Middleware and Web Services

Lecture 3: Application Protocols

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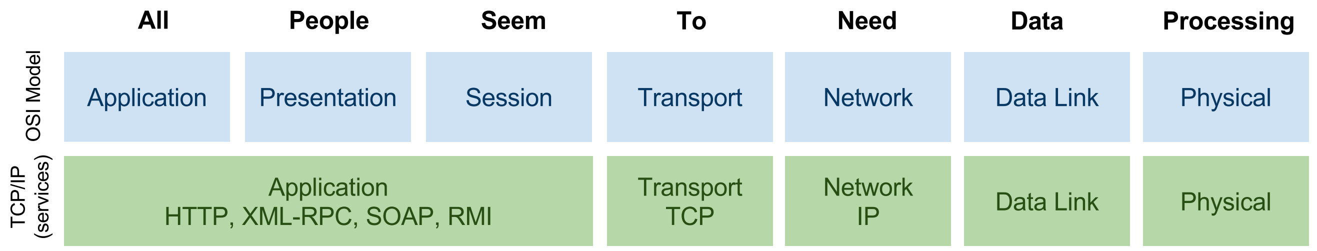
Overview

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

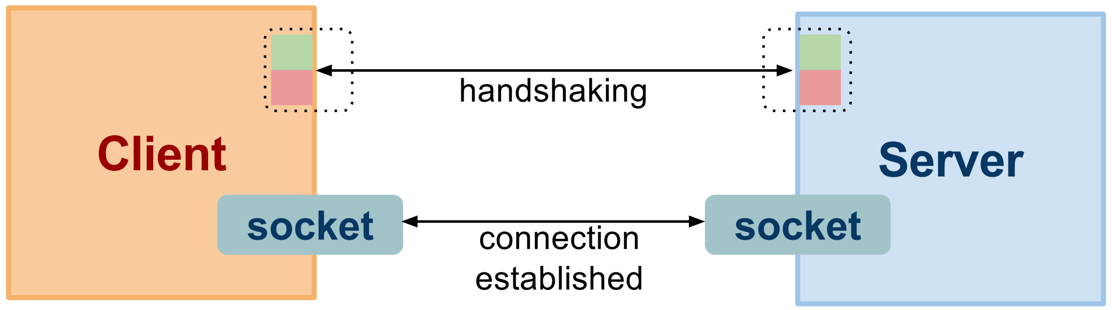
Application Protocols

- Remember this



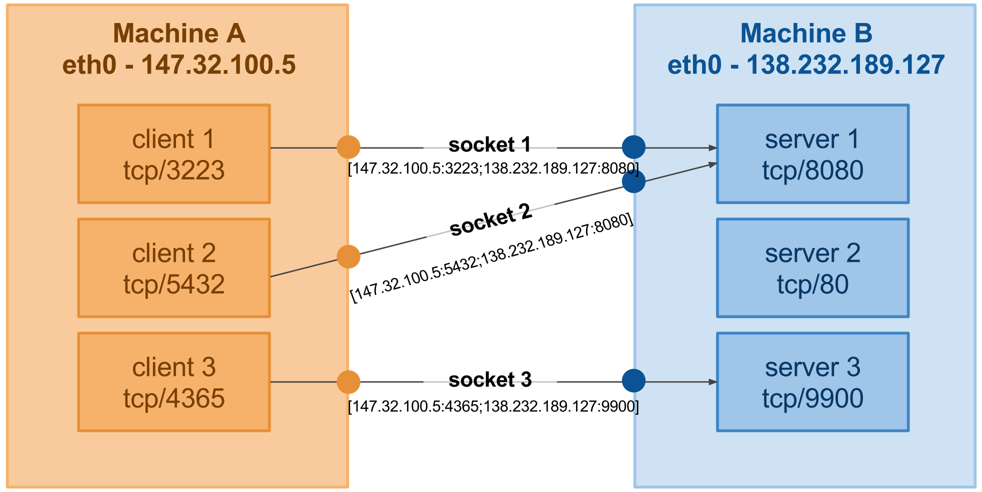
- App protocols mostly on top of the TCP Layer
  – *use TCP socket for communication*
- Major protocols
  – *HTTP – most of the app protocols layered on HTTP*
    → *wide spread, but: implementors often break HTTP semantics*
  – *RMI – Remote Method Invocation*
    → *Java-specific, rather interface*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

Socket



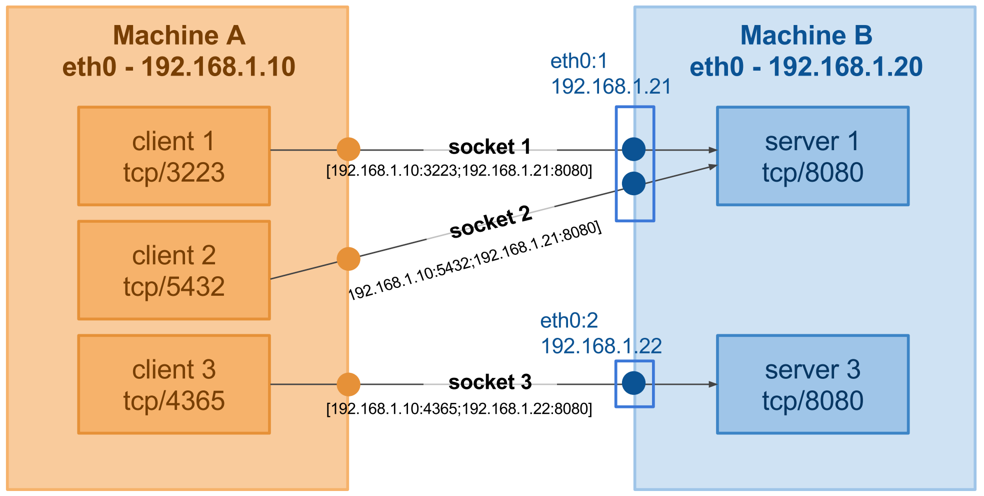
- Handshaking (connection establishment)
  - *The server listens at* `[dst_ip,dsp_port]`
  - *Three-way handshake:*
    - → *the client at* `[src_ip,src_port]` *sends a connection request*
    - → *the server responds*
    - → *the client acknowledges the response, can send data along*
  - *Result is 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:255.255.255.0
```

  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`

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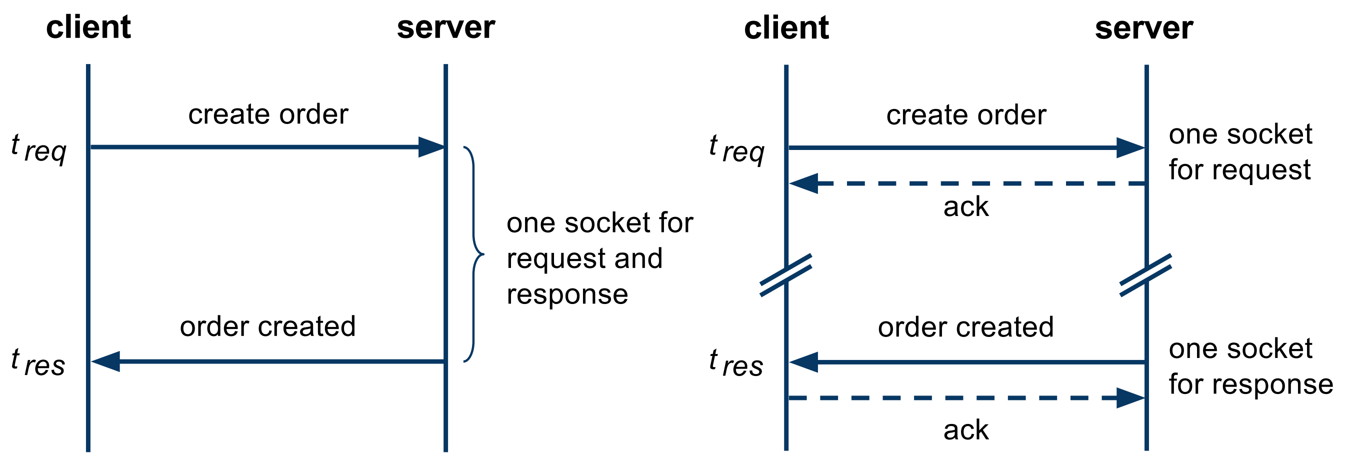
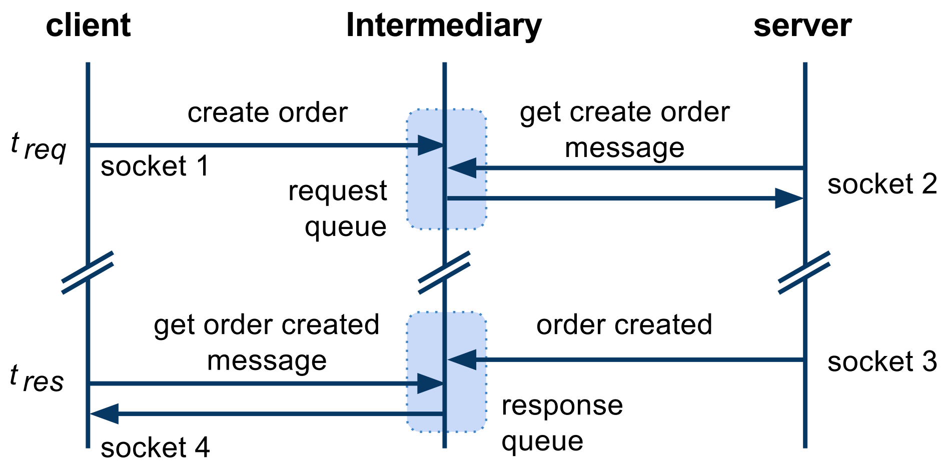
Synchronous and Asynchronous Communication



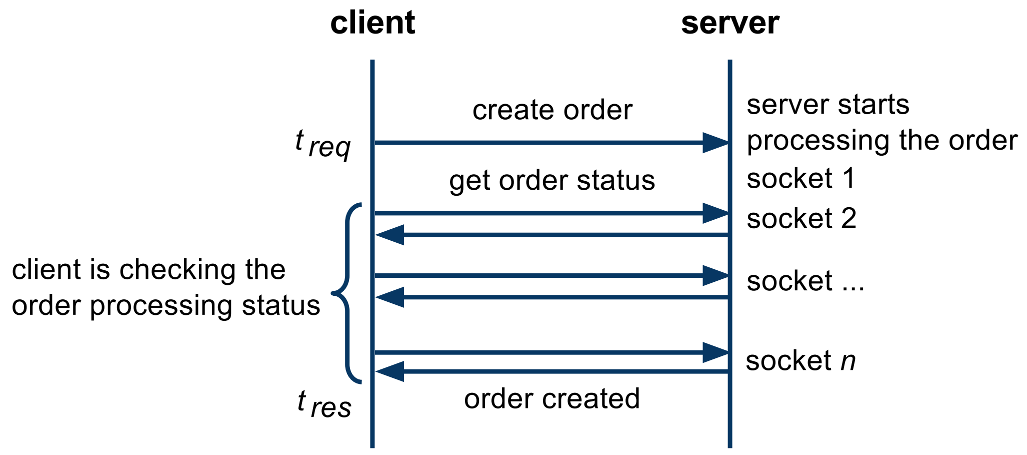
- Synchronous
  - *one socket, $|t_{req} - t_{res}|$ is small*
  - *easy to implement and deploy, only standard firewall config*
  - *only the server defines endpoint*
- Asynchronous
  - *request, response each has socket, client and server define endpoints*
  - *$|t_{req} - t_{res}|$ can be large (hours,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

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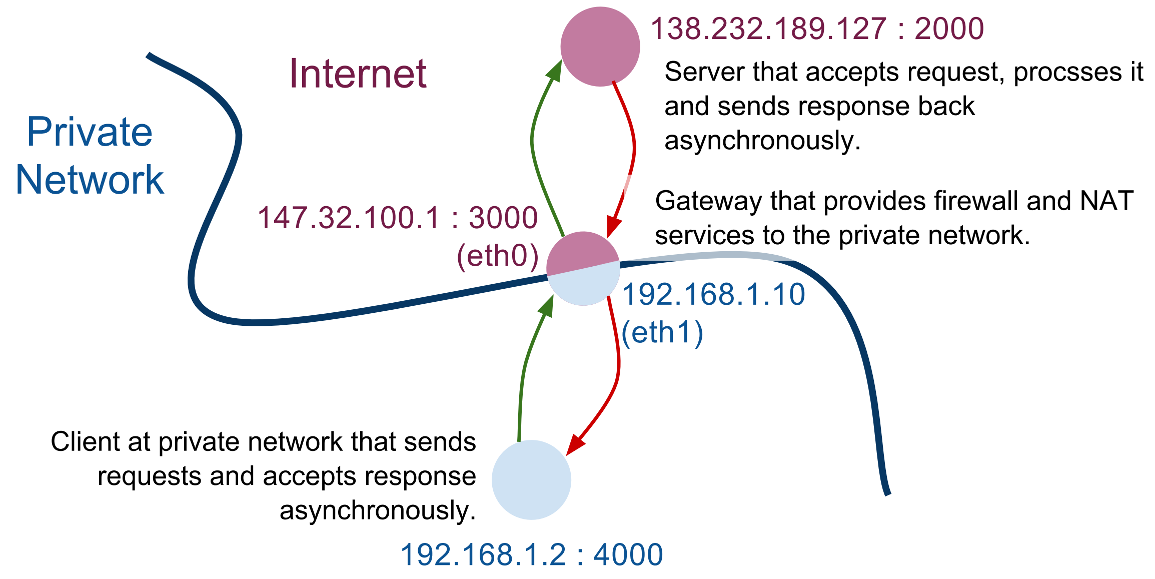
Public/Private Network Configuration

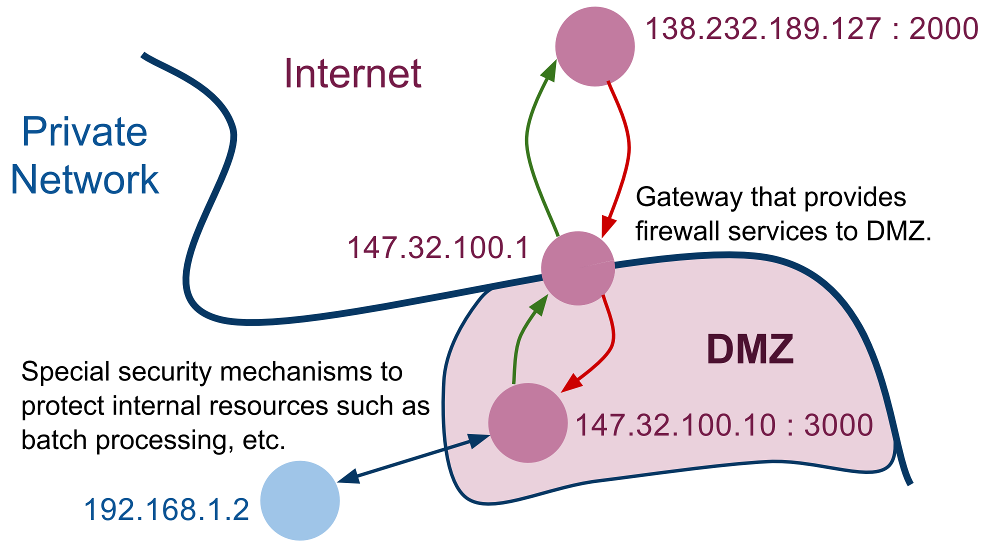


Internet
Private Network
138.232.189.127 : 2000
Server that accepts request, procsses it and sends response back asynchronously.
Gateway that provides firewall and NAT services to the private network.
147.32.100.1 : 3000 (eth0)
192.168.1.10 (eth1)
Client at private network that sends requests and accepts response asynchronously.
192.168.1.2 : 4000

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

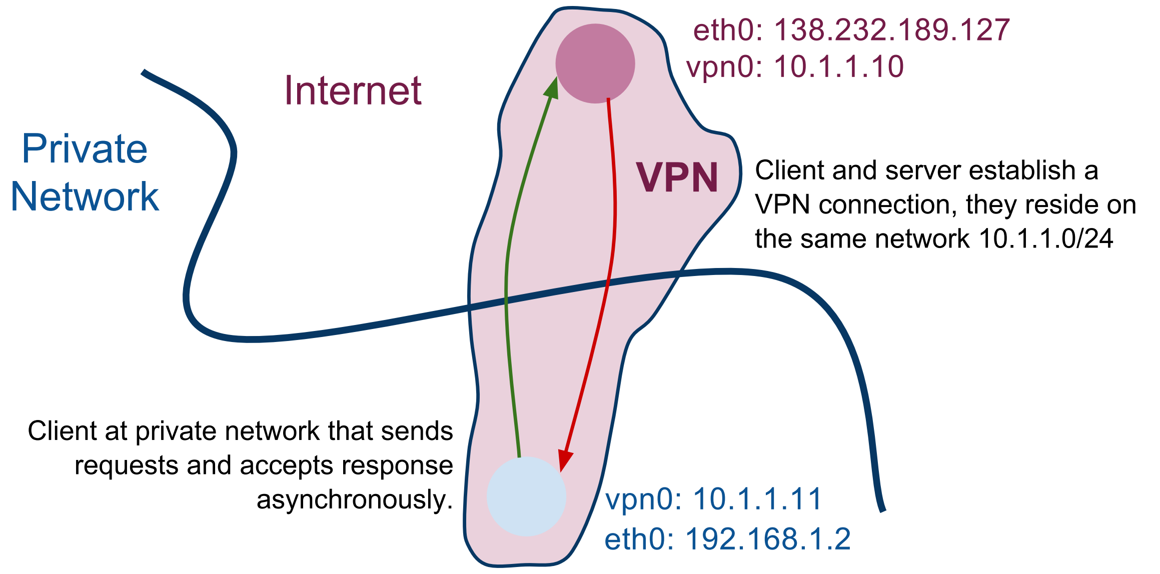
```
# enable ip forwarding from one interface to another within linux core
echo 1 > /proc/sys/net/ipv4/ip_forward

# 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


138.232.189.127 : 2000
Internet
Private Network
Gateway that provides firewall services to DMZ.
147.32.100.1
DMZ
Special security mechanisms to protect internal resources such as batch processing, etc.
147.32.100.10 : 3000
192.168.1.2

- 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*

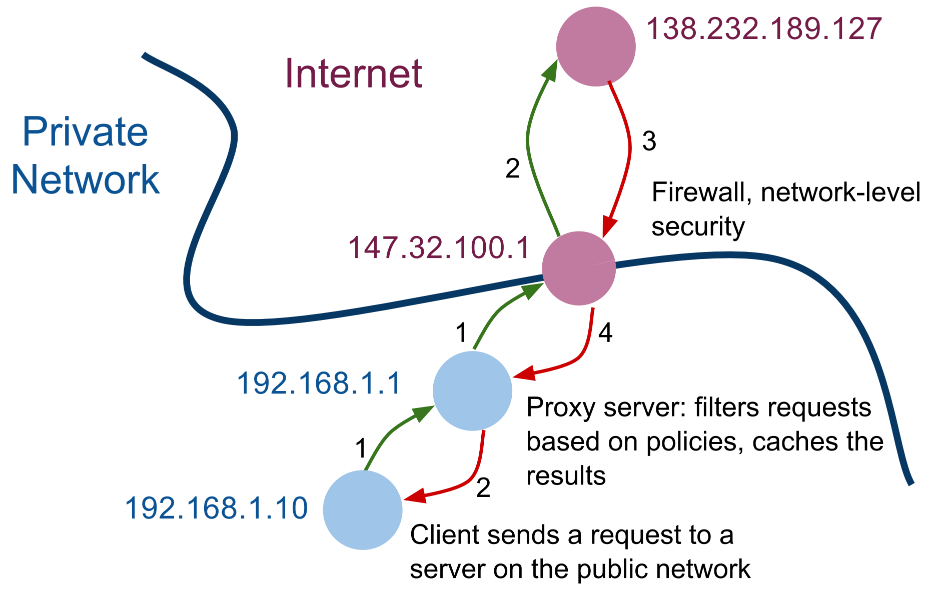
Virtual Private Network



Internet
eth0: 138.232.189.127
vpn0: 10.1.1.10
Private Network
VPN
Client and server establish a VPN connection, they reside on the same network 10.1.1.0/24
Client at private network that sends requests and accepts response asynchronously.
vpn0: 10.1.1.11
eth0: 192.168.1.2

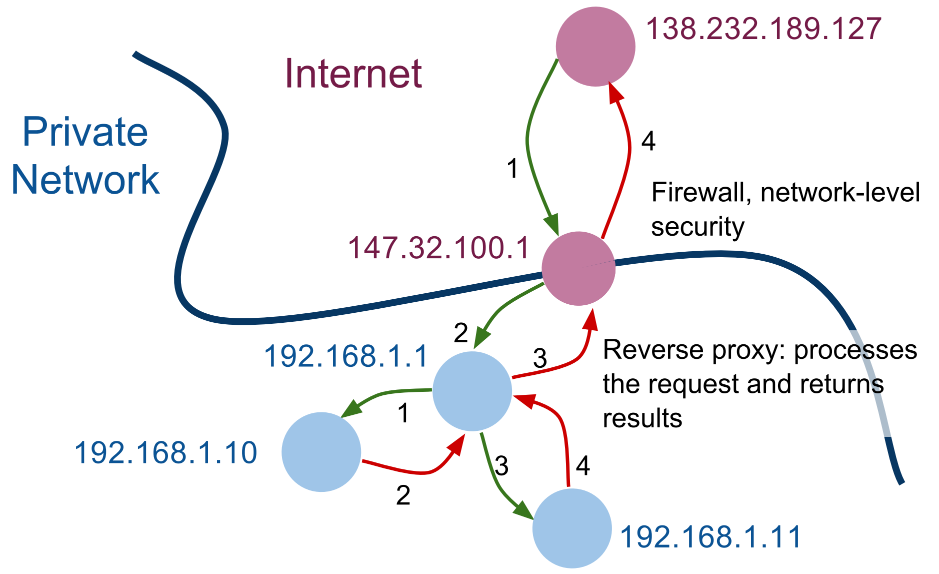
- VPN = Virtual Private Network
  - *an overlay network between a client and a server*
  - *the network spans accross underlying network elements*
  - *Example:*
    - → *VPN client starts a VPN connection with the VPN server via network interfaces*
    - → *VPN server assigns an IP address to the VPN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

Proxy Server


138.232.189.127
Internet
Private Network
2
3
Firewall, network-level security
147.32.100.1
1
4
192.168.1.1
Proxy server: filters requests based on policies, caches the results
1
2
192.168.1.10
Client sends a request to a server on the public network

- 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*

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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!
```

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  – *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 ]
```

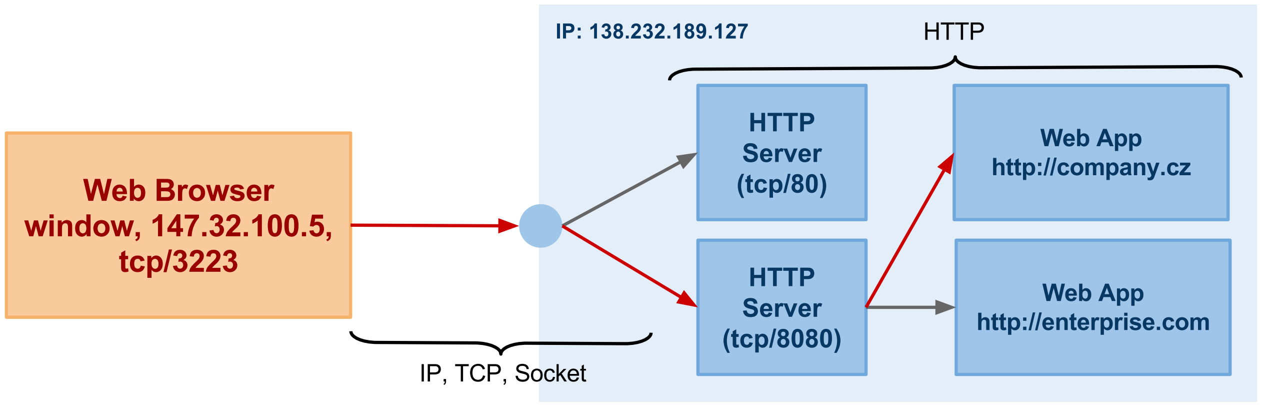
- Response Syntax

```
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: 138.232.189.127
HTTP
Web Browser window, 147.32.100.5, tcp/3223
HTTP Server (tcp/80)
HTTP Server (tcp/8080)
Web App http://company.cz
Web App http://enterprise.com
IP, TCP, Socket

- 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.*

```java
/** 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/0.9.8n
> Accept: */*
> Host: company.cz
>
< HTTP/1.1 201 OK
< Connection: keep-alive
< Content-Type: plain/text
<
< This is the response...
```

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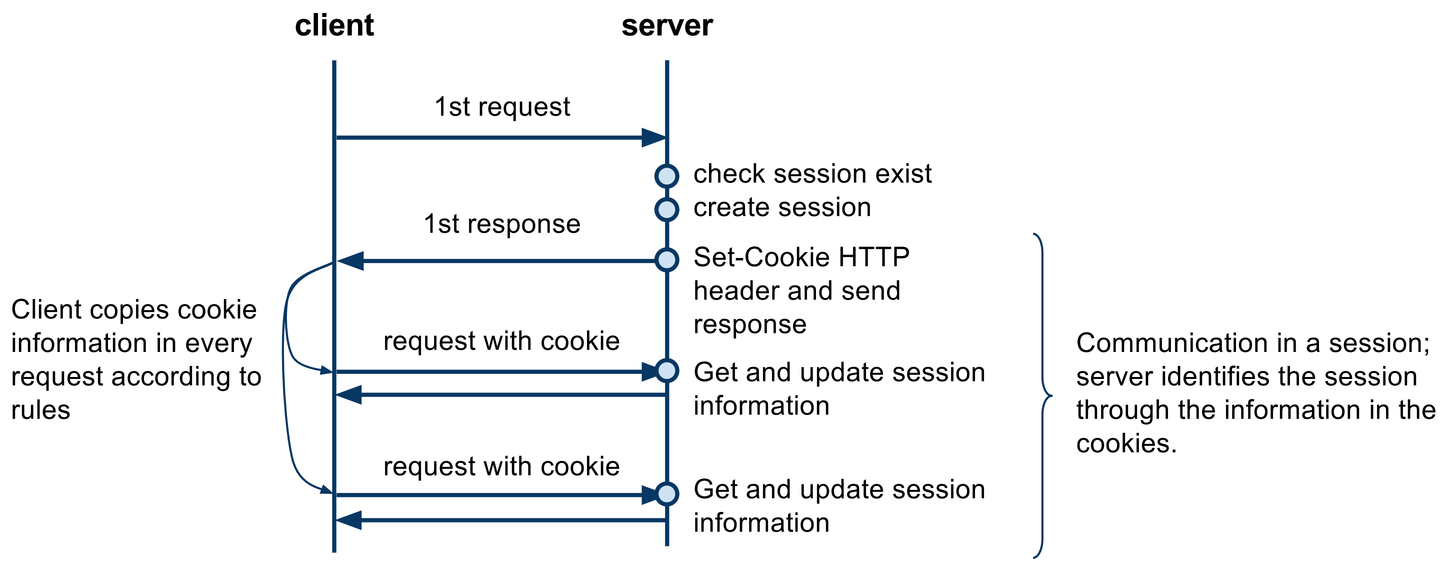
  – *State Management*

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*


client
server
1st request
check session exist
create session
1st response
Set-Cookie HTTP header and send response
Client copies cookie information in every request according to rules
request with cookie
Get and update session information
request with cookie
Get and update session information
Communication in a session; server identifies the session through the information in the cookies.

- 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
```