Computer Networking : Principles, Protocols and Practice

Part 2 : Applications

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The Application Layer

Contents

→ The client-server model

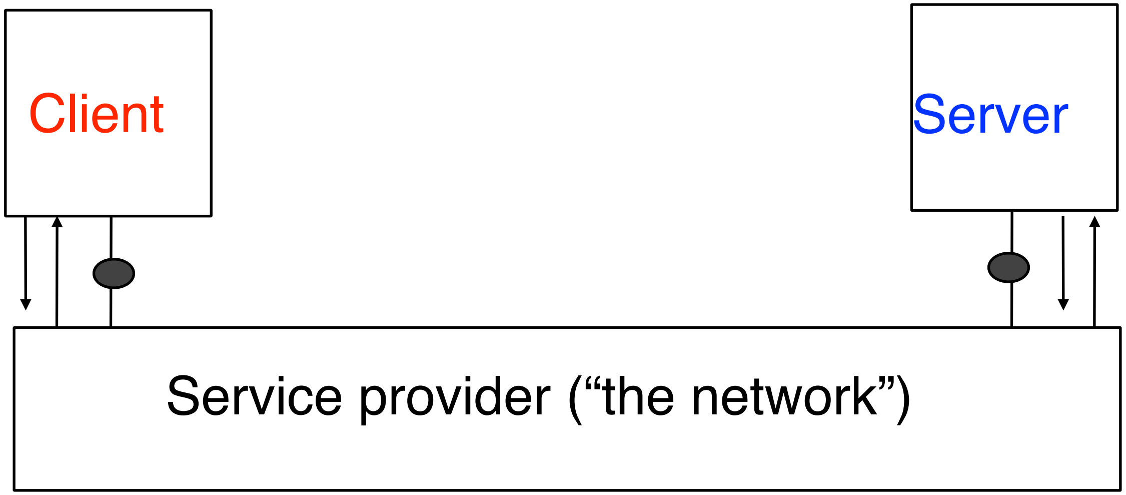
Name to address resolution

email

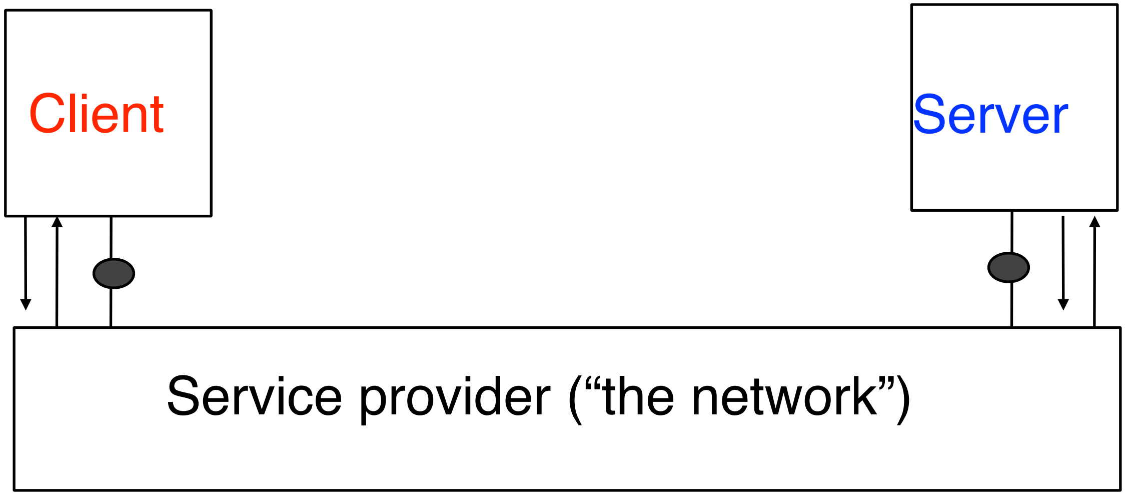
world wide web

peer-to-peer applications

The client server model



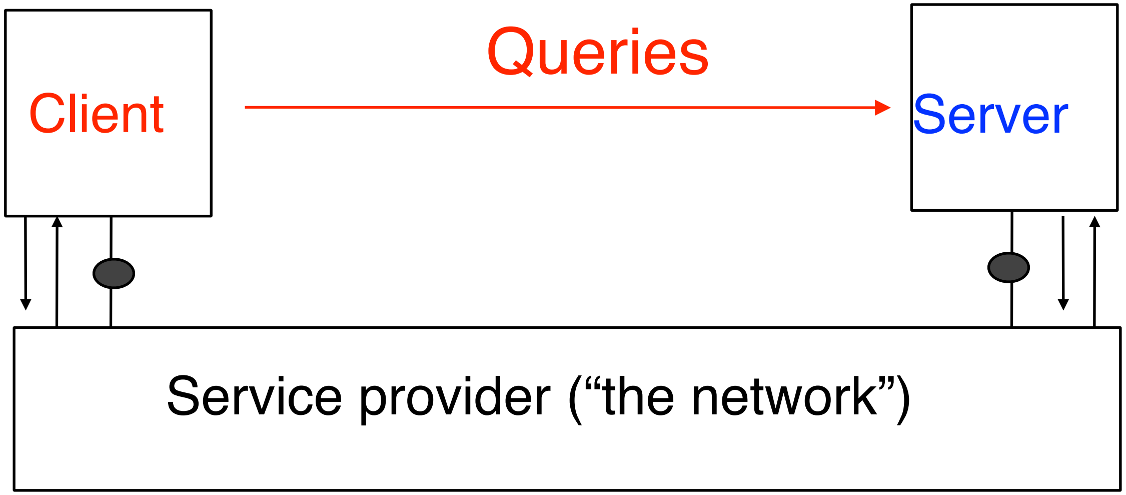
The client server model



Client

- interacts with server through transport layer
- sends queries or commands

The client server model



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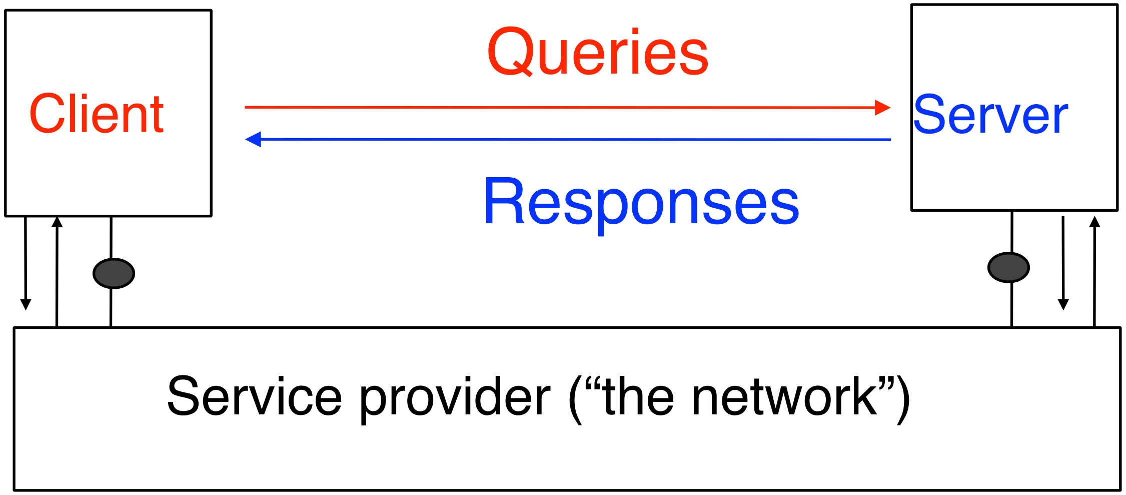
The client server model



Client

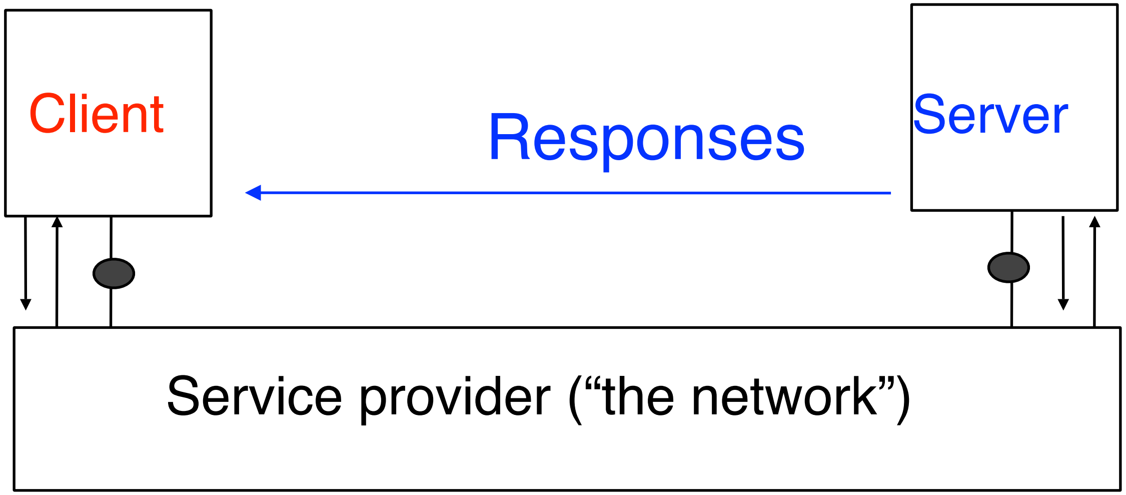
- interacts with server through transport layer
- sends queries or commands

Server

- Answers the queries received from clients
- Executes the commands from clients
- Many clients can use the same server

Example : email, www, ...

The client server model (2)

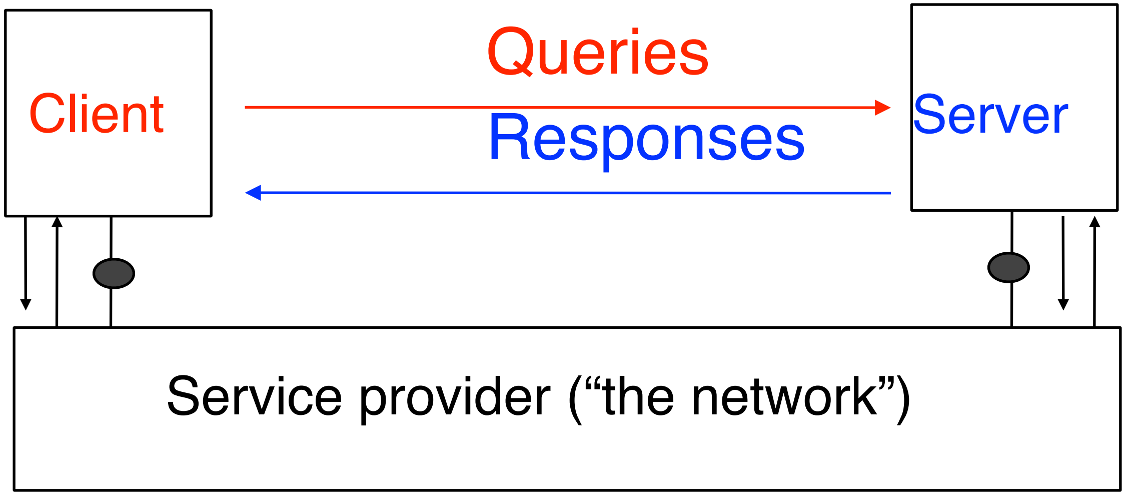


Client and servers interact with service provider

Both the client and the server must speak the same language

- Application-level protocol : set of syntactical and semantical rules that define the messages exchanged between the client and the server and their ordering

The client server model (2)



Client and servers interact with service provider

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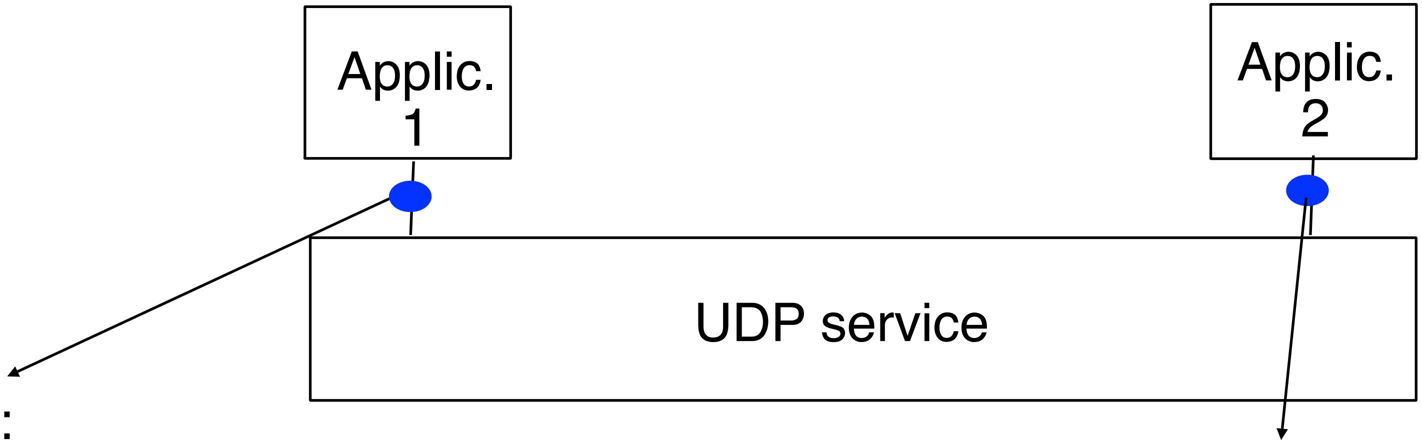
Transport service on the Internet

On the Internet, applications can use two different transport services

- The service provided by the User Datagram Protocol (UDP)
  - unreliable connectionless service with error detection
- The service provided by the Transmission Control Protocol (TCP)
  - reliable bytestream connection-oriented service

UDP service

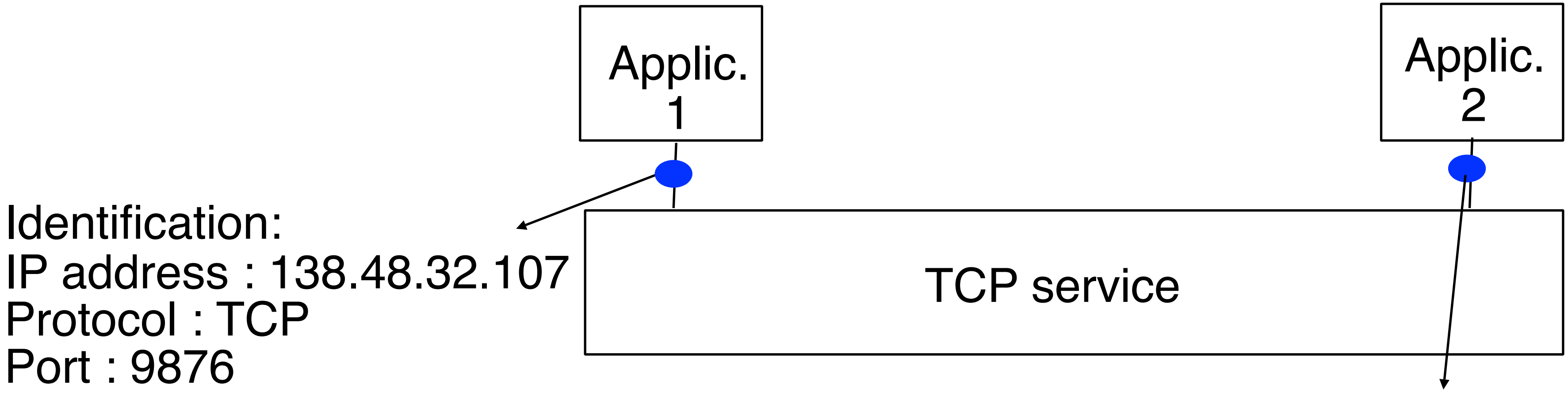


Identification:
IP address : 2001:6a8:3080:2:217:f2ff:fed6:65c0
Protocol : UDP
Port : 1234

Identification
IP address : 2001:4860:a005::68
Protocol : UDP
Port : 53

- Identification of an application
  - IP address + UDP + port number
- Characteristics of UDP service
  - connectionless
  - unreliable
    - messages can be lost
    - transmission errors can be detected but not recovered
    - sequence is not preserved
  - Maximum size of messages : almost 64 Kbytes

TCP service



Identification
IP address: 139.165.16.12
Protocol : TCP
Port : 80

- Identification of an application
  - IP address + UDP + port number
- Characteristics of TCP service
  - connection-oriented
  - bidirectional
  - reliable
  - byte stream
  - connection release
    - abrupt if initiated by service provider
    - graceful or abrupt if initiated by user

Internet applications

Contents

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Names and addresses

Names and addresses

Address of a server

- IP Address of the host on which the server is running
- port number (TCP or UDP)
  - usually well known port number

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Drawback

- Difficult to remember an IP address for a human

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Drawback
- Difficult to remember an IP address for a human

Idea
- Replace IP address by a hostname
- Easier for humans
  - but IP address is necessary to contact server

- How to translate a hostname in an IP address ?

Names and addresses (2)

`hosts.txt` file

- contains the name-address table
- must be updated regularly

```
#
# Internet host table
#
127.0.0.1        localhost
138.48.32.99     babbage
138.48.32.100    leibniz
138.48.32.1      routeur
138.48.32.92     corneille
138.48.32.107    backus
138.48.20.152    arzach
138.48.32.137    almin01
138.48.32.170    duke
```

- cannot be used in a large network

Hostnames

Requirement

- Host names should be unique

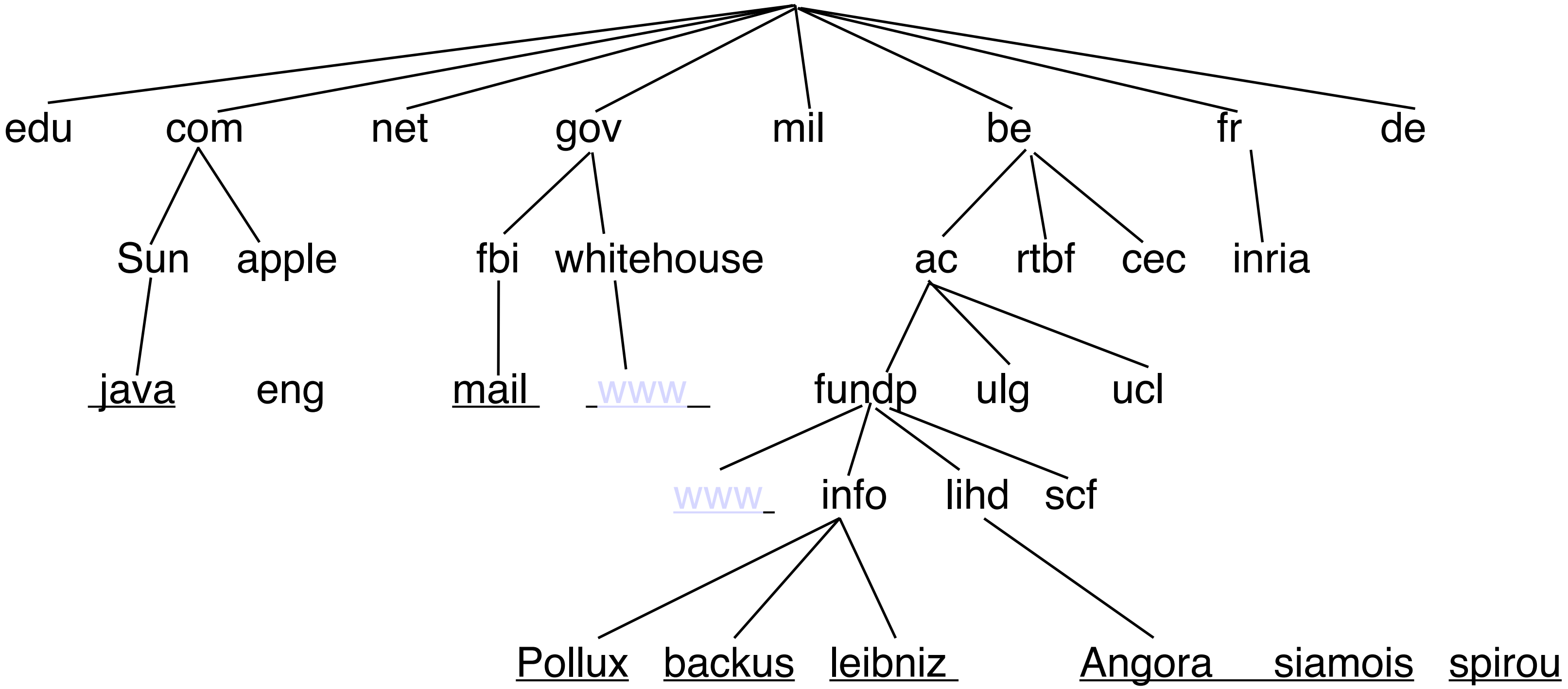
How to achieve this in a scalable manner ?

- Introduce hierarchy
- Each hostname is composed of two parts
  - domain name (globally unique)
  - hostname (unique within a given domain)

- How to uniquely distribute domain names ?
  - Introduce hierarchy
  - A small number of top-level domain names
  - Inside each top-level domain, allocate uniquely second level domain names
  - Inside each seconde-level domain, allocate uniquely either third-level domain names or host names,
  - ...

Host names and domain names

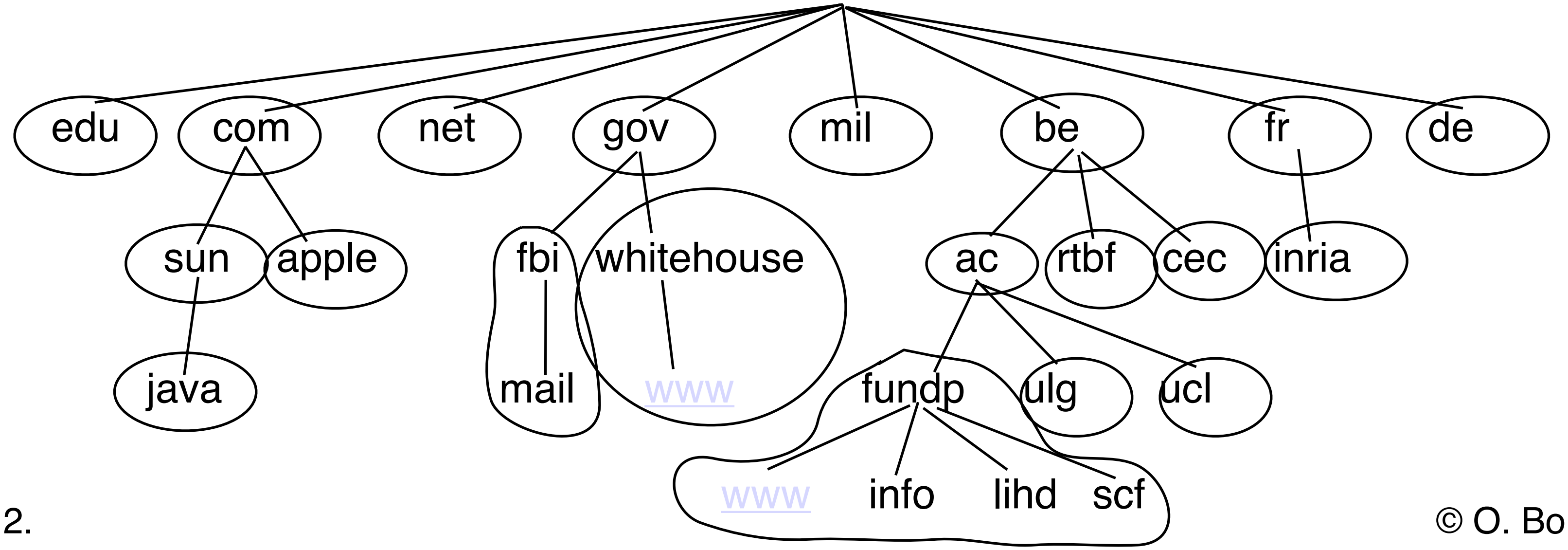
Tree of all host names



How to translate names into addresses ?

How to efficiently translate a host name ?

- By using a centralised database
  - there are more than 1 billion host names today
- By using a distributed database
  - DNS : Domain Name System
  - relies on the hierarchy of domain names
  - there is one server responsible for each domain and this server must be queried to translate host names inside this domain



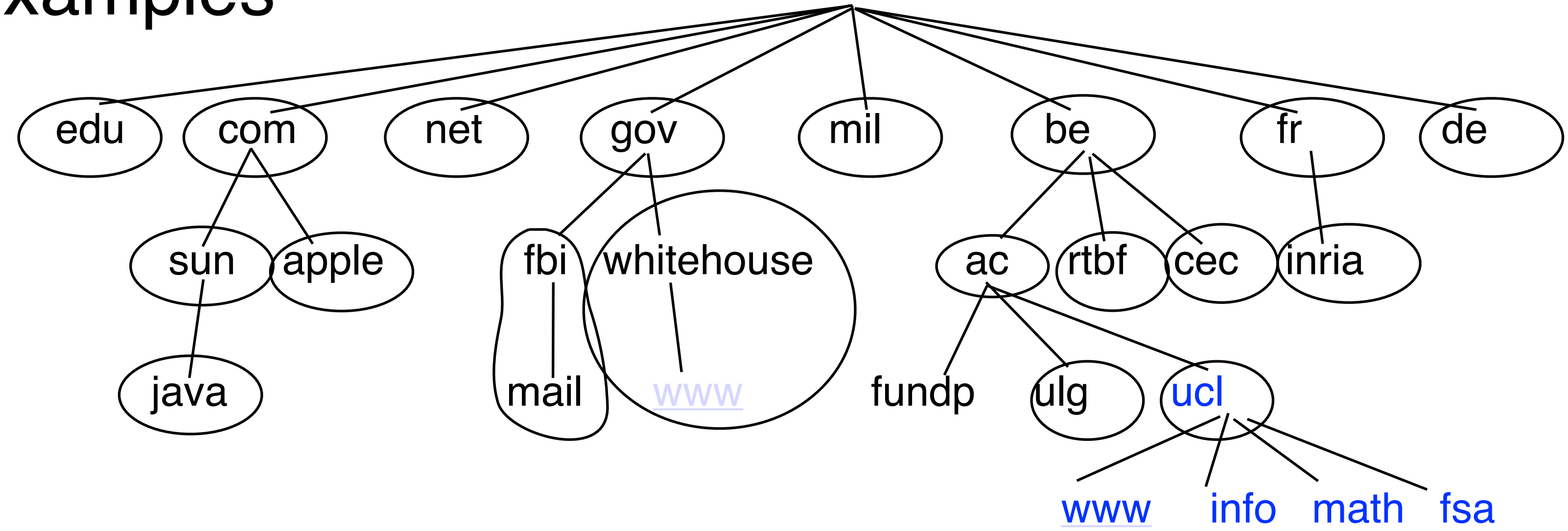
How to translate names into addresses ?

Domain Name Service (DNS)

Each DNS server is responsible for a domain and knows

- The IP addresses of all host names in this domain
- The IP addresses of the DNS servers responsible for subdomains

Examples



java.sun.com

www.ucl.ac.be

DNS resolver

To be able to translate name to addresses, a DNS implementation needs

- to know actual list of IP addresses of root servers
- to implement the DNS protocol and traverse the domain names hierarchy
- Difficult to do this on all endhosts

Solution

- DNS resolver
  - one resolver for a set of endhosts
  - maintains up-to-date list of IP addresses of root servers
  - implements DNS protocol
- endhosts
  - only need to be able to send DNS requests to resolver
  - must know IP address of closest DNS resolvers

DNS : optimisations

Reduce risk of failures

- several root-servers
- server DNS servers authoritative for each domain
- each endhost can send queries to multiple resolvers

Improved performance

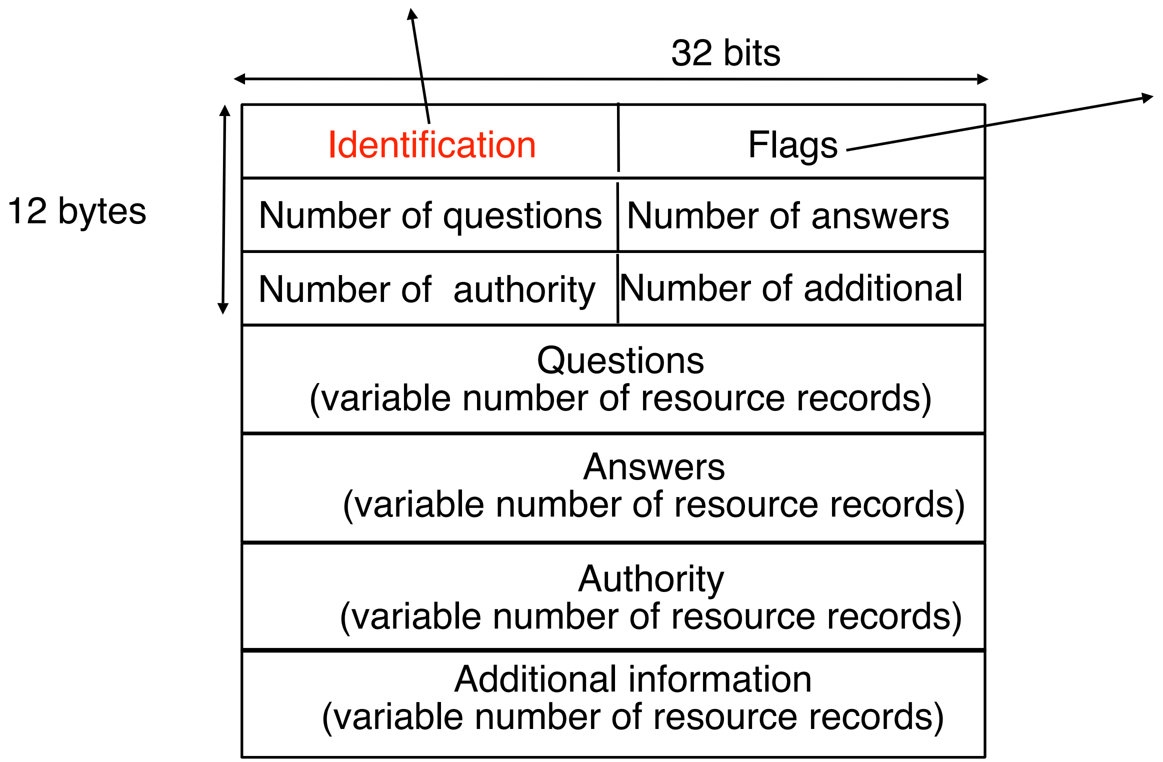
- avoid sending several times the same query
- cache memory on DNS resolvers containing
  - recent name-addresses translations
  - addresses of DNS servers recently contacted

DNS protocol

- usually runs over UDP
- sometimes is also used over TCP

DNS : message format

Each DNS request contains a number that will be returned in the response by the server to allow the client to match the request.



Identification	Flags
Number of questions	Number of answers
Number of authority	Number of additional
Questions (variable number of resource records)	
Answers (variable number of resource records)	
Authority (variable number of resource records)	
Additional information (variable number of resource records)	

Question/Response
Recursive question or not
Authoritative answer or not
Possible error

DNS : resource records

Each DNS messages is composed of resource records (RR) encoded as TLV

< Name, Value, Type, TTL>

Lifetime of the RR in server's cache

Types de RR

- A (Address)
  - Name is a hostname and Value an **IPv4 address**
- AAAA (Address)
  - Name is a hostname and Value an **IPv6 address**
- NS (NameServer)
  - Name is a domain name and Value is the hostname of the DNS server responsible for this domain
- MX (Mail Exchange)
  - Name is a domain name and Value is the name of the SMTP server that must be contacted to send emails to this domain
- Type CNAME
  - Alias

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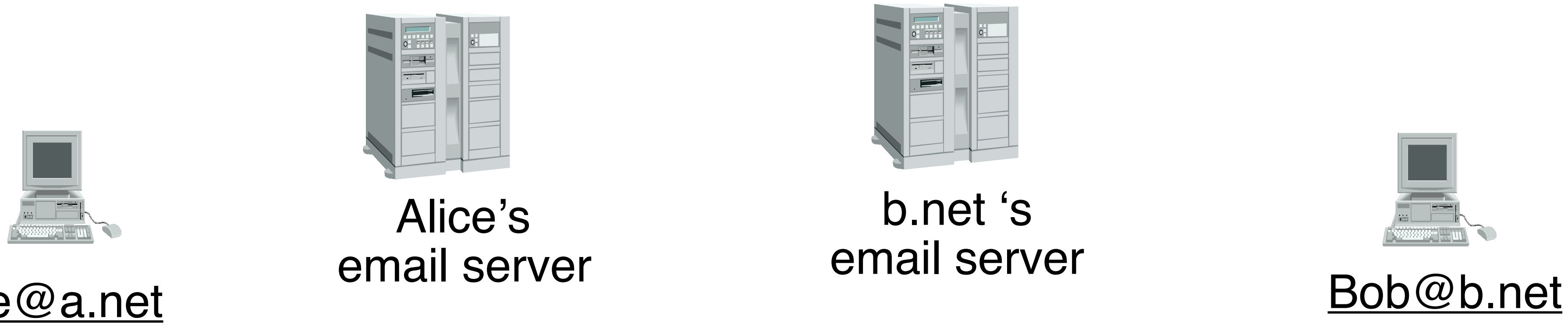
Email

Simplified model

Alice sends an email to Bob



Alice@a.net

Alice's
email server

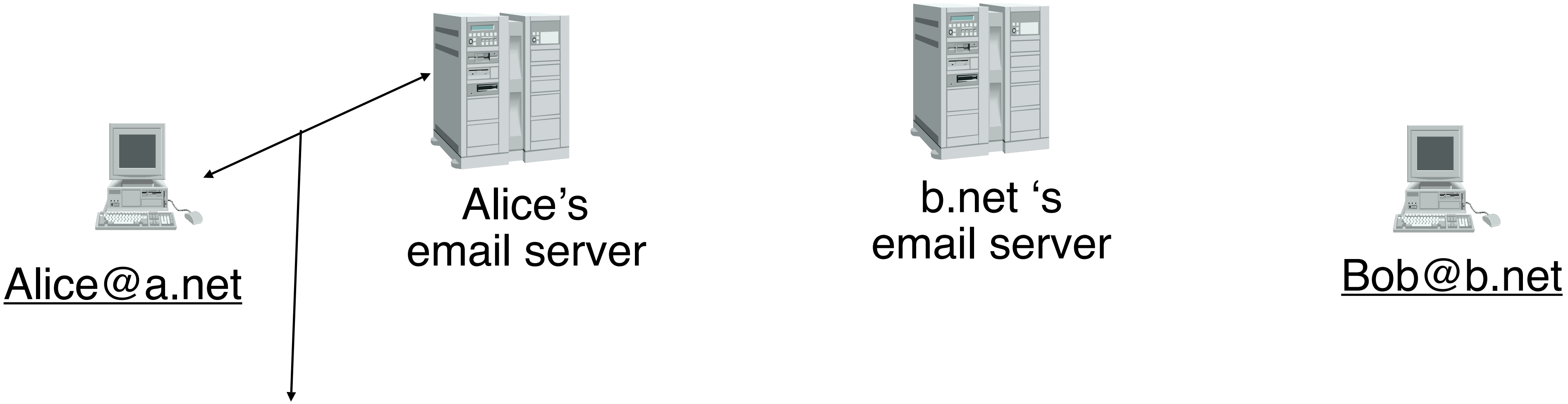
b.net 's
email server

Bob@b.net

Email

Simplified model

Alice sends an email to Bob

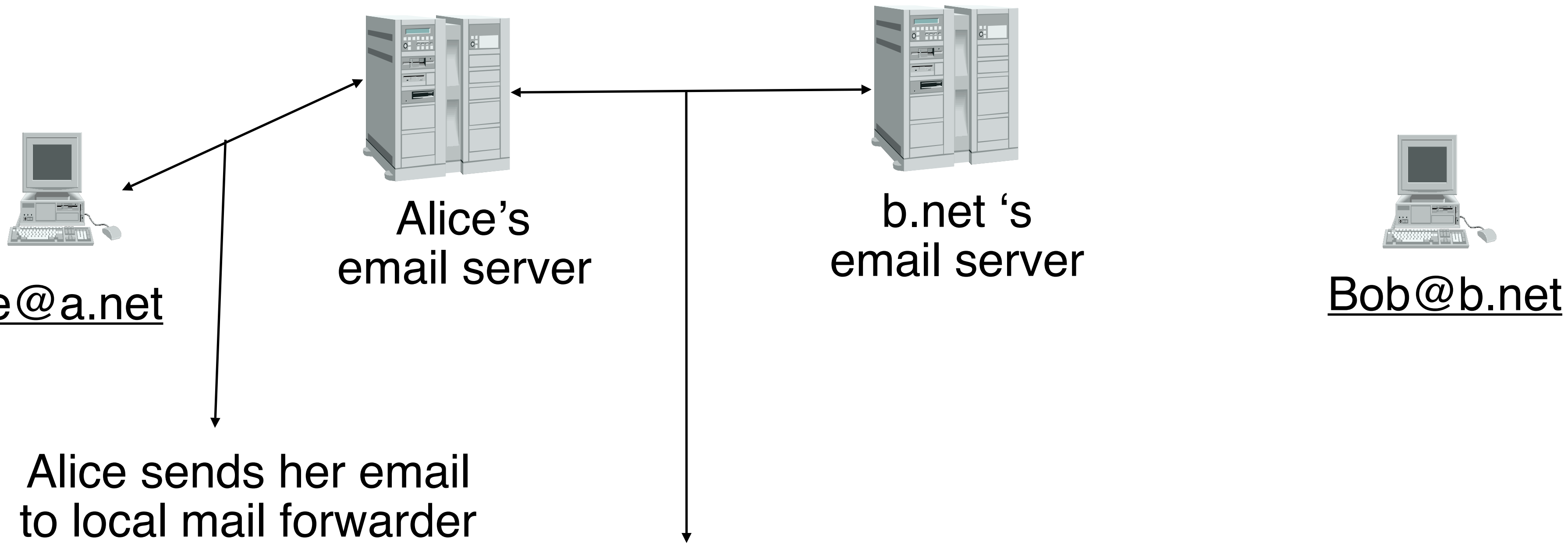


Alice sends her email
to local mail forwarder

Email

Simplified model

Alice sends an email to Bob



Alice@a.net

Alice's
email server

b.net 's
email server

Bob@b.net

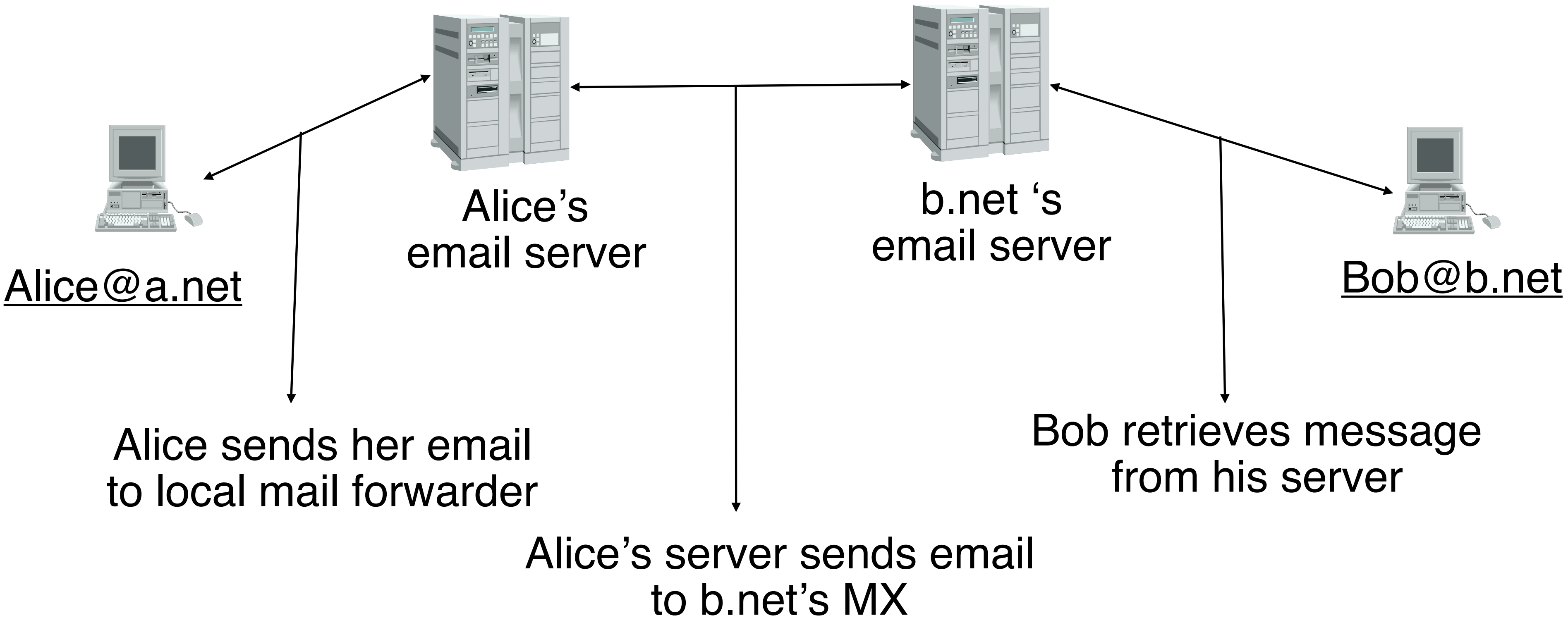
Alice sends her email
to local mail forwarder

Alice's server sends email
to b.net's MX

Email

Simplified model

Alice sends an email to Bob



Alice@a.net

Alice's email server

b.net 's email server

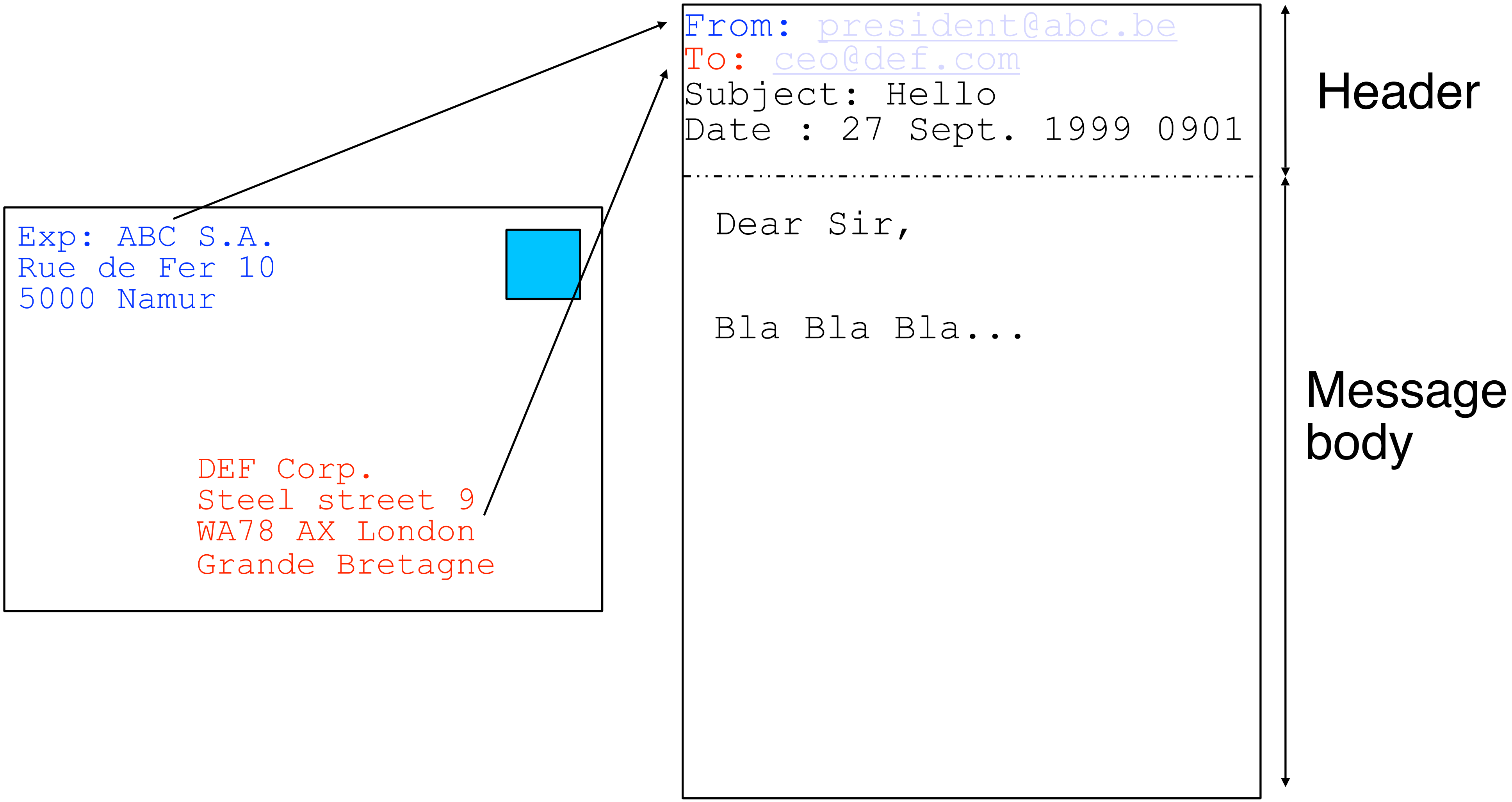
Bob@b.net

Alice sends her email to local mail forwarder

Alice's server sends email to b.net's MX

Bob retrieves message from his server

Email message format



Exp: ABC S.A.
Rue de Fer 10
5000 Namur

DEF Corp.
Steel street 9
WA78 AX London
Grande Bretagne

From: president@abc.be
To: ceo@def.com
Subject: Hello
Date : 27 Sept. 1999 0901

Dear Sir,

Bla Bla Bla...

Message format (2)

Header format

- Contains only US-ASCII (7bits) characters
- At least three lines that end with <CRLF>
  - From: sender@domain
  - To:recipient@domain
  - Date: <creation date of message>
    - example : 26 Aug 199 1445 EDT
- Optional fields
  - Subject: subject of message
  - cc: copy@domain
  - Message-ID: <number@domain>
  - Received: information on path followed by message
  - In-Reply-To: <message-ID>
- Header ends with empty line (<CRLF>)

MIME

MIME

Internet email was designed for US-ASCII

- How to transmit more complex messages ?

MIME

- Internet email was designed for US-ASCII
  - How to transmit more complex messages ?
- Multipurpose Internet Mail Extensions
  - Improved email message format
  - Constraints
    - must remain compatible with old email servers
      - most of them only support US-ASCII and short lines
    - must support non-English text
      - character set must be beyond 7bits US-ASCII
    - must support various formats in a single message
      - message body, attachments, ...
    - must allow to transmit audio, video, ...
      - need to identify the type of content

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      - need to identify the type of content
- Solution
  - add new optional fields in header
  - add optional fields inside message body when

MIME (2)

New header fields

- MIME-Version:
  - version of MIME used to encode message
  - current version : 1.0
- Content-Description:
  - comment describing the content of the message
- Content-Type:
  - type of information inside message
- Content-Transfer-Encoding:
  - how the message has been encoded
- Content-Id:
  - unique identifier for the content

MIME: Content-Type

- Content-Type : type/encoding
  - type of content
    - text, image, video, application
    - multipart
  - encoding of content
    - text/plain , text/html
    - image/gif, image/jpeg
    - audio/basic
    - video/mpeg, video/quicktime
    - application/octet-stream, application/postscript
    - multipart/alternative
      - message contains several times the same information with different encodings
    - multipart/mixed
      - message contains several information of different types
        - example : text of message body and attachment

Character sets and content encoding

- How to support rich character sets ?
  - Content-Type: text/plain; charset=us-ascii
    - ASCII 7bits, default
  - Content-Type: text/plain; charset=iso-8859-1
    - Character set suitable for Western European languages, defined by ISO, 8 bits per character
    - Content-Type: text/plain; charset=unicode
    - Universal character set, defined by ISO, 16 bits per character
- How to encode non-text data ?
  - data must be encoded in US-ASCII 7 bits characters
  - Base64
  - uses ASCII characteres A...Z,a...z,0...9, "+" et "/"
    - A=0, B=1, C=2, ... +=62 et /=63
  - Each character is used to encode 6 bits
    - 24 bits from initial message -> 4 ASCII characters
  - Special character “=” used for padding

Multipart/mixed

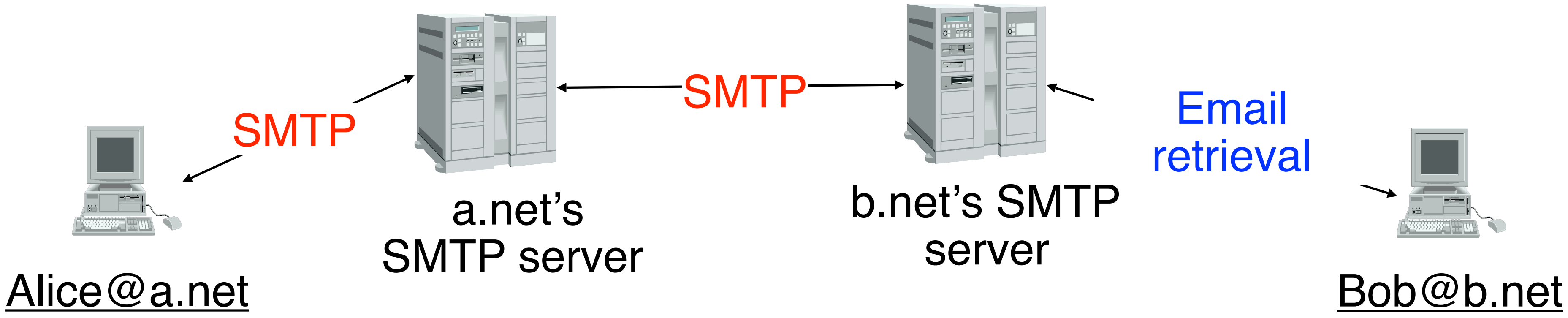
- How to place different contents and encoding in a single message ?
  - We need a delimiter between the different content types placed inside message body

```
Date: Mon, 20 Sep 1999 16:33:16 +0200
From: Nathaniel Borenstein <nsb@bellcore.com>
To: Ned Freed <ned@innosoft.com>
Subject: Test
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary="simple boundary"

preamble, to be ignored

--simple boundary
Content-Type: text/plain; charset=us-ascii

partie 1

--simple boundary
Content-Type: text/plain; charset=us-ascii

partie 2
--simple boundary
```

Email transmission

SMTP : Simple Mail Transfer protocol

- uses TCP service
- Address of SMTP server
  - IP address of server + TCP + port number: 25
    - RR of type MX can be used to find the SMTP server responsible for a given domain



SMTP

- Client-server model
  - Server waits for email messages to relay/deliver
  - Client sends email messages through server

- Application-level protocol
  - client opens TCP connection
  - Client sends commands composed of
    - `command parameter <CRLF>`
      - HELO
      - MAIL FROM:
      - RCPT TO:
      - DATA
      - QUIT
  - Server answers with one-line replies
    - `numeric_code comment (text) <CRLF>`
      - 250 OK
      - 221 closing

SMTP (2)

Three phases of SMTP

1. Establishment of an SMTP association
   - TCP connection established upon request from client
   - Server greetings
   - HELO command from client
2. Message transfer
   - MAIL FROM: <user@domaine>
   - RCPT TO: <user@domaine>
   - DATA
     - transmission of entire message including headers
     - one line containing only the dot "." characters marks end of message
   - Other subsequent messages can be transmitted after
3. Release of the SMTP association
   - QUIT
   - Closing message from server
   - TCP connection is closed

Retrieval of email messages

In the old days

1. Destination is always connected to the Internet
   - email addresses are username@hostname
   - When an email arrives, it is stored in a file that belongs to the user, e.g. `/var/mail` on Unix

Today

- Most networks have one or a few SMTP servers used to receive emails, but also detect spam, viruses, ...
- Endusers retrieve their emails from this server
  - Post Office Protocol (POP)
  - Internet Mail Access Protocol (IMAP)
  - Webmail

POP

- Goal
  - Allow authenticated users to retrieve email messages from server
- Operation
  - POP uses TCP service
  - Address of POP server
    - Host address + TCP + port number : 110
  - Client send commands
    - command : one ASCII line ending with <CRLF>
    - `USER, PASS, STAT, RETR, DELE, QUIT`
  - server replies with
    - `+OK` if command was successful
      - email messages follow some +OK replies
    - `-ERR` in case of errors

POP (2)

Three phases of the protocol

1. Authorisation : checking the user credentials
   - USER <username>
   - PASS <password>
2. Transaction
   - retrieval and removal of messages
   - STAT
     - list headers of stored messages
   - RETR <n>
     - retrieval of the nth message
   - DELE <n>
     - the nth message is marked for deletion
3. Update
   - End of the retrieval phase
     - Messages marked for deletion are removed from server
     - TCP connection is closed

Internet applications

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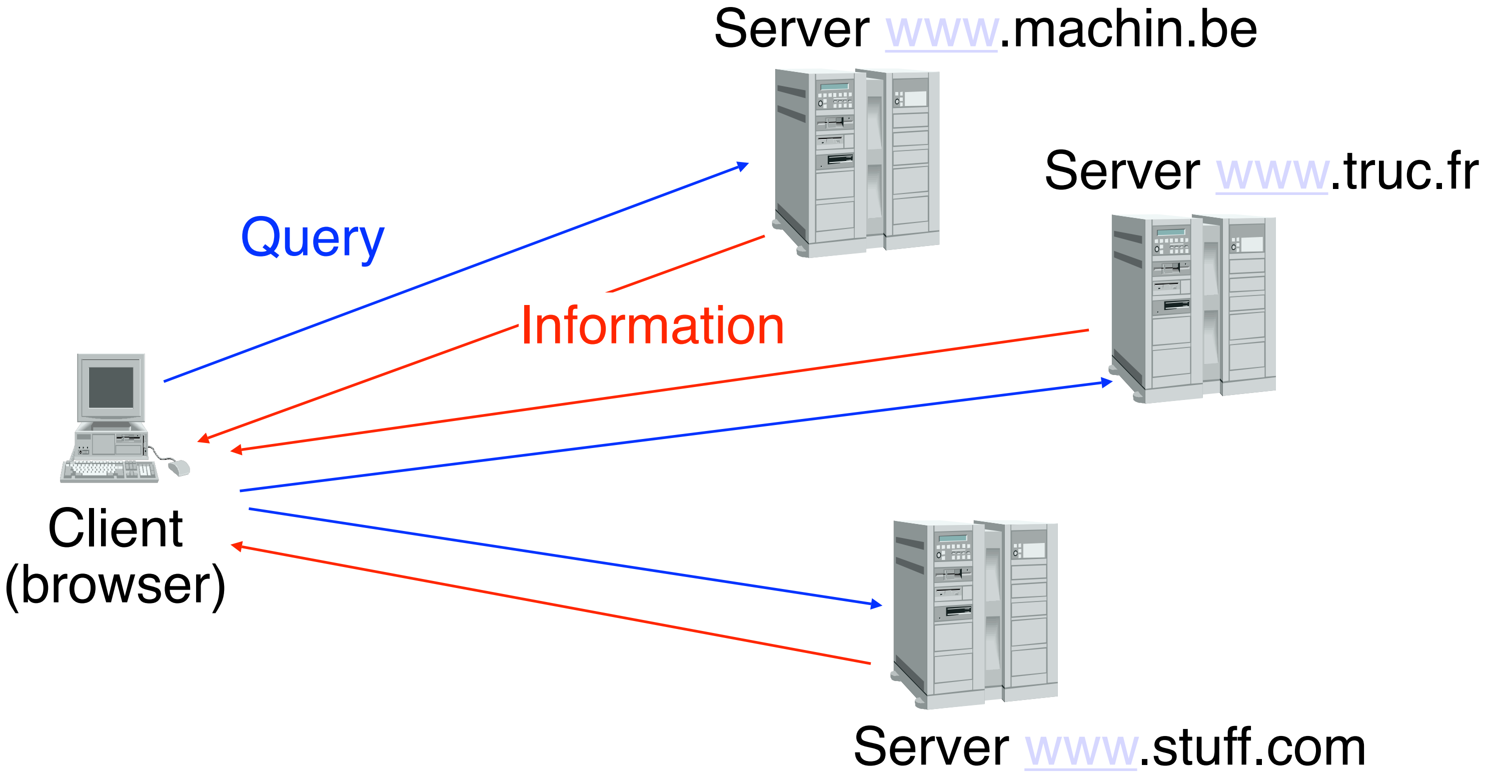
World Wide Web

Goals

- Allow browsers to browse hypertext documents stored on multiple servers



World Wide Web (2)

The five key elements of www

1. An addressing scheme that allows to identify any document stored on a server
   URL : Uniform Resource Locator
2. An hypertext language that allows to easily write documents with hypertext links
   HTML : HyperText Markup Language
3. An efficient and lightweight application-level protocol to exchange documents
   HTTP : HyperText Transfer Protocol
4. Servers
5. Clients (browsers)

Uniform Resource Locator (URL)

Uniform Resource Locator (URL)

- generic syntax : <protocol>://<document>
  - protocol used to retrieve document from server
    - http is the most common one but others are frequently used
  - document indicates the server and the location of the document
  - *<user>:<password>@*<server>*:<port>*/<path>
    - <user> : optional username
    - <password> : optional password
    - <machine> : hostname or IP address of the server that hosts the document
    - <port> : optional port number
    - <path> : document location on server
  - examples
    - http://www.info.ucl.ac.be
    - http://alice:secret@inl.info.ucl.ac.be:80/index.html

HTML

HyperText Markup Langage

Language used to encode documents on the web

Keywords

```
<HTML>...</HTML>
<HEAD>...</HEAD>
<BODY>...</BODY>
<TITLE>..</TITLE>
<B>...</B>
<I>...</I>
<H1>...</H1>
<P>
<HR>
<UL>...</UL>
<OL>...</OL>
<IMG SRC="URL">
<A HREF="URL">text anchor</A>
```

HTML (2)

Example

Header

Body

```
<HTML>

<HEAD>
<TITLE>HTML test page</TITLE>
</HEAD>

<BODY>
<IMG SRC="http://www.images.be/logo.gif">
<H1>Web servers from UCL UCL<P></H1>
<HR>
<UL>
 <LI><A HREF="http://www.uclouvain.be">UCL</A>
 <LI><A HREF="http://www.info.ucl.ac.be">CSE Dept.</A>
 <LI><A HREF="http://www.math.ucl.ac.be">Math</A>
</UL>
</BODY>

</HTML>
```

Image on remote server

First level title

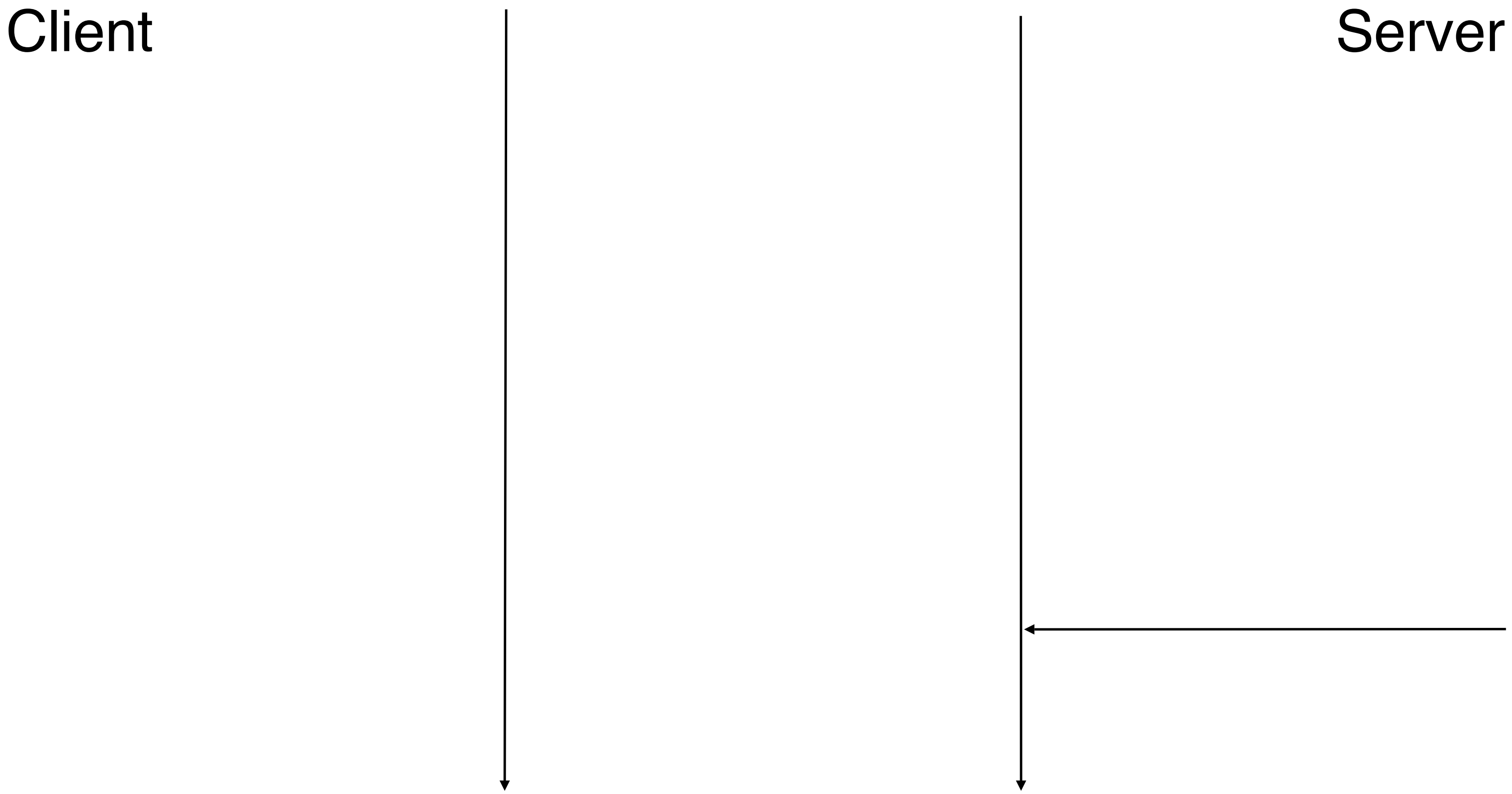
External hypertext link

Information transfer www

HTTP 1.0 - non-persistent connection

Principle

relies on TPC service (default port : 80)
Client sends request, server sends reply



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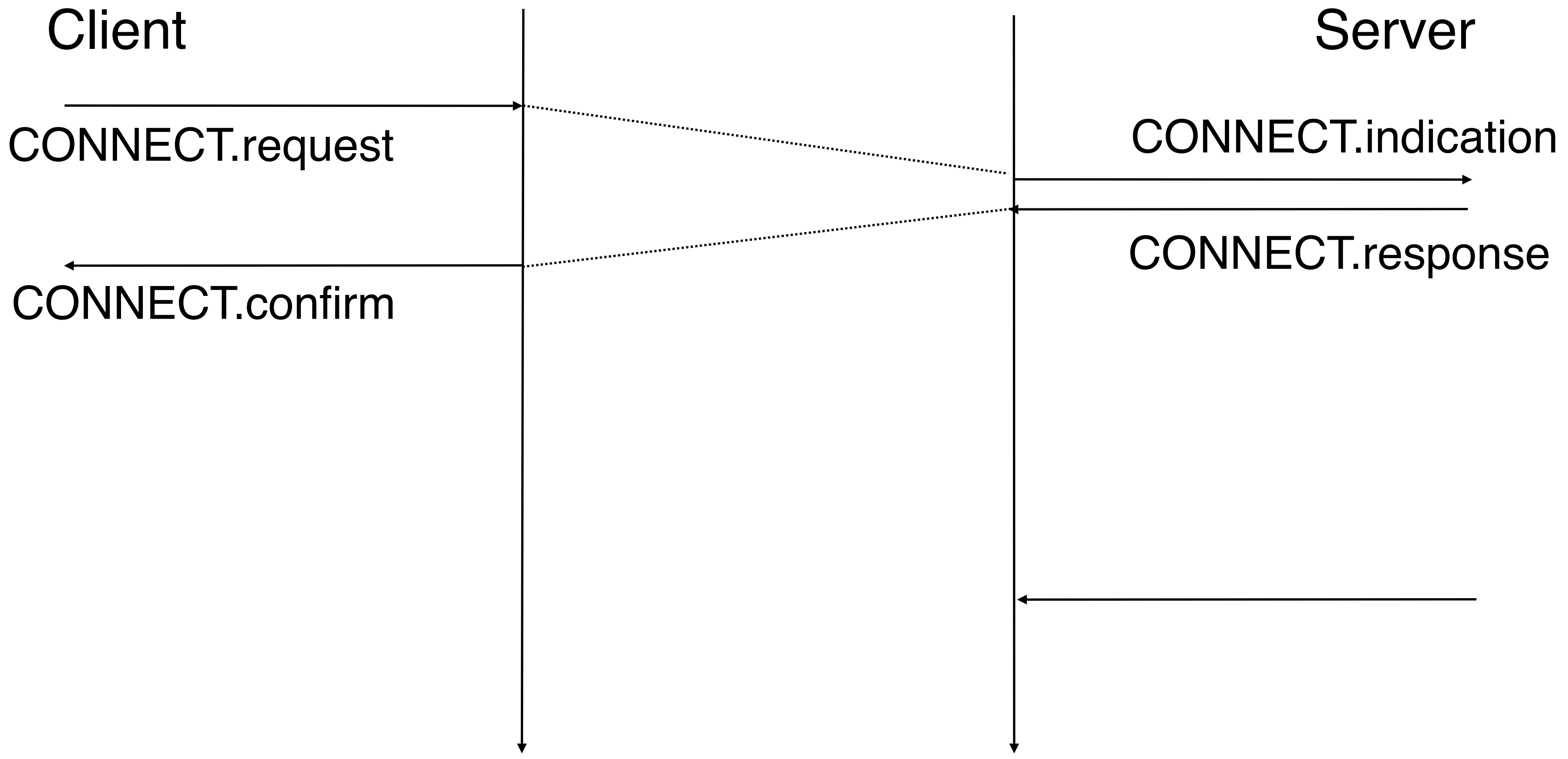

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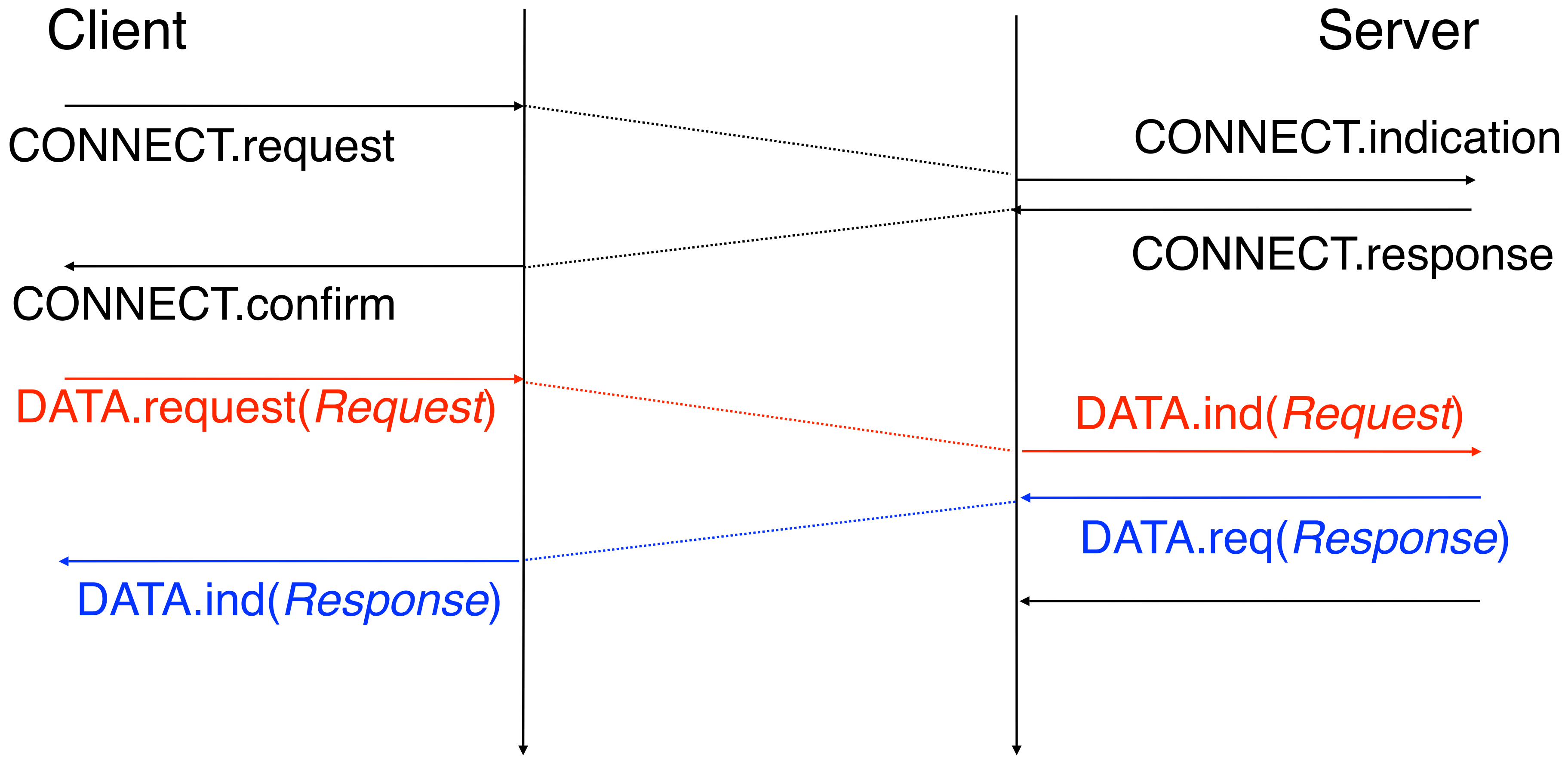

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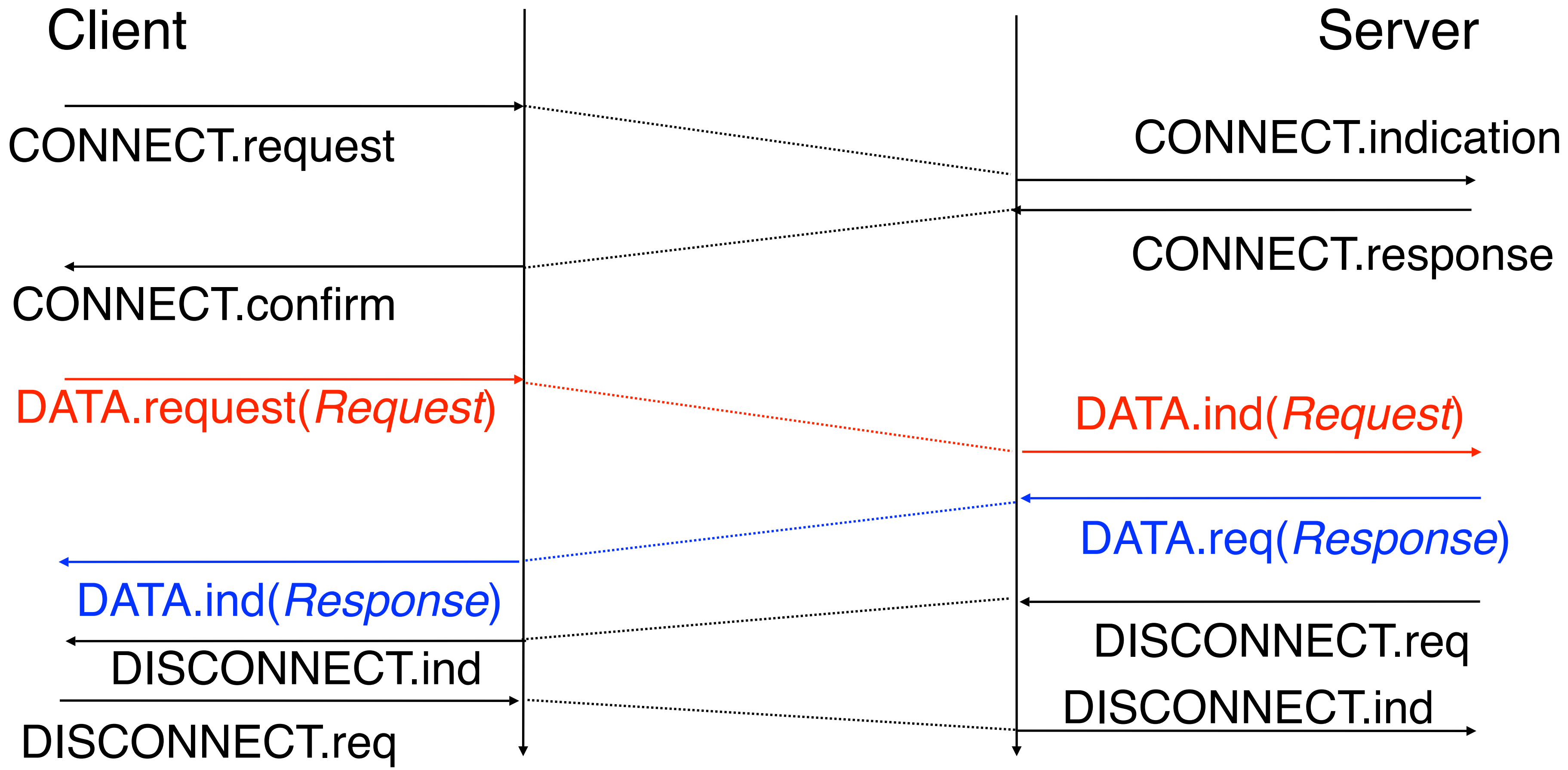


Client

Server

CONNECT.request

CONNECT.indication

CONNECT.response

CONNECT.confirm

DATA.request(*Request*)

DATA.ind(*Request*)

DATA.req(*Response*)

DATA.ind(*Response*)

DISCONNECT.req

DISCONNECT.ind

DISCONNECT.ind

DISCONNECT.req

HTTP

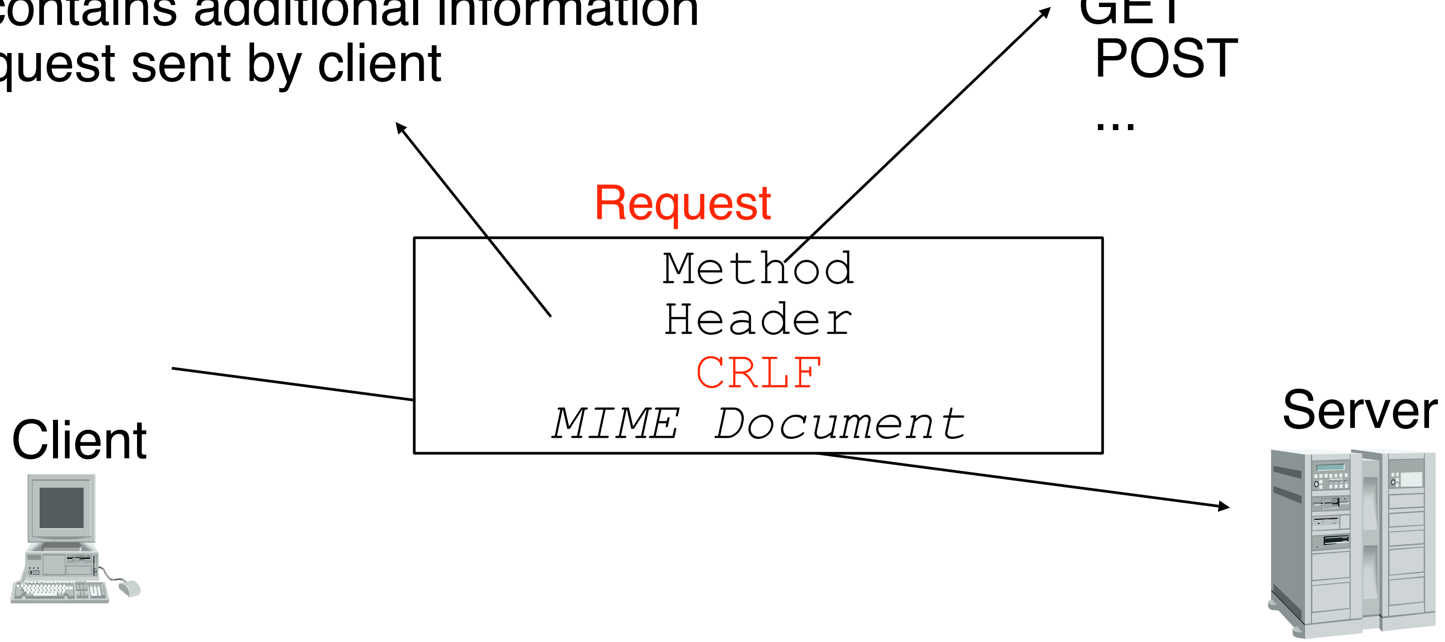
Client

Server

HTTP

Header contains additional information about request sent by client

Method
GET
POST
...



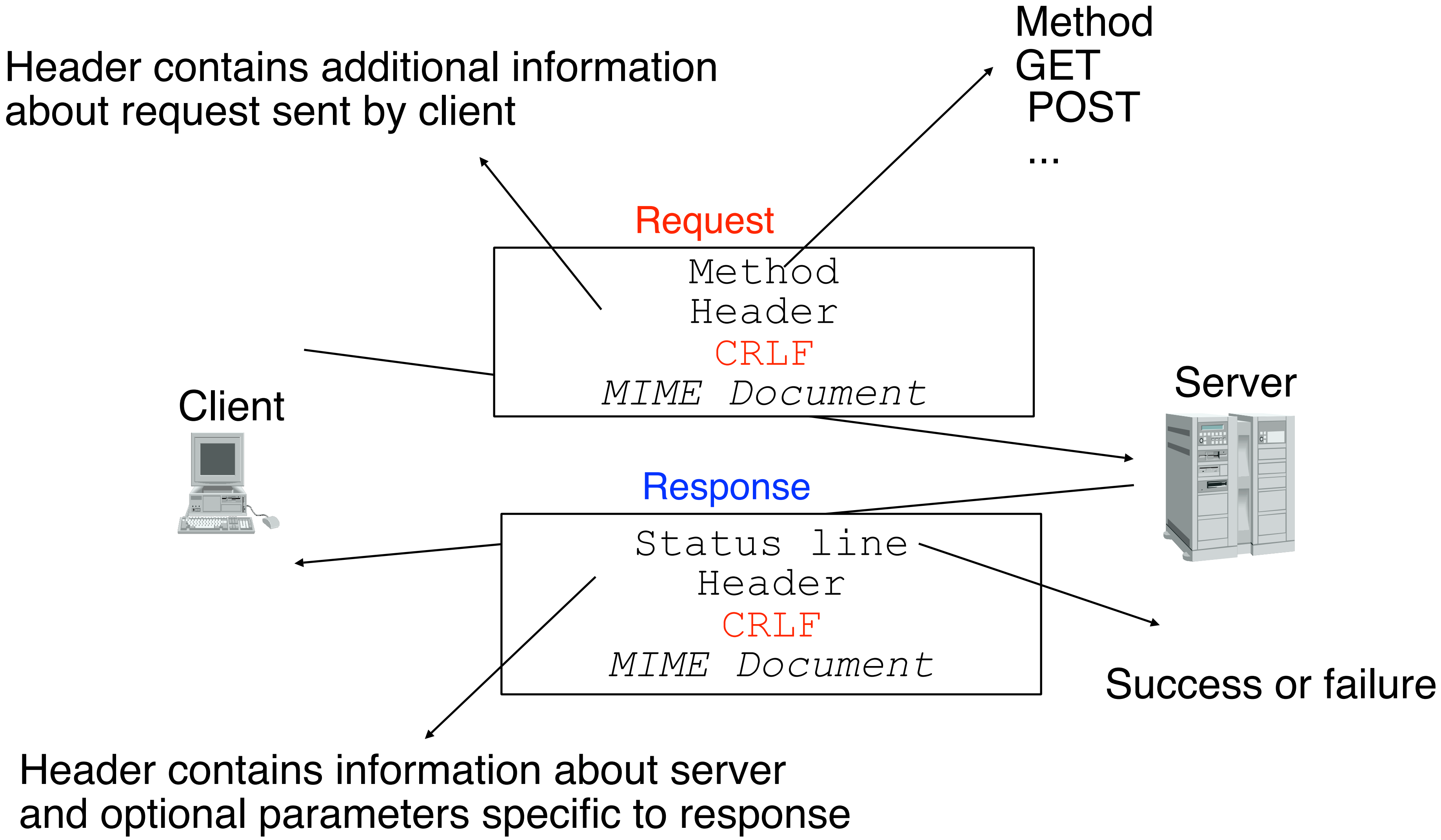
Request

```
Method
Header
CRLF
MIME Document
```

Client

Server

HTTP



Method
GET
POST
...

Header contains additional information
about request sent by client

Request

```
Method
Header
CRLF
MIME Document
```

Client

Server

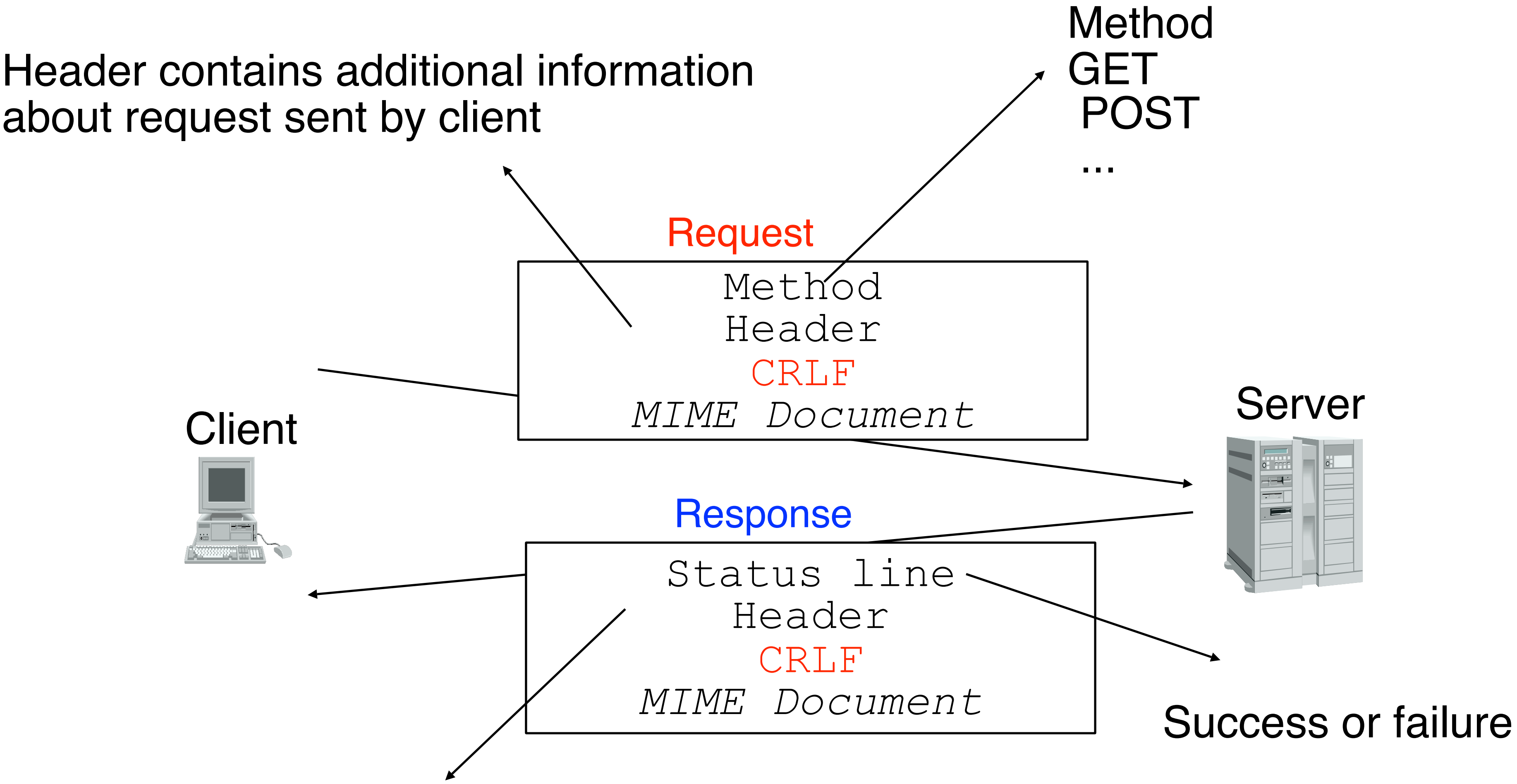
Response

```
Status line
Header
CRLF
MIME Document
```

Success or failure

Header contains information about server
and optional parameters specific to response

HTTP



Header contains additional information about request sent by client

Method
GET
POST
...

Success or failure

Header contains information about server and optional parameters specific to response

HTTP is a stateless protocol, server does not maintain any state from one request to another

POP, FTP, SMTP are examples of stateful protocols in contrast

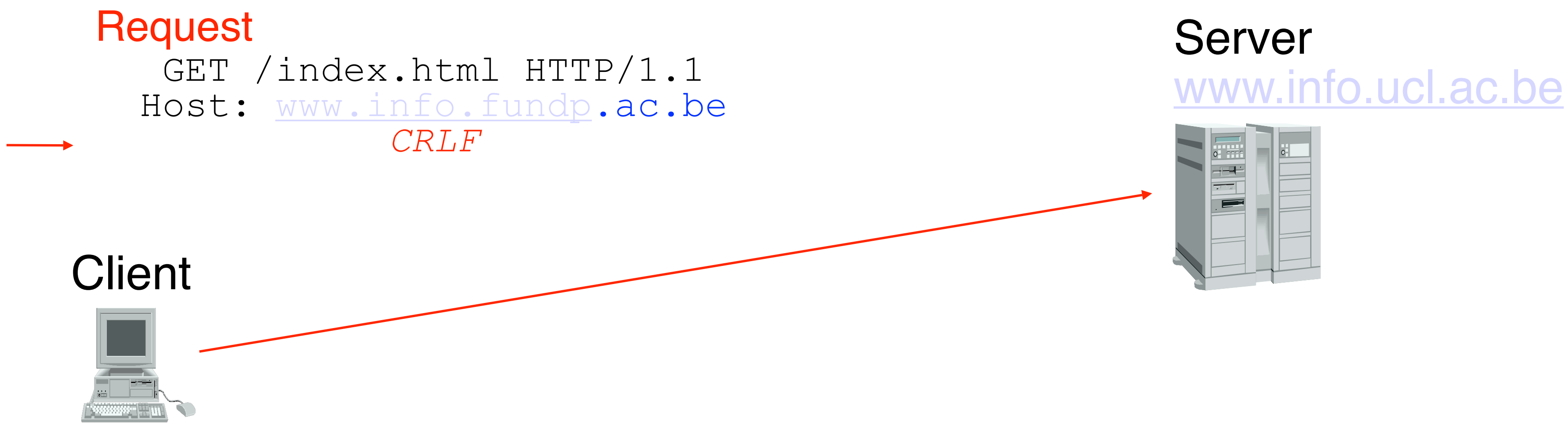
HTTP : Example

Server

www.info.ucl.ac.be

Client

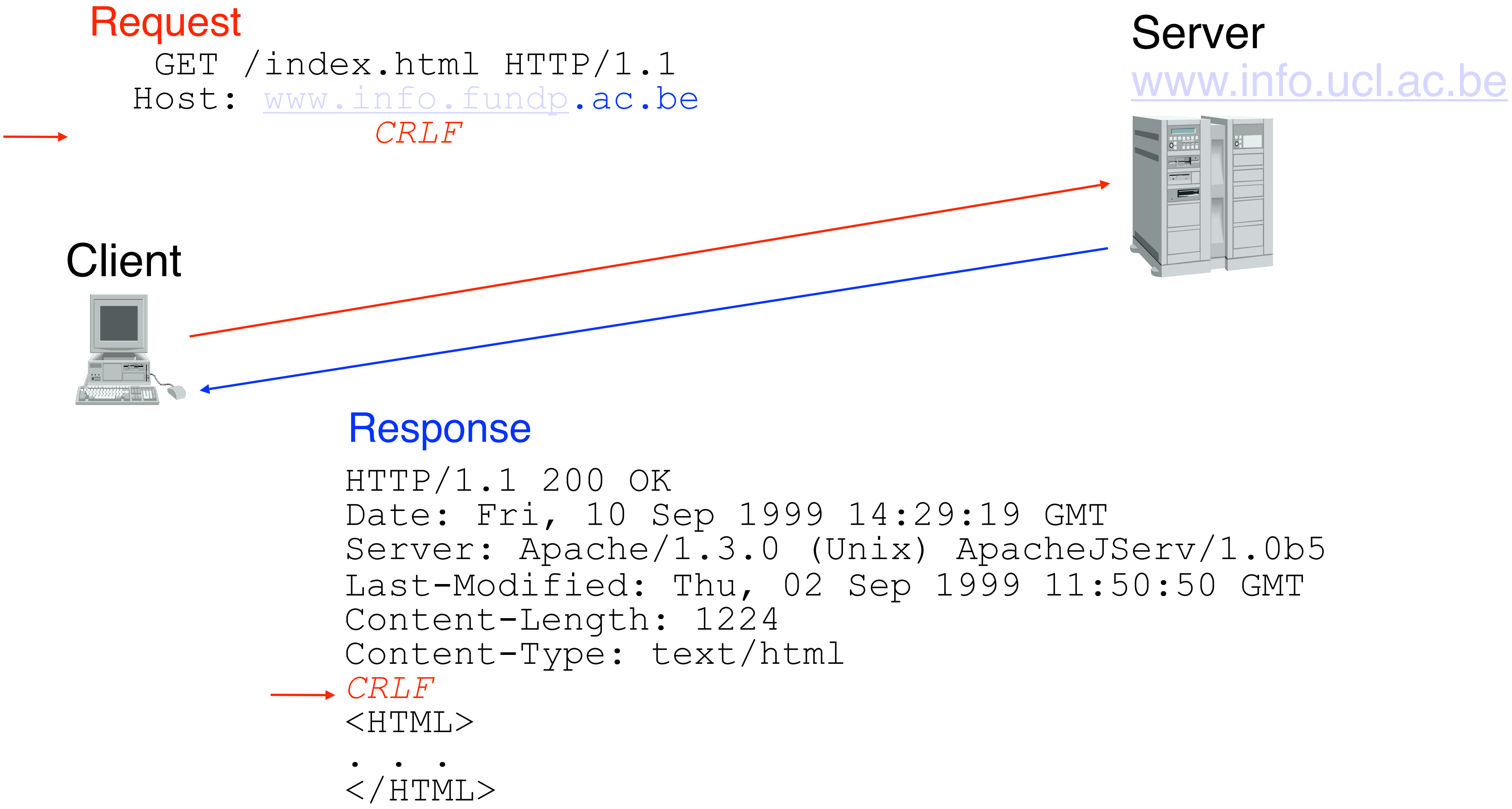
HTTP : Example



Request

```
  GET /index.html HTTP/1.1
Host: www.info.fundp.ac.be
           CRLF
```

HTTP : Example



Request

```
  GET /index.html HTTP/1.1
Host: www.info.fundp.ac.be
           CRLF
```

Server

www.info.ucl.ac.be

Client

Response

```
HTTP/1.1 200 OK
Date: Fri, 10 Sep 1999 14:29:19 GMT
Server: Apache/1.3.0 (Unix) ApacheJServ/1.0b5
Last-Modified: Thu, 02 Sep 1999 11:50:50 GMT
Content-Length: 1224
Content-Type: text/html
CRLF
<HTML>
. . .
</HTML>
```

HTTP : Methods

Methods

- GET
  - method used to request a "document" stored on server
    - GET <document> HTTP/1.0
  - example
    - `GET /index.html  HTTP/1.0`
- POST
  - method used to send a "document" to a server
    - document is part of the request and encoded as a MIME document

HTTP : Request headers

Request headers

Allow to add information about the client or the request

- `Host: <name>`
  - Name of the server where the document is stored
- `Authorization`
  - allows to perform access control
- `If-Modified-Since:  <date>`
  - server will only send the requested document if the document is more recent than date
- `Referer: <url>`
  - Information, indicates the URL visited by the client before this request
- `User-Agent: <agent>`
  - information, indicates the browser used on the client

HTTP : Status line

Status liine

- Format : `Version_HTTP Code Comment`
- Success/Failure
  - `1xx` : For information (unused)
  - `2xx` : Success
    - Example : `HTTP/1.0 200 OK`
  - `3xx` : Redirection
    - Request could not be handled on local server and should be sent to another server
    - Example :
      - `HTTP/1.0 301 Moved permanently`
      - attached MIME document will contain URL of document
  - `4xx` : Client-side error
    - examples
      - syntax error, unreachable URL, unauthorised, ...
  - `5xx` : Server-side error
    - examples :
      - internal error, method not implemented on server, ...

HTTP : Response headers

Header

- Optional information about the server, the response or the document attached to the response
- Date
  - date of the document attached to response
  - example : `Date: Wed, 05 Sep 2001 13:27:34 GMT`
- Server
  - Name and version of http server used
  - example :

    ```
    Server: Apache/1.3.20 (Unix)ApacheJServ/1.1.2 PHP/4.0.6
    ```
- Content-*
  - MIME header of the attached document
  - example :

    ```
    Content-Length: 5891
    Content-Type: text/html
    ```

HTTP 1.1

HTTP 1.1

HTTP 1.0

- a single TCP connection used to transmit a single document (html file, image,...)
  - the establishment and release of the TCP connection induce a significant overhead, in particular for small pages

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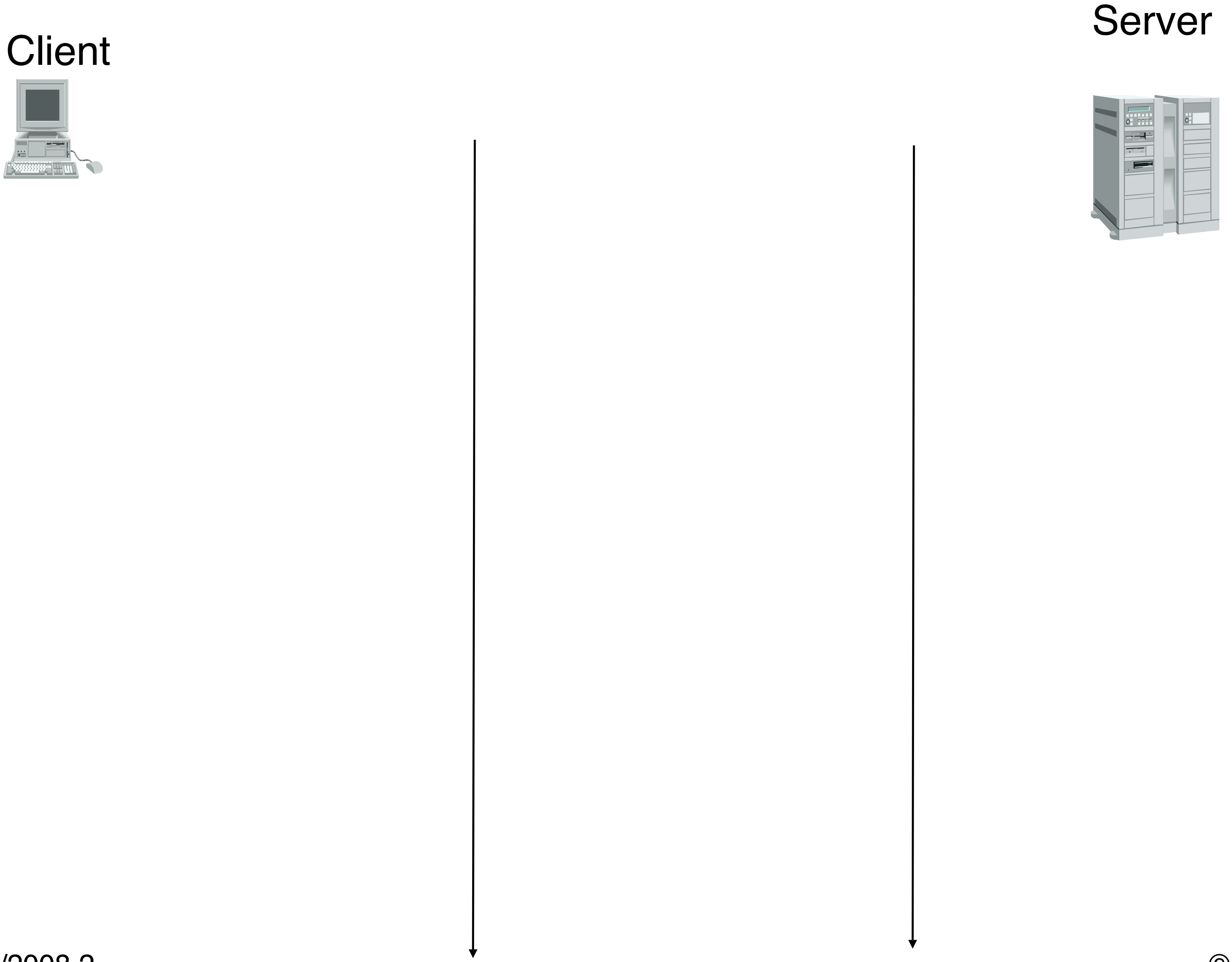
- a single TCP connection used to transmit a single document (html file, image,...)
  - the establishment and release of the TCP connection induce a significant overhead, in particular for small pages

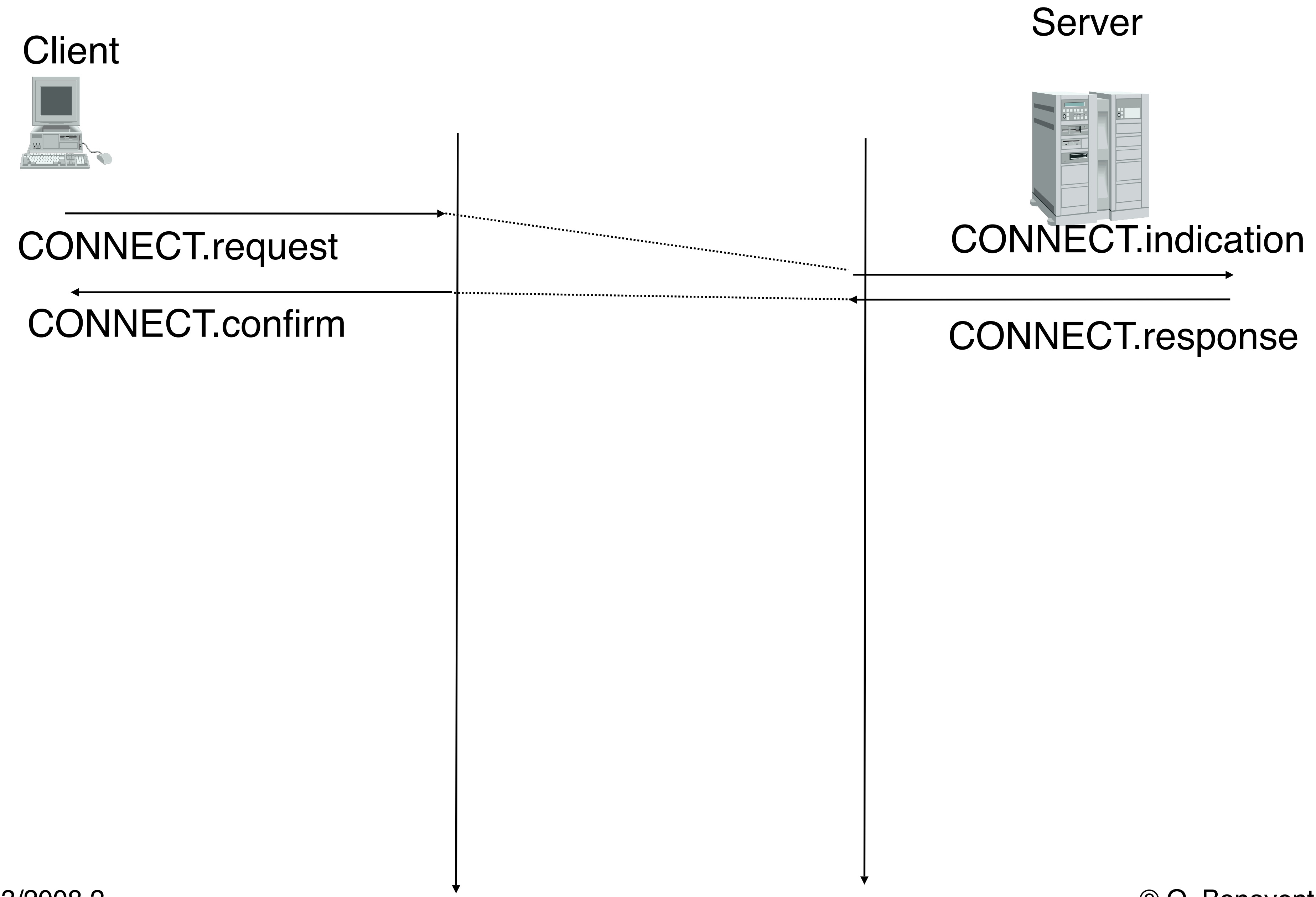
HTTP 1.1

- uses a single persistent TCP connection
  - This TPC connection can be used for several requests and the corresponding responses
  - the cost of establishing and releasing the TCP connection is amortised over multiple requests
  - Although HTTP 1.1 uses a single TCP connection for multiple requests, HTTP 1.1 remains stateless

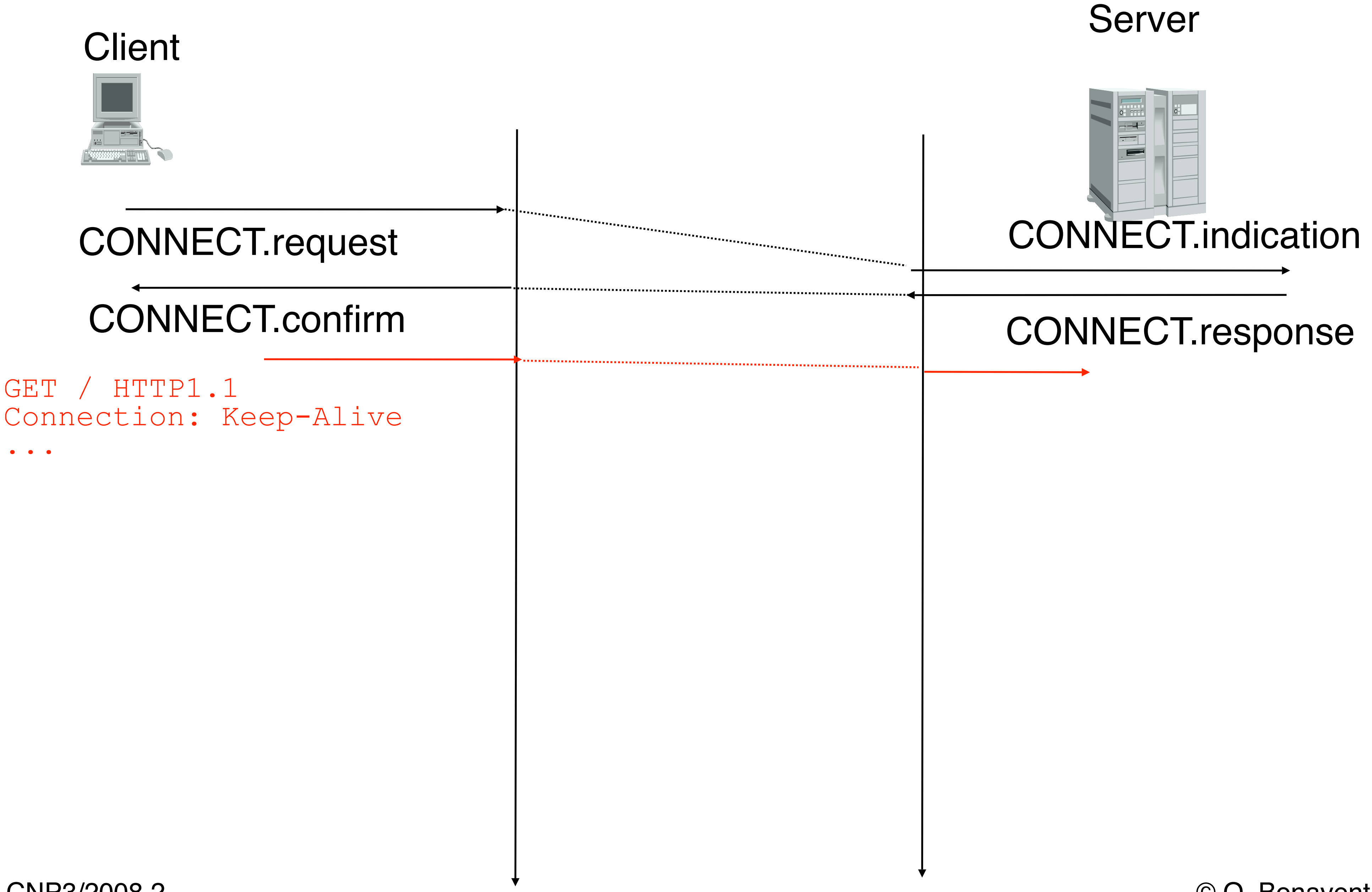
HTTP 1.1 : Persistent connection



HTTP 1.1 : Persistent connection



HTTP 1.1 : Persistent connection



Client

Server

CONNECT.request

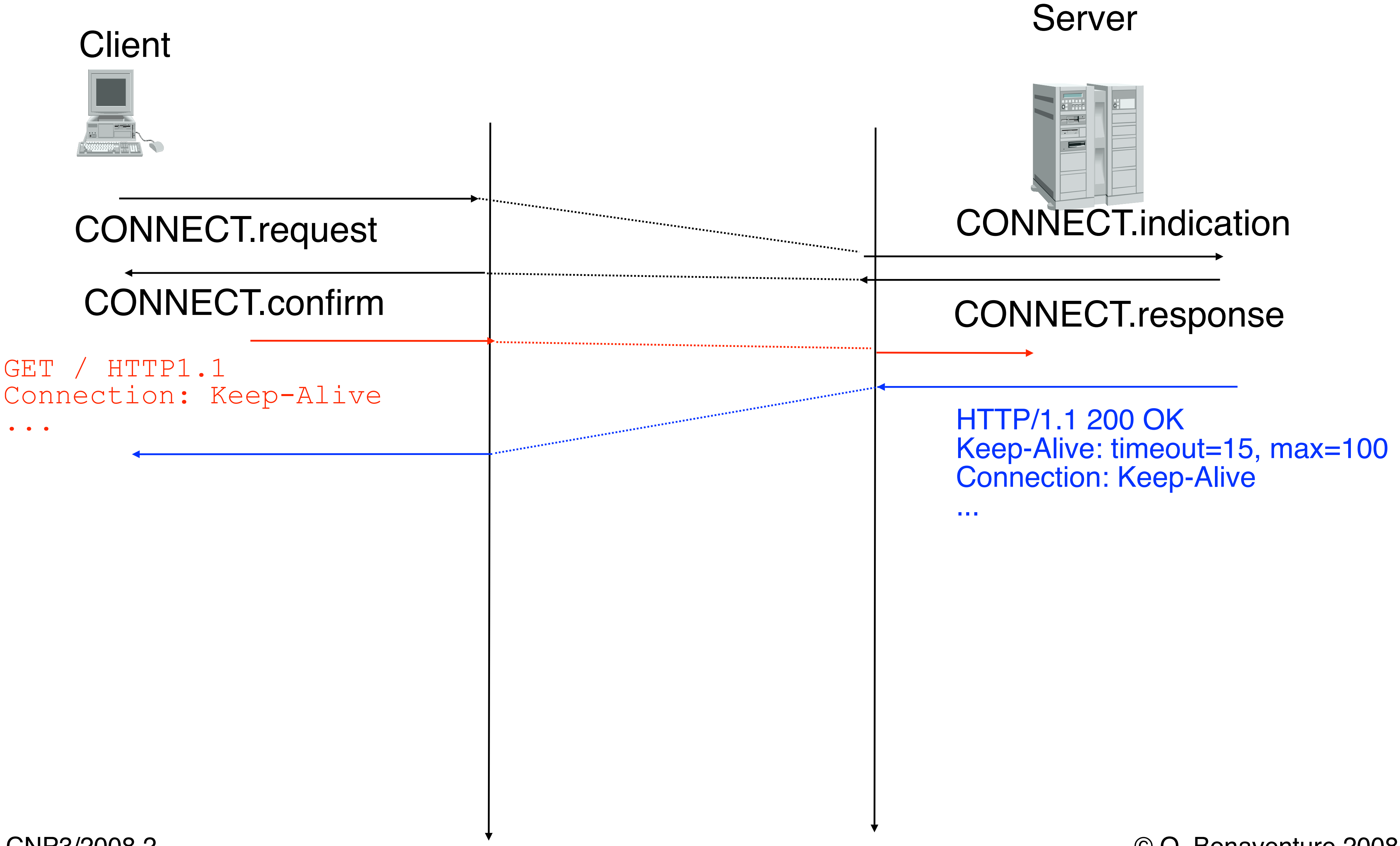
CONNECT.indication

CONNECT.response

CONNECT.confirm

```
GET / HTTP1.1
Connection: Keep-Alive
...
```

HTTP 1.1 : Persistent connection



Client

Server

CONNECT.request

CONNECT.indication

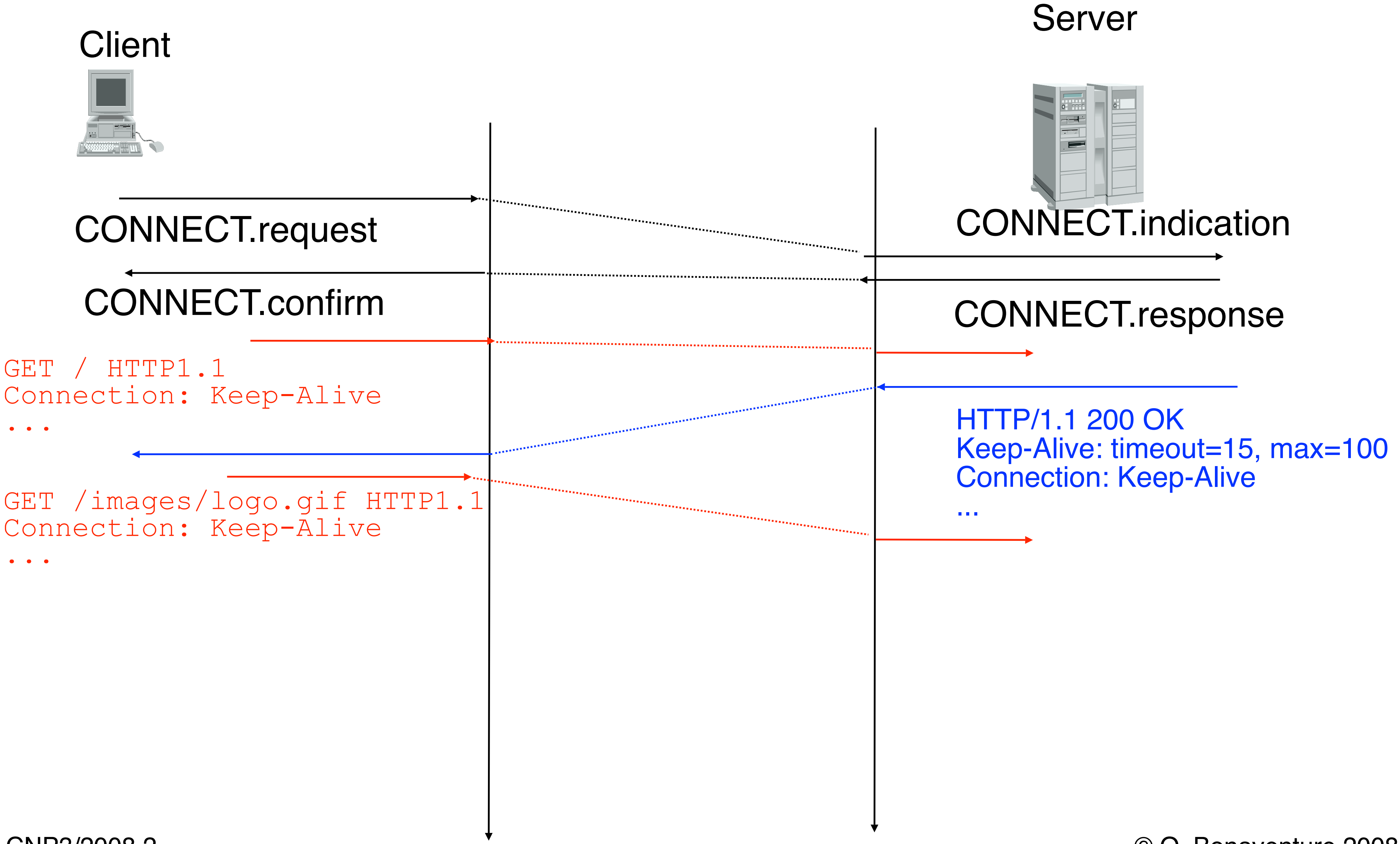
CONNECT.confirm

CONNECT.response

```
GET / HTTP1.1
Connection: Keep-Alive
...
```

```
HTTP/1.1 200 OK
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
...
```

HTTP 1.1 : Persistent connection

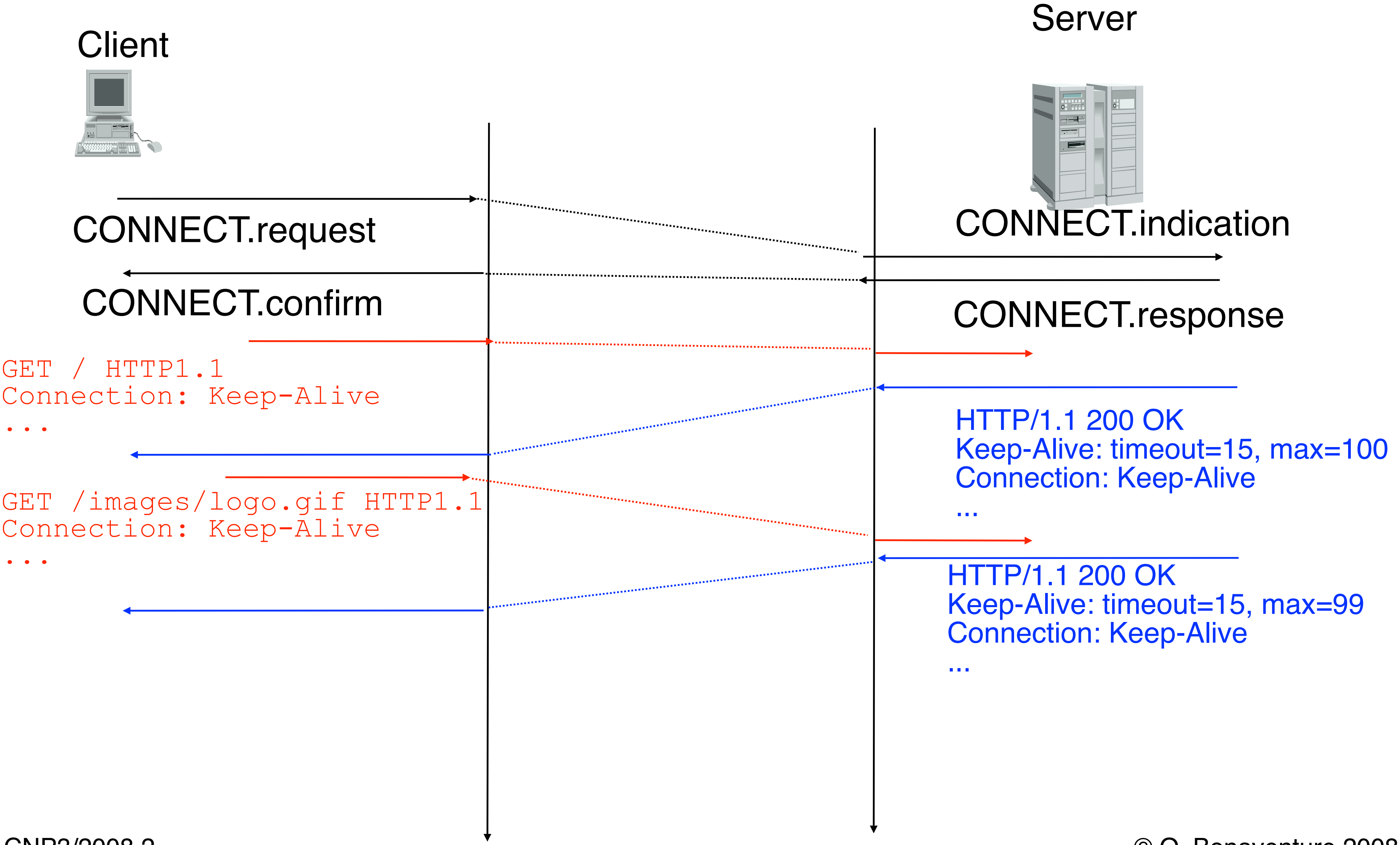


```
GET / HTTP1.1
Connection: Keep-Alive
...
```

HTTP/1.1 200 OK
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
...

```
GET /images/logo.gif HTTP1.1
Connection: Keep-Alive
...
```

HTTP 1.1 : Persistent connection



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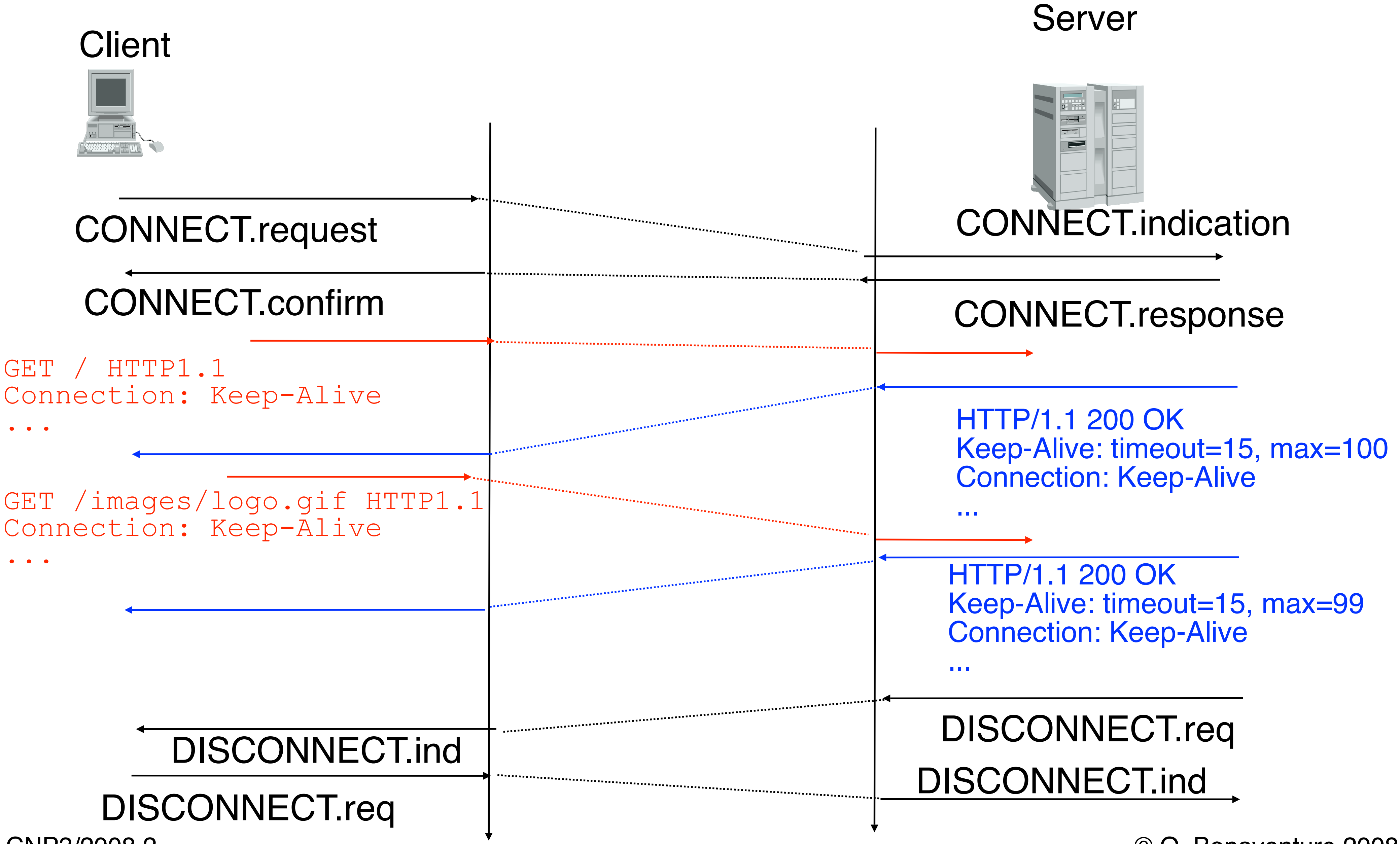
```
GET / HTTP1.1
Connection: Keep-Alive
...
```

```
HTTP/1.1 200 OK
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
...
```

```
GET /images/logo.gif HTTP1.1
Connection: Keep-Alive
...
```

```
HTTP/1.1 200 OK
Keep-Alive: timeout=15, max=99
Connection: Keep-Alive
...
```

HTTP 1.1 : Persistent connection



Client

Server

CONNECT.request

CONNECT.indication

CONNECT.confirm

CONNECT.response

```
GET / HTTP1.1
Connection: Keep-Alive
...
```

```
HTTP/1.1 200 OK
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
...
```

```
GET /images/logo.gif HTTP1.1
Connection: Keep-Alive
...
```

```
HTTP/1.1 200 OK
Keep-Alive: timeout=15, max=99
Connection: Keep-Alive
...
```

DISCONNECT.req

DISCONNECT.ind

DISCONNECT.ind

DISCONNECT.req

Improving performance

- Observation
  - Many pages are requested multiple times or from close endhosts
- Solution
  - local cache on each client
    - `if-modified-since` header helps
  - one cache for multiple endhosts

Improving performance

Observation

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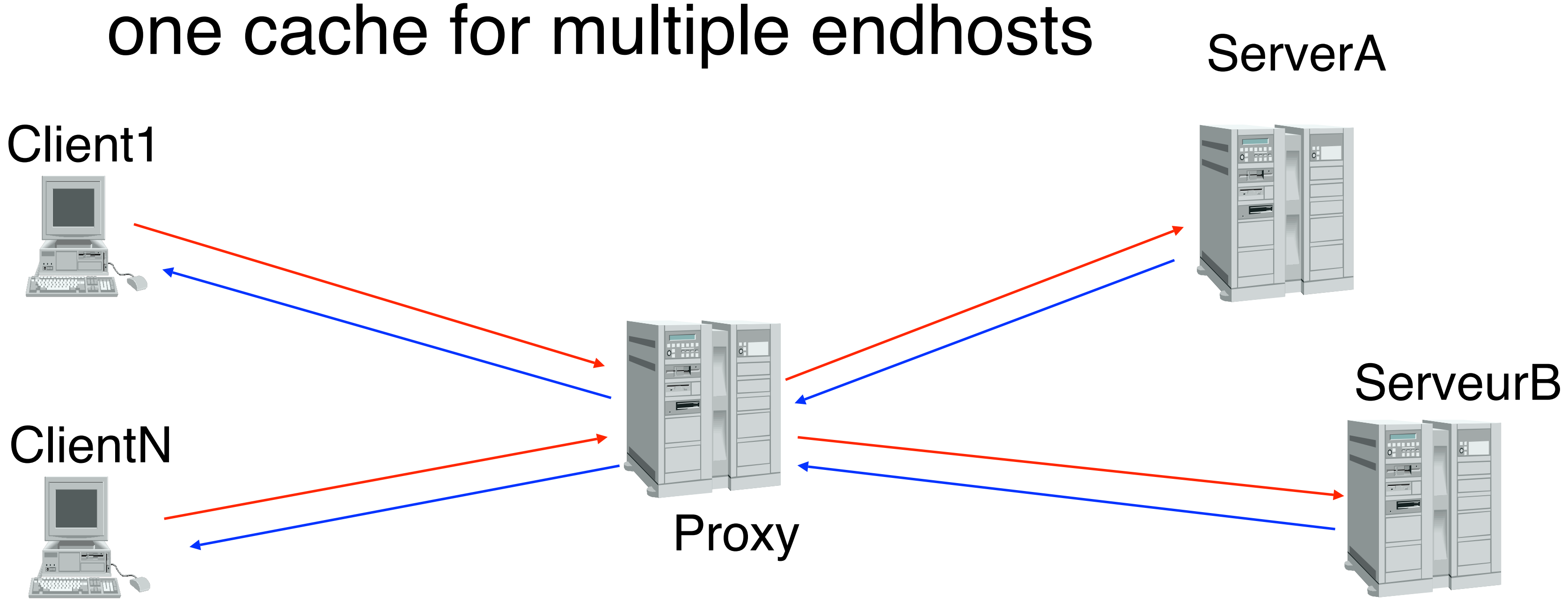
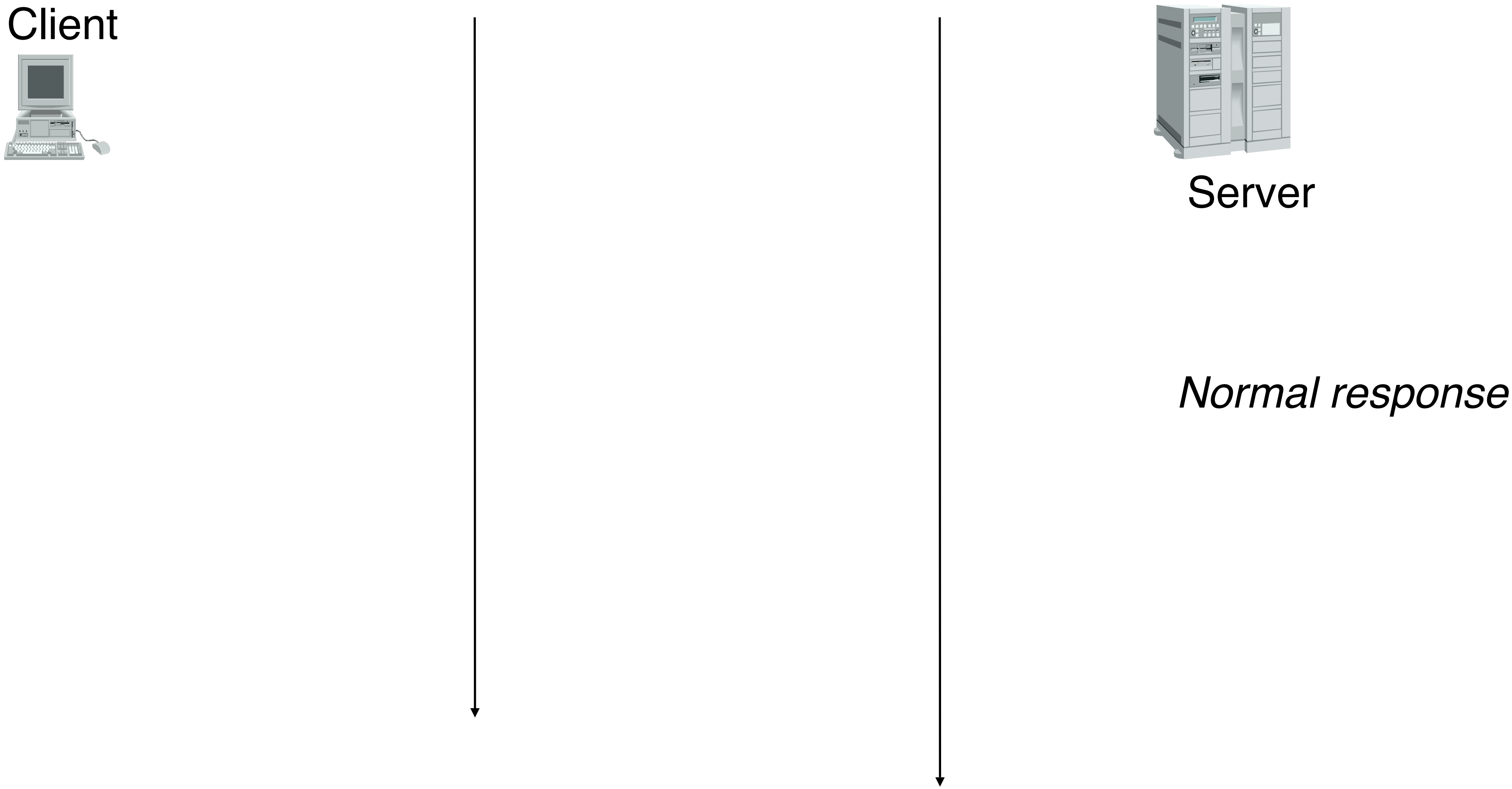
Solution

- local cache on each client
  - `if-modified-since` header helps
- one cache for multiple endhosts



HTTP Cookies

Example



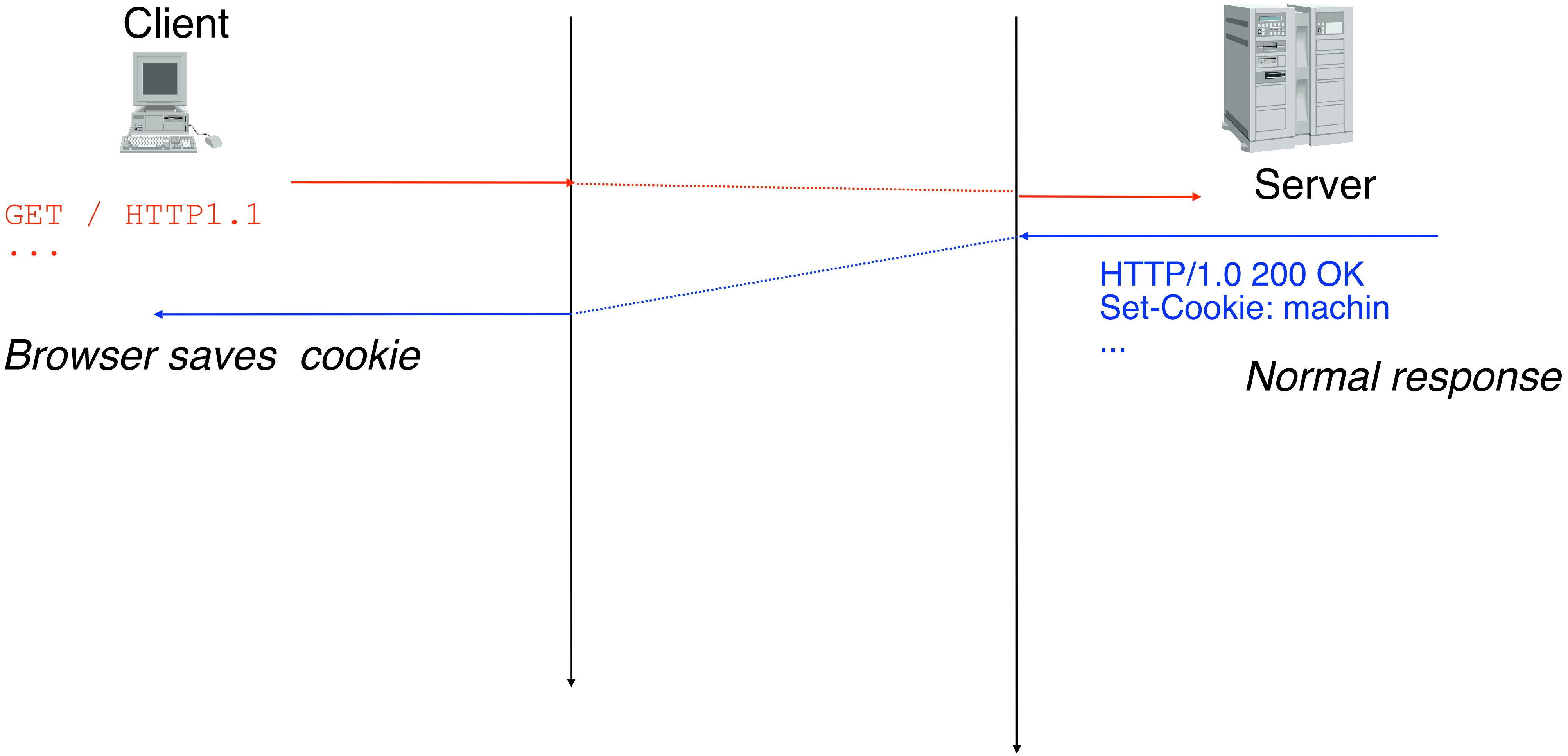
Client

Server

Normal response

HTTP Cookies

Example



Client

```
GET / HTTP1.1
...
```

Server

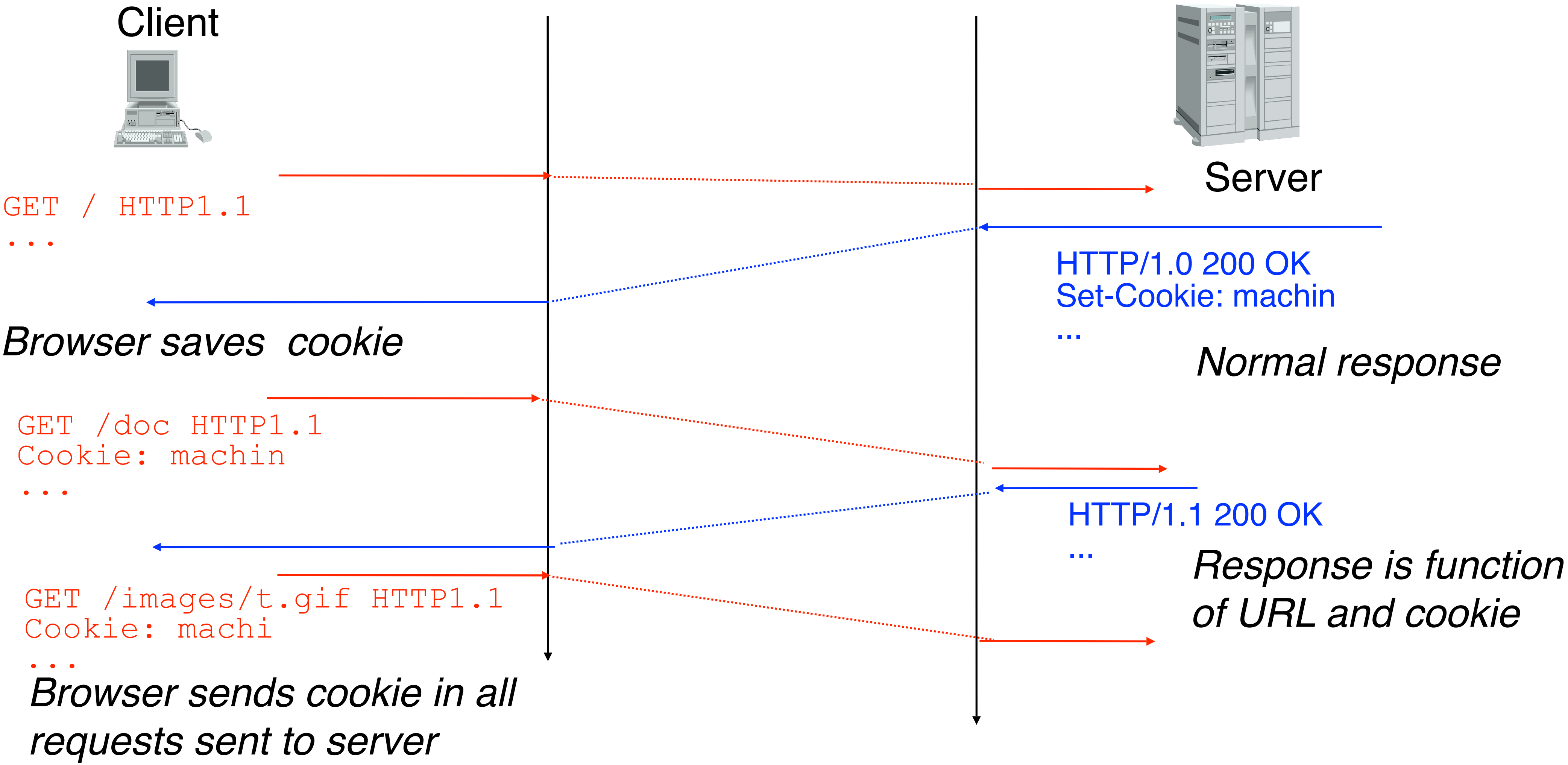
HTTP/1.0 200 OK
Set-Cookie: machin
...

Normal response

Browser saves cookie

HTTP Cookies

Example



Client

Server

```
GET / HTTP1.1
...
```

```
HTTP/1.0 200 OK
Set-Cookie: machin
...
```

Normal response

Browser saves cookie

```
GET /doc HTTP1.1
Cookie: machin
...
```

```
HTTP/1.1 200 OK
...
```

Response is function of URL and cookie

```
GET /images/t.gif HTTP1.1
Cookie: machi
...
```

Browser sends cookie in all requests sent to server