Middleware Architectures 1

Lecture 3: Communication Protocols

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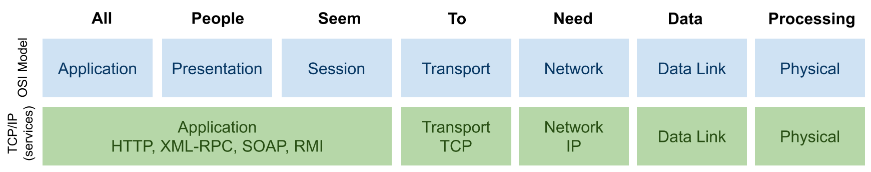
Overview

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

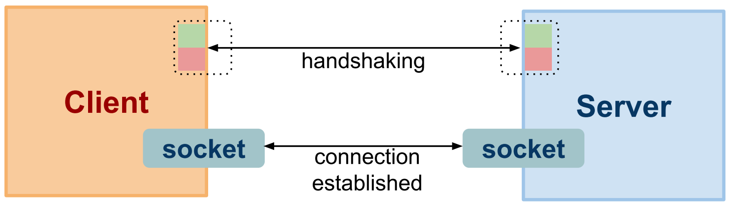
Application Protocols

- 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

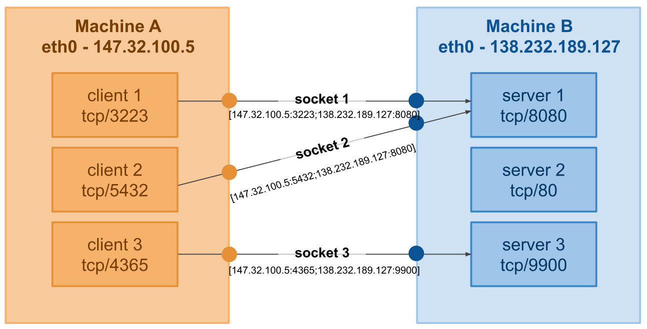


- Handshaking (connection establishment)
  – *The server listens at* `[dst_ip,dsp_port]`
  – *Three-way handshake:*
    → the client sends a connection request with TCP flags (SYN, x=rand)
    → the server respons with its own TCP flags (SYN ACK, x+1 y=rand)
    → the client acknowledges the response, 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 handskake 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 successfive 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

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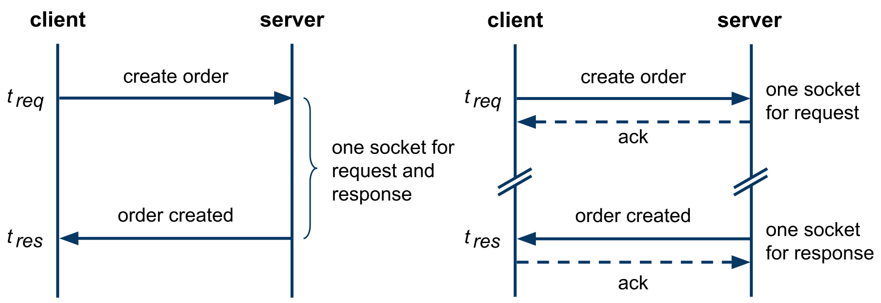
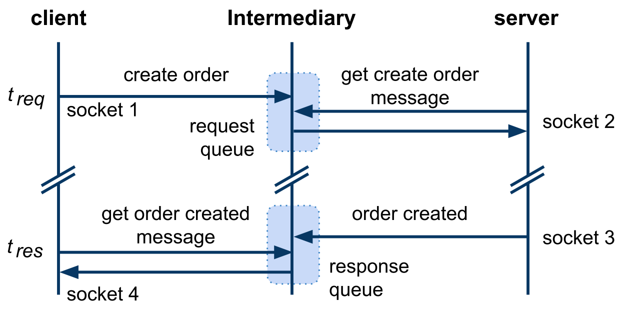
Synchronous and Asynchronous Communication



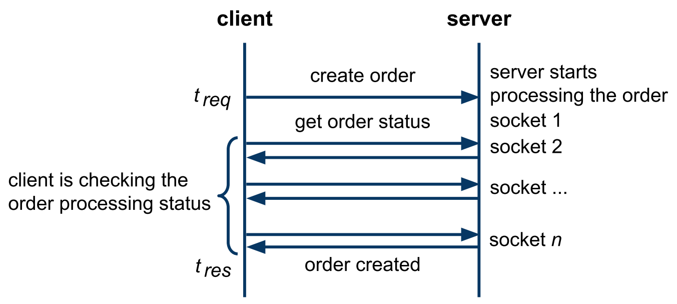
- Synchronous
  – *one socket, $|t_{req} - t_{res}|$ is small*
  – *easy to implement and deploy, only standard firewall config*
  – *only the server defines endpoint*
- Asynchronous
  – *request, response each has socket, client and server define endpoints*
  – *$|t_{req} - t_{res}|$ can be large (hours,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

Asynchronous via Intermediary



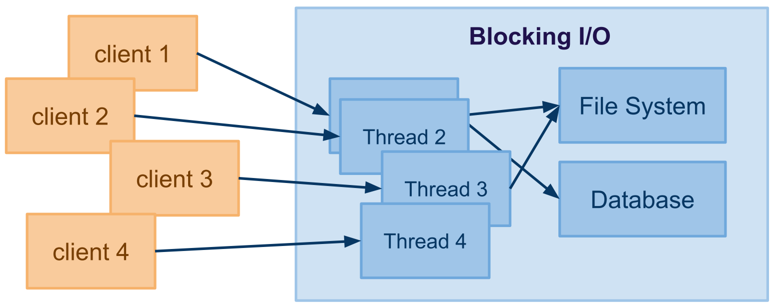
- Intermediary
  - *A component that decouples a client-server communication*
  - *It increases reliability and performance*
    - → *The server may not be available when a client sends a request*
    - → *There can be multiple servers that can handle the request*
- Further Concepts
  - *Message Queues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

Asynchronous via Polling



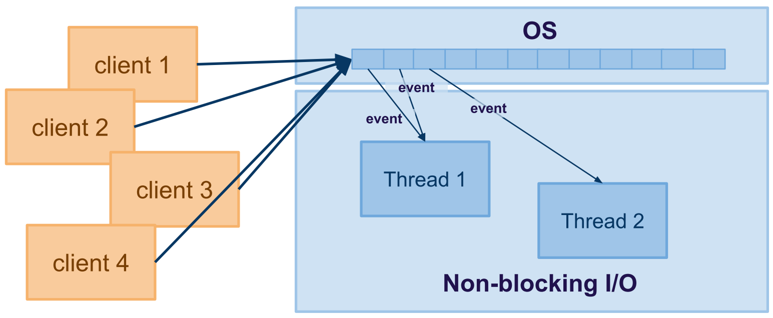
- Polling – only clients open sockets
  - *A client performs multiple request-response interactions*
    - → *The first interaction initiates a process on the server*
    - → *Subsequent interactions check for the processing status*
    - → *The last interaction retrieves the processing result*
- Properties 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 (Asynchrnous) 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*
- Outound 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 respectivelly*
- Without HTTP keepalive
  – *three-way handshake 84ms before the data is received on the server*
  – *Response received at 152ms and 132ms respectivelly*
  – *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) x 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 reuqests*
    - → *Images: 55 requests*
    - → *Javascript: 15 requests*
    - → *CSS: 5 requests*
    - → *Other: 5 requests*

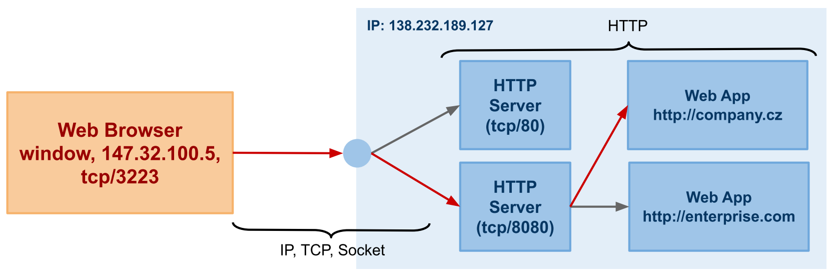
HTTP pipelining

- Important optimization – response queuing
  - *Allows to relecote FIFO queue from the client to the server*
- Requests are pipelined one after another
  - *This allows the server to process requests immediatelly 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 (dupplicate 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 paralellism 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


IP: 138.232.189.127
HTTP
Web Browser window, 147.32.100.5, tcp/3223
HTTP Server (tcp/80)
HTTP Server (tcp/8080)
Web App http://company.cz
Web App http://enterprise.com
IP, TCP, Socket

- 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:*

```
GET /orders HTTP/1.1
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*

```
# all IP addresses will be used for named virtual hosts
NameVirtualHost *:80

<VirtualHost *:80>
        ServerName www.example.com
        ServerAlias shard1.example.com shard2.example.com
        ServerAdmin admin@example.com
        DocumentRoot /var/www/apache/example.com
</VirtualHost>

<VirtualHost *:80>
        ServerName company.cz
        ServerAdmin admin@firm.cz
        DocumentRoot /var/www/apache/company.cz
</VirtualHost>
```

Better Support for HTTP Testing

- Use `curl` to test HTTP protocol

```
Usage: curl [options...] <url>

-X/--request <command>          Specify request command to use
-H/--header <line>              Custom header to pass to server
-d/--data <data>                HTTP POST data
-b/--cookie <name=string/file>  Cookie string or file to read cookies from
-v/--verbose                    Make the operation more talkative
```

- Example

```
curl -v -H "Host: company.cz"  127.0.0.1:8080

* About to connect() to 127.0.0.1 port 8080
*   Trying 127.0.0.1... connected
* Connected to 127.0.0.1 port 8080
> GET / HTTP/1.1
> User-Agent: curl/7.20.0 (i386-apple-darwin10.3.2) libcurl/7.20.0 OpenSSL/0.9
> Accept: */*
> Host: company.cz
>
< HTTP/1.1 201 OK
< Connection: keep-alive
< Content-Type: plain/text
<
< This is the response...
```

Overview

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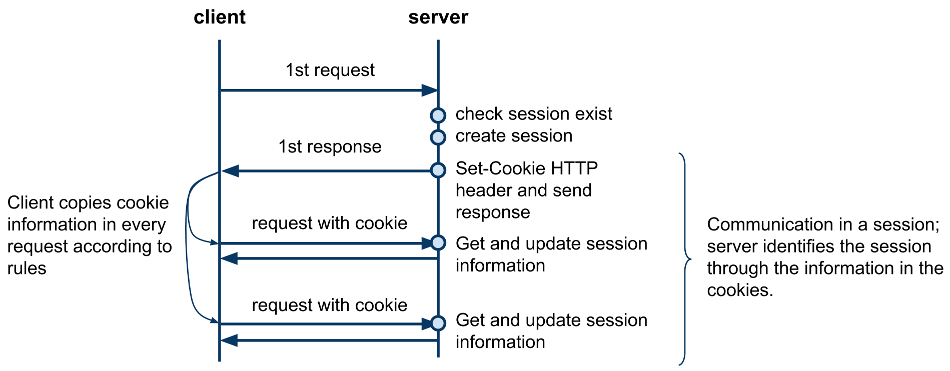
  – *State Management*
- SOAP and WSDL

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*


client
server
1st request
check session exist
create session
1st response
Set-Cookie HTTP header and send response
Client copies cookie information in every request according to rules
request with cookie
Get and update session information
request with cookie
Get and update session information
Communication in a session; server identifies the session through the information in the cookies.

- 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

```
set-cookie = "Set-Cookie:" cookie ("," cookie)*
  cookie     = NAME "=" VALUE (";" cookie-av)*
  cookie-av = "Comment" "=" value
            | "Domain" "=" value
            | "Max-Age" "=" value
            | "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*

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

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

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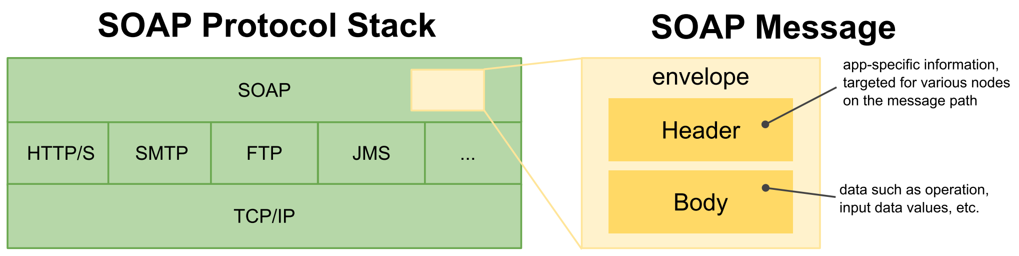
SOAP Protocol

- SOAP defines a messaging framework


SOAP Protocol Stack
SOAP
HTTP/S
SMTP
FTP
JMS
...
TCP/IP
SOAP Message
envelope
Header
Body
app-specific information, targeted for various nodes on the message path
data such as operation, input data values, etc.

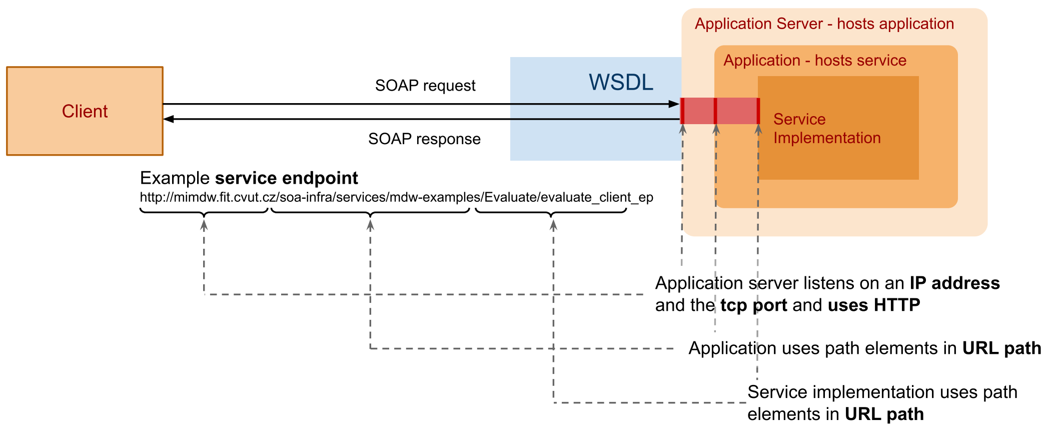
– *XML-based protocol*
– *a layer over transport protocols*
→ binding to HTTP, SMTP, JMS, ...
– *involves multiple nodes (message path)*
→ sender, receiver, intermediary

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

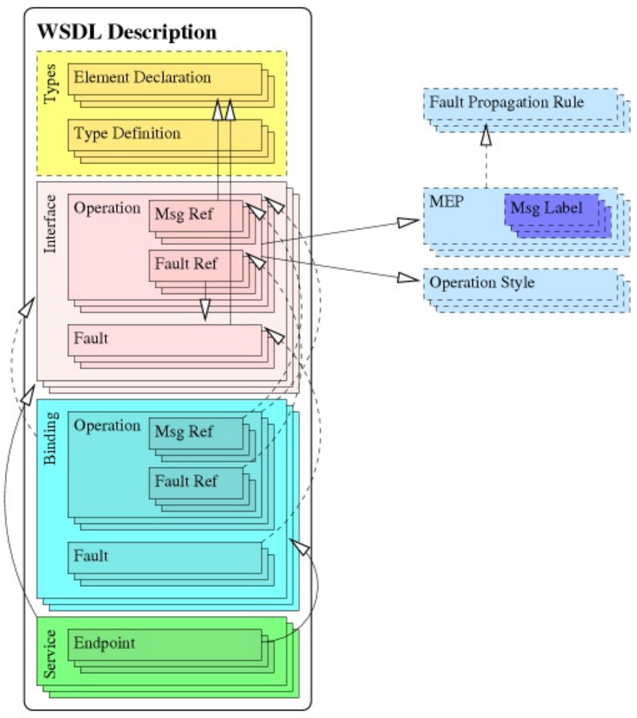

Application Server - hosts application
Application - hosts service
Client
SOAP request
WSDL
SOAP response
Service Implementation
Example **service endpoint**
http://mimdw.fit.cvut.cz/soa-infra/services/mdw-examples/Evaluate/evaluate_client_ep
Application server listens on an **IP address** and the **tcp port** and **uses HTTP**
Application uses path elements in **URL path**
Service implementation uses path elements in **URL path**

- *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 transfered 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


WSDL Description
Types
Element Declaration
Type Definition
Interface
Operation
Msg Ref
Fault Ref
Fault
Binding
Operation
Msg Ref
Fault Ref
Fault
Service
Endpoint
Fault Propagation Rule
MEP
Msg Label
Operation Style