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

	All	People	Seem	To	Need	Data	Processing
OSI Model	Application	Presentation	Session	Transport	Network	Data Link	Physical
TCP/IP (services)	Application HTTP, XML-RPC, SOAP, RMI			Transport TCP	Network IP	Data Link	Physical

- 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
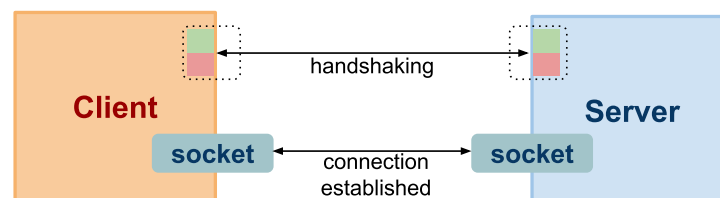
- Handshaking (connection establishment)
  - *The server listens at* `[dst_ip,dsp_port]`
  - *Three-way handshake:*
    - → *the client sends a connection request with TCP flags (SYN, x=rand)*
    - → *the server respons with its own TCP flags (SYN ACK, x+1 y=rand)*
    - → *the client acknowledges the 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*
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Synchronous and Asynchronous Communication
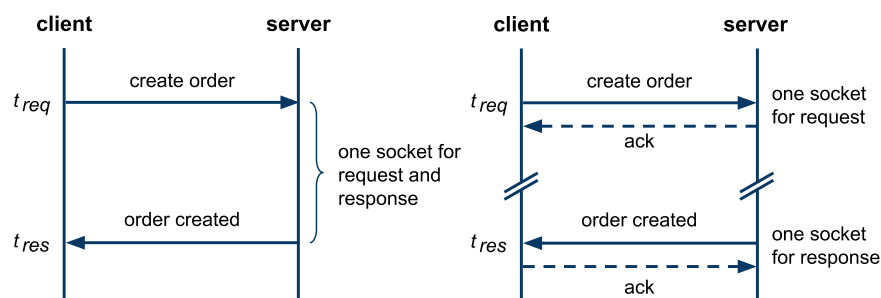
- Synchronous
  - *one socket, $|t_{req} - t_{res}|$ is small*
  - *easy to implement and deploy, only standard firewall config*
  - *only the server defines endpoint*
- Asynchronous
  - *request, response each has socket, client and server define endpoints*
  - *$|t_{req} - t_{res}|$ can be large (hours, even days)*
  - *harder to do across network elements (private/public networks issue)*

Asynchronous via Intermediary
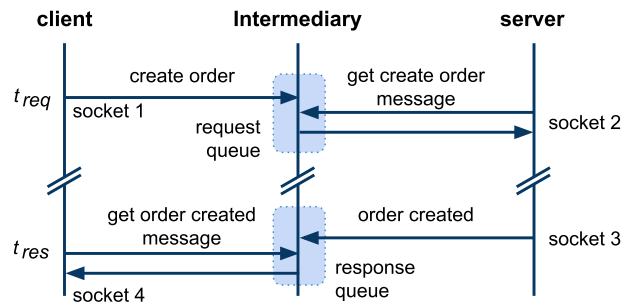
- Intermediary
  - *A component that decouples a client-server communication*
  - *It increases reliability and performance*
    - → *The server may not be available when a client sends a request*
    - → *There can be multiple servers that can handle the request*

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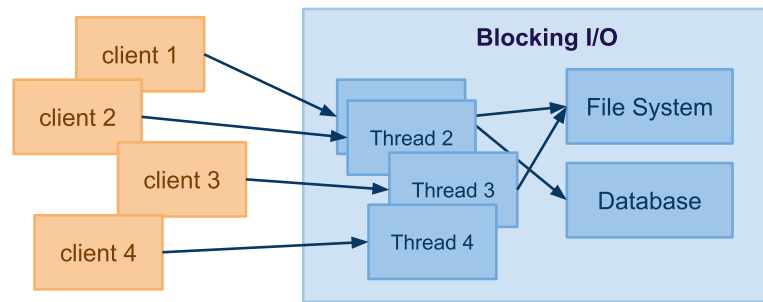
- **Inbound connection**
  - *A server creates a thread for every inbound connection*
  - *For example, 1K connections = 1K threads, big overhead*
  - *A thread is reserved for the entire duration of the request processing*
- **Outbound connection**
  - *A thread is blocked when outbound connection is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

Non-Blocking (Asynchrnous) I/O
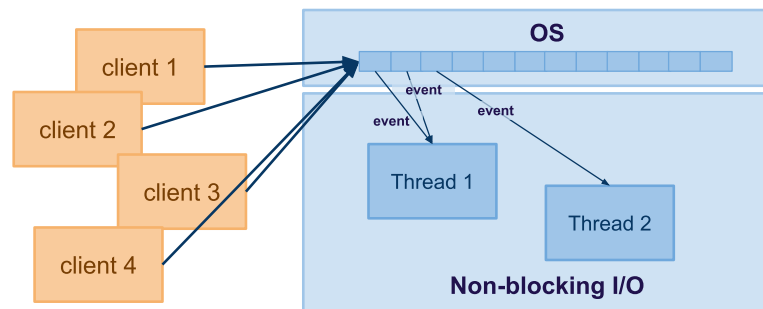
- **Inbound connections**
  - *The connection is maintained by the OS, not the server app*
  - *The Web app registers events, OS triggers events when they occur*
  - *The app may create working threads and controls their number*
- **Outound connections**
  - *The app registers a callback that is called 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
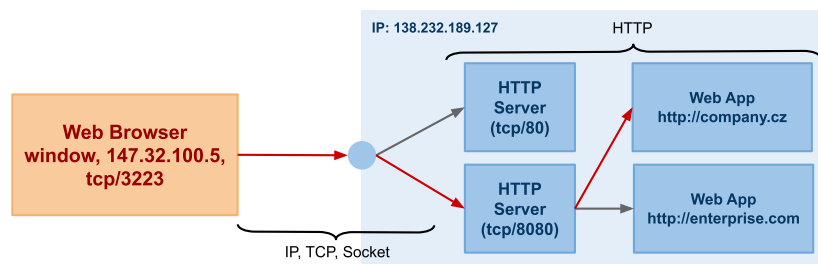
- Serving HTTP request
  1. *User enters URL* `http://shard1.example.com/orders` *to the browser*
  2. *DNS resolution: browser gets an IP address for* `shard1.example.com`
  3. *Three-way handshake: browser and Web Server creates a socket*
  4. *Browser sends ACK and HTTP request:*
     ```
     1  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
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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- 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
```
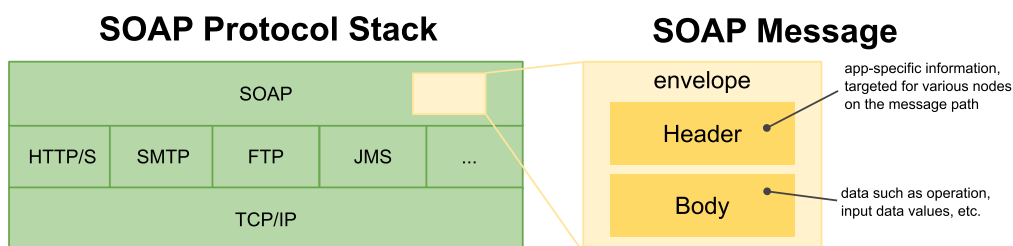
  - `domain`, *and* `path` *are values from corresponding attributes of the* `Set-Cookie` *header*

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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 — app-specific information, targeted for various nodes on the message path

Header

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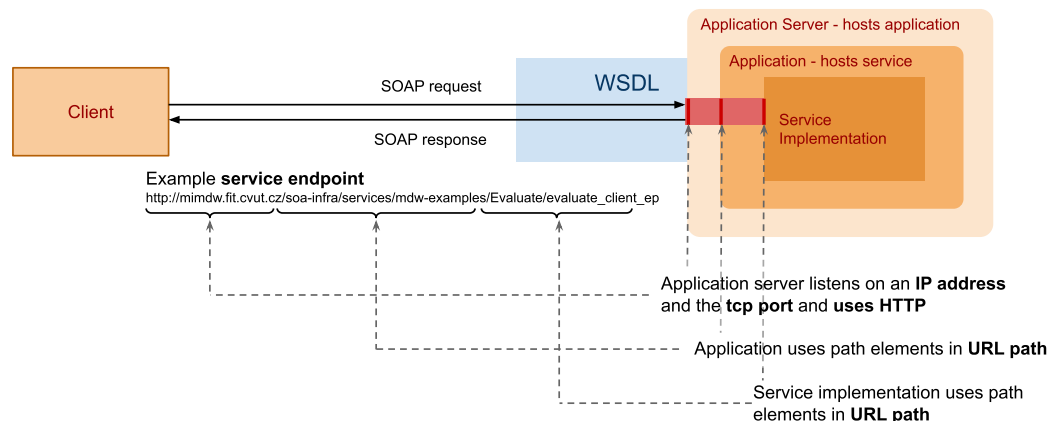
- *Endpoint – a network address used for communication*
- *Communication – request-response, SOAP messages over a communication (application) protocol*
- *Synchronous communication – only service defines endpoint*
- *Asynchronous communication – service and client define endpoints*

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