

# Middleware Architectures 1

## Lecture 3: Communication Protocols

**doc. Ing. Tomáš Vitvar, Ph.D.**

tomas@vitvar.com • @TomasVitvar • <http://vitvar.com>



Czech Technical University in Prague

Faculty of Information Technologies • Software and Web Engineering • <http://vitvar.com/courses/mdw>



Modified: Mon Nov 02 2020, 12:49:39  
Humla v0.3

# 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

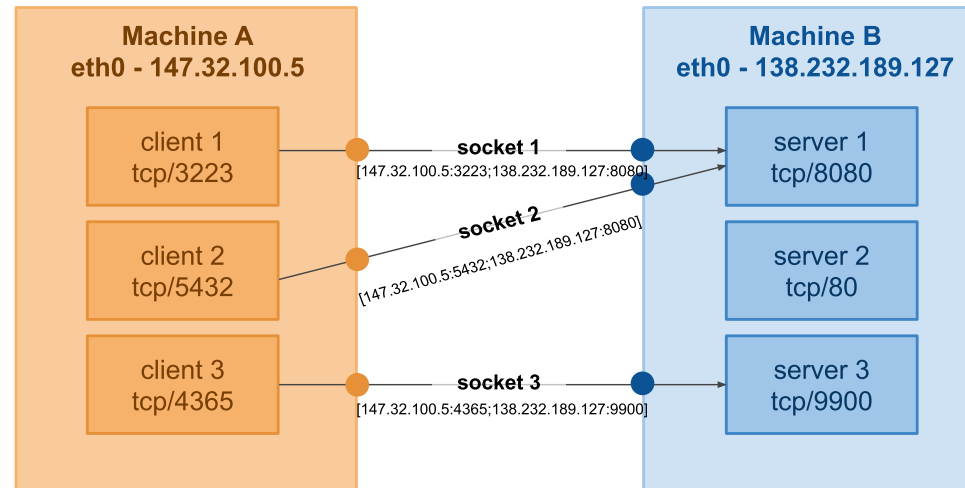


- Handshaking (connection establishment)
  - The server listens at `[dst_ip, dsp_port]`
  - Three-way handshake:
    - the client sends a connection request with TCP flags (SYN,  $x=rand$ )
    - the server responds with its own TCP flags (SYN ACK,  $x+1$   $y=rand$ )
    - the client acknowledges the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

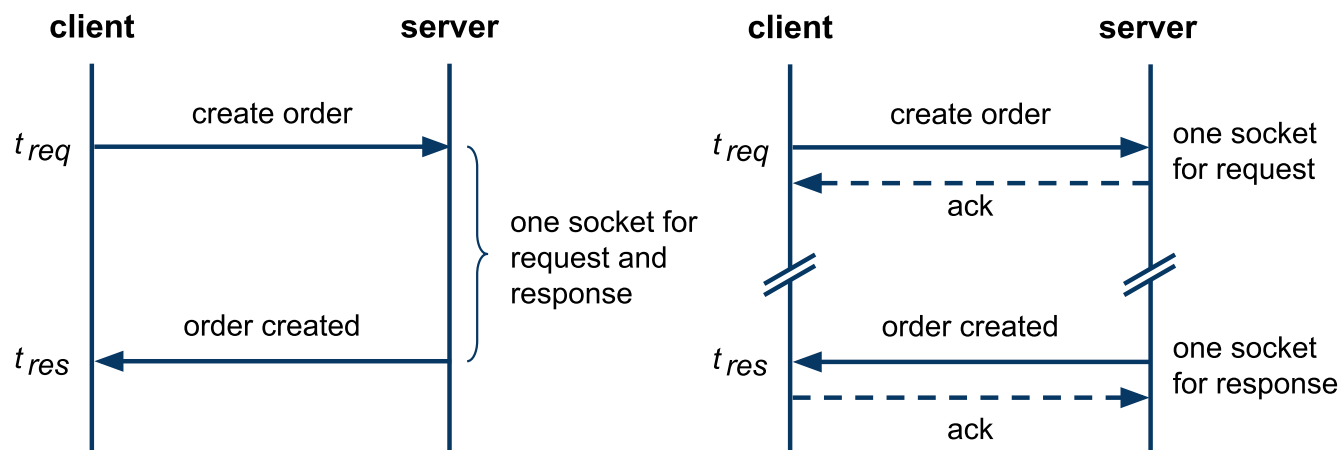


- IP addressing: IP is an address of a machine interface
  - *A machine can have multiple interfaces (eth0, eth1, bond0, ...)*
- TCP addressing: TCP port is an address of an app running on a machine and listening on a machine interface
  - *Multiple applications with different TCP ports may listen on 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:  **$(N-1) \times RTT$**
- 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*

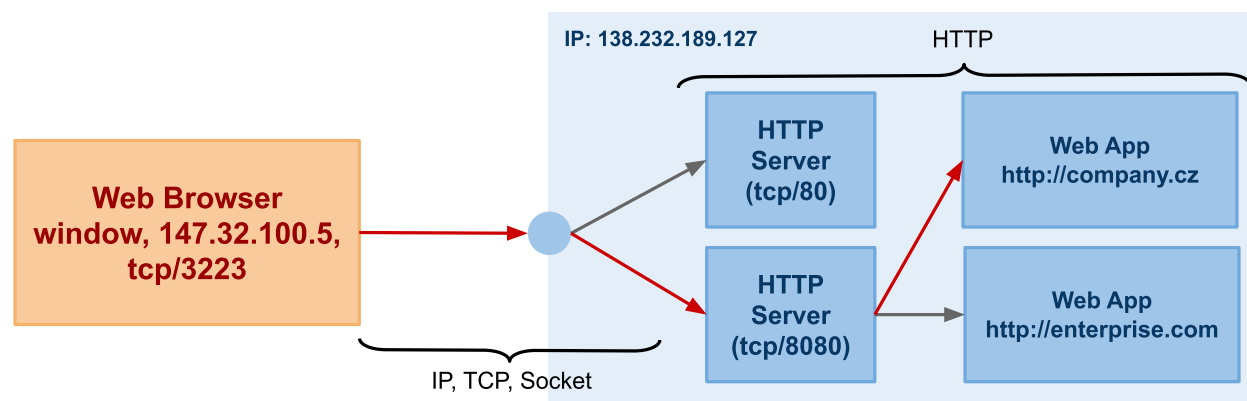
# HTTP pipelining

- 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/0.9.8n
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

- Introduction to Application Protocols
- Introduction to HTTP
  - *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
```

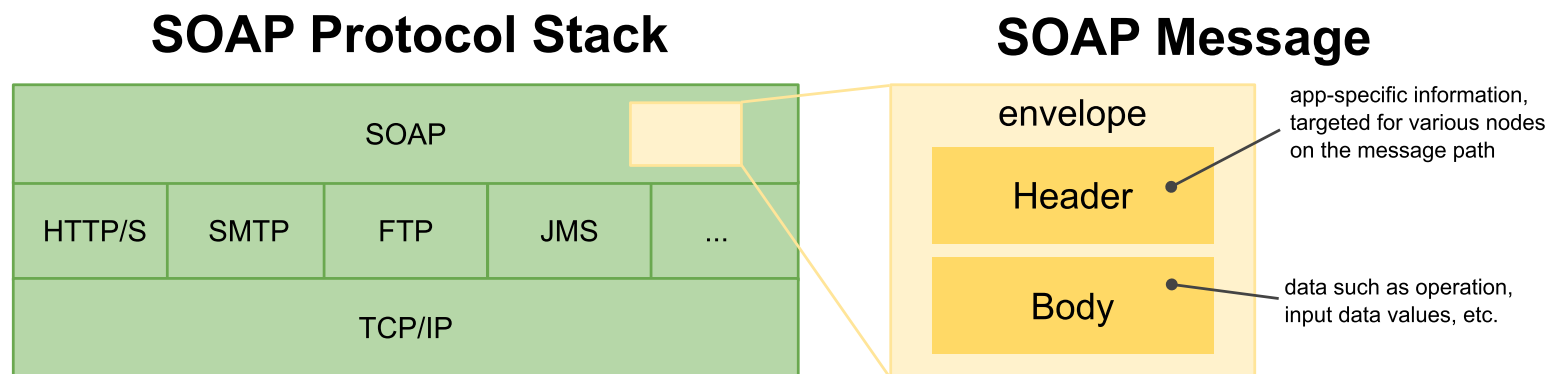
- **domain**, and **path** *are values from corresponding attributes of the Set-Cookie header*

# Overview

- Introduction to Application Protocols
- Introduction to HTTP
- SOAP and WSDL

# SOAP Protocol

- SOAP defines a messaging framework



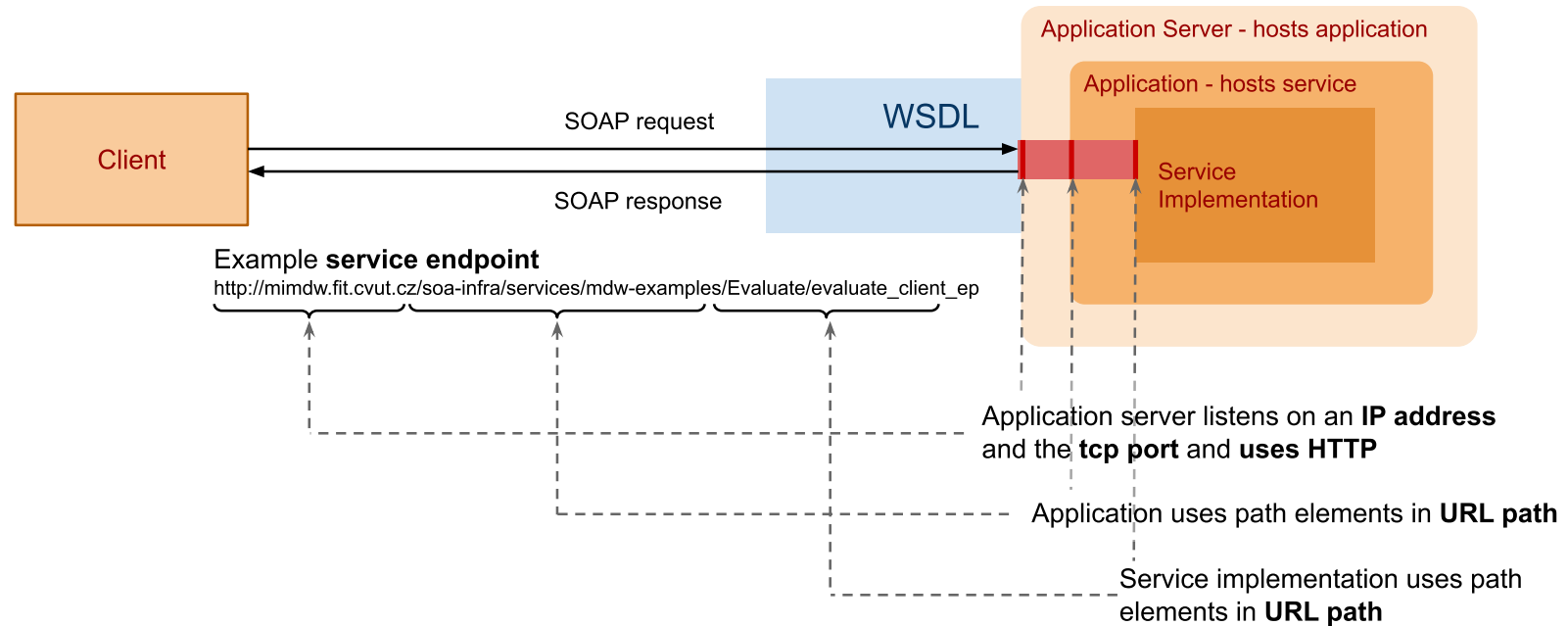
- *XML-based protocol*
- *a layer over transport protocols*
  - *binding to HTTP, SMTP, JMS, ...*
- *involves multiple nodes (message path)*
  - *sender, receiver, intermediary*

# 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

