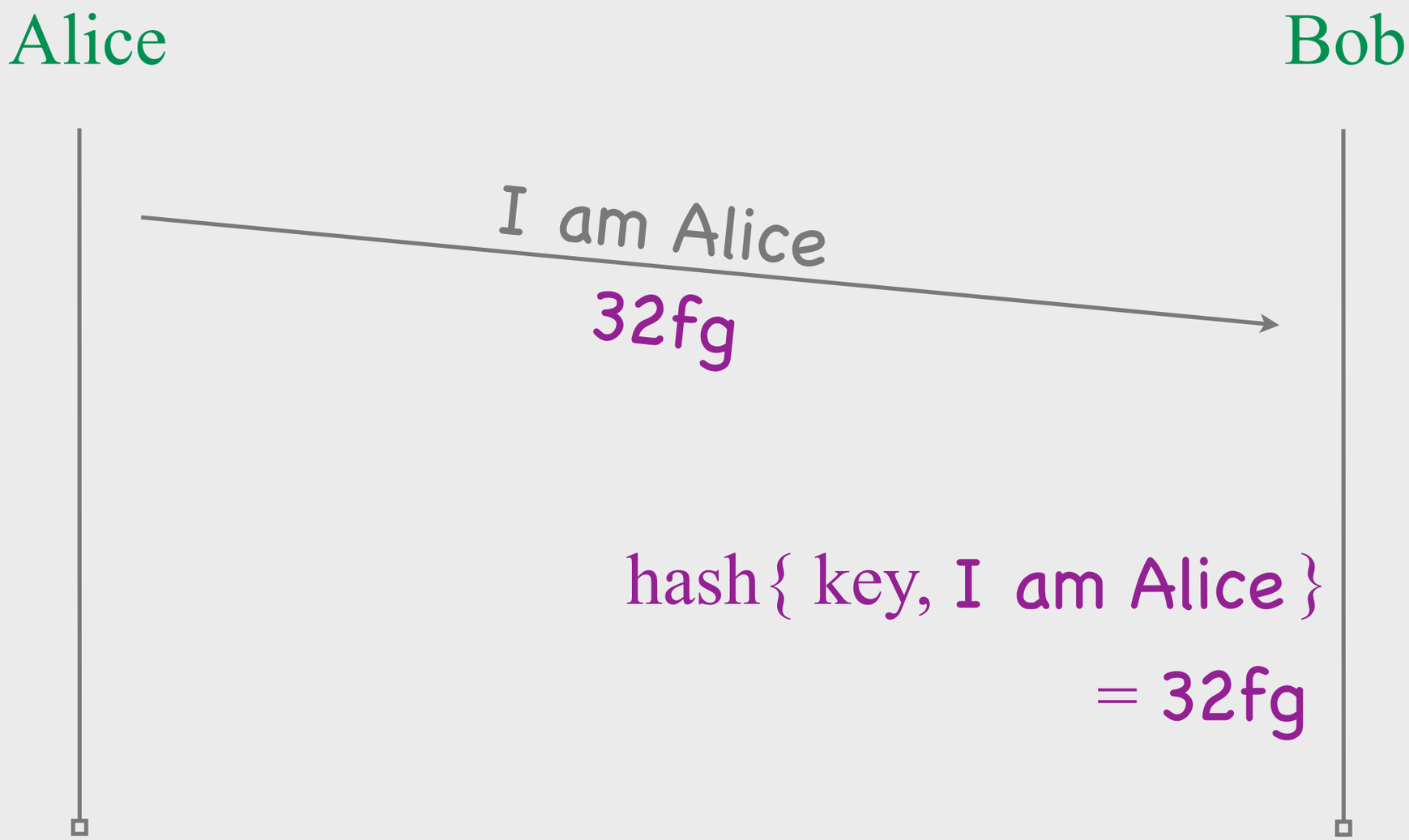

Alice
Bob
I am Alice
key{ I am Alice }


Alice
Bob
I am Alice
gfhjsgfjf67
key{I am Alice}
= gfhjsgfjf67


Persa
Bob
I am Alice
sghaagshaj
key{I am Alice}
= gfhjsgfjf67

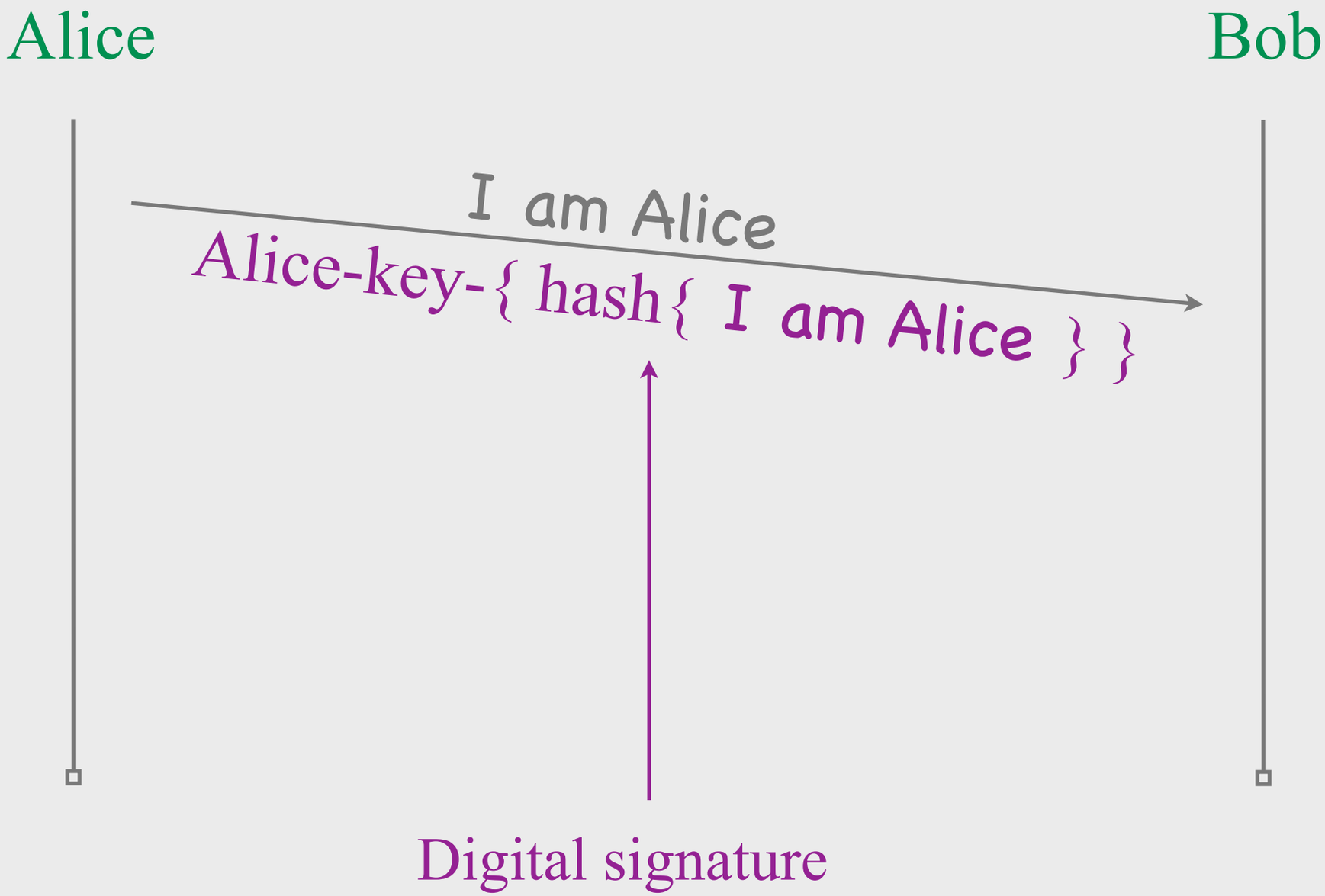

Alice
Bob
I am Alice
key{ I am Alice }

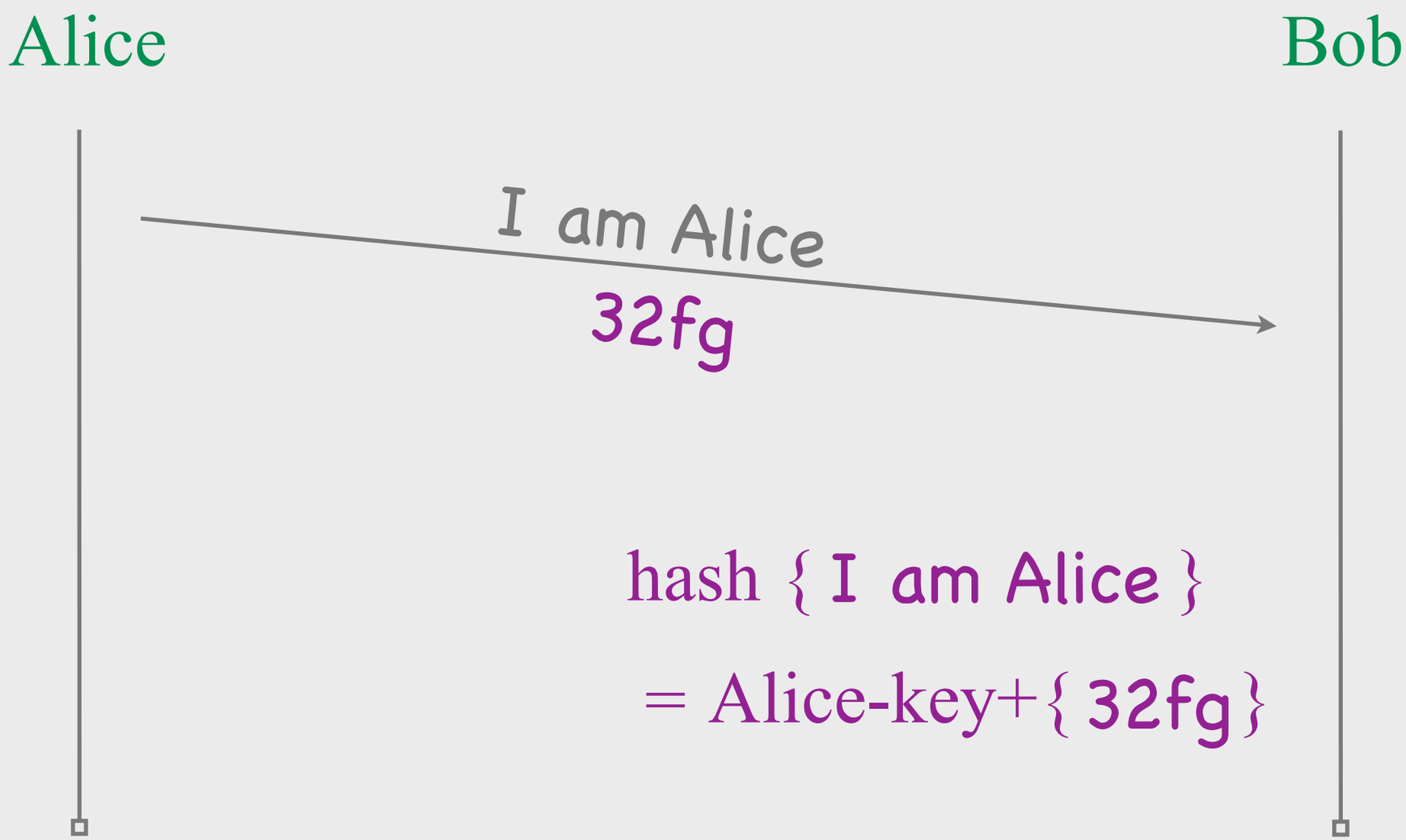

Alice
Bob
I am Alice
hash{ key, I am Alice }
Message Authentication Code
(MAC)


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

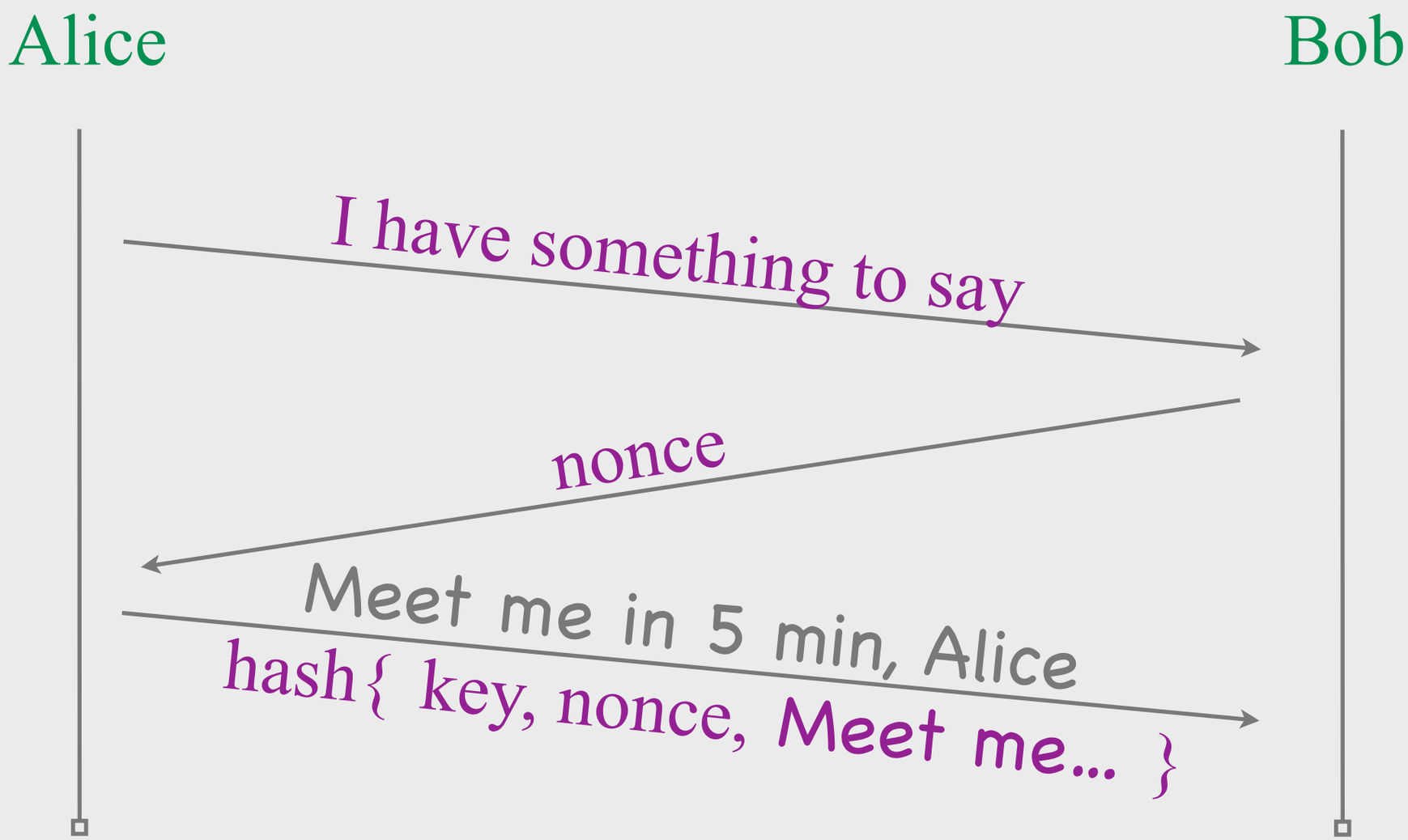

Alice
Bob
I am Alice
Alice-key-{ hash{ I am Alice } }
Digital signature


Alice
Bob
I am Alice
32fg
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

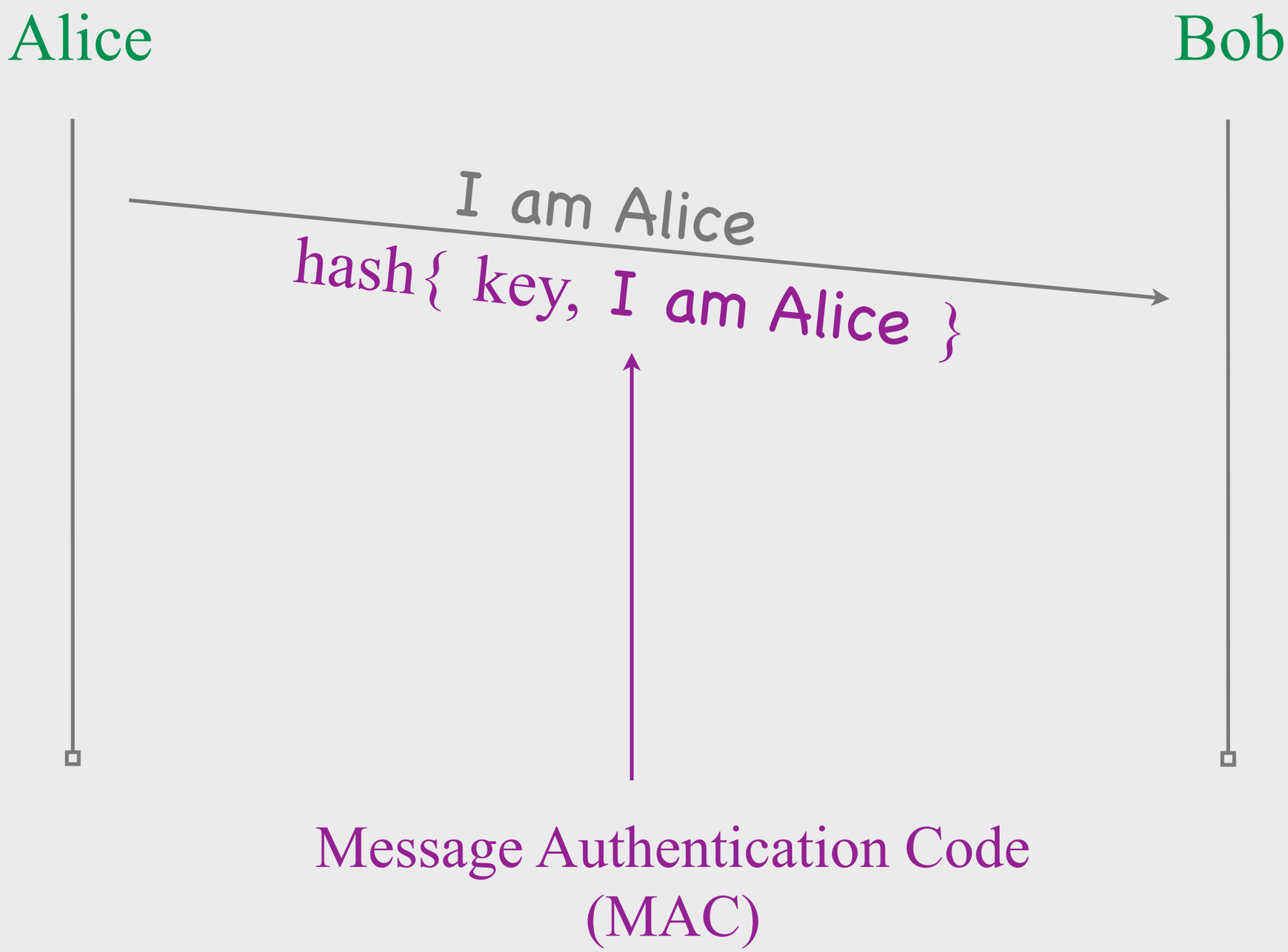
- With symmetric key crypto
  - Alice appends MAC
  - Bob checks that it is correct (using shared key)

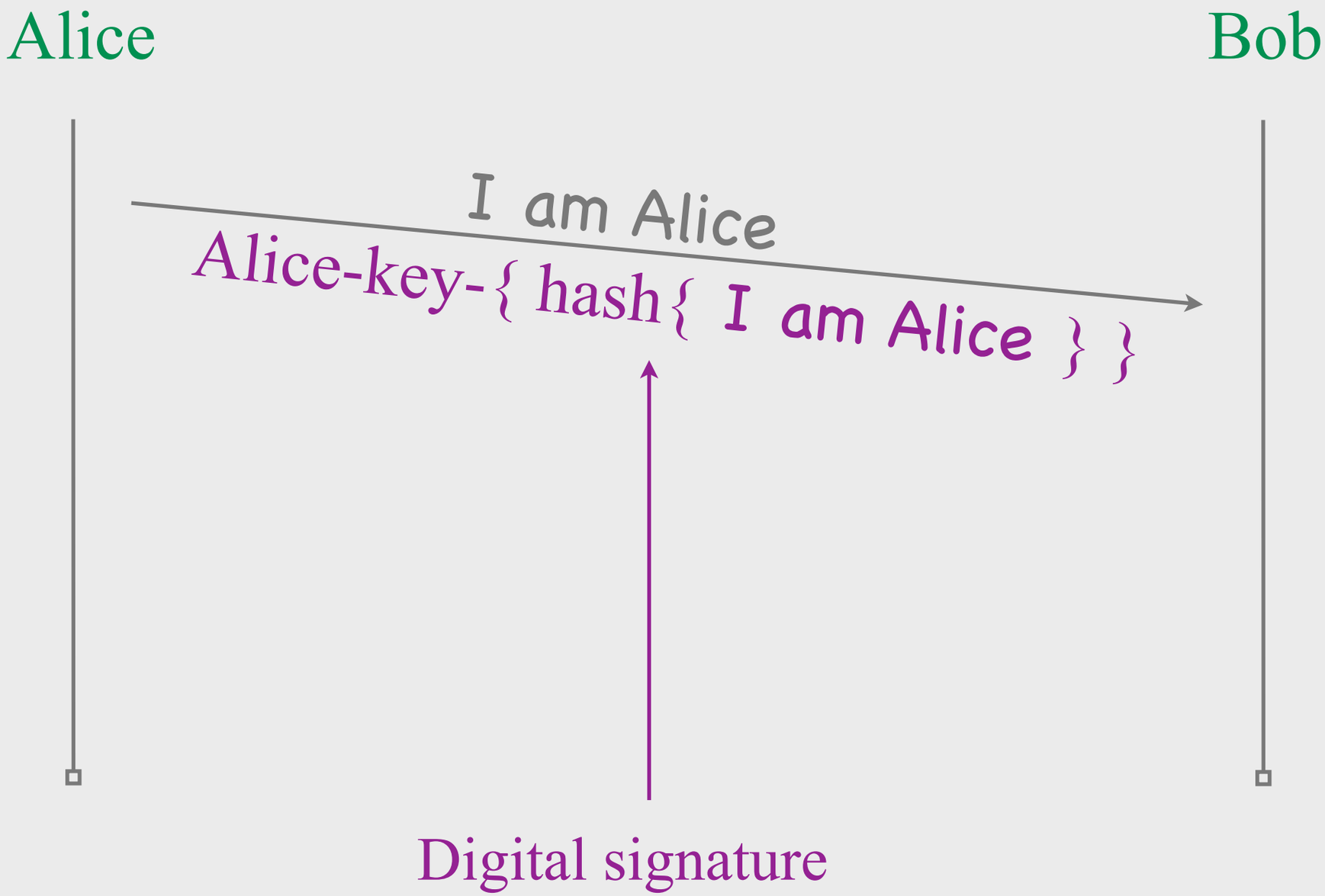
- With asymmetric key crypto
  - Alice appends digital signature (using her private key)
  - Bob checks that it is correct (using Alice's public key)

Providing authenticity

- Use nonce to prevent replay attacks
  - Alice appends MAC of nonce + message
  - Bob verifies that it is correct (using shared key)

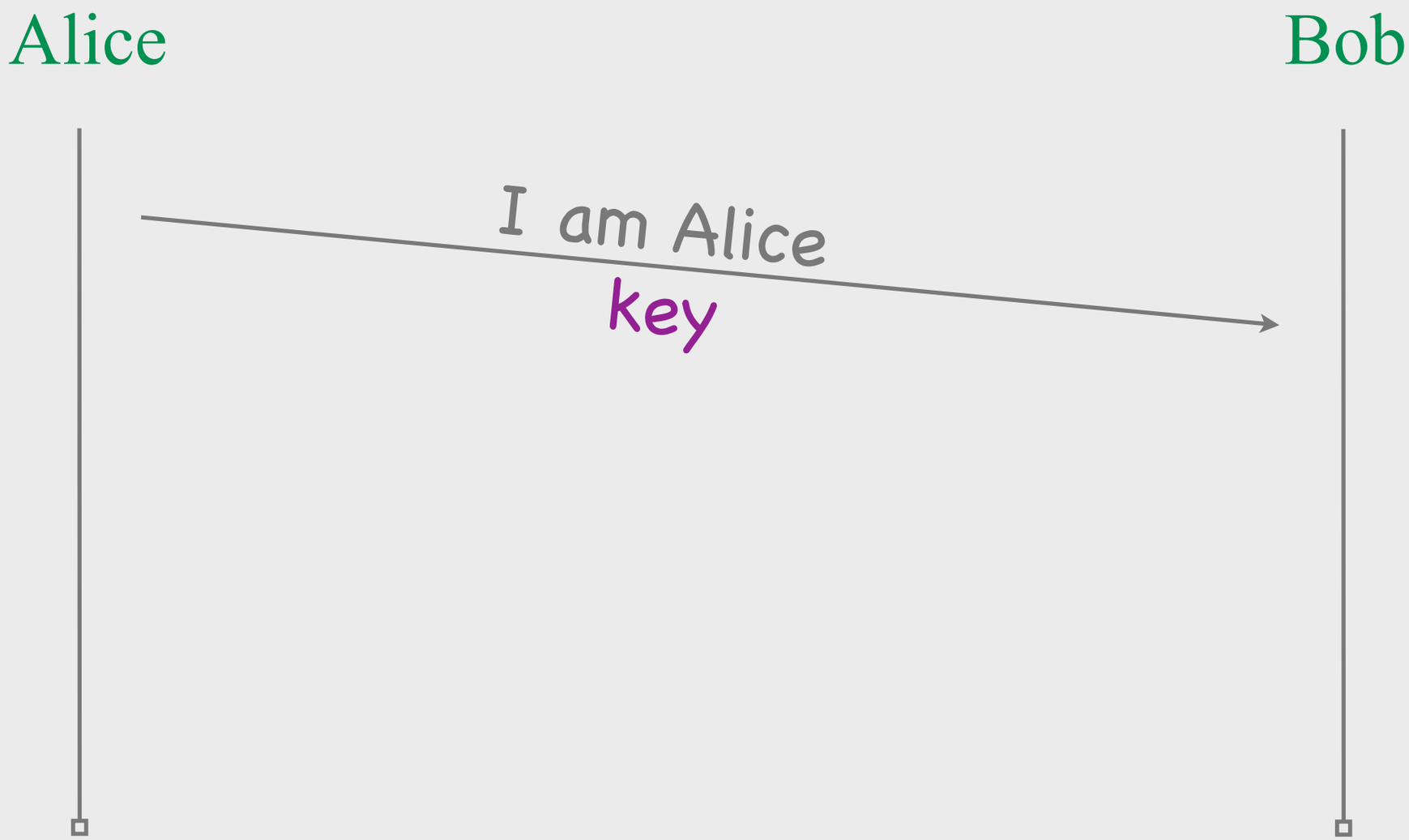
Providing data integrity


Alice
Bob
I am Alice
hash{ key, I am Alice }
Message Authentication Code
(MAC)

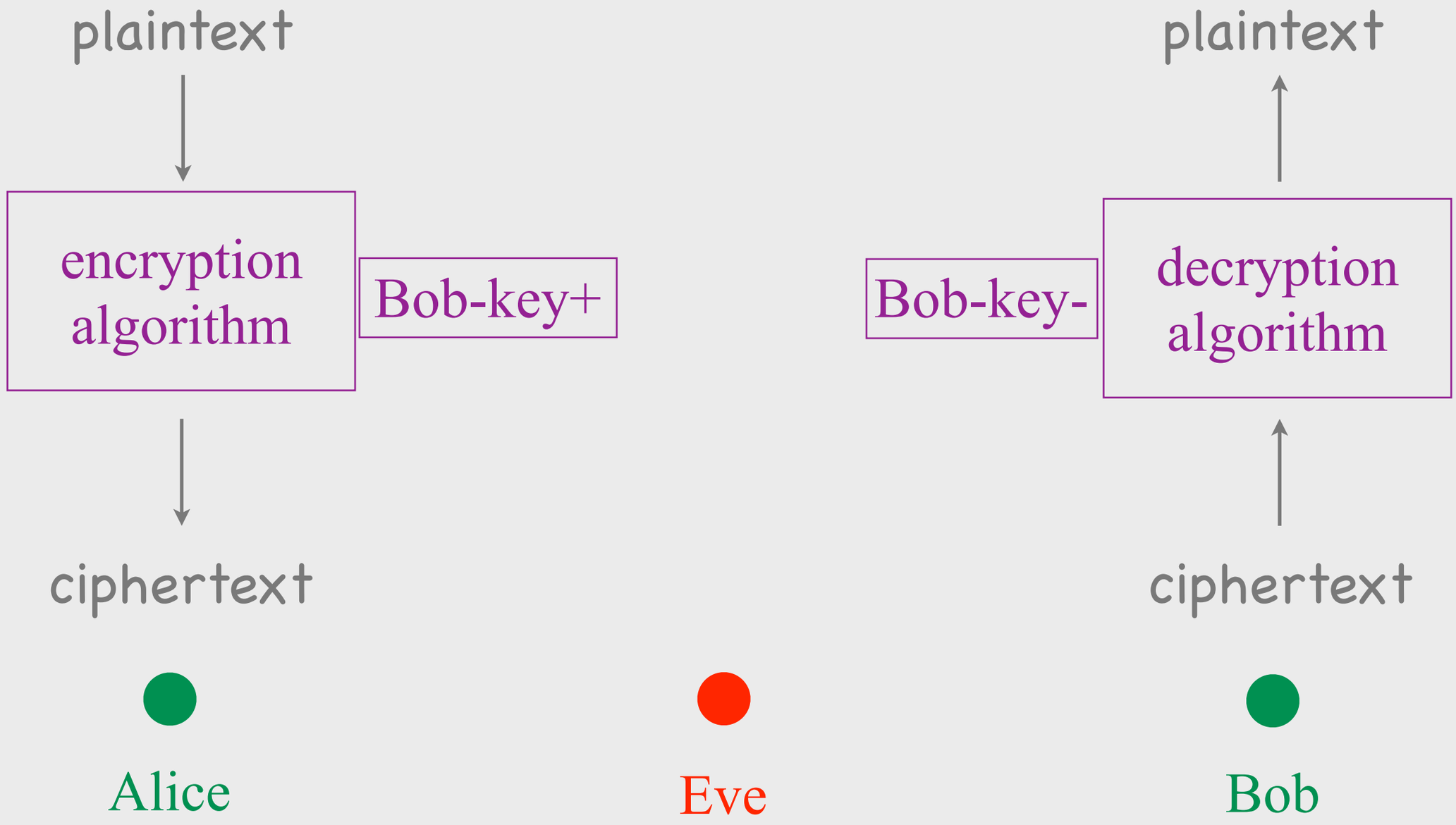

Alice
Bob
I am Alice
Alice-key-{ hash{ I am Alice } }
Digital signature

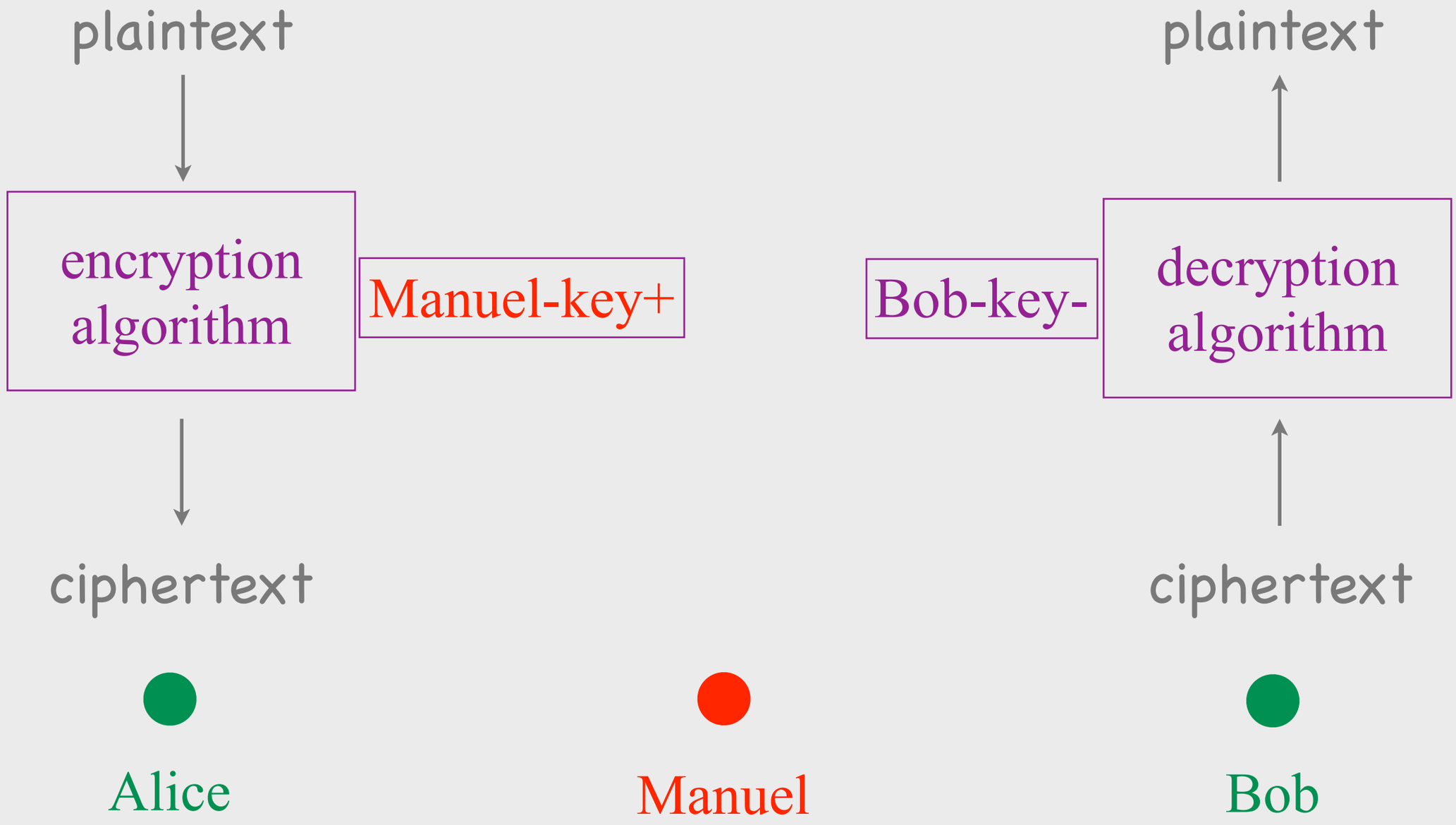
Providing integrity

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


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

“10h00 ”

Manuel-key+

encryption algorithm

gfjdhsjfsgh

Alice

“10h00”

Manuel-key-

decryption algorithm

“10h00”

encryption algorithm

Bob-key+

ztie67843

Manuel

“10h00”

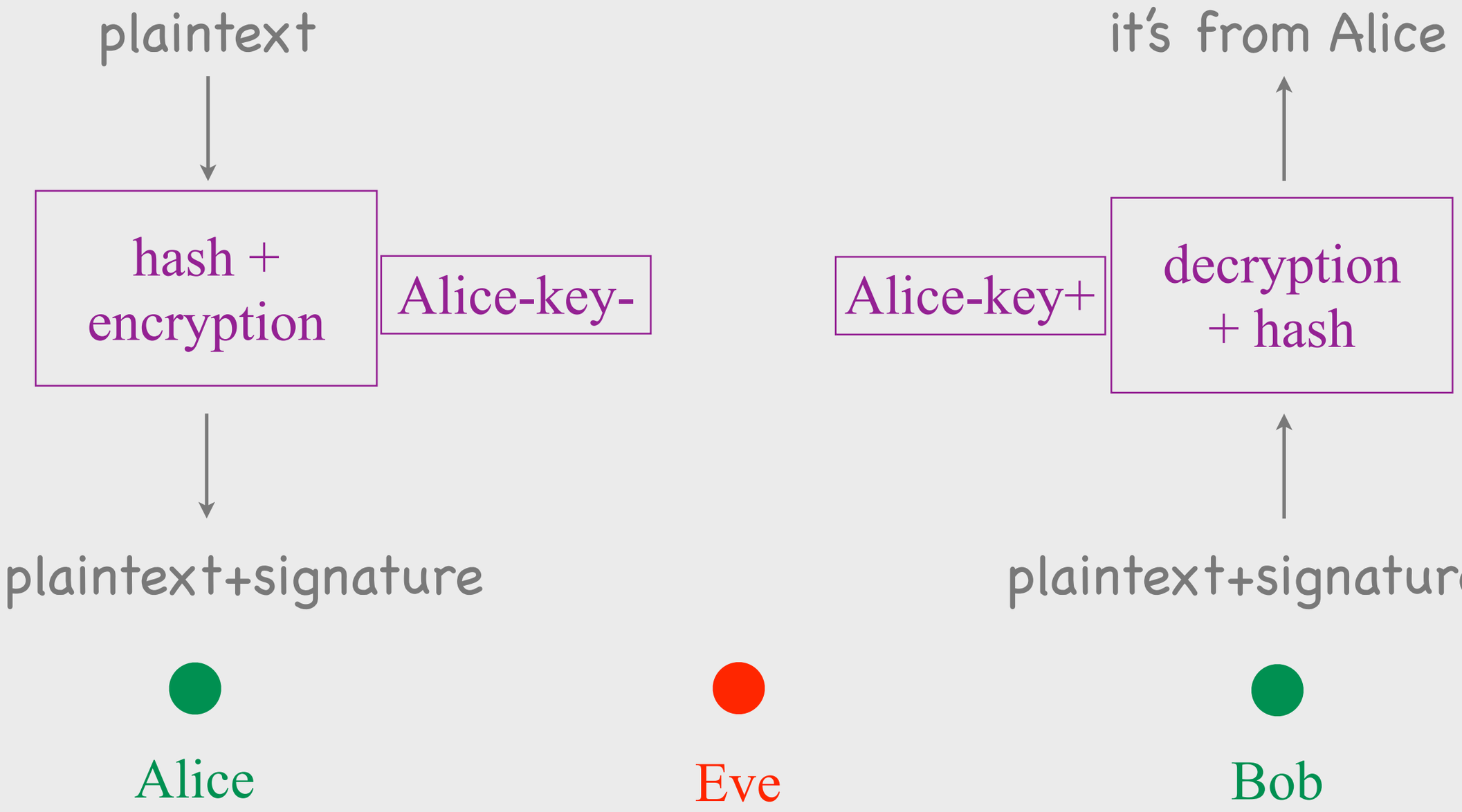
decryption algorithm

Bob-key-

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


plaintext
hash +
encryption
Alice-key-
it's from Alice
Alice-key+
decryption
+ hash
plaintext+signature
plaintext+signature
Alice
Eve
Bob

plaintext

hash + encryption

Alice-key-

plaintext+signature

Alice

Manuel-key+

Manuel

it's from Alice

decryption + hash

plaintext+signature

Bob

"10h00"

Alice-key-

hash +
encryption

"11h00"

hash +
encryption

Manuel-key-

It's from Alice

decryption
+ hash

Manuel-key+

10h00, gfjd

Alice

11h00, ztie

Manuel

Bob

Man in the middle

- Can break authenticity/data integrity
  - Manuel convinces Bob to use his public key instead of Alice's
  - re-computes the digital signatures on Alice-Bob messages
- Cause: no way to verify public-keys
  - when Bob learns Alice's public key, he must verify that it is indeed hers

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 digitally signs the certificate
  - CA-key-{ hash{ Bob owns Bob-key+ } }

Solution: public-key certificates

- Alice needs Bob's true public key
  - to communicate with Bob with confidentiality and/or authenticity/data integrity
- 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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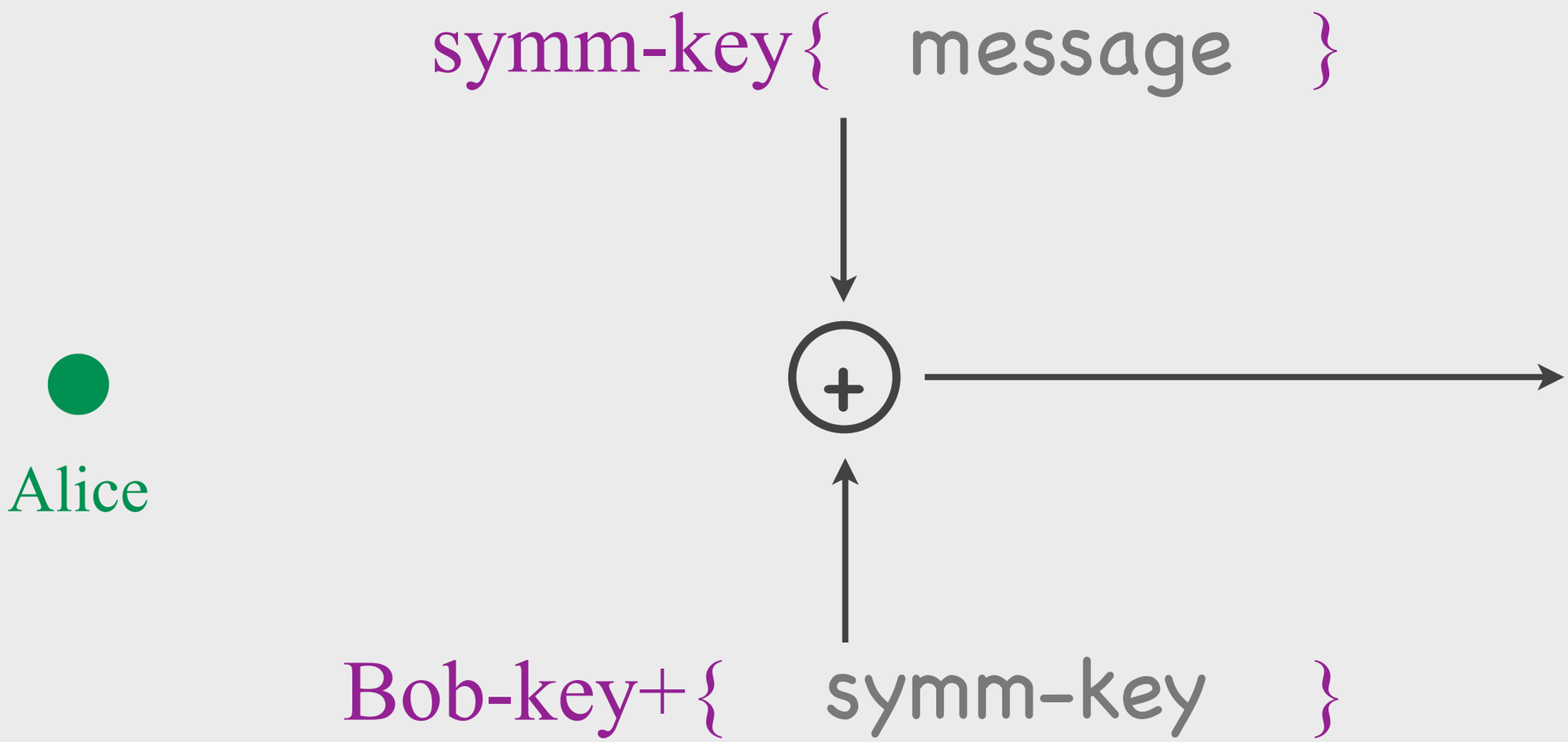
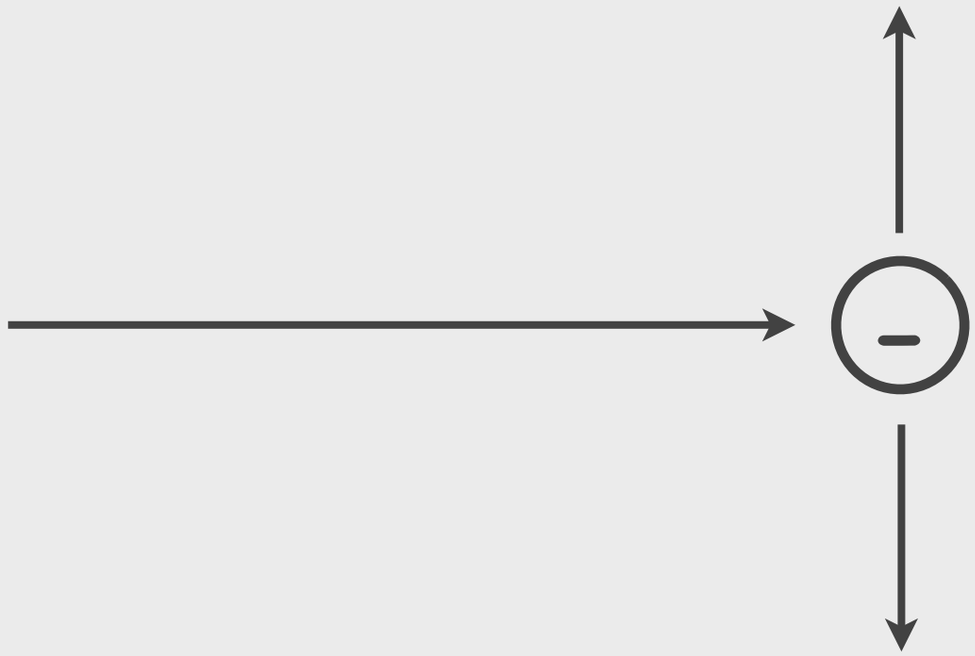

symm-key{ message }
Alice
Bob-key+{ symm-key }

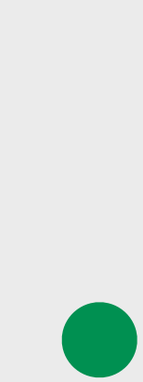
symm-key{ symm-key{ message } }



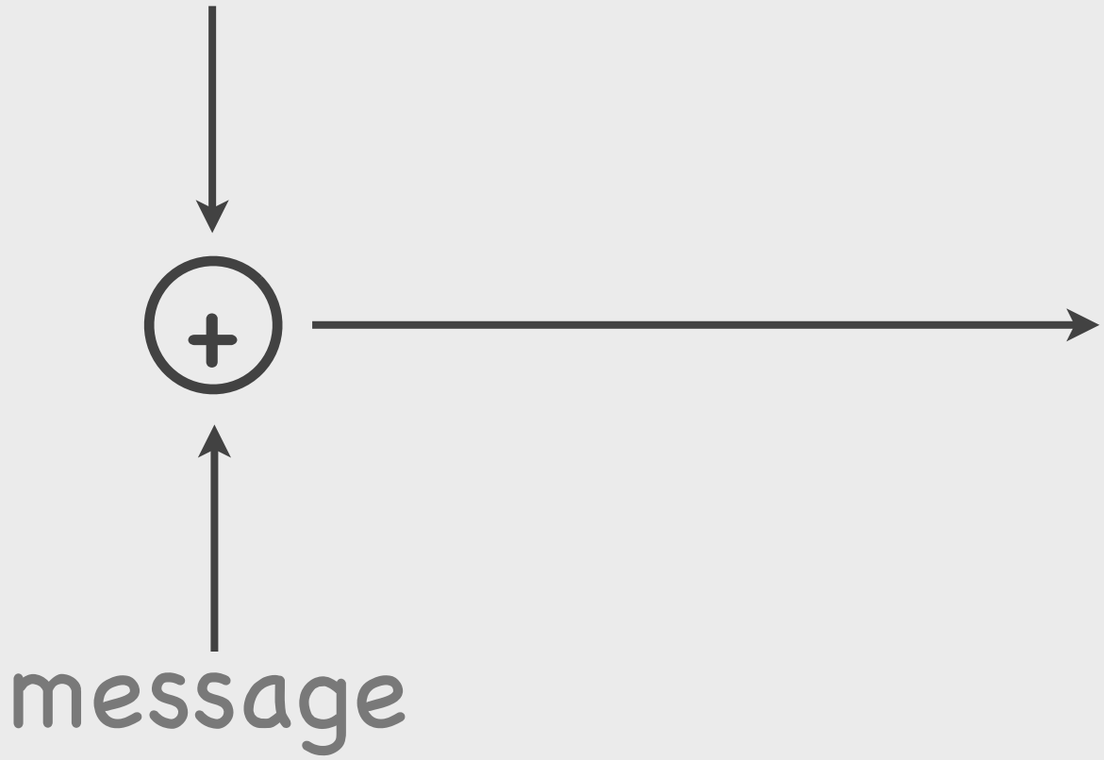
Bob

Bob-key-{ Bob-key+{ symm-key } }

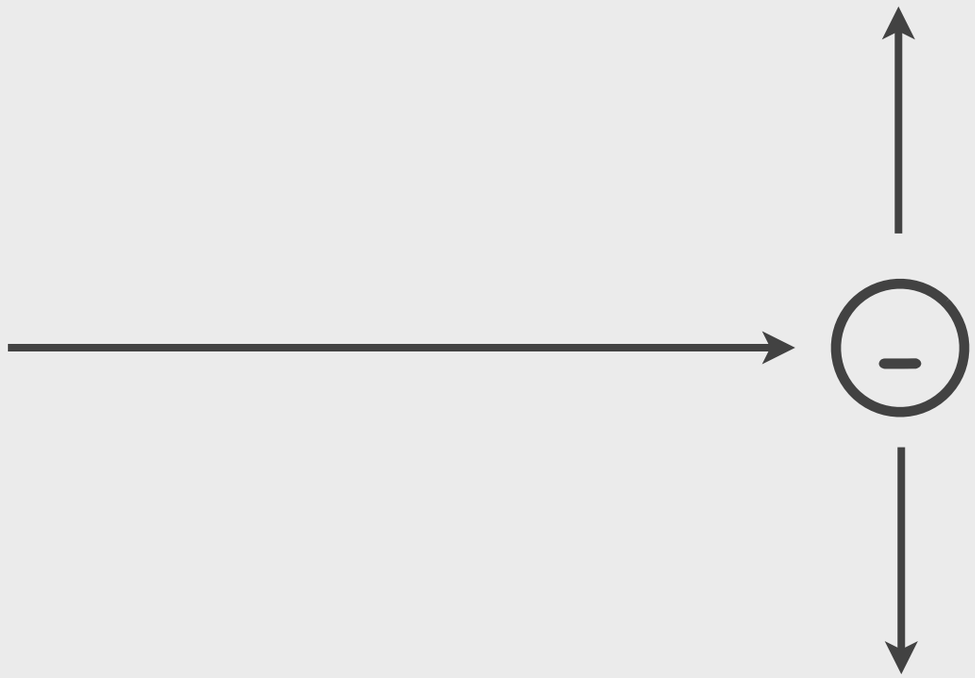
Alice-key-{ hash { message } }



Alice

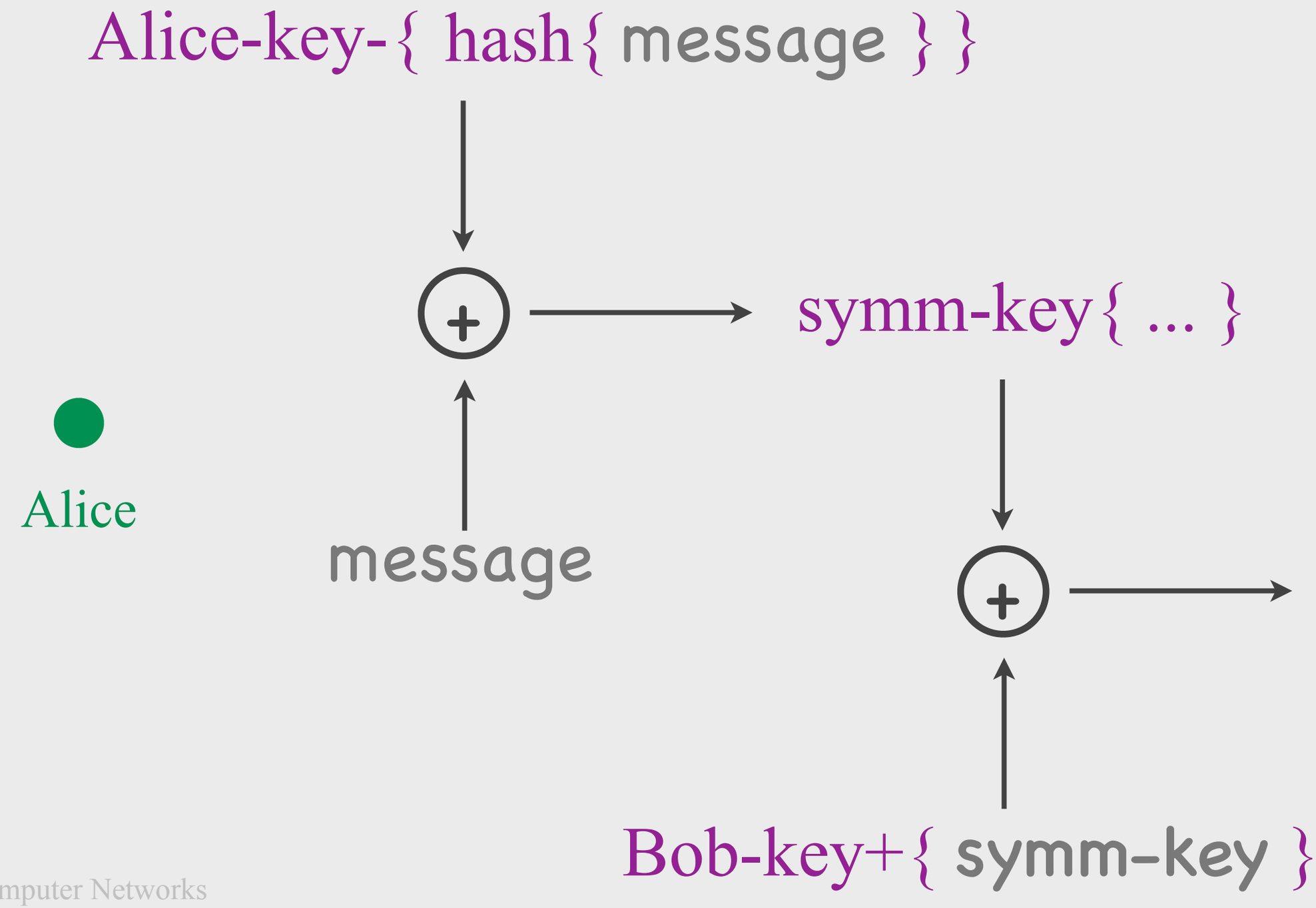


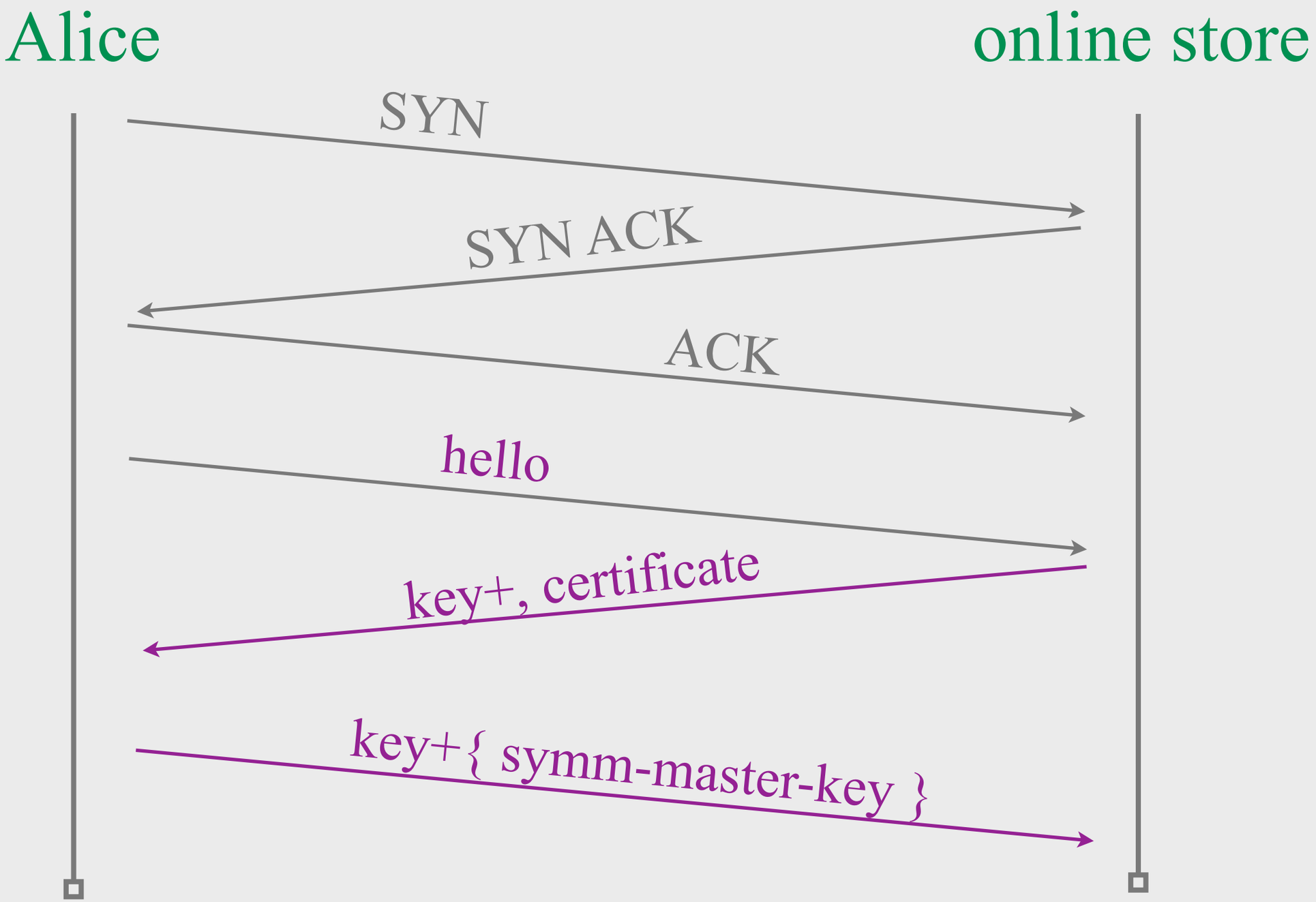
Alice-key+{ Alice-key-{ hash{ message }}}



Bob

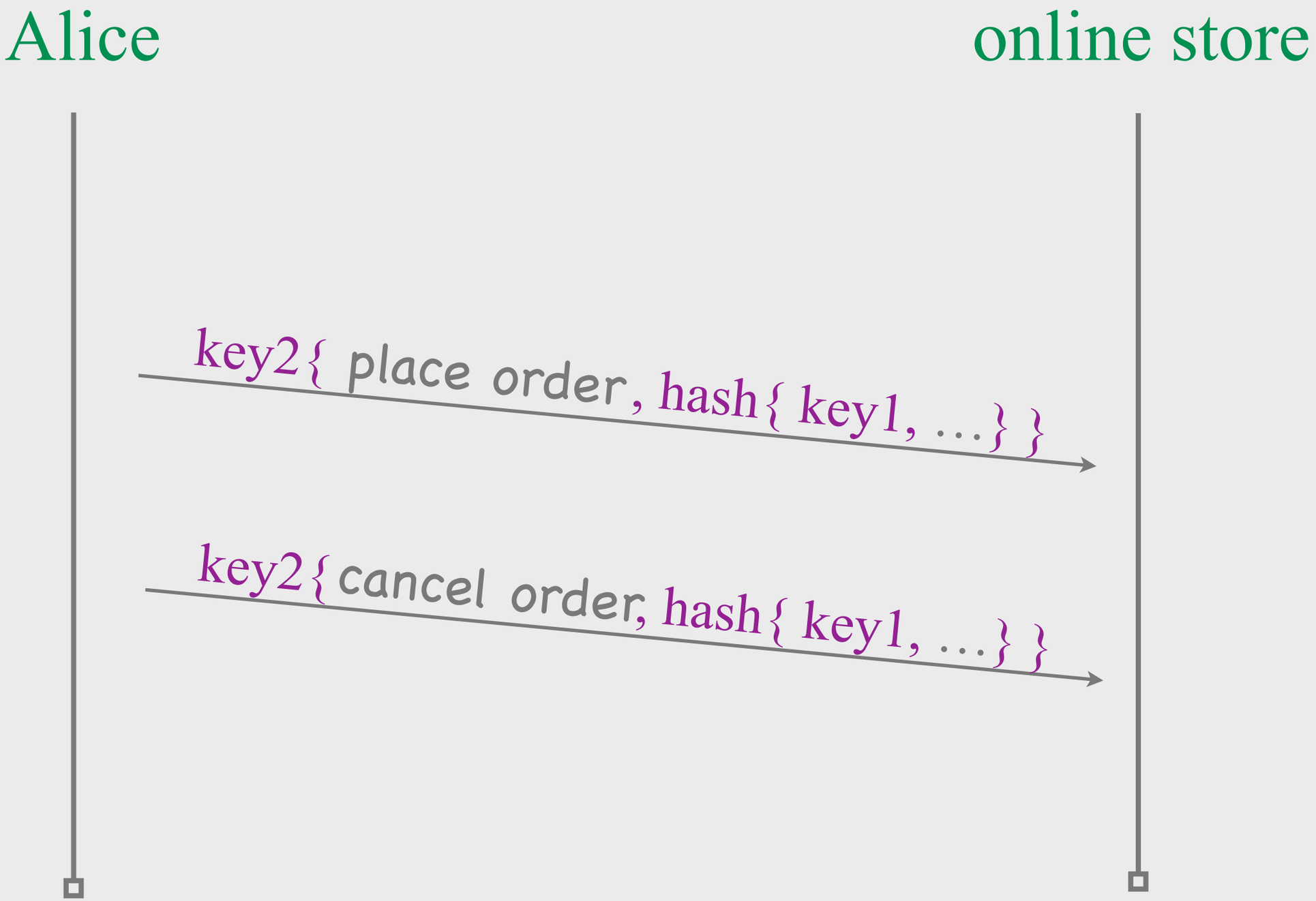
hash{ message }

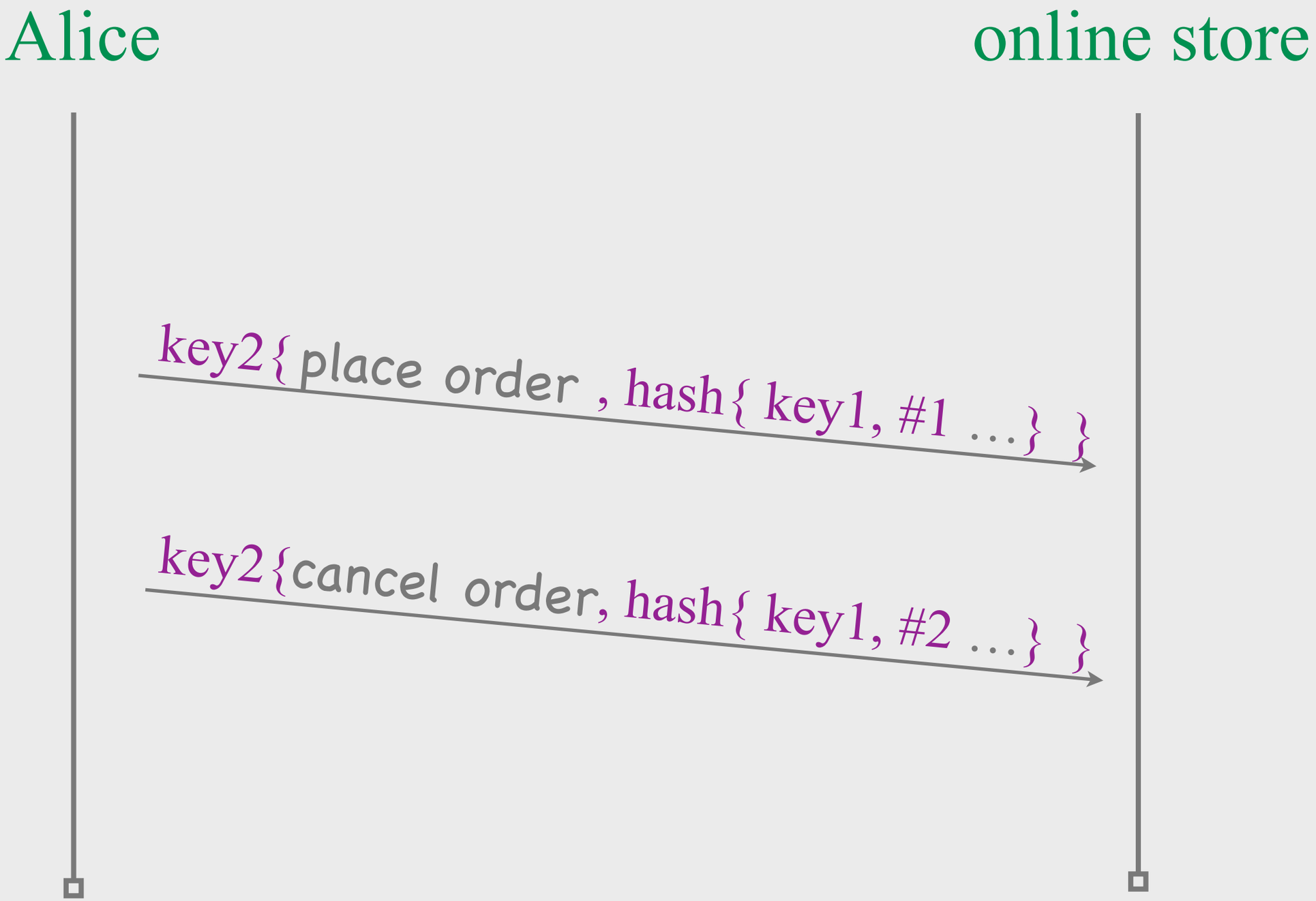

Alice-key-{ hash{ message } }
symm-key{ ... }
Alice
message
Bob-key+{ symm-key }


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

Securing TCP applications

- Server sends its public key & certificate
- Client creates and sends a symmetric 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 symmetric 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	any	80
allow	any	167.67/16	TCP	80	any
deny	all	all	all	all	all