

# Middleware Architectures 1

## Lecture 3: Communication Protocols

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## Overview

- **Introduction to Application Protocols**
  - *Synchronous and Asynchronous Communication*
- Introduction to HTTP
- SOAP and WSDL

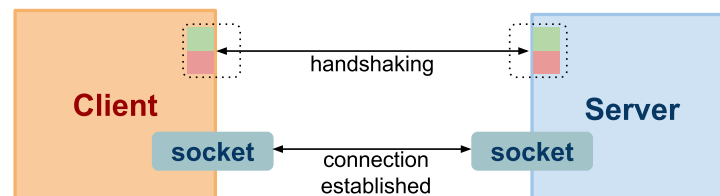
# Application Protocols

- Remember this



- App protocols mostly on top of the TCP Layer
  - use TCP socket for communication
- Major protocols
  - HTTP – most of the app protocols layered on HTTP
    - widely spread
  - RMI – Remote Method Invocation
    - Java-specific; vendor-interoperability problem
    - may use HTTP underneath (among other things)
  - XML-RPC and SOAP – Remote Procedure Call and SOAP
    - HTTP-based
  - WebSocket – new protocol part of HTML5

# Socket



- Handshaking (connection establishment)
  - The server listens at `[dst_ip, dst_port]`
  - Three-way handshake:
    - the client sends a connection request with TCP flags (SYN,  $x=rand$ )
    - the server responds with its own TCP flags (SYN ACK,  $x+1$   $y=rand$ )
    - the client acknowledges the response, can send data along (ACK,  $y+1$   $x+1$ )
  - Result is a socket (virtual communication channel) with unique identification:
 `socket=[src_ip,src_port;dst_ip,dst_port]`
- Data transfer (resource usage)
  - Client/server writes/reads data to/from the socket
  - TCP features: reliable delivery, correct order of packets, flow control
- Connection close

## New Connection Costs

- Creating a new TCP connection is expensive
  - It requires to complete a full roundtrip
  - It is limited by a network latency, not bandwidth
- Example
  - Distance from London to New York is approx. 5500 km
  - Communication over a fibre link will take at least 28ms one way
  - Three-way handshake will take a minimum of 56ms
- Connection reuse is critical for any app running over TCP
  - HTTP Keep-alive
  - HTTP pipelining
- TCP Fast Open (TFO)
  - TFO allows to speed up the opening of successive TCP connections
  - TCP cookie stored on the client that was established on initial connection
  - The client sends the TCP cookie with SYN packet
  - The server verifies the TCP cookie and can send the data without final ACK
  - Can reduce network transaction latency by 15%
  - TFO is supported by Linux in 3.7+ kernels

## Addressing in Application Protocol

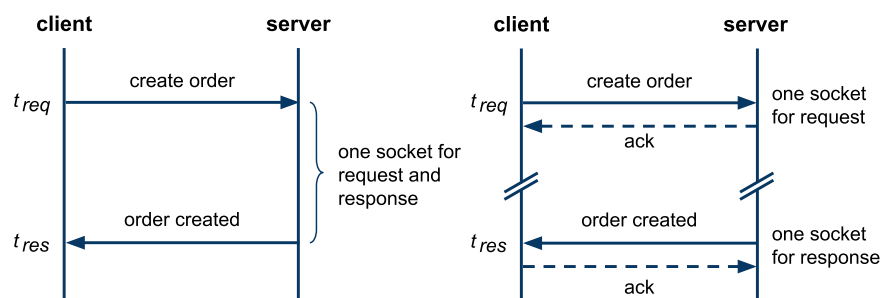


- IP addressing: IP is an address of a machine interface
  - A machine can have multiple interfaces (eth0, eth1, bond0, ...)
- TCP addressing: TCP port is an address of an app running on a machine and listening on a machine interface
  - Multiple applications with different TCP ports may listen on a machine interface
- Application addressing
  - Additional mechanisms to address entities within an application
  - They are out of scope of IP/TCP, they are app specific
    - for example, Web apps served by a single Web server

## Overview

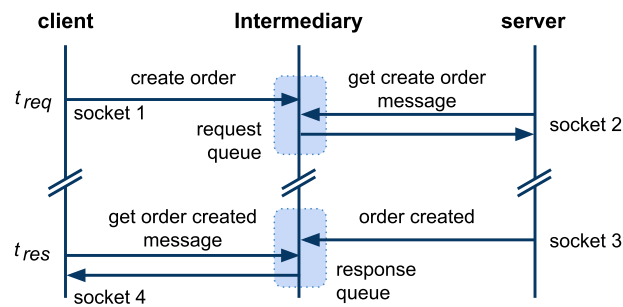
- Introduction to Application Protocols
  - *Synchronous and Asynchronous Communication*
- Introduction to HTTP
- SOAP and WSDL

## Synchronous and Asynchronous Communication



- Synchronous
  - one socket,  $|t_{req} - t_{res}|$  is small
  - easy to implement and deploy, only standard firewall config
  - only the server defines endpoint
- Asynchronous
  - request, response each has socket, client and server define endpoints
  - $|t_{req} - t_{res}|$  can be large (hours, even days)
  - harder to do across network elements (private/public networks issue)

## Asynchronous via Intermediary



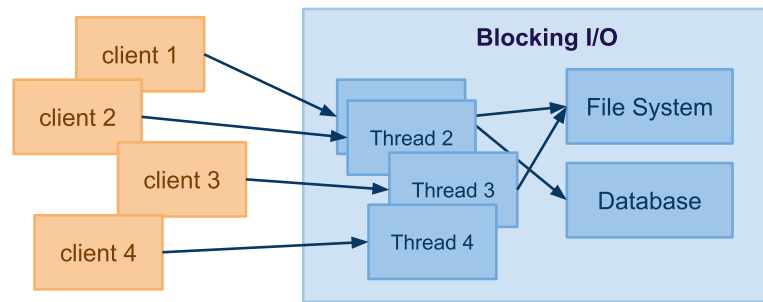
- Intermediary
  - A component that decouples a client-server communication
  - It increases reliability and performance
    - The server may not be available when a client sends a request
    - There can be multiple servers that can handle the request
- Further Concepts
  - Message Queues (MQ) – queue-based communication
  - Publish/Subscribe (P/S) – event-driven communication

## Asynchronous via Polling



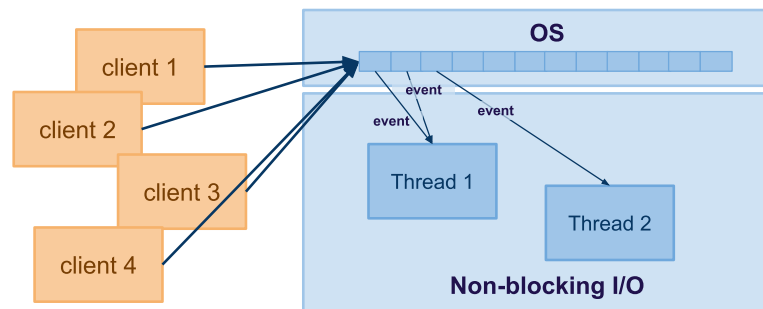
- Polling – only clients open sockets
  - A client performs multiple request-response interactions
    - The first interaction initiates a process on the server
    - Subsequent interactions check for the processing status
    - The last interaction retrieves the processing result
- Properties of environments
  - A server cannot open a socket with the client (network restrictions)
  - Typically on the Web (a client runs in a browser)

## Blocking (Synchronous) I/O



- Inbound connection
  - A server creates a thread for every inbound connection
  - For example, 1K connections = 1K threads, big overhead
  - A thread is reserved for the entire duration of the request processing
- Outbound connection
  - A thread is blocked when outbound connection is made
  - When outbound connection is slow, the scalability is poor

## Non-Blocking (Asynchronous) I/O



- Inbound connections
  - The connection is maintained by the OS, not the server app
  - The Web app registers events, OS triggers events when they occur
  - The app may create working threads and controls their number
- Outbound connections
  - The app registers a callback that is called when the data is available
  - Event loop

## Overview

- Introduction to Application Protocols
- **Introduction to HTTP**
  - *State Management*
- SOAP and WSDL

## Hypertext Transfer Protocol – HTTP

- Application protocol, basis of Web architecture
  - *Part of HTTP, URI, and HTML family*
  - *Request-response protocol*
- One socket for single request-response
  - *original specification*
  - *have changed due to performance issues*
    - *many concurrent requests*
    - *overhead when establishing same connections*
    - *HTTP 1.1 offers persistent connection and pipelining*
    - *Domain sharding*
- HTTP is stateless
  - *Multiple HTTP requests cannot be normally related at the server*
    - *"problems" with state management*
    - *REST goes back to the original HTTP idea*

# HTTP Request and Response

- Request Syntax

```
method uri http-version <crLf>
(header : value <crLf>)*
<crLf>
[ data ]
```

- Response Syntax

```
http-version response-code [ message ] <crLf>
(header : value <crLf>)*
<crLf>
[ data ]
```

- Semantics of terms

```
method          = "GET" | "POST" | "DELETE" | "PUT" | "HEAD" | "OPTIONS"
uri              = [ path ] [ ";" params ] [ "?" query ]
http-version     = "HTTP/1.0" | "HTTP/1.1"
response-code    = valid response code
header : value   = valid HTTP header and its value
data             = resource state representation (hypertext)
```

## Persistent connections

- Persistent HTTP connection = HTTP keepalive
  - TCP established connection used for multiple requests/responses
  - Avoids TCP three-way handshake to be performed on every request
  - Reduces latency
  - FIFO queuing order on the client (request queuing)
    - dispatch first request, get response, dispatch next request
- Example: **GET /html**, **GET /css**
  - server processing time 40ms and 20ms respectively
- Without HTTP keepalive
  - three-way handshake 84ms before the data is received on the server
  - Response received at 152ms and 132ms respectively
  - The total time is 284ms
- HTTP keepalive
  - One TCP connection for both requests
  - In our example this will save one RTT, i.e. 56ms
  - The total time will be 228ms



## Persistent connections savings

- Each request needs
  - Without keepalive, 2 RTT of latency
  - With keepalive, the first request needs 2 RTT, a following request needs 1 RTT
- Savings for **N** requests: **(N-1) × RTT**
- Average value of **N** is 90 requests for a Web app
  - Measured by HTTP Archive (<http://httparchive.org>) as of 2013
  - Average Web application is composed of 90 requests fetched from 15 hosts
    - HTML: 10 requests
    - Images: 55 requests
    - Javascript: 15 requests
    - CSS: 5 requests
    - Other: 5 requests

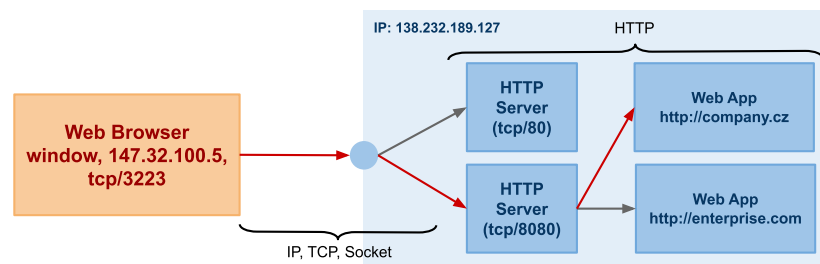
## HTTP pipelining

- Important optimization – response queuing
  - Allows to relegate FIFO queue from the client to the server
- Requests are pipelined one after another
  - This allows the server to process requests immediately one after another
  - This saves one request and response propagation latency
  - In our example, the total time will be 172ms
- Parallel processing of requests
  - In our example this saves another 20ms of latency
  - **Head of line blocking**
    - Slower response (css with processing time 20ms) must be buffered until the first response is generated and sent (no interleaving of responses)
- Issues
  - A single slow response blocks all requests behind it
  - Buffered (large or many) responses may exhaust server resources
  - A failed response may terminate TCP connection
    - A client must request all sub-sequent resources again (duplicate processing)
  - Some intermediaries may not support pipelining and abort connection
- HTTP pipelining support today is limited

## Multiple TCP connections

- Using only one TCP connection is slow
  - Client must queue HTTP requests and process one after another
- Multiple TCP connections work in parallel
- **There are 6 connections per host**
  - The client can dispatch up to 6 requests in parallel
  - The server can process up to 6 requests in parallel
  - This is a trade-off between higher request parallelism and the client and server overhead
- The maximum number of connections prevents from DoS attacks
  - The client could exhaust server resources
- Domain sharding
  - The connection limit as per host (origin)
  - There can be multiple origins used in a page
    - Each origin has 6 maximum connection limit
  - A domain can be sharded
    - `www.example.com` → `shard1.example.com`, `shard2.example.com`
    - Each shard can resolve to the same IP or different IP, it does not matter
    - How many shards?

## Serving HTTP Request



- Serving HTTP request
  1. User enters URL `http://shard1.example.com/orders` to the browser
  2. DNS resolution: browser gets an IP address for `shard1.example.com`
  3. Three-way handshake: browser and Web Server creates a socket
  4. Browser sends ACK and HTTP request:

```
1 | GET /orders HTTP/1.1
2 | Host: shard1.example.com
```
  5. Web server passes the request to the web application `shard1.example.com` which serves `GET orders` and that writes a response back to the socket.

## Virtual Web Server

- Virtual server
  - Configuration of a named virtual web server
  - Web server uses host request header to distinguish among multiple virtual web servers on a single physical host.
- Apache virtual Web server configuration
  - Two virtual servers hosted on a single physical host

```
1 # all IP addresses will be used for named virtual hosts
2 NameVirtualHost *:80
3
4 <VirtualHost *:80>
5     ServerName www.example.com
6     ServerAlias shard1.example.com shard2.example.com
7     ServerAdmin admin@example.com
8     DocumentRoot /var/www/apache/example.com
9 </VirtualHost>
10
11 <VirtualHost *:80>
12     ServerName company.cz
13     ServerAdmin admin@firm.cz
14     DocumentRoot /var/www/apache/company.cz
15 </VirtualHost>
```

## Better Support for HTTP Testing

- Use **curl** to test HTTP protocol

```
1 Usage: curl [options...] <url>
2
3 -X/--request <command>      Specify request command to use
4 -H/--header <line>          Custom header to pass to server
5 -d/--data <data>            HTTP POST data
6 -b/--cookie <name=string/file> Cookie string or file to read cookies from
7 -v/--verbose                 Make the operation more talkative
```

- Example

```
1 curl -v -H "Host: company.cz" 127.0.0.1:8080
2
3 * About to connect() to 127.0.0.1 port 8080
4 * Trying 127.0.0.1... connected
5 * Connected to 127.0.0.1 port 8080
6 > GET / HTTP/1.1
7 > User-Agent: curl/7.20.0 (i386-apple-darwin10.3.2) libcurl/7.20.0 OpenSSL/0.9.8
8 > Accept: */*
9 > Host: company.cz
10 >
11 < HTTP/1.1 201 OK
12 < Connection: keep-alive
13 < Content-Type: plain/text
14 <
15 < This is the response...
```

## Overview

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  - *State Management*
- SOAP and WSDL

## State Management

- HTTP is a stateless protocol – original design
  - *No information to relate multiple interactions at server-side*
    - Except **Authorization** header is copied in every request
    - IP addresses do not work, one public IP can be shared by multiple clients
- Solutions to check for a valid state at server-side
  - **Cookies** – obvious and the most common workaround
    - RFC 2109 – HTTP State Management Mechanism [🔗](#)
    - Allow clients and servers to talk in a context called **sessions**
  - **Hypertext** – original HTTP design principle
    - App states represented by resources (hypermedia), links define transitions between states
    - Adopted by the REST principle **statelessness**

## Interaction with Cookies

- Request-response interaction with cookies
  - *Session is a logical channel maintained by the server*



- Stateful Server
  - *Server remembers the session information in a server memory*
  - *Server memory is a non-persistent storage, when server restarts the memory content is lost!*

## Set-Cookie and Cookie Headers

- **Set-Cookie** response header

```
1 set-cookie = "Set-Cookie:" cookie (";" cookie)*
2 cookie    = NAME "=" VALUE (";" cookie-av)*
3 cookie-av = "Comment" "=" value
4           | "Domain" "=" value
5           | "Max-Age" "=" value
6           | "Path" "=" value
```

- **domain** – a domain for which the cookie is applied
- **Max-Age** – number of seconds the cookie is valid
- **Path** – URL path for which the cookie is applied

- **Cookie** request header. A client sends the cookie in a request if:
  - **domain** matches the origin server's fully-qualified host name
  - **path** matches a prefix of the request-URI
  - **Max-Age** has not expired

```
1 cookie = "Cookie:" cookie-value (";" cookie-value)*
2 cookie-value = NAME "=" VALUE [";" path] [";" domain]
3 path        = "$Path" "=" value
4 domain      = "$Domain" "=" value
```

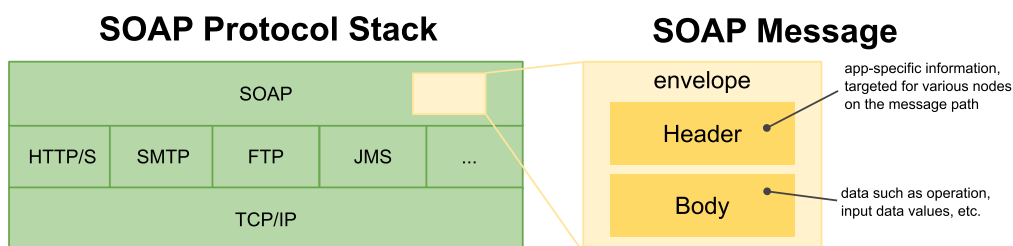
- **domain**, and **path** are values from corresponding attributes of the **Set-Cookie** header

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## SOAP Protocol

- SOAP defines a messaging framework



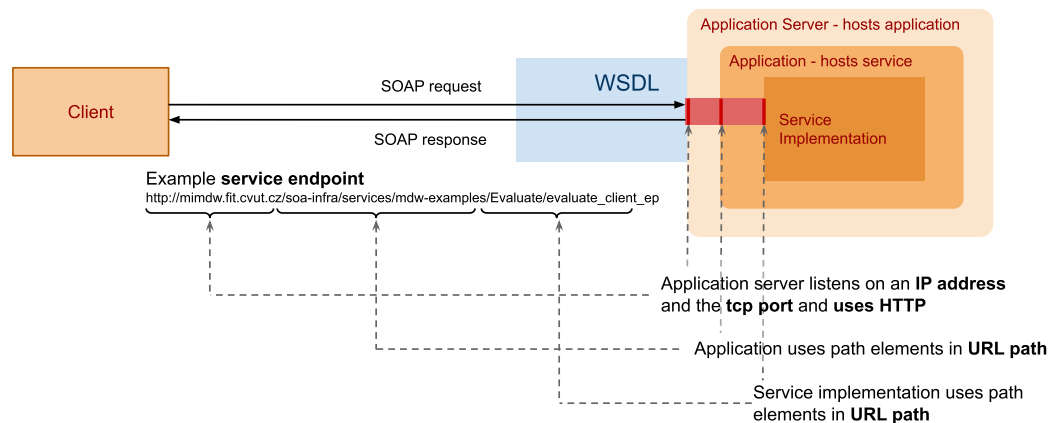
- *XML-based protocol*
- *a layer over transport protocols*
  - *binding to HTTP, SMTP, JMS, ...*
- *involves multiple nodes (message path)*
  - *sender, receiver, intermediary*

# SOAP Message

- Envelope
  - *A container of a message*
- Header
  - *Metadata – describe a message, organized in header blocks*
    - *routing information*
    - *security measures implemented in the message*
    - *reliability rules related to delivery of the message*
    - *context and transaction management*
    - *correlation information (request and response message relation)*
  - *WS extensions (WS-\*) utilize the message header*
- Body (payload)
  - *Actual contents of the message, XML formatted*
  - *Contains also faults for exception handling*
- Attachment
  - *Data that cannot be serialized into XML such as binary data*

# Endpoint

- SOAP service endpoint definition



- *Endpoint – a network address used for communication*
- *Communication – request-response, SOAP messages over a communication (application) protocol*
- *Synchronous communication – only service defines endpoint*
- *Asynchronous communication – service and client define endpoints*

# WSDL Overview and WSDL 1.1 Syntax

- Components of WSDL
  - Information model (**types**)
    - Element types, message declarations (XML Schema)
  - Set of operations (**portType**)
    - A set of operations is "interface" in the WSDL terminology
    - operation name, input, output, fault
  - Binding (**binding**)
    - How messages are transferred over the network using a concrete transport protocol
    - Transport protocols: HTTP, SMTP, FTP, JMS, ...
  - Endpoint (**service**)
    - Where the service is physically present on the network
- Types of WSDL documents
  - **Abstract WSDL** – only information model and a set of operations
  - **Concrete WSDL** – everything, a concrete service available in the environment

## WSDL Components and Dependencies

