

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

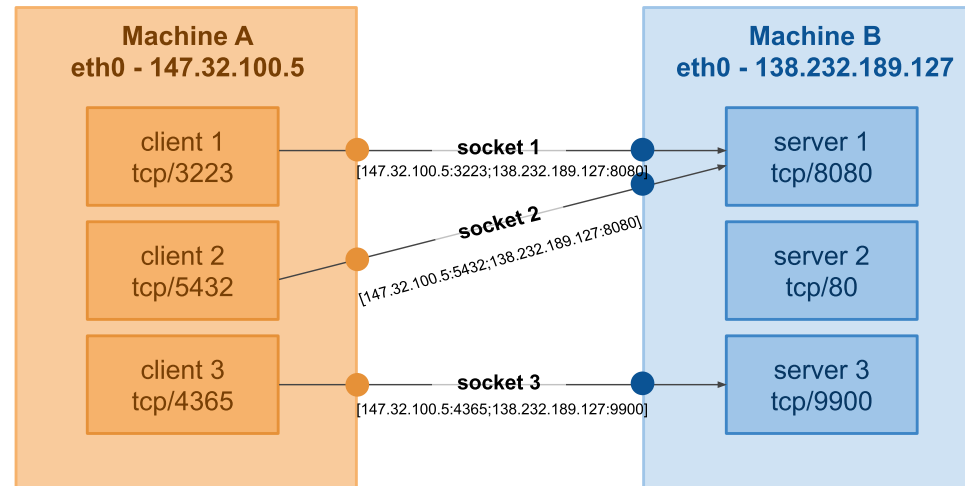


- Handshaking (connection establishment)
 - The server listens at `[dst_ip, dst_port]`
 - Three-way handshake:
 - the client sends a connection request with TCP flags (SYN, $x=rand$)
 - the server responds with its own TCP flags (SYN ACK, $x+1$ $y=rand$)
 - the client acknowledges the response, can send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

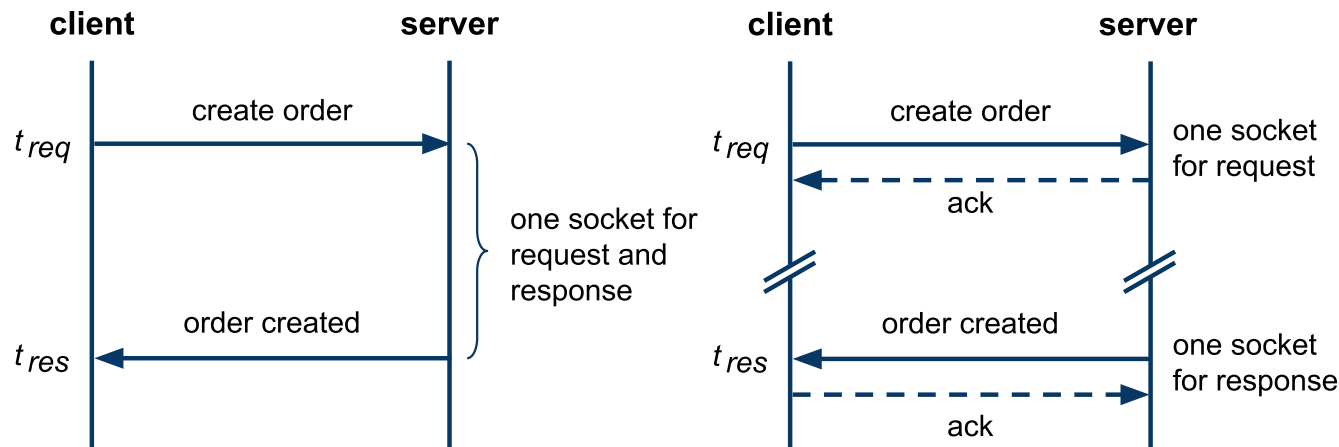


- IP addressing: IP is an address of a machine interface
 - *A machine can have multiple interfaces (eth0, eth1, bond0, ...)*
- TCP addressing: TCP port is an address of an app running on a machine and listening on a machine interface
 - *Multiple applications with different TCP ports may listen on a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

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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 (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*

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 - *State Management*
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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: **$(N-1) \times \text{RTT}$**
- 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*

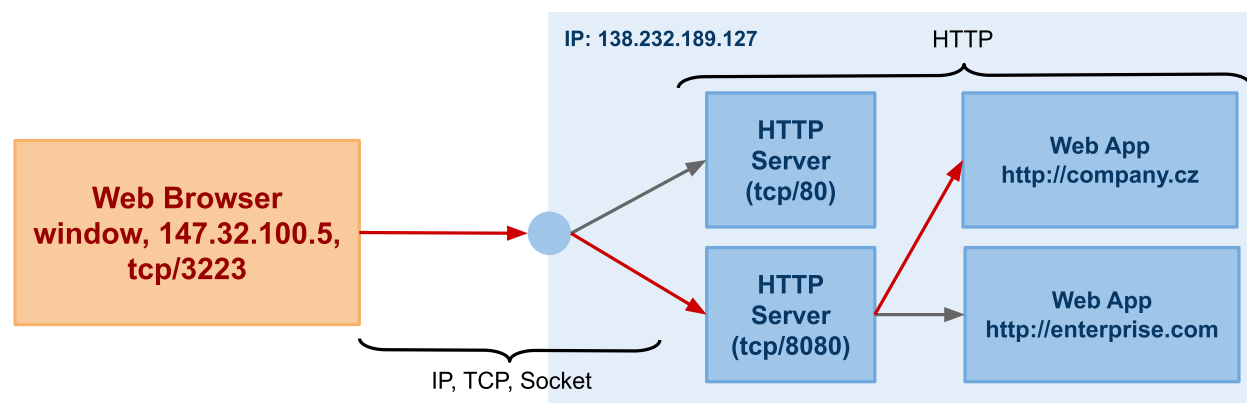
HTTP pipelining

- 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 Host

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

```
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...
```

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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
```

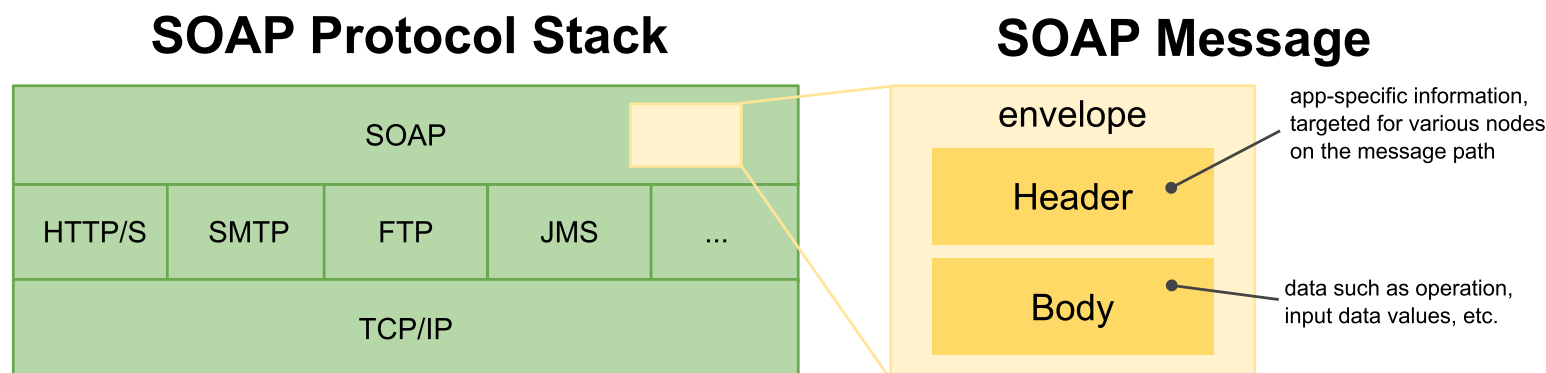
- **domain**, and **path** *are values from corresponding attributes of the Set-Cookie header*

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SOAP Protocol

- SOAP defines a messaging framework



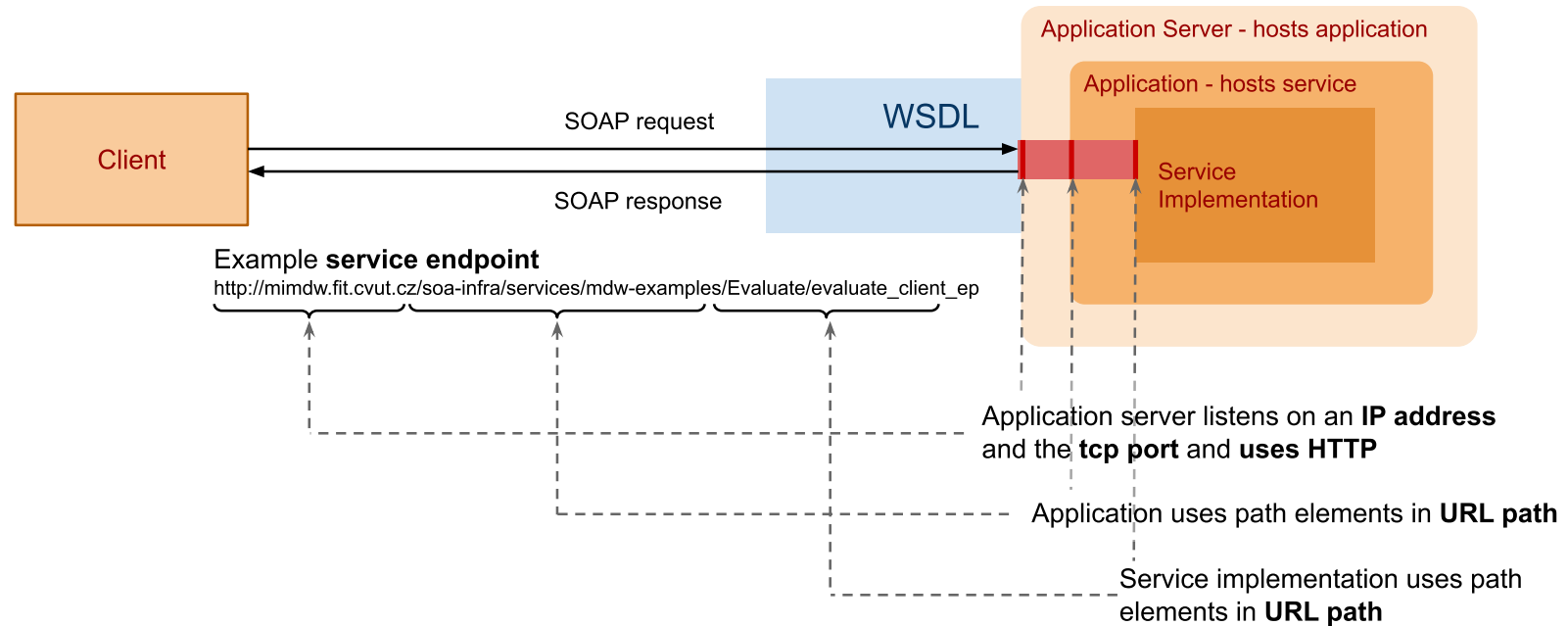
- *XML-based protocol*
- *a layer over transport protocols*
 - *binding to HTTP, SMTP, JMS, ...*
- *involves multiple nodes (message path)*
 - *sender, receiver, intermediary*

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

