Middleware and Web Services

Lecture 3: Application 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: Thu Nov 12 2015, 10:38:46
Humla v0.3

Overview

- Introduction to Application Protocols
  – *Synchronous and Asynchronous Communication*
  – *Selected Networking Concepts*
- Simple Protocol Example
- Introduction to HTTP

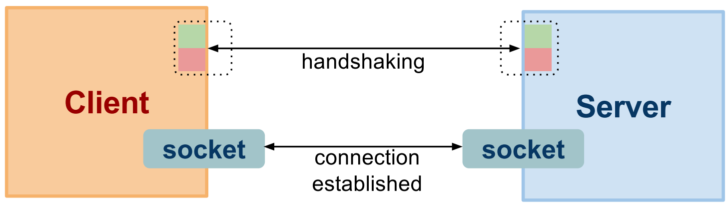
Application Protocols

- 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

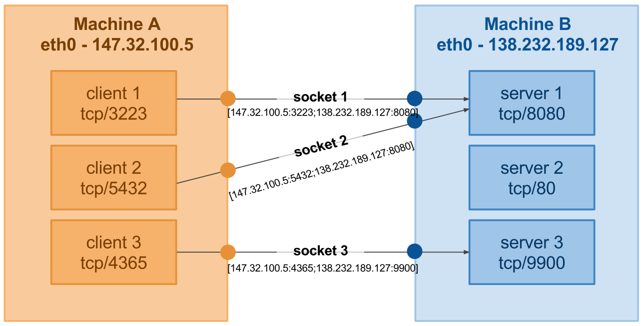
- App protocols mostly on top of the TCP Layer
  – *use TCP socket for communication*
- Major protocols
  – *HTTP – most of the app protocols layered on HTTP*
    → *wide spread, but: implementors often break HTTP semantics*
  – *RMI – Remote Method Invocation*
    → *Java-specific, rather interface*
    → *may use HTTP underneath (among other things)*
  – *XML-RPC – Remote Procedure Call and SOAP*
    → *Again, HTTP underneath*
  – *WebSocket – new protocol part of HTML5*

Socket



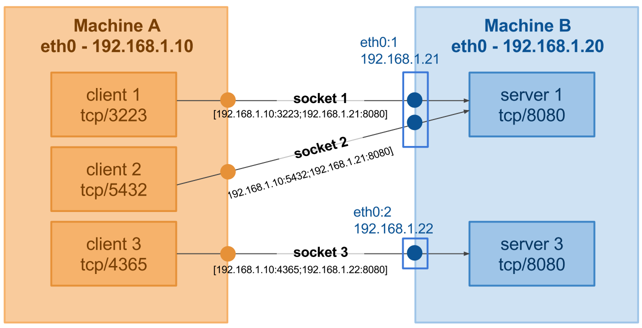
- Handshaking (connection establishment)
  – *The server listens at* `[dst_ip,dsp_port]`
  – *Three-way handshake:*
    → *the client at* `[src_ip,src_port]` *sends a connection request*
    → *the server responds*
    → *the client acknowledges the response, can send data along*
  – *Result is a socket (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

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*

Virtual IP



- Virtual IP
  – *Additional IP addresses assigned to a network interface*
    → *For example,* `eth0 – eth0:1, eth0:2, eth0:3, ...`
    → *A process can bind to the virtual IP*
    → *Multiple processes can listen on the same tcp port but on different virtual IPs*
- Benefits
  – *Floating IP – a process can move transparently to another physical machine*
  – *Network configuration can be preserved, no need to reconfigure*
  – *Failover concept uses floating IPs*

Virtual IP Configuration

- Steps to configure virtual IP in Linux (example for `eth0`)
  1. *Find out the interface's network mask*

```
$ ifconfig eth0
eth0      Link encap:Ethernet  HWaddr 00:0C:29:AB:5E:6A
inet addr:172.16.169.184  Bcast:172.16.169.255  Mask:255.255.255.0
...
```

  2. *Create virtual IP using* `ifconfig`
     – *it should use the same network mask*
     – *it should be free, usually allocated to be used as a virtual IP*

```
$ sudo ifconfig eth0:1 172.16.169.184 netmask 255.255.255.0
$ ifconfig eth0:1
eth0:1    Link encap:Ethernet  HWaddr 00:0C:29:AB:5E:6A
          inet addr:172.16.169.186  Bcast:172.16.169.255  Mask:255.255.25
```

  3. *Update neighbours' ARP (Address Resolution Protocol) caches*
     – *to associate the virtual IP with MAC address of* `eth0`
     – *when the virtual IP was in use on other node or interface*

```
$ sudo arping -q -U -c 3 -I eht0 172.16.169.184
```

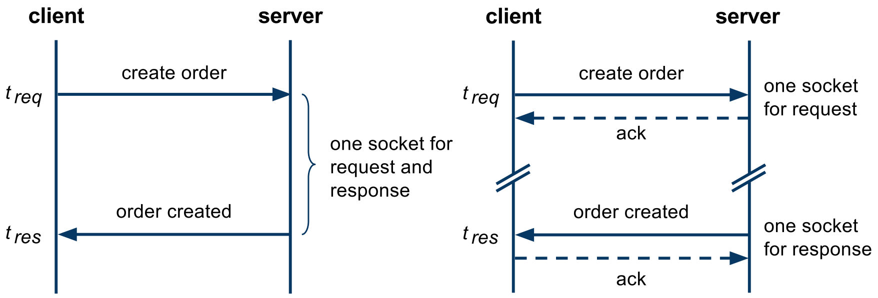
Tasks

– *Configure a virtual IP on your computer and test it using* `ping`

Overview

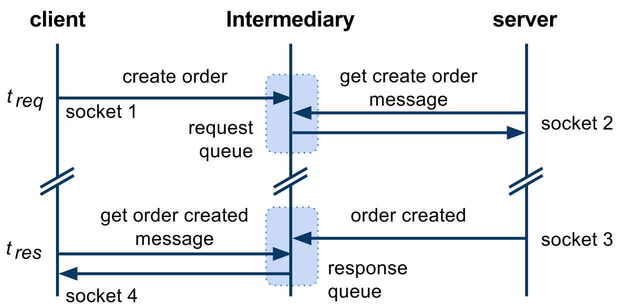
- Introduction to Application Protocols
  – *Synchronous and Asynchronous Communication*
  – *Selected Networking Concepts*
- Simple Protocol Example
- Introduction to HTTP

Synchronous and Asynchronous Communication



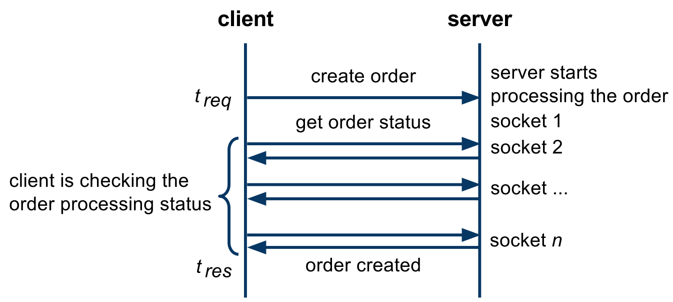
- Synchronous
  - *one socket, $|t_{req} - t_{res}|$ is small*
  - *easy to implement and deploy, only standard firewall config*
  - *only the server defines endpoint*
- Asynchronous
  - *request, response each has socket, client and server define endpoints*
  - *$|t_{req} - t_{res}|$ can be large (hours, 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

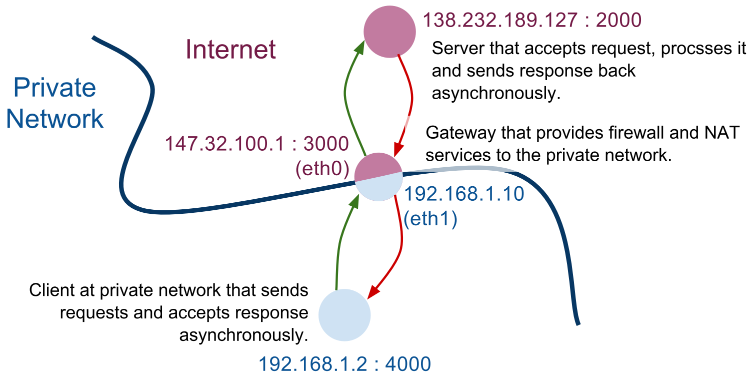


- Polling – only clients open sockets
  – *A client performs multiple request-response interactions*
    → *The first interaction initiates a process on the server*
    → *Subsequent interactions check for the processing status*
    → *The last interaction retrieves the processing result*
- Properties of environments
  – *A server cannot open a socket with the client (network restrictions)*
  – *Typically on the Web (a client runs in a browser)*

Overview

- Introduction to Application Protocols
  – *Synchronous and Asynchronous Communication*
  – *Selected Networking Concepts*
- Simple Protocol Example
- Introduction to HTTP

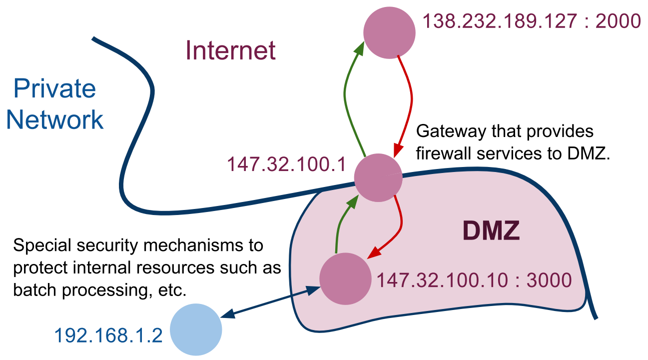
Public/Private Network Configuration



- Adds complexity to configuration of application
  – *Config example at server with* `eth0 = 147.32.100.1` *(iptables)*

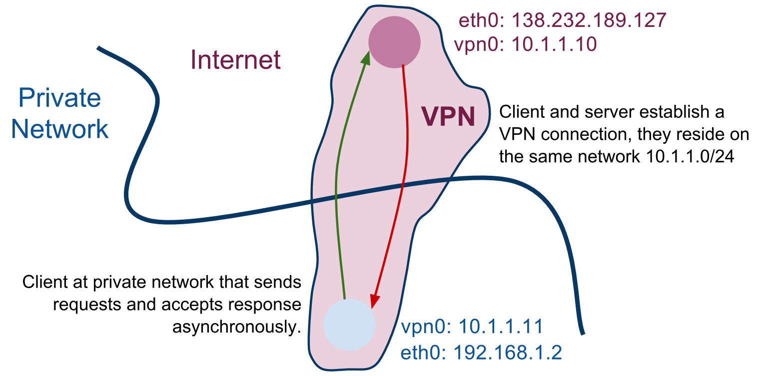
```
# enable ip forwarding from one interface to another within linux core
echo 1 > /proc/sys/net/ipv4/ip_forward

# redirect all communication coming to tcp/3000 to 192.168.1.2:4000
iptables -t nat -A PREROUTING -i eth0 -p tcp --dport 3000 -j DNAT \
    --to-dest 192.168.1.2 --to-port 4000
```


Demilitarized Zones



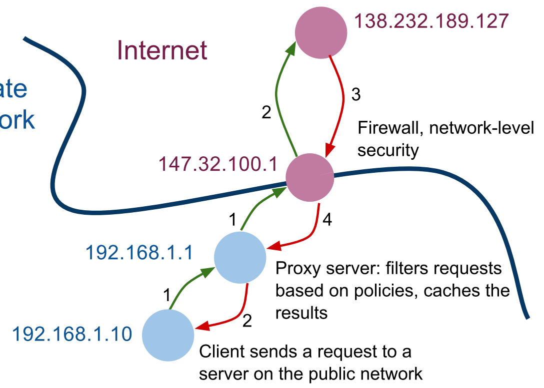
- DMZ = Demilitarized Zone
  – *subnet within an organization's network on a public network*
  – *special care of security enforced through internal policies*
  – *For example:*
    → *no access to all live data, subsets copied in batches*
    → *frequent monitoring*

Virtual Private Network



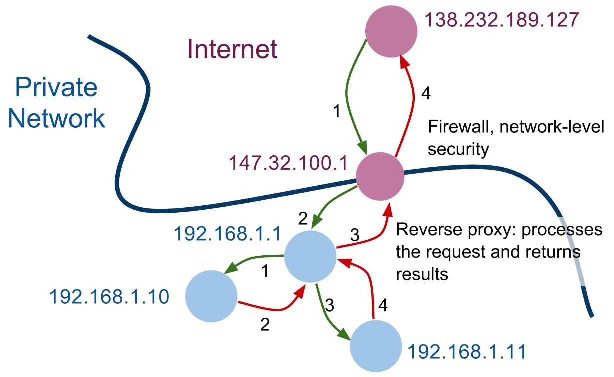
- VPN = Virtual Private Network
  - *an overlay network between a client and a server*
  - *the network spans accross underlying network elements*
  - *Example:*
    - → *VPN client starts a VPN connection with the VPN server via network interfaces*
    - → *VPN server assigns an IP address to the VPN client from the server's subnet*
    - → *Packets in VPN communication are encrypted and sent out in an outer VPN*

Proxy Server



- Proxy Server
  - *Centralized access control based on content*
  - *Perfoms request on behalf of the client*
    - → *Caches content to increase performance, limits network traffic*
    - → *Filters requests based on their destinations*
  - *Widely used in private networks in companies*
  - *Most of the proxy servers today are Web proxy servers*

Reverse Proxy Server



- Reverse Proxy Server
  - *Aggregates multiple request-response interactions with back-end systems*
  - *Processes the request on behalf of the client*
  - *Provides additional values to communication*
    - → *Data transformations*
    - → *Security – authentication, authorization*
    - → *Orchestration of communication with back-end systems*
  - *Examples: Enterprise Service Bus, Security Gateway*

Overview

- Introduction to Application Protocols
- Simple Protocol Example
- Introduction to HTTP

TCP Socket Protocol

- Example simple TCP Socket protocol in Java
  - *functions (verbs):* `add` *and* `bye`
  - *data syntax:* `add "^[0-9]+ [0-9]+$"`, `bye "^$"` *(regular grammars)*
  - *data semantics:* `add` *decimal numbers,* `bye` *none*
  - *process: transitions* `S1—add—S1`, `S1—bye—S0`, *where* `S0`, `S1` *are states such that* `S1=connection established`, `S0=connection closed`.

```java
package com.vitvar.ctu.mdw;

import java.io.*;
import java.net.*;
import java.util.regex.*;

/**
 * Simple protocol example. The class starts a listener on the port 8080.
 * When a client connects, the server parses the input in a form "add a b",
 * where "a" and "b" are integer values, adds the two numbers and sends
 * the result back to the client. The communication ends when the client sends "bye".
 *
 * @author tomas@vitvar.com
 *
 */
public class SimpleProtocol {

    public static void main(String[] args) throws IOException {
        // info message to the console
        System.out.println("Listening on port 8080...");
```


TCP Socket Protocol (Cont.)

```java
        // listen on port 8080
        ServerSocket serverSocket = new ServerSocket(8080);
        Socket clientSocket = serverSocket.accept();

        // create reader and writer to read from and write to the socket
        PrintWriter out = new PrintWriter(clientSocket.getOutputStream(), true);
        BufferedReader in = new BufferedReader(
            new InputStreamReader(clientSocket.getInputStream()));

        // print information to the client
        out.println("verbs: add a b, bye");

        // grammar definition
        Pattern p = Pattern.compile("^add ([0-9]+) ([0-9]+)$");
        Matcher m; String message;

        // read input from the client and process the input
        while ((message = in.readLine()) != null) {
            if ((m = p.matcher(message)).matches())
                out.println("Result: " + (Integer.parseInt(m.group(1)) +
                    Integer.parseInt(m.group(2))));
            else
                if (message.equals("bye")) {
                    out.println("Goodbye!");
                    break;
                } else
                    out.println("Do not understand: " + message);
        }
    }
}
```

Testing

- Many app protocols communicate in plain text
  – *messages in ASCII or Base64 encoded (printable chars only)*
  – *this allows to test them just with Telnet*
    → *Telnet does not know about any protocol-specific semantics*
    → *only opens, reads/writes, and closes the socket*
- Testing our protocol

```
# 1. run the listener
bin/simple_protocol.sh
Listening on port 8080...

# 2. open the socket using telnet but first dig for DNS lookup
telnet 127.0.0.1 8080
Trying 127.0.0.1...
Connected to localhost.
Escape character is '^]'.
Verbs: add a b, bye.
add 3 4
The result is: 7
minus 7 5
Do not understand: minus 7 5
bye
Goodbye!
```


Overview

- Introduction to Application Protocols
- Simple Protocol Example
- Introduction to HTTP
  – *State Management*

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*
- 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 ]
```

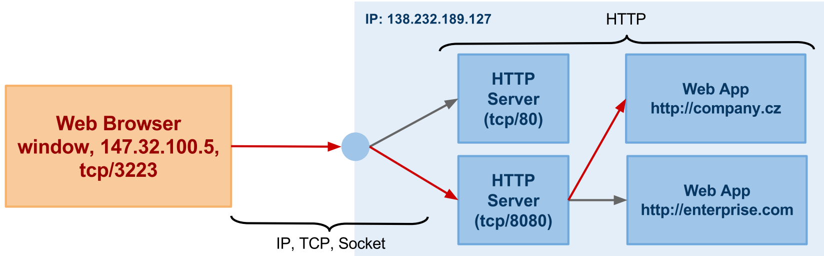
- Response Syntax

```
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)
```

Serving HTTP Request



- IP and TCP addressing
  1. *User enters URL* `http://company.cz:8080/orders` *to the browser*
  2. *Browser gets an IP address for* `company.cz`, `IP:138.232.189.127`
  3. *Browser and Web Server creates a socket* `[147.32.100.5:3223;138.232.189.127:8080]`
- Application addressing
  4. *Browser sends HTTP request, that is, writes following data to the socket*

```
GET /orders HTTP/1.1
Host: company.cz
```

  5. *Web server passes the request to the web application* `company.cz` *which serves* `GET orders` *and that writes a response back to the socket.*

HTTP Listener

- HTTP listener implementation in Java using Jetty
  – *Server listens on port* `8080`
  – *Jetty parses HTTP request data into* `HttpServletRequest` *object.*
  – *When a client connects, the method* `handleRequest` *is called*
  – *The method tests the value of the* `host` *header and responds back if the header matches* `company.cz` *value.*

```
/** handles the request when client connects **/
public void handleRequest(HttpServletRequest request,
        HttpServletResponse response) throws IOException, ServletException {

    // test if the host is company.cz
    if (request.getHeader("Host").equals("company.cz")) {
        response.setStatus(200);
        response.setHeader("Content-Type", "text/plain");
        response.getWriter().write("This is the response");
        response.flushBuffer();
    } else
        response.sendError(400); // bad request
}
```

HTTP Listener (Cont.)

- Test it using Telnet

```
telnet 127.0.0.1 8080
# ...lines omitted due to brevity
GET /orders HTTP/1.1
Host: company.cz

HTTP/1.1 201 OK
Content-Type: plain/text

This is the response...
```

- HTTP listener in bash
  - *Use it to test incomming HTTP connections quickly*
  - *Uses* nc *utility (netcat)*

```
# ctrl-c to stop http listener
control_c() {
  echo -en "\n* Exiting\n"
  exit $?
}
trap control_c SIGINT

for (( ; ; ))
do
        echo -e "\n\n* Listening on port $1..."
        echo -e "\nHTTP/1.0 204 No Content\n\n" | nc -l $port
done
```


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 company.com
        ServerAdmin admin@company.com
        DocumentRoot /var/www/apache/company.com
</VirtualHost>

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

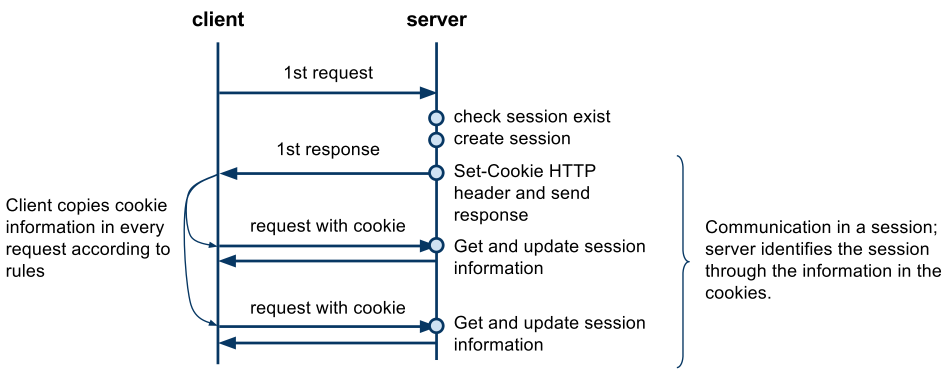
- Introduction to Application Protocols
- Simple Protocol Example
- Introduction to HTTP
  - *State Management*

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

```
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*

Session Management Java Class

- Manages client sessions in a server memory

```java
public class Sessions<E> {

    // storage for the session data;
    private Hashtable<String, E> sessions = new Hashtable<String, E>();

    /** Returns session id based on the information in the http request **/
    public String getSessionID(HttpServletRequest request) throws Exception {
        String sid = null;

        // extract the session id from the cookie
        if (request.getHeader("cookie") != null) {
            Pattern p = Pattern.compile(".*session-id=([a-zA-Z0-9]+).*");
            Matcher m = p.matcher(request.getHeader("cookie"));
            if (m.matches()) sid = m.group(1);
        }

        // create the session id md5 hash; use random number to generate a client-id
        // note that this is a simple solution but not very reliable
        if (sid == null || sessions.get(sid) == null) {
            MessageDigest md = MessageDigest.getInstance("MD5");
            md.update(new String(request.getRemoteAddr() +
                Math.floor(Math.random()*1000)).getBytes());
            sid = Utils.toHexString(md.digest());
        }
        return sid;
    }

    public E getData(String sid) ... // returns session data from sessions object
    public void setData(String sid, E d) ... // sets session data to sessions object
}
```

Stateful Server Implementation

- Simple per-client counter

```java
public void handleRequest(HttpServletRequest request,
        HttpServletResponse response) throws Exception {
    // get the session id
    String sid = sessions.getSessionID(request);

    // create the new data if none exists
    if (sessions.getData(sid) != null)
        sessions.setData(sid,
            Integer.valueOf(sessions.getData(sid).intValue() + 1));
    else
        sessions.setData(sid, Integer.valueOf(1));

    // send the response
    response.setStatus(200);
    response.setHeader("Set-Cookie", "session-id="+ sid + "; MaxAge=3600");
    response.setHeader("Content-Type", "text/plain");
    response.getWriter().write("Number of hits from you: " +
        sessions.getData(sid).toString());
    response.flushBuffer();
}
```

Task

– *What happens when the server restarts?*
– *How do you change the code to count requests from all clients?*

Testing

- Testing
  – `curl` *will require you to specify cookies in every request*
  – *Browser handles cookies automatically*

```
# run curl for the first time
curl -v 127.0.0.1:8080
> GET / HTTP/1.1
> Host: 127.0.0.1:8080
>
< HTTP/1.1 200 OK
< Set-Cookie: session-id=3a9c3cdc5ff36434aa1ba860727ca401;max-age=3600
<
Number of hits from you: 1

# copy the cookie session-id from previous response
curl -v -b session-id=3a9c3cdc5ff36434aa1ba860727ca401 127.0.0.1:8080
> GET / HTTP/1.1
> Host: 127.0.0.1:9900
> Cookie: session-id=3a9c3cdc5ff36434aa1ba860727ca401
>
< HTTP/1.1 200 OK
< Set-Cookie: session-id=3a9c3cdc5ff36434aa1ba860727ca401;max-age=3600
<
Number of hits from you: 2
```