

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

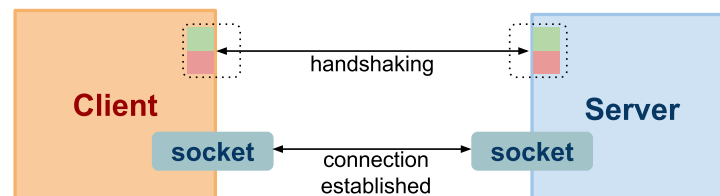
Application Protocols

- 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

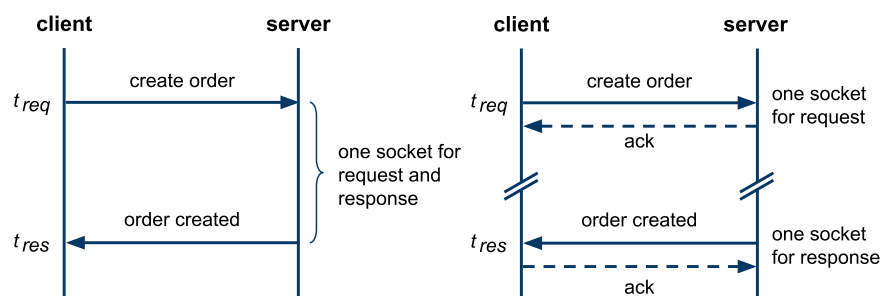


- IP addressing: IP is an address of a machine interface
 - A machine can have multiple interfaces (eth0, eth1, bond0, ...)
- TCP addressing: TCP port is an address of an app running on a machine and listening on a machine interface
 - Multiple applications with different TCP ports may listen on a machine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

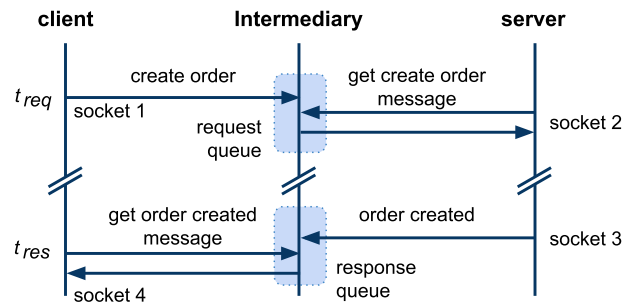
- Introduction to Application Protocols
 - *Synchronous and Asynchronous Communication*
- Introduction to HTTP
- SOAP and WSDL

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



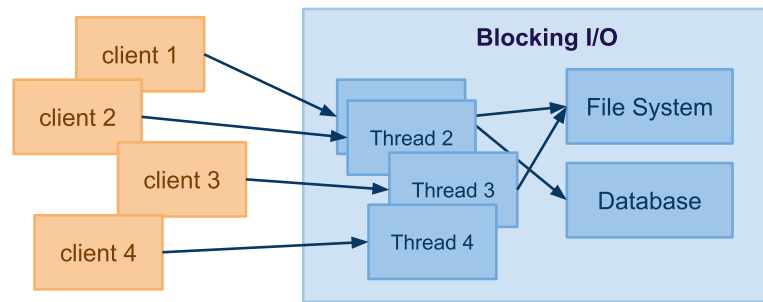
- **Intermediary**
 - A component that decouples a client-server communication
 - It increases reliability and performance
 - The server may not be available when a client sends a request
 - There can be multiple servers that can handle the request
- **Further Concepts**
 - Message Queues (MQ) – queue-based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

Asynchronous via Polling



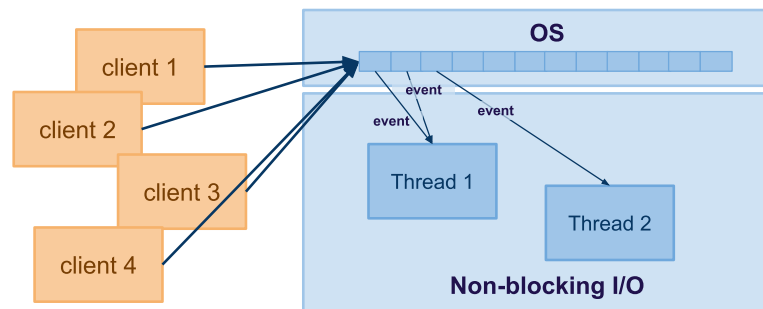
- **Polling** – only clients open sockets
 - A client performs multiple request-response interactions
 - The first interaction initiates a process on the server
 - Subsequent interactions check for the processing status
 - The last interaction retrieves the processing result
- **Properties of environments**
 - 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

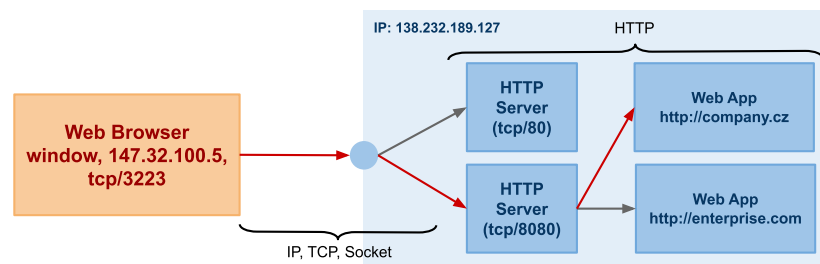
HTTP pipelining

- 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...
```

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 - *State Management*
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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
```

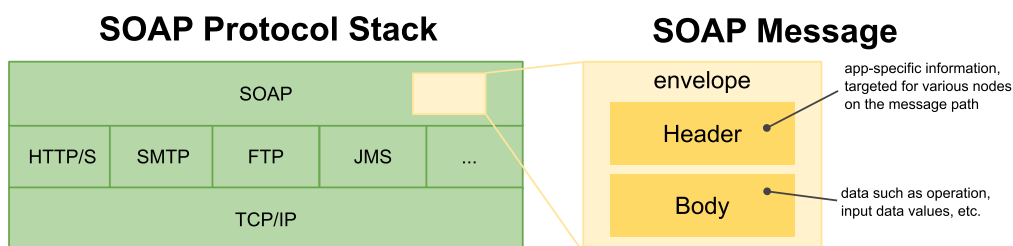
- domain**, and **path** are values from corresponding attributes of the **Set-Cookie** header

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SOAP Protocol

- SOAP defines a messaging framework



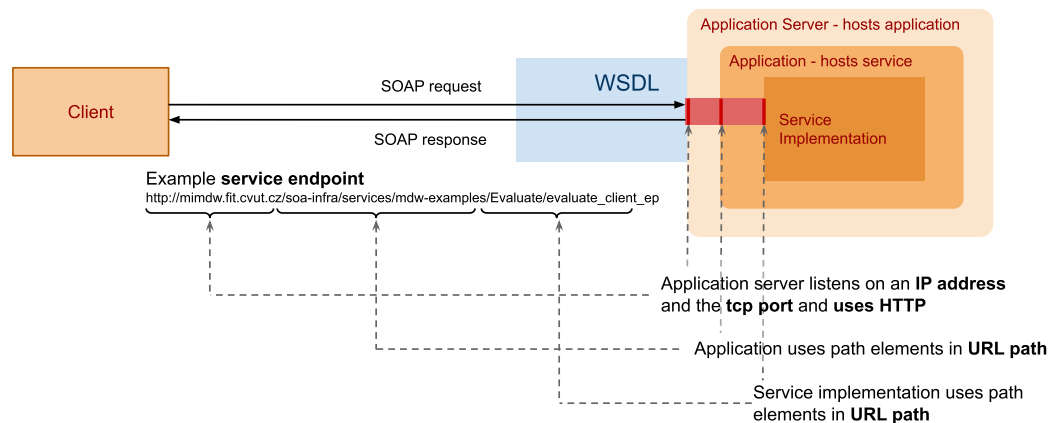
- *XML-based protocol*
- *a layer over transport protocols*
 - *binding to HTTP, SMTP, JMS, ...*
- *involves multiple nodes (message path)*
 - *sender, receiver, intermediary*

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

