Lecture 3:

The Application Layer

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- Tesla Model 3 controller
- your washing machine
- heart pacemaker

Google servers

- end-system
- laptop
- smartphone

World of warcraft servers

```
while (...) {
    message = ...;
    send ( message, ... );
}
```

processes

```
while (...) {
    message = receive ( ... );
}
```

Alice

Bob

IP address

port number

process name: 128.156.17.23, 80

Design an application =

- Design the architecture
  - which process does what?
- Design the communication protocol
  - what sequences of messages can be exchanged?
- Choose the transport-layer technology
  - what kind of delivery is needed?

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a process that is always running

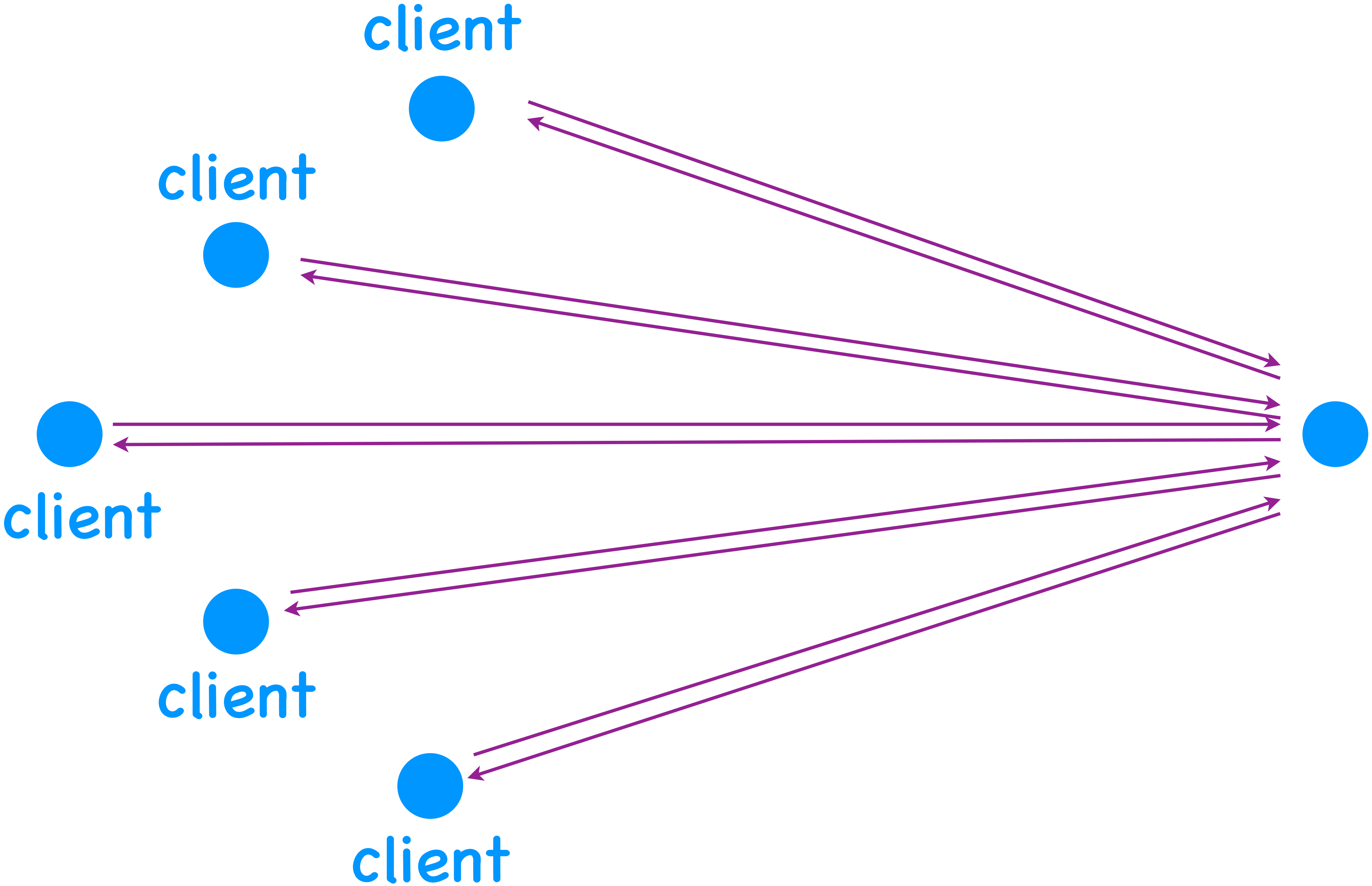
reachable at a fixed,
known process name

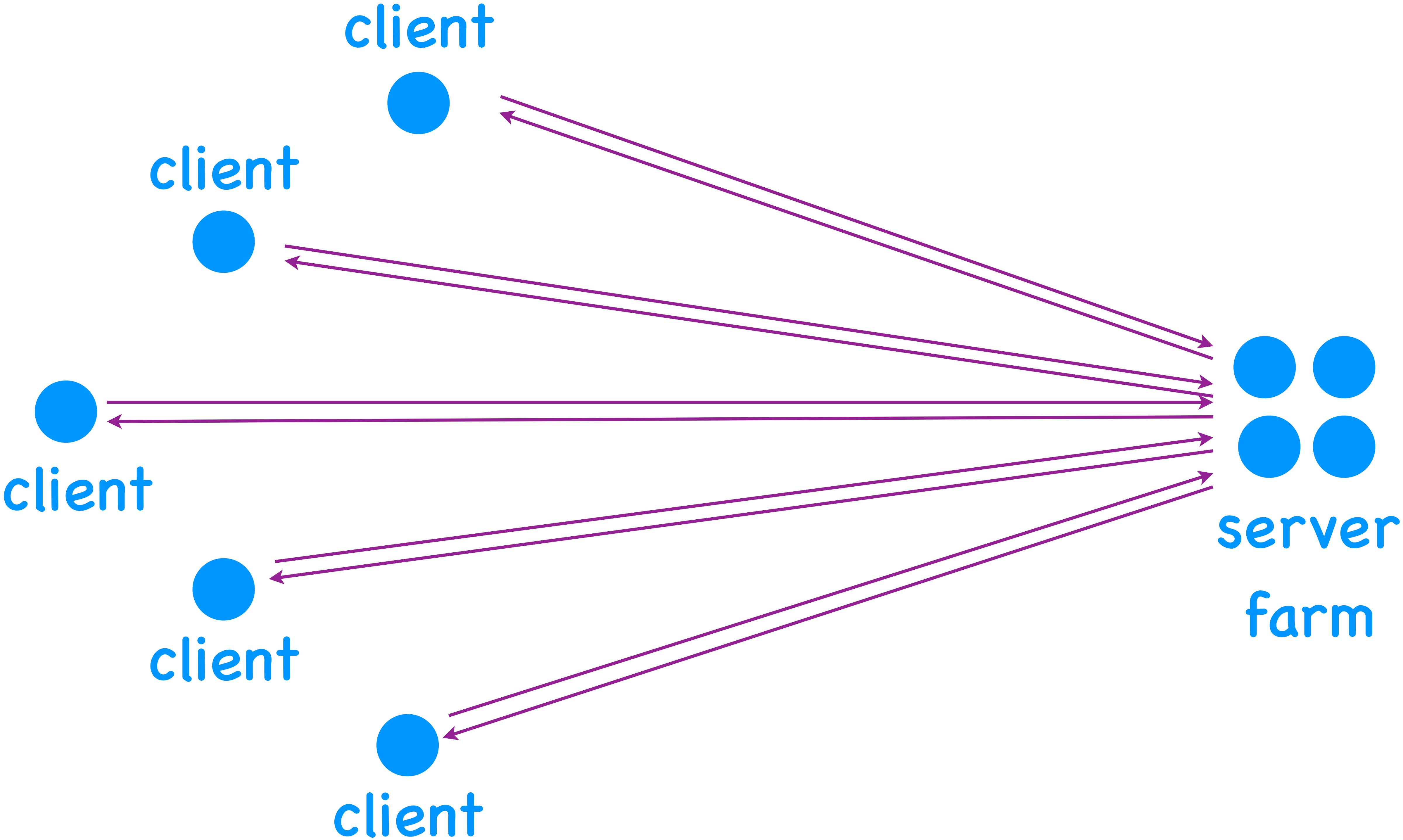
answers service requests

client

a process that generates
service requests

server


client
client
client
client
client


client
client
client
client
client
server
farm

Client-server architecture

- Clear separation of roles
  - a client generates service requests
  - a server answers (or denies) the requests
- Server runs on dedicated infrastructure
  - could be one computer
  - or an entire data-center

a process that may both generate and answer requests

Peer-to-peer architecture

- A peer may act as both server and client
  - generates service requests
  - answer (or deny) requests
- Runs on personally owned end-system
  - PC, laptop, smartphone
  - no dedicated infrastructure

Client-server or peer-to-peer?

Design an application =

- Design the architecture
  - which process does what?

- Design the communication protocol
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- Choose the transport service
  - what delivery guarantees are needed?

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Reliable data delivery

- Deliver message to the destination process or signal failure
  - detect and recover from packet loss or corruption
  - loss-sensitive applications, e.g., web, file transfer, email, …

Guaranteed performance

- Minimum throughput
  - throughput-sensitive applications,
    e.g., video-conferencing
- Maximum end-to-end packet delay
  - delay-sensitive applications,
    e.g., emergency services, voice, gaming, …

Guaranteed security

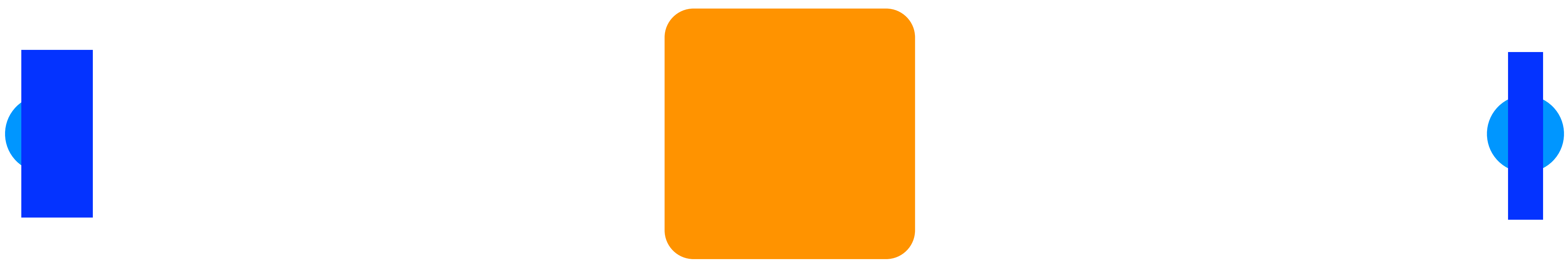
- Confidentiality
  - message is revealed only to the destination
- Authenticity
  - message indeed came from claimed source
- Data integrity
  - message is not changed along the way

Internet transport-layer protocols

- TCP: Transmission Control Protocol
  - reliable, in-order data delivery, flow control, congestion control
- UDP: User Datagram Protocol
  - detection of packet corruption
- No protocol offering guaranteed performance

application	web file transfer email
SSL	encryption, decryption, authentication, …
transport	TCP UDP
network	
link	
physical	

TCP code at the destination
keeps state on the source



TCP code at the source
keeps state on the destination

Connection = memory

- TCP is "connection-oriented" or "stateful"
  = maintains state on all the local/remote
  process pairs that use TCP

- UDP is "connection-less" or "stateless"
  = does not maintain state
  on remote processes

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Example 1: the web

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answers web requests

web client = web browser

web server

a process that generates
web requests

Web page

- Base file + referenced files
  - base file specifies structure and potentially content
  - referenced files can be images, video, scripts, …
- Each file has its own URL
  - URL = address for Internet resources
  - e.g., http://www.epfl.ch/index.html

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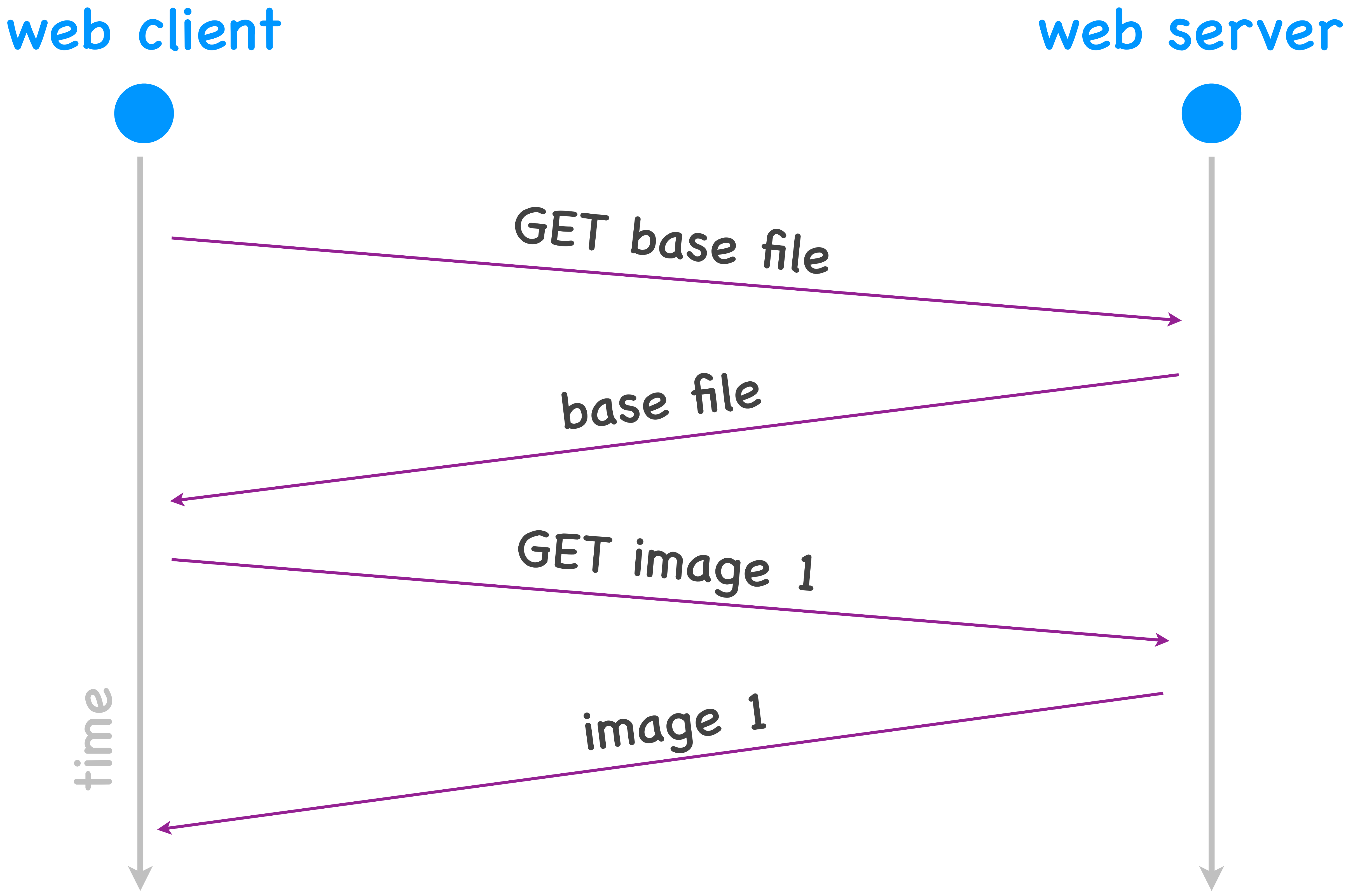
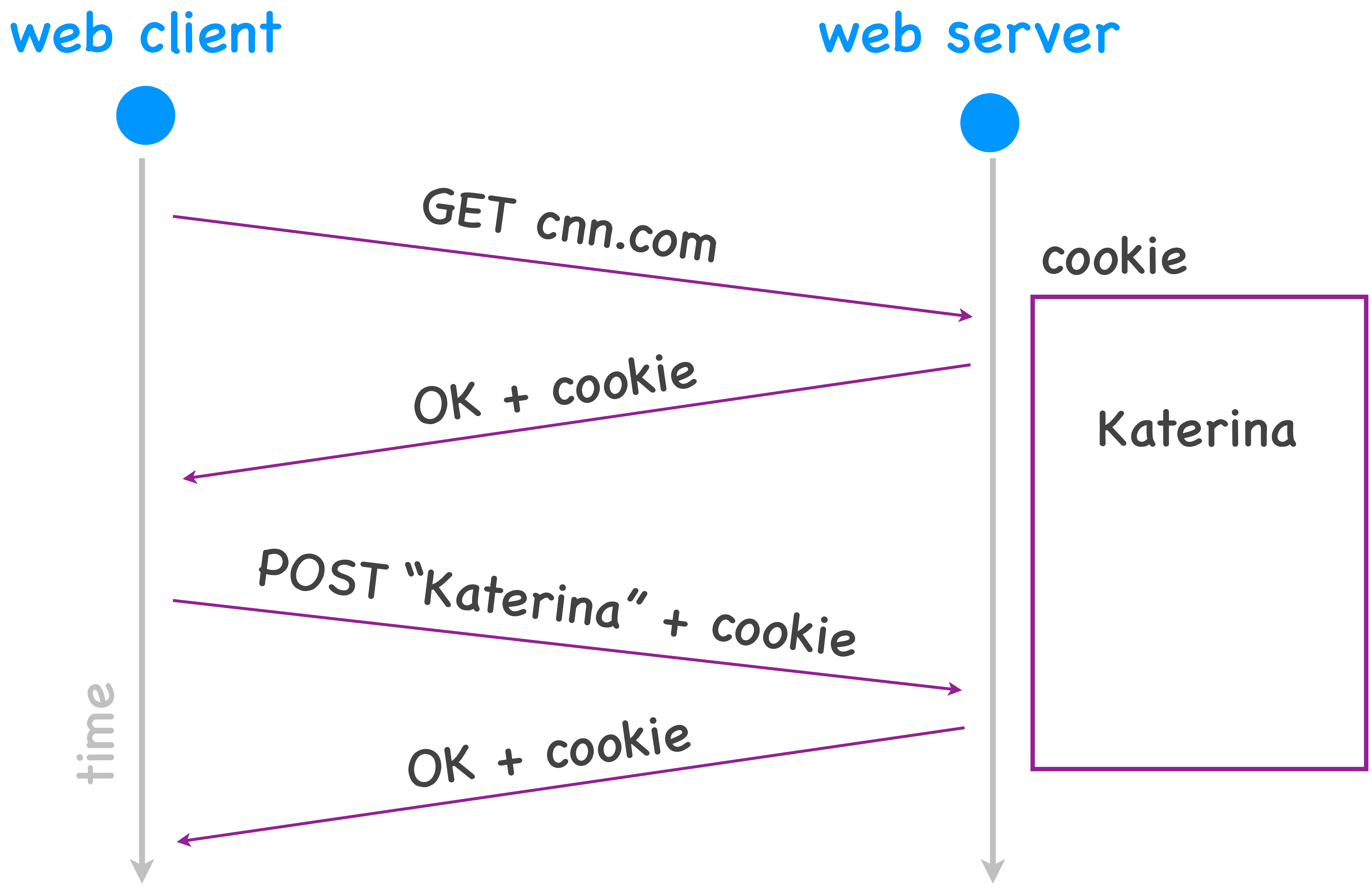
HTTP request types

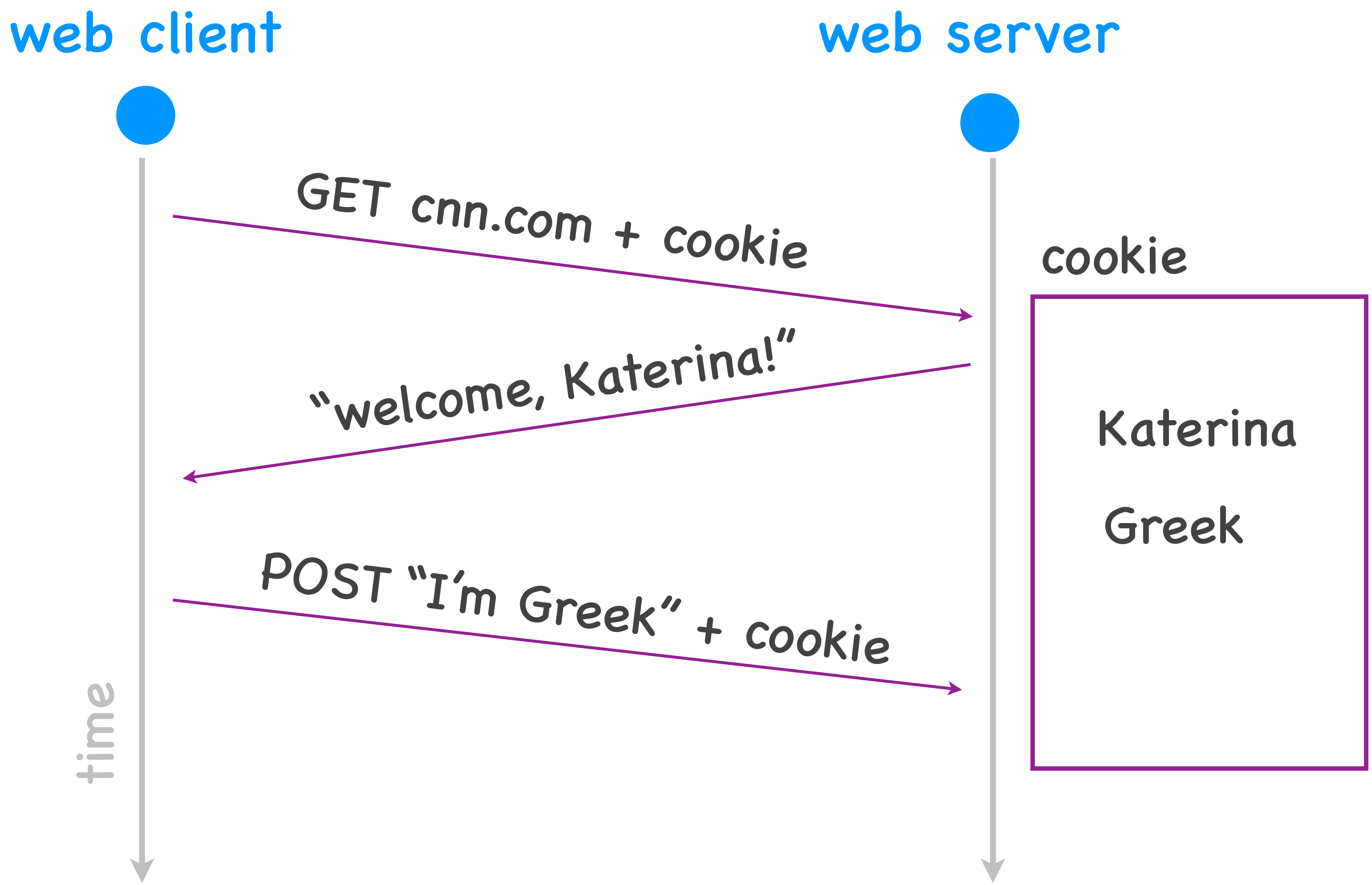
- GET: client requests to download a file
- POST: client provides information
- HEAD: client requests file metadata
- PUT: client requests to upload a file
- …

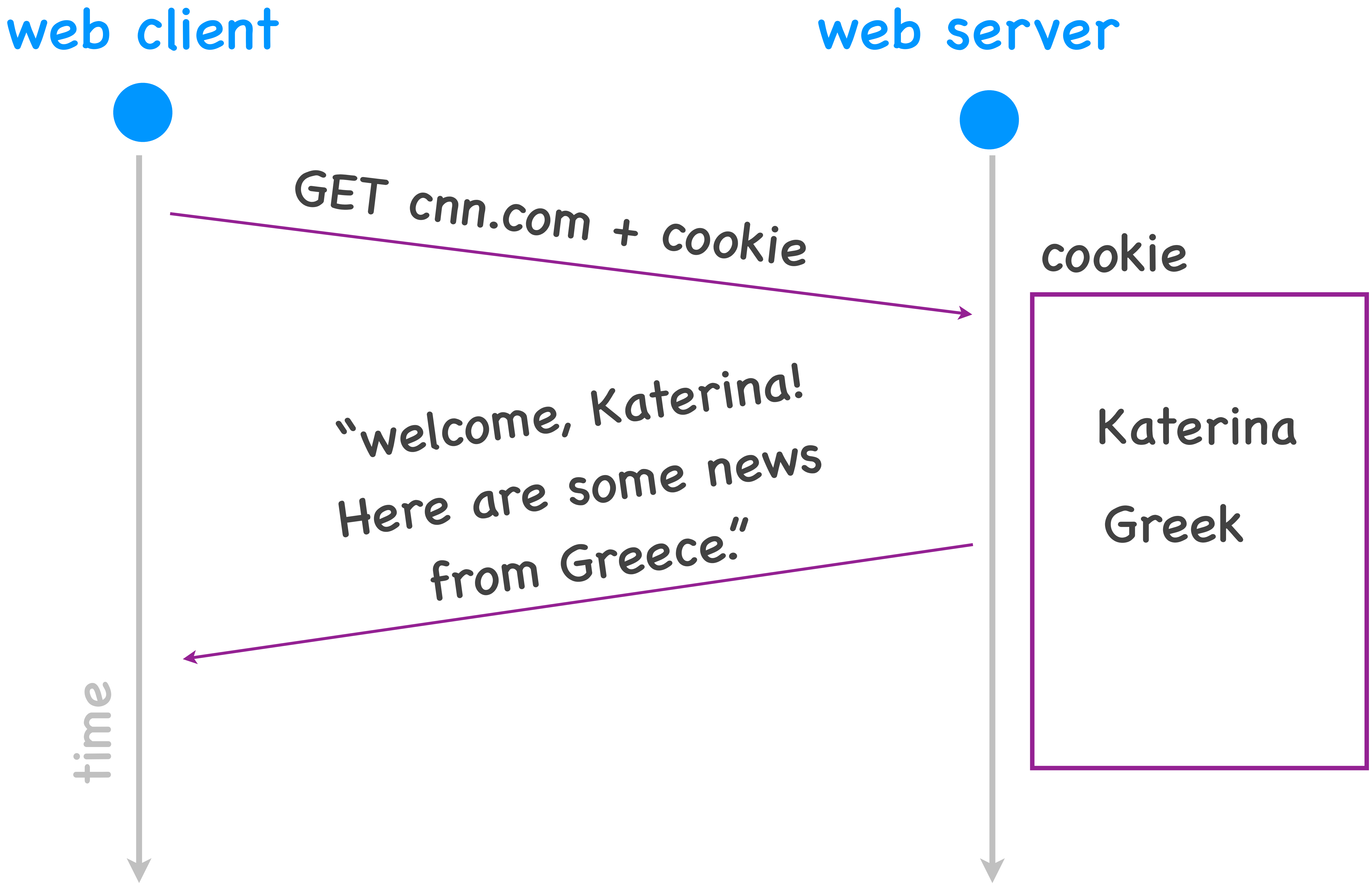
HTTP response types

- OK
- Not found
- Moved permanently
- Bad request
- …


web client
web server
GET base file
base file
GET image 1
image 1
time


web client
web server
GET cnn.com
cookie
OK + cookie
Katerina
POST "Katerina" + cookie
time
OK + cookie


web client
web server
GET cnn.com + cookie
"welcome, Katerina!"
POST "I'm Greek" + cookie
cookie
Katerina
Greek
time


web client
web server
GET cnn.com + cookie
cookie
"welcome, Katerina!
Here are some news
from Greece."
Katerina
Greek
time

Cookies

- Cookie = state created by the web server, stored by the web client and potentially the web server

- It links subsequent HTTP requests to the same web client

Anything wrong with cookies?

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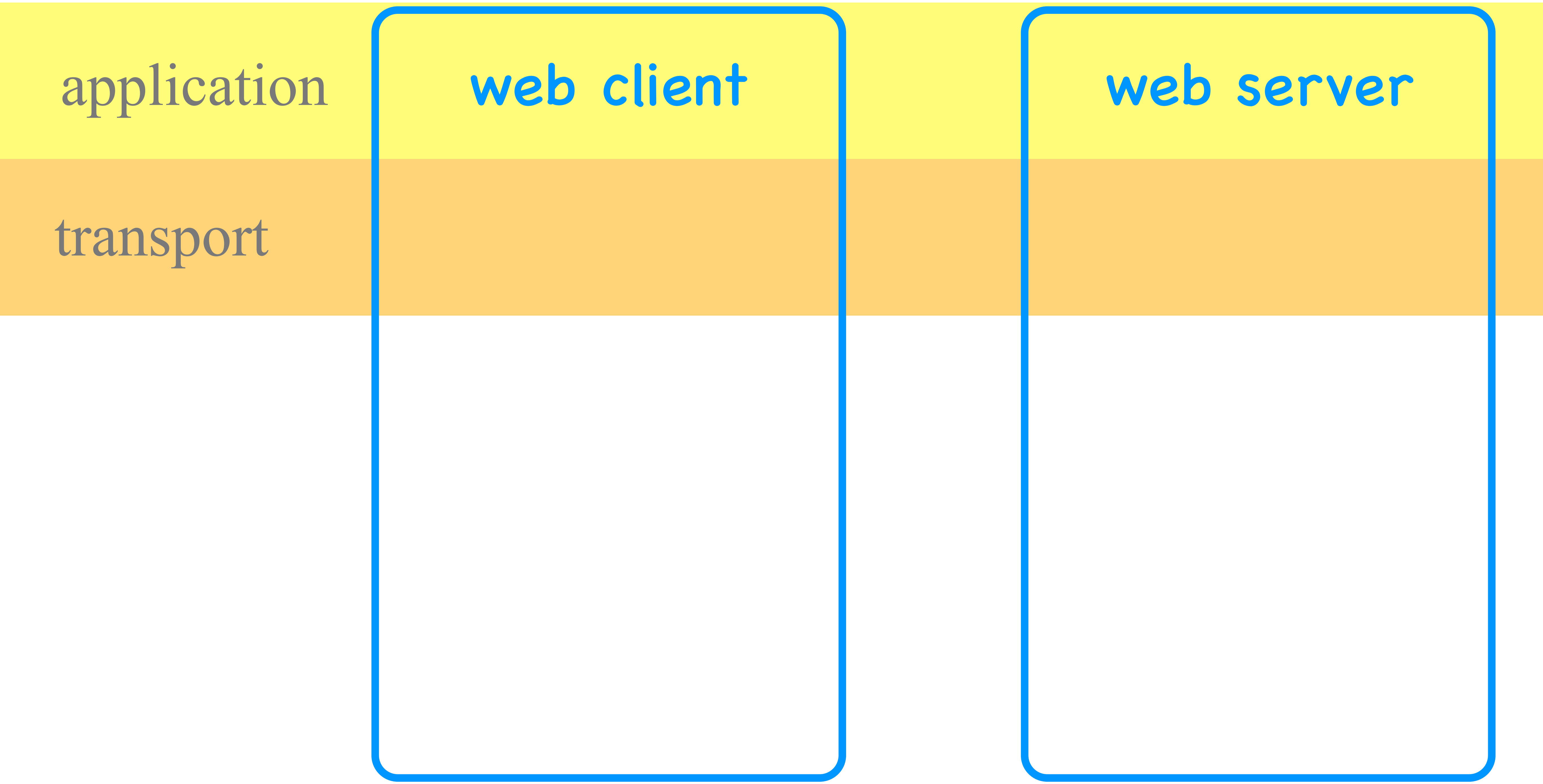
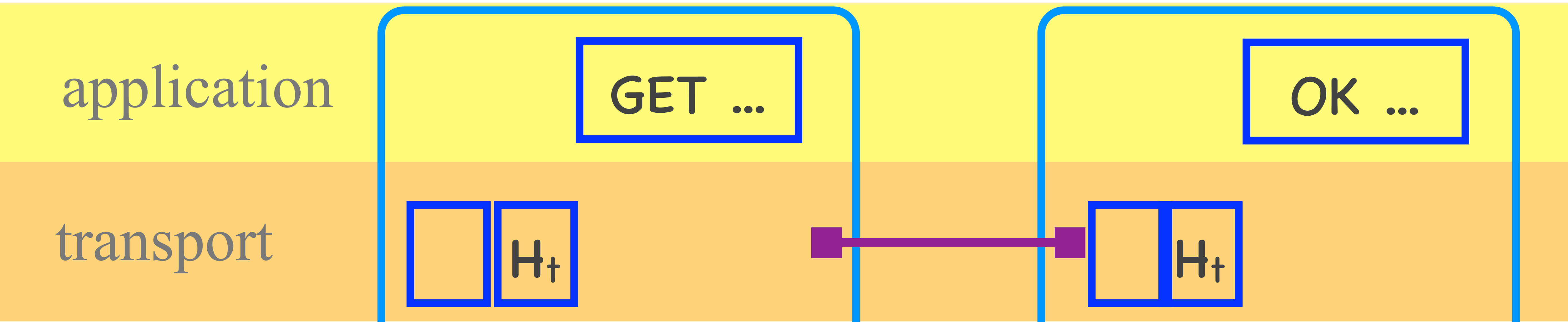

application
transport
web client
web server



Delay to receive file:

1 RTT = round-trip time

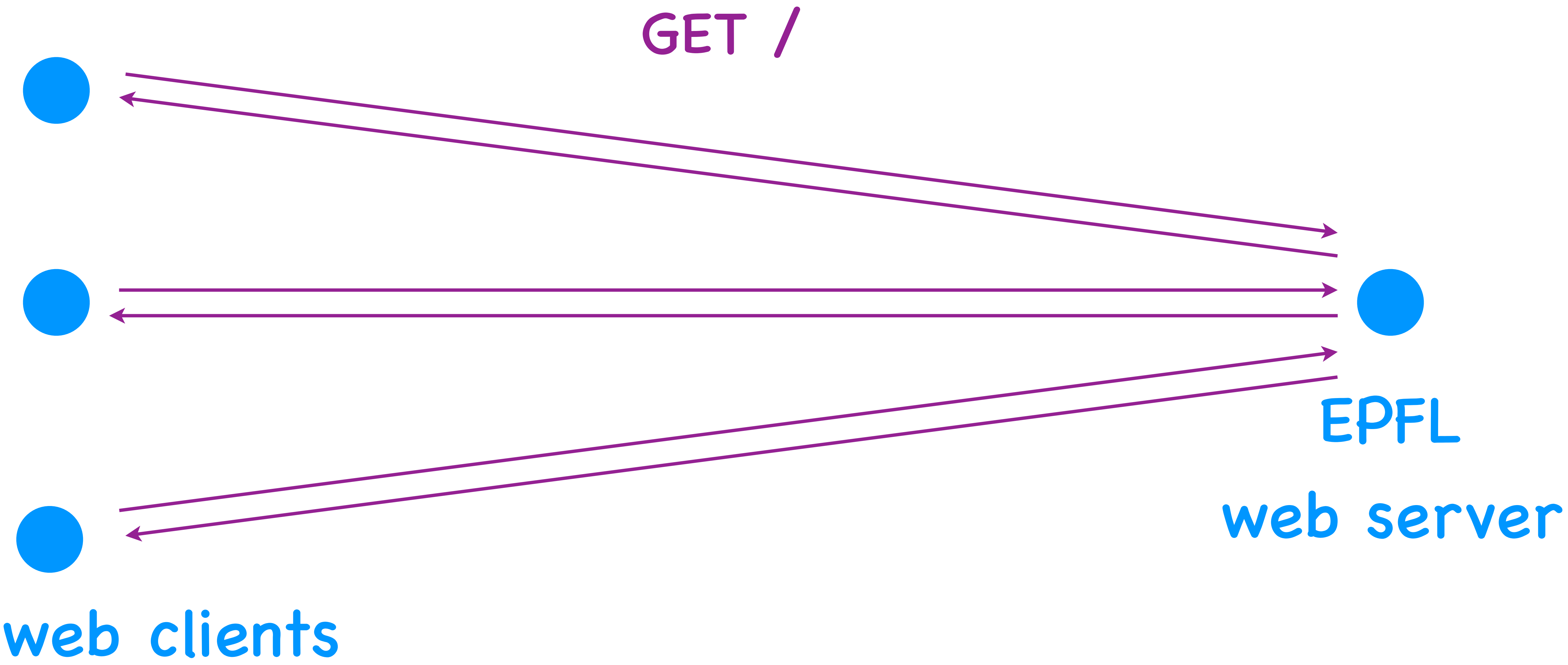
+ delay for request packet to go to server

+ delay for response packet(s) to go to client

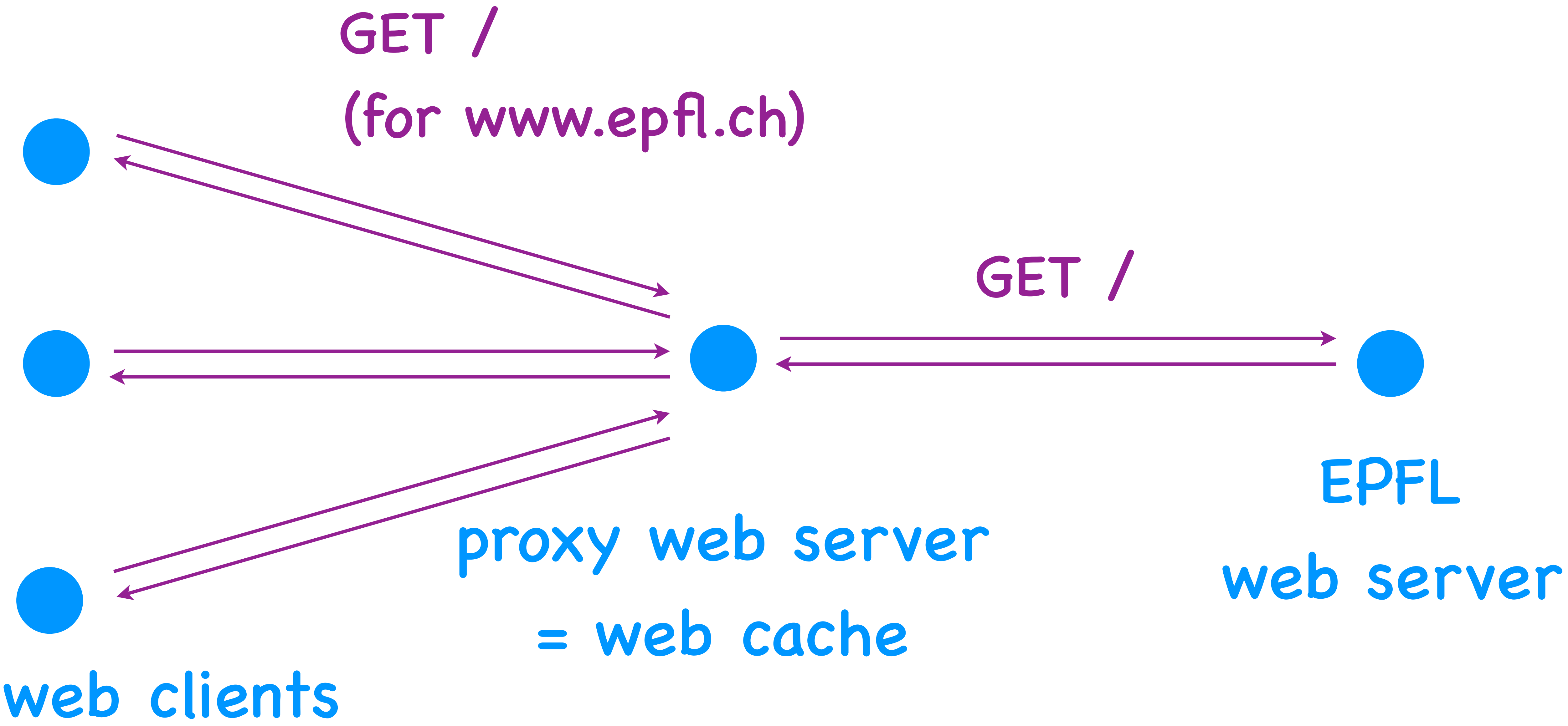
Typical ways to use TCP

- Persistent TCP connections
  - reuse the same TCP connection
    for multiple HTTP requests and responses
- Parallel TCP connections
  - exchange multiple HTTP requests
    and responses in parallel

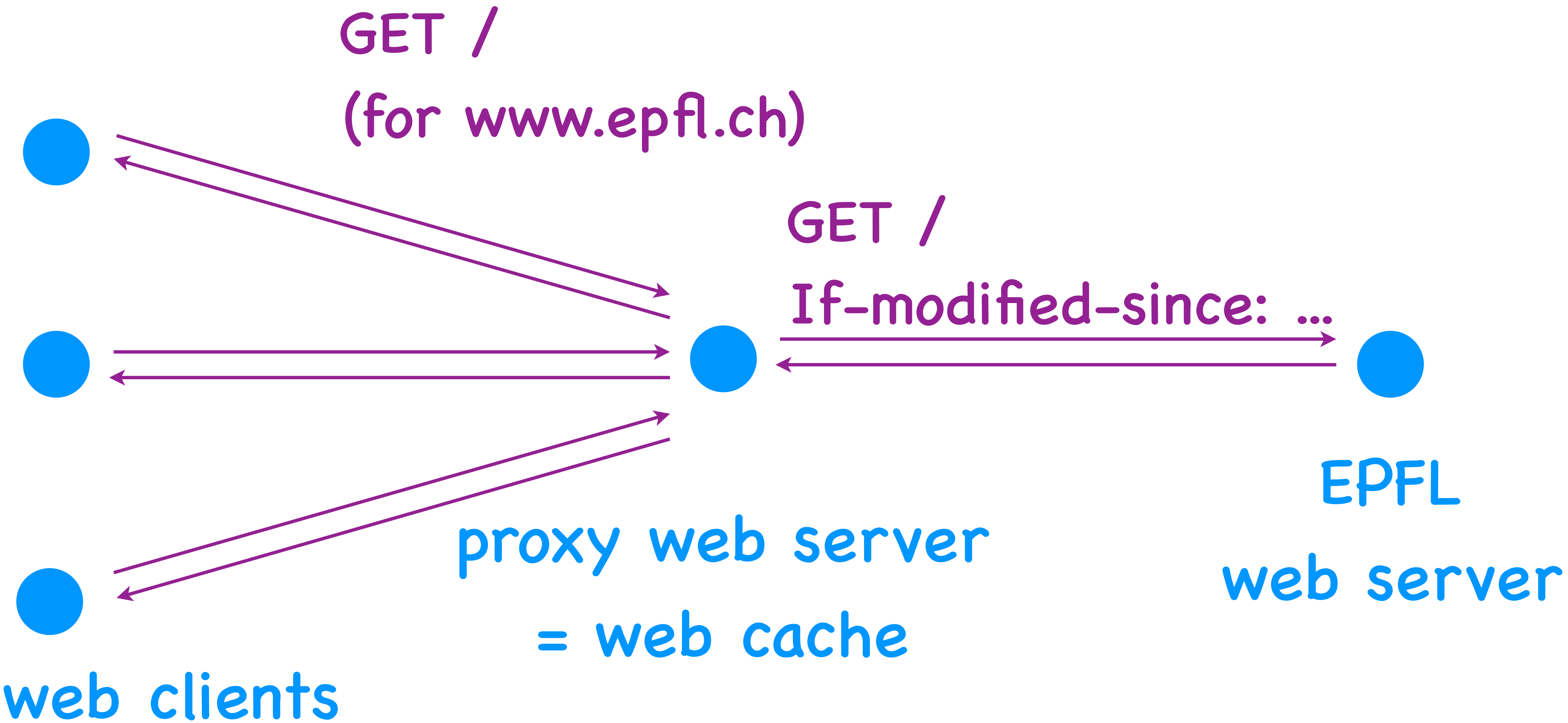
Silicon Valley



Silicon Valley



Silicon Valley



Web caching

- Proxy web server or web cache
  - caches copies of other web-server files
  - acts as a web server to nearby web clients
- Reduces delay experienced by web clients
- Relies on conditional GET to ensure data freshness

Caching

- Universal technique for improving performance

- Challenge: stale data
  - option #1: dynamic check for staleness
  - may introduce significant delay