FS20

APPLICATION PROTOCOLS

DNS, HTTP, RPC

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HSR
HOCHSCHULE FÜR TECHNIK
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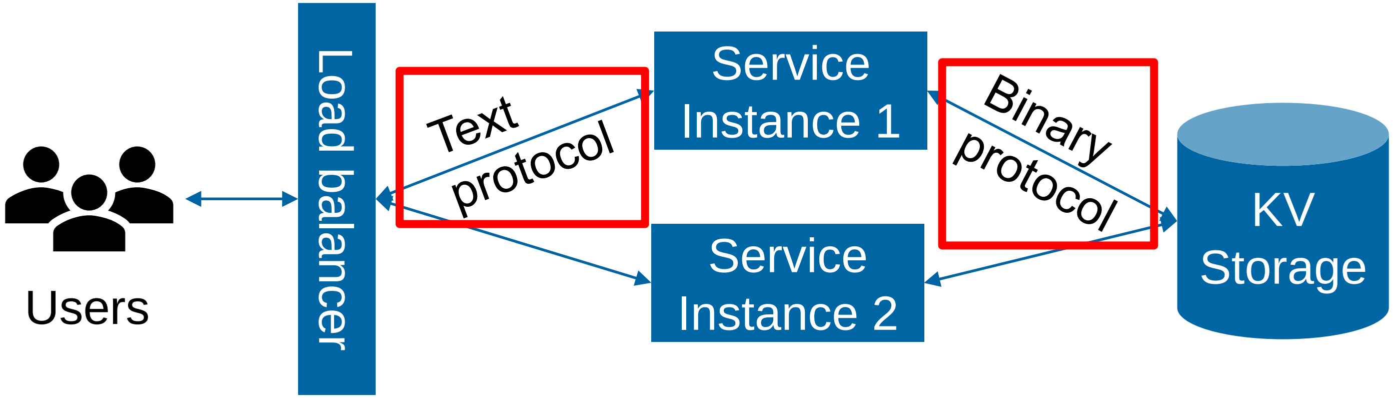
Agenda

- **Distributed Systems in the News**
- **RPC / binary protocols**
- **HTTP / text protocols**
- **DNS (protocol and distributed system)**

Distributed Systems - In the News

- **13.02.2020: [Internet's safe-keepers forced to postpone crucial DNSSEC root key signing ceremony – no, not a hacker attack, but because they can't open a safe]**
  - 40th Root Key Signing Key Ceremony postponed, notarization, legal representation, witnesses
  - quarterly ceremony since 2010
  - 15.02.2020: "We have successfully opened the safe"
  - Key signing ceremony: online, next 23.4.2020
- **01.03.2020: Pingdom Website Speed Test**
  - Test dsl.hsr.ch from San Francisco: >1sec for first byte
- **24.02.2020: Berners-Lee's Solid project: Schneier joins team to give you back control over data**
  - People behind Solid/Inrupt
    - Tim Berners Lee (creator of www)
    - Bruce Schneier (security researcher, writer)
  - "Solid is the technically potent, open-source platform built to decentralize the web"
  - Decentralized infrastructure: manage your data in Pods. You own the data, and give permission who can access it
    - Linked/structured data
    - Solid React applications
    - Web Access Control and Linked Data Platform

Challenge Task FS 2020



- **Check https://dsl.hsr.ch/lect/**
  - See if your name is there
- **Todays lecture is about text/binary protocols**

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Important dates

- Lecture dates 17.02.2020 - 29.05.2020
- Exam sessions 10.08.2020 - 11.09.2020

Verteilte SW-Systeme (VSS)

Nr	Date Lecture	Date Exercise	Topics	Slides	Milestones
01	18.02.2020	-	Admin, Introduction	VSS-FS20-01-Admin_v1.pdf, VSS-FS20-01-Introduction_v2.pdf, alpine-fs20_v3.ova (VirtualBox Image - root/hsr12345 (47MB))	Group forming idea for services
02	25.02.2020	25/26.02.2020	Protocols, Basics, Scalability	VSS-FS20-02-Proto_v3.pdf	Setup dev environment
03	03.03.2020	03/04.03.2020	Application Protocols	VSS-FS20-03-App-proto_v1.pdf	Information flow
04	10.03.2020	10/11.03.2020	Deployment, Infrastructure		Load balancer
05	17.03.2020	17/18.03.2020	RPC and Queues		Authentication

Last Lecture

- **DDoS - Amplification Attacks**

Protocols

- **Protocols, lecture 2: layer 4**
  - TCP, UDP, (QUIC)
- **Designing custom protocols (e.g. Kafka, [atp-go]())**

  \- Needs more time to develop / test

  \+ Can be more efficient (space/performance)
- **Protocol generators (binary): Thrift / Avro / Protocol Buffers / (ASN1)**

  \+ IDL (interface description language) generates code

  \+ Standard

  \- Has more overhead

  e.g, Avro IDL - higher-level language for authoring Avro schemata → generates Avro schema

```
//Avro IDL
@namespace("ch.hsr.dsl")

protocol MyProtocol{
  record AMessage {
     string request;
     int code;
  }
  record BMessage {
     string reply;
  }

  BMessage GetMessage(AMessage msg);
}

{"namespace": "ch.hsr.dsl",
 "type": "record",  "name":
"AMessage",
 "fields": [
  {"name": "request", "type":
"string"},
  {"name": "code", "type": "int"}
 ]
}
```

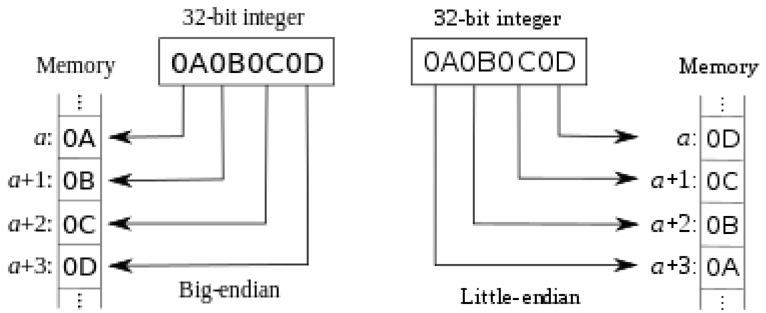
Protocols

```java
    public static boolean decodeHeader(final ByteBuf buffer, final InetSocketAddress recipientSocket,
            final InetSocketAddress senderSocket, final Message message) {
        LOG.debug("Decode message. Recipient: {}, Sender:{}.", recipientSocket, senderSocket);
        final int versionAndType = buffer.readInt();
        message.version(versionAndType >>> 4);
        message.type(Type.values()[(versionAndType & Utils.MASK_0F)]);
        message.protocolType(ProtocolType.values()[versionAndType >>> 30]);
        message.messageId(buffer.readInt());
        final int command = buffer.readUnsignedByte();
        message.command((byte) command);
        final Number160 recipientID = Number160.decode(buffer);

        //we only get the id for the recipient, the rest we already know
        final PeerAddress recipient = PeerAddress.builder().peerId(recipientID).build();
        message.recipient(recipient);


        final int contentTypes = buffer.readInt();
        message.hasContent(contentTypes != 0);
        message.contentTypes(decodeContentTypes(contentTypes, message));
```

- **Custom encoding/decoding**
  - You control every aspect
  - You send more time on it
- **[Little-endian / Big-endian](#)**
  - sequential order where bytes are converted into numbers
- **Networking, e.g. TCP headers: Big-endian**
- **Most CPUs e.g., x86: Little-endian**



- **UDP example in repo [VSS-RPC]**
  - Why is it failing?

```
func main() {
   fmt.Println("connecting...")
   conn, _ := net.Dial("udp", "127.0.0.1:7000")
   defer conn.Close()
   buf := make([]byte, 4)
   binary.LittleEndian.PutUint32(buf, 77)
   conn.Write(buf)
}

func main() {
   fmt.Println("listening...")
   inet := &net.UDPAddr{net.IPv4zero, 7000, ""}
   udpConn, _ := net.ListenUDP("udp", inet)
   b := make([]byte, 4)
   n, b2, _ := udpConn.ReadFromUDP(b);
   fmt.Printf("connecting... read: %d, addr: %v, data: %v," +
     " decoded: %v\n", n, b2, b[:n], binary.BigEndian.Uint32(b))
}
```

- **TCP**
  - Custom serialization 5,Anybody there?
    - 15 bytes

```
func main() {
   fmt.Println("connecting...")
   conn, _ := net.Dial(“tcp", "127.0.0.1:7000")
   defer conn.Close()
   buf := make([]byte, 15)
   buf[0]=5
   copy(buf[1:],[]byte("Anybody there?"))
   _, _ = conn.Write(buf)
}

func main() {
   fmt.Println("listening...")
   tcpConn, _ := net.Listen("tcp", ":7000")
   conn, _ := tcpConn.Accept() //do this in a go routine
   b := make([]byte, 15)
   n, _ := conn.Read(b)
   fmt.Printf("connecting... read: %d, addr: %v, data: [% x], decoded: %v\n",
      n, conn.RemoteAddr(), b[:n], string(b[1:]))}
```

Protocols Example ASN1

```
30 13 02 01 05 16 0e 41 6e 79 62 6f 64 79 20 74 68 65 72 65 3f
```

- **ASN1**
  - Defined in 1984. Standard interface description language (IDL)
  - Define data structures - can be serialized and deserialized
  - Used e.g., in: X.509 (hsr.ch)
  - Generic binary protocol, Golang package
  - Example: 21 bytes, XML: 48 bytes

```
30 — type tag indicating SEQUENCE
13 — length in octets of value that follows
  02 — type tag indicating INTEGER
  01 — length in octets of value that follows
    05 — value (5)
  16 — type tag indicating IA5String
     (IA5 means the full 7-bit ISO 646 set, including
variants,
      but is generally US-ASCII)
  0e — length in octets of value that follows
    41 6e 79 62 6f 64 79 20 74 68 65 72 65 3f — value
("Anybody there?")
```

```
<code>5</code>
<message>Anybody there?</message>
```

```go
type TestASN struct {
		Code *big.Int
		Message string
}
…
func main() {
…
   var t TestASN
   _, err = asn1.Unmarshal(b, &t)
}
```

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Room: HSR

Protocols Example Avro

- **Avro: data serialization system**
  - Remote procedure call and data serialization framework
  - Use: Hadoop (Big-data framework)
- **LinkedIn go-avro library**
  - Define a message in JSON (benchmarks) or IDL (slide 12) – no code generation

```
func main() {
  schema, _ := ioutil.ReadFile("schema.avsc")
  codec, _ := goavro.NewCodec(string(schema))
  map1 := map[string]interface{}{
    "request": "Anybody there?",
    "code":  5,
  }
  binary, _ := codec.BinaryFromNative(nil, map1)
  conn, _ := net.Dial("tcp", "127.0.0.1:7000")
  defer conn.Close()
  n, _ := conn.Write(binary)
  fmt.Printf("wrote %d bytes: [% x]\n", n, binary)
}
```

- **Server**
  - Example 16 bytes, assuming both have the same IDL

```
{"namespace": "ch.hsr.dsl",
  "type": "record",  "name": "AMessage",
  "fields": [
      {"name": "request", "type": "string"},
      {"name": "code", "type": "int"}
  ]
}
```

```
func main() {
  schema, _ := ioutil.ReadFile("schema.avsc")
  codec, _ := goavro.NewCodec(string(schema))
  tcpConn, _ := net.Listen("tcp", ":7000")
  conn, _ := tcpConn.Accept() //do this in a go routine
  binary := make([]byte, 100)
  n, _ := conn.Read(binary)
  native, _, _ := codec.NativeFromBinary(binary[:n])
  fmt.Printf("read: %v\n", native)
}
```

Protocol Buffers Example

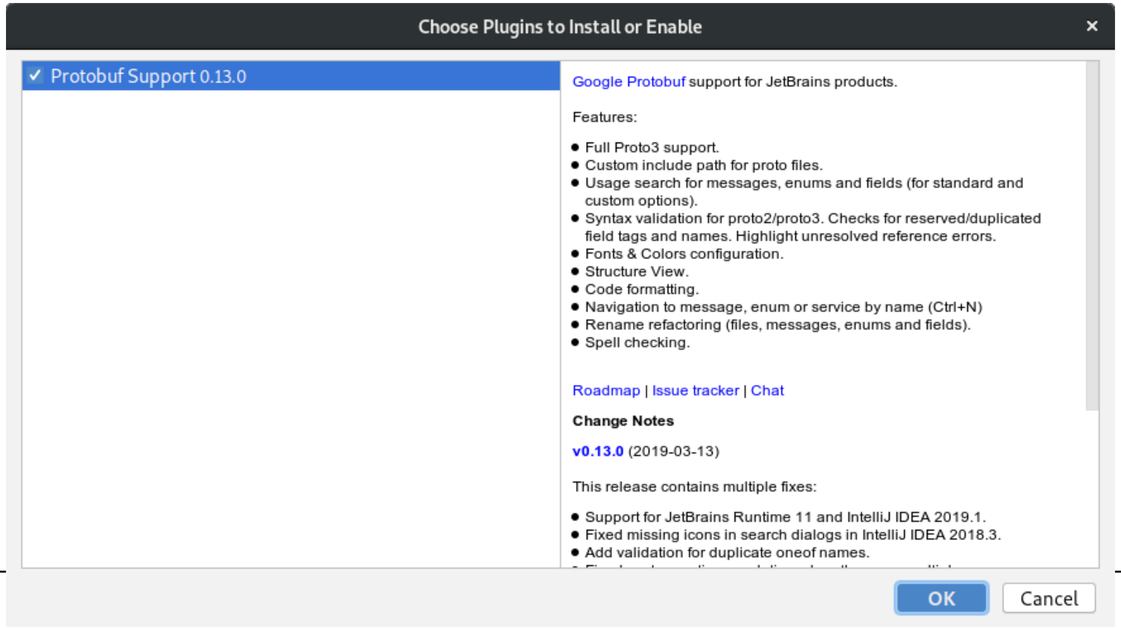
- **Protobuf: data serialization system from Google (2.3.2020 – new Go API)**
  - Design goals: smaller and faster than XML
  - Use: nearly all inter-machine communication at Google
- **Generate 1 go file**
  - protoc schema.proto --go_out go-gen2
  - integers to identify fields. Protocol buffer contains only numbers, not field names
- **18 bytes**

```
m := &pb.AMessage{Id: 5, Message: "Anybody there?"}
out, err := proto.Marshal(m)

m := &pb.AMessage{}
if err := proto.Unmarshal(binary[:n], m); err != nil {
  panic(err)
}
```

- **Not self-describing, but has gzipped description**

```
syntax = "proto3";
message AMessage {
  int32 id = 1;
  string message = 2;
}
```



RPC Example Thrift

- **RPC Framework from Facebook**
  - IDL and binary protocol
  - For building cross-platform application in ActionScript, C, C++, C#, Cappuccino, Cocoa, Delphi, Erlang, Go, Haskell, Java, Node.js, Objective-C, OCaml, Perl, PHP, Python, Ruby, Rust, Smalltalk, and Swift
- **Installation**
  - sudo apt install thrift-compiler
  - thrift -r --gen go schema.thrift
  - Creates go files (client)

```
service TestService {
    void AMessage(1:i32 int, 2:string message)
}
```

- **Example generic server**
  - go run simple-gen-srv.go
  - go run simple-thrift.go -p 7000
  - go run simple-thrift.go -p 7000 AMessage 5 'Anybody there?’
- **49 bytes transferred**
- **Thrift also encodes which function to call, larger size**

RPC Example gRPC

- **gRPC**
  - Uses HTTP/2 for transport
  - Uses Protocol Buffers as IDL
  - Features: authentication, bidirectional streaming and flow control, blocking or nonblocking bindings, and cancellation and timeouts, many languages
  - Installation
    - go get -u google.golang.org/grpc
    - go get -u github.com/golang/protobuf/protoc-gen-go
    - protoc schema-grpc.proto --go_out=plugins=grpc:go-gen3
  - 198 / 135 (wireshark)

```
grpcServer := grpc.NewServer()
s := Server{}
schemagrpc.RegisterMessageServiceServer(grpcServer, &s)
grpcServer.Serve(tcpConn)
```

- **Define services and message**
  - Generate 1 source file with functions (service)

```
syntax = "proto3";

service MessageService {
  rpc SendMessage (AMessage) returns(Empty);
}

message AMessage {
  int32 code = 1;
  string message = 2;
}

message Empty {}
```

```
var conn *grpc.ClientConn
conn, _ := grpc.Dial(":7000", grpc.WithInsecure())
if err != nil {
  log.Fatalf("did not connect: %s", err)
}
defer conn.Close()
c := schema_grpc.NewMessageServiceClient(conn)
response, _ := c.SendMessage(context.Background(),
     &schema_grpc.AMessage{Code:5,Message:"Anybody there?"})
```

JSON example

- **JSON + REST**
  - Human-readable text to transmit data
  - Often used for web apps
- **187 bytes**

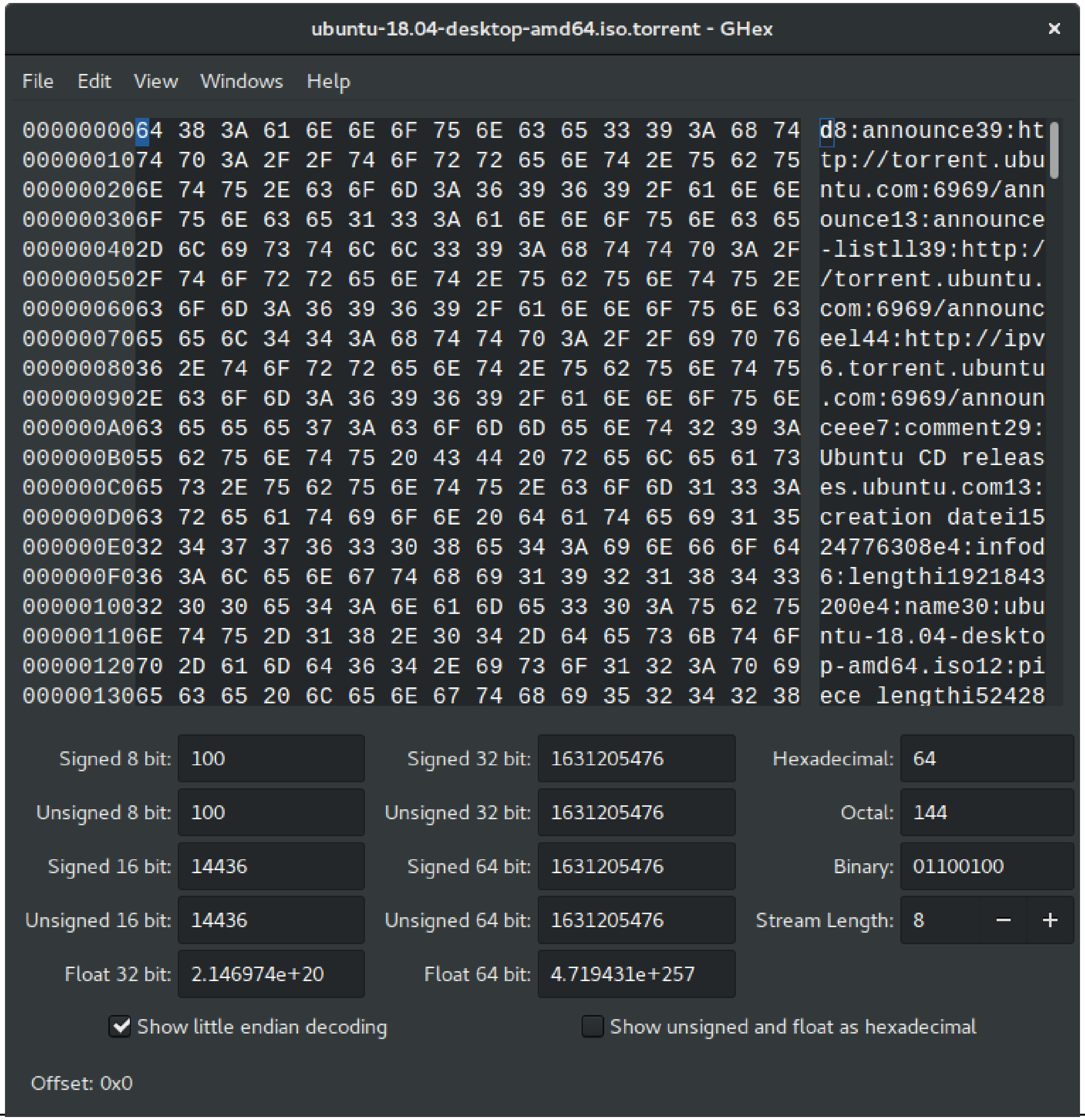
```
func main() {
  fmt.Println("Connecting...")
  req, _ := http.NewRequest("POST", "http://localhost:7000",
    strings.NewReader(`{"code": 5,"message": "Anybody there?"}`))
  req.Header.Set("Content-Type", "application/json")
  client := &http.Client{}
  resp, err := client.Do(req)
  if err != nil {
    panic(err)
  }
  defer resp.Body.Close()
  fmt.Printf("wrote request")
}
```

- **Parsing overhead, JSON slower than binary protocol - benchmarks**


```
[
    {
        "id": "bitcoin",
        "name": "Bitcoin",
        "symbol": "BTC",
        "rank": "1",
        "price_usd": "9324.08",
        "price_btc": "1.0",
        "24h_volume_usd": "9039300000.0",
        "market_cap_usd": "158560288125",
        "available_supply": "17005462.0",
        "total_supply": "17005462.0",
        "max_supply": "21000000.0",
        "percent_change_1h": "0.46",
        "percent_change_24h": "-0.27",
        "percent_change_7d": "4.5",
        "last_updated": "1525011874‟
    }, ...
]
```

Protocols Bencoding and Others

- **Benconding**
  - Integers: i42e
  - Byte string: 4:test
  - List: l4:testi42ee
  - Map/dictionary: d4:test3:hsr3:tomi42ee
- **Use: BitTorrent**
- **Cap’n Proto , FlatBuffers**
  - Do not serialize, just copy, little-endian
- **Apache Arrow**
  - Do not serialize, copy, and optimally layout for memory access
- **… and many others**
- **Benchmarks, benchmarks, benchmarks**



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Application Protocol: HTTP

- **HTTP (HyperText Transfer Protocol): foundation of data communication for www**
- **Started in 1989 byt Tim Berners-Lee**
  - HTTP/1.1 published in 1997
  - HTTP/2 published in 2015
    - More efficient, header compression, multiplexing
- **Request / response (resource)**
- **HTTP resources identified by URL**
  - https://dsl.hsr.ch/design/hsr_logo.svg

```
          userinfo       host      port
      ┌───────┴───────┐ ┌────┴────────┐ ┌┴┐
http://john.doe:password@www.example.com:123/forum/questions/?tag=networking&order=newest#top
└─┬─┘ └───────────┬────────────────────┘└─┬─────────────┘└────────┬──────────────┘└┬┘
scheme        authority                  path                   query           fragment
```

https://en.wikipedia.org/wiki/Hypertext_Transfer_Protocol

- **Text-based protocol**

```
openssl s_client -connect dsl.hsr.ch:443
… TLS handshake …
GET /
```

- **Browser sends a bit more…**

Request Headers (359 B)

```
Host: dsl.hsr.ch
User-Agent: Mozilla/5.0 (X11; Linux x86_64; rv:73.0) Gecko/20100101 Firefox/73.0
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,*/*;q=0.8
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate, br
DNT: 1
Connection: keep-alive
Upgrade-Insecure-Requests: 1
Cache-Control: max-age=0
TE: Trailers
```

Application Protocol: HTTP

- **Response**
  - Header

Response Headers (227 B)

```
HTTP/2 200 OK
server: cloudflare-nginx
content-type: text/html; charset=UTF-8
date: Mon, 02 Mar 2020 14:29:39 GMT
x-page-speed: 1.13.35.2-0
cache-control: max-age=0, no-cache
content-encoding: gzip
X-Firefox-Spdy: h2
```

  - Status Code: 200
    - List: from 1xx (information response), 2xx (success) – 200 OK, 3xx (redirection), 4xx (client error), 404 Not Found, 403 Forbidden (access slides outside HSR), 5xx (server errors)
  - Content

```
<!DOCTYPE html>
<html>
<head>
    <title>Distributed Systems and Ledgers Lab</title>
    <link rel="stylesheet" type="text/css" href="design/layout.css"/>
…
```

- **HTTP is a stateless protocol**
  - Server maintains no state
- **Request methods: GET, HEAD, POST, PUT, DELETE, TRACE, OPTIONS, CONNECT, PATCH**
- **Web server one-liner - with netcat:**
  - while true; do { echo -e 'HTTP/1.1 200 OK\r\n\r\n Hallo'; } | nc -l 8080 -q 1; done
- **Every Webbrowser has dev tools to show request / responses**
  - Firefox, Chrome: ctrl+shift+i / F12
  - Used regularly

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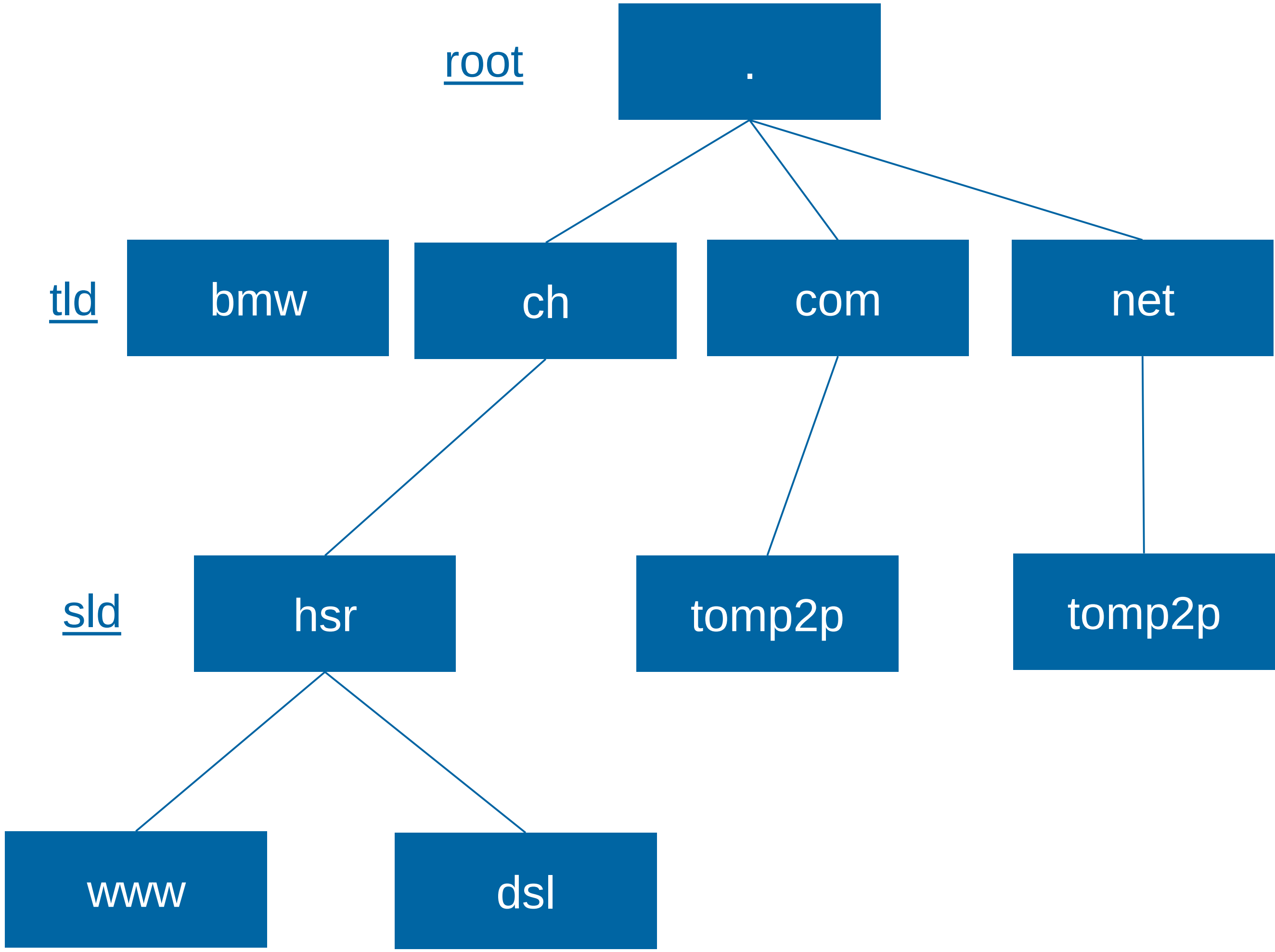
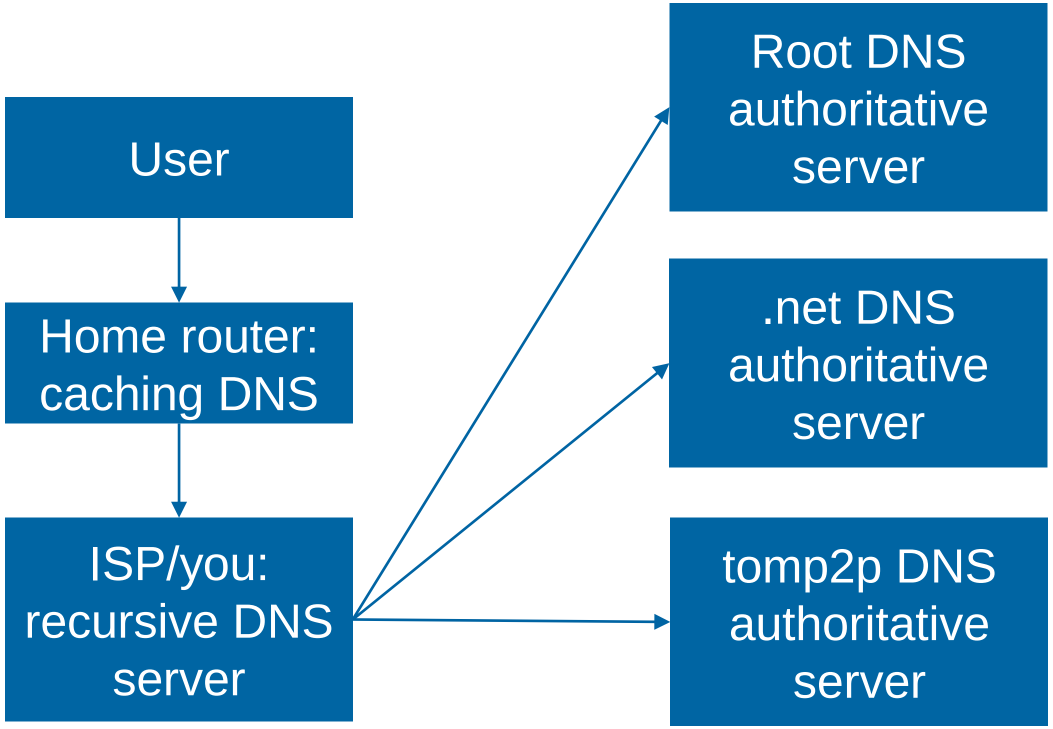
- **Translates human readable domain names to IP addresses "phonebook of the Internet"**
  - Delegate authority over sub-domains to other name servers
- **Lots of new TLD: .zuerich, .bmw, .americanexpress, .youtube, .გე**
  - No special characters: ASCII (no UTF)
  - Punycode: bücher.tld → xn--bcher-kva.tld
- **Hierarchical and decentralized naming system for computers**
  - E.g., dsl.hsr.ch
  - Uses UDP, port 53
  - Designed in 1983: unencrypted, unsigned
- **Before DNS: exchange of hosts.txt**
  - Does not scale



- **Primary + secondary DNS in case of failure**
  - Secondary DNS gets data from primary
- **Typical setup**
  - User
  - Caching/forwarding DNS (e.g., dnsmasq)
  - Recursive servers: DNS name resolution for applications (e.g, bind/unbound)
  - Authoritative servers: providing a definitive answer of e.g., tomp2p.net (e.g., bind/nsd)
    - Authoritative DNS service allows **others** to find **your** domain; Recursive DNS allows **you** to resolve **other** domains
- **Restriction to 13 root servers due to 512 byte packet limit**
  - With anycast, ~600 root servers around the world

E.g. BIND

```
zone tomp2p.net  {
        type master;
        file "zones/tomp2p.net";
        allow-transfer { 192.168.0.3; };
};
```



Application Protocol: DNS

- **l.root-servers.net , 1 root IP with anycast**
  mirrored in 128 locations
- **2015: [Internet DNS servers withstand huge DDoS attack]()**
  - 5m requests/s – some DNS could handle it
- **Root zone is controlled by the United States Department of Commerce , operations by ICANN**
- **Root zone file: [download]()**

https://www.iana.org/domains/root/se

HOSTNAME	IP ADDRESSES	MANAGER
a.root-servers.net	198.41.0.4, 2001:503:ba3e::2:30	VeriSign, Inc.
b.root-servers.net	199.9.14.201, 2001:500:200::b	University of Southern California (ISI)
c.root-servers.net	192.33.4.12, 2001:500:2::c	Cogent Communications
d.root-servers.net	199.7.91.13, 2001:500:2d::d	University of Maryland
e.root-servers.net	192.203.230.10, 2001:500:a8::e	NASA (Ames Research Center)
f.root-servers.net	192.5.5.241, 2001:500:2f::f	Internet Systems Consortium, Inc.
g.root-servers.net	192.112.36.4, 2001:500:12::d0d	US Department of Defense (NIC)
h.root-servers.net	198.97.190.53, 2001:500:1::53	US Army (Research Lab)
i.root-servers.net	192.36.148.17, 2001:7fe::53	Netnod
j.root-servers.net	192.58.128.30, 2001:503:c27::2:30	VeriSign, Inc.
k.root-servers.net	193.0.14.129, 2001:7fd::1	RIPE NCC
l.root-servers.net	199.7.83.42, 2001:500:9f::42	ICANN
m.root-servers.net	202.12.27.33, 2001:dc3::35	WIDE Project

Many of the locations of L.ROOT-SERVERS.ORG instances.
Map courtesy of ICANN, operators of "L".

Application Protocol: DNS

- **DNS structure**
  - TTL defines the duration in seconds that the record may be cached by any resolver. “0” means no cache. Recommendation: > 1d
- **Type of records**
  - SOA - Start of Authority record: serial number and different caching times for 2nd DNS, emails (no @). Last time (3H) is for negative caching
  - NS - Name Server Record – sets the authoritative name server for this zone. 2 NS records – round robin! more sophisticated LB: split horizon
  - MX - name and relative preference of mail servers
  - A/AAAA - IPv4/IPv6 Address Record
  - TXT - arbitrary and unformatted text
  - PTR - opposite of A /AAAA

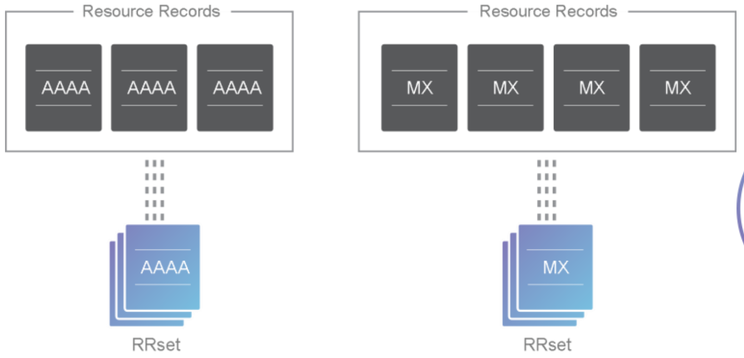
```
$TTL 3D
$ORIGIN tomp2p.net.
@ SOA ns.nope.ch. root.nope.ch. (2018030404 8H 2H 4W 3H)
                NS              ns.nope.ch.
                NS              ns.jos.li.
                MX      10      mail.nope.ch.
                A               188.40.119.115
                TXT             "v=spf1 mx -all“
www             A               188.40.119.115
bootstrap       A               188.40.119.115
$INCLUDE "/etc/opendkim/keys/mail.txt“
$INCLUDE "/etc/bind/dmarc.txt"
```

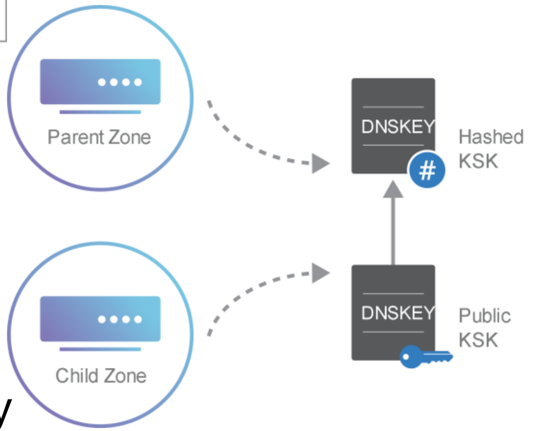
```
dig dsl.hsr.ch
dig -x 152.96.80.48
dig mx tomp2p.net
dig tomp2p.net @ns.nope.ch
```

- **Lets add dsl.tomp2p.net!**

- **To run your own DynDNS service: [TSIG]**
  - Enables DNS queries to authenticate updates to a DNS database
  - Uses shared secret and cryptographic hashing for authentication
- **DNSSEC (security extension)**
  - Authenticated and data integrity, **not** confidentiality
  - Can be used to bootstrap other security systems
    - Certificates, SSH fingerprints, IPSec pub keys
  - KSK: key signing keys to sign other DNSKEY records
  - ZSK: zone signing keys to sign records
    - Example: dig DNSKEY tomp2p.net

- **New record types: RRSIG, DNSKEY, DS, …**
  - RRSIG, sign all resource sets

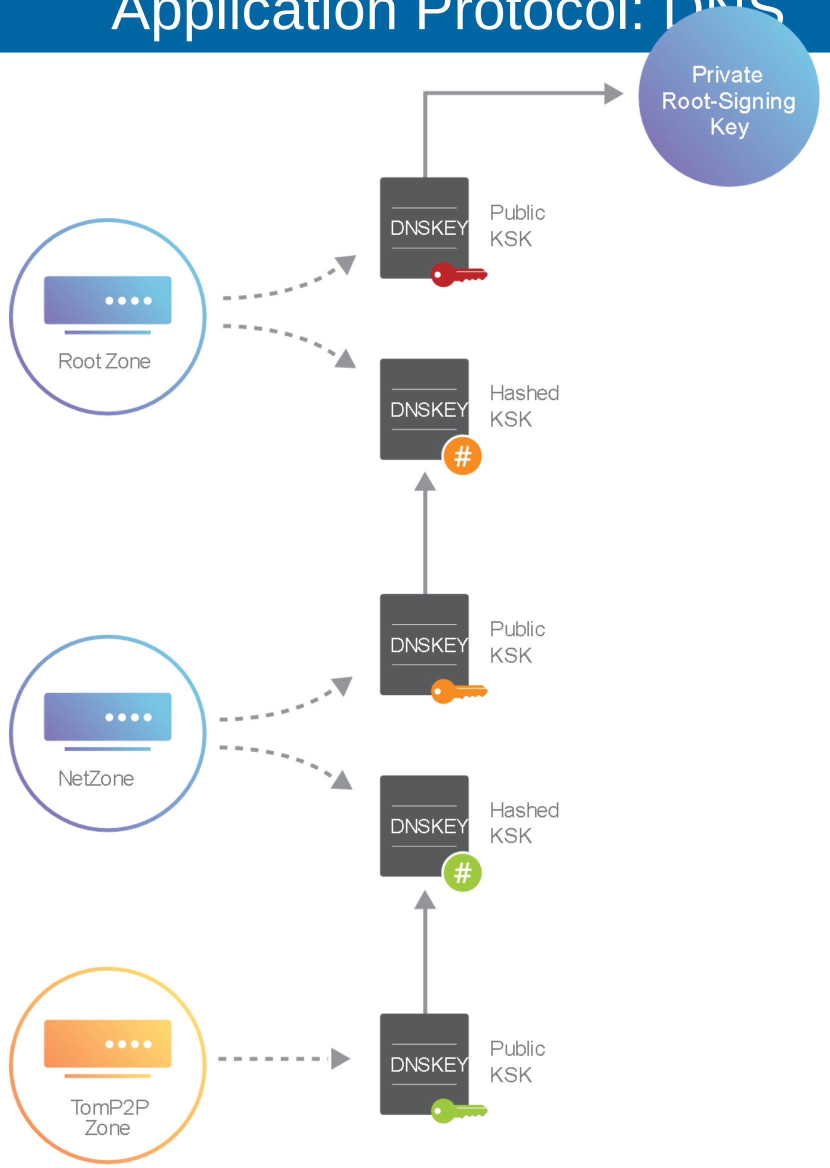




  - ZSK used to sign RRset
    - How to validate ZSK?
  - KSK used to sign ZSK pub key
    - With 2 keys, its easier to change ZSK
  - We now know that entries are signed. KSK signes ZSK, ZSK signs Rrset
    - dig any tomp2p.net
  - DS (delegation signer) record in the parent zone

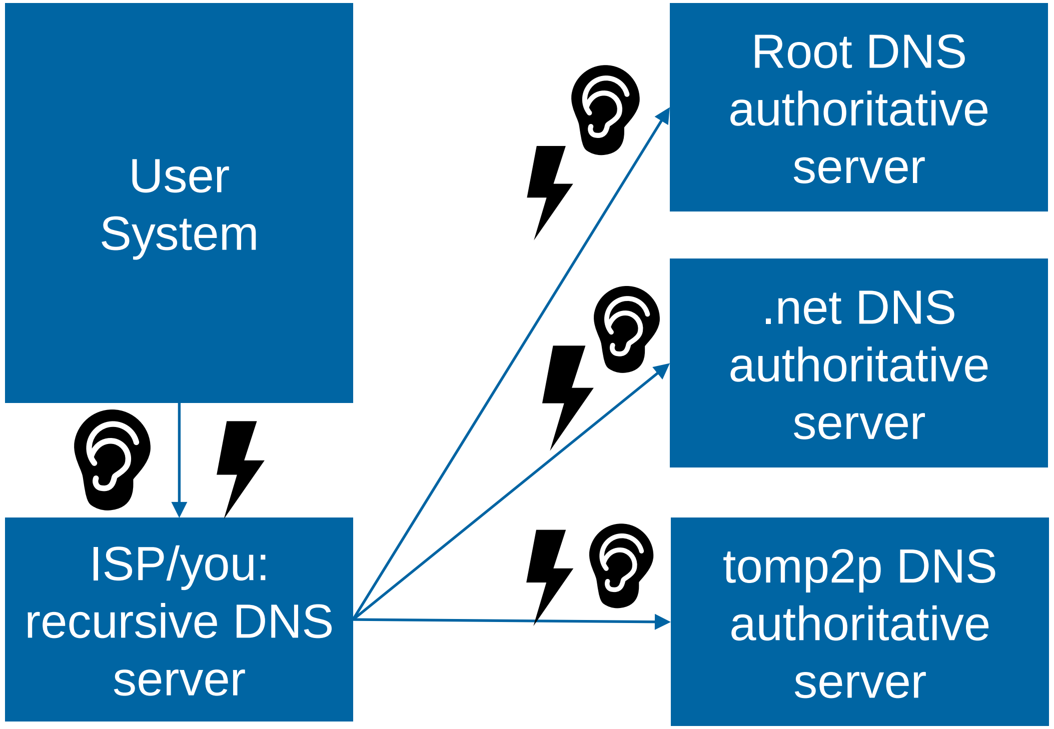
https://www.cloudflare.com/dns/dnssec/how-dnssec-works/

Application Protocol: DNS

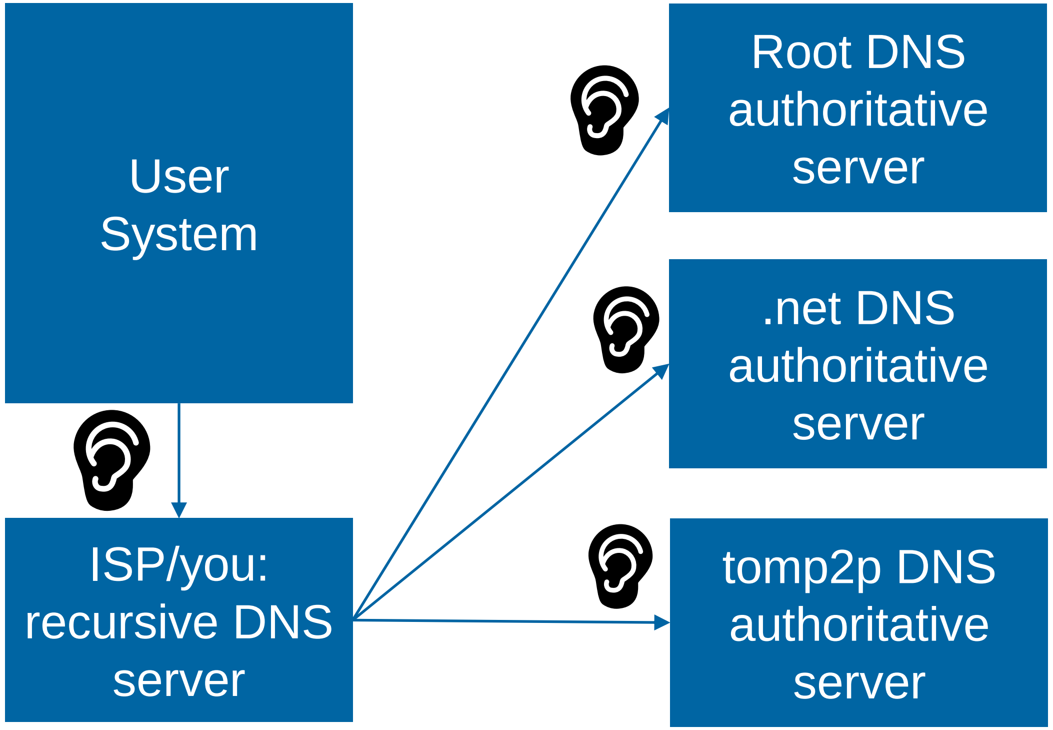


- **25.02.2020: [The Facts: Mozilla's DNS over HTTPs (DoH)]**
  - DNS is unencrypted → DNSSEC signs but does not encrypt
  - DNS war
    - DNS over TLS (DoT) vs. DNS over HTTPS (DoH)
  - Mozilla: "Today in practice, DNS is centralized because consumer devices are locked to the DNS service of ISPs"
  - Very controversial topic:
    - Argument: 5 ISPs per country, this is centralized, DoH with cloudflare is less centralized?
    - Application manages DNS, different result for different applications, but possible to query DNS from Javascript
    - https://ungleich.ch/en-us/cms/blog/2019/09/11/turn-off-doh-firefox/
    - Google: wont override choice of DNS provider

- **DNS**


User System
Root DNS authoritative server
.net DNS authoritative server
ISP/you: recursive DNS server
tomp2p DNS authoritative server

- **DNSSEC**


User System
Root DNS authoritative server
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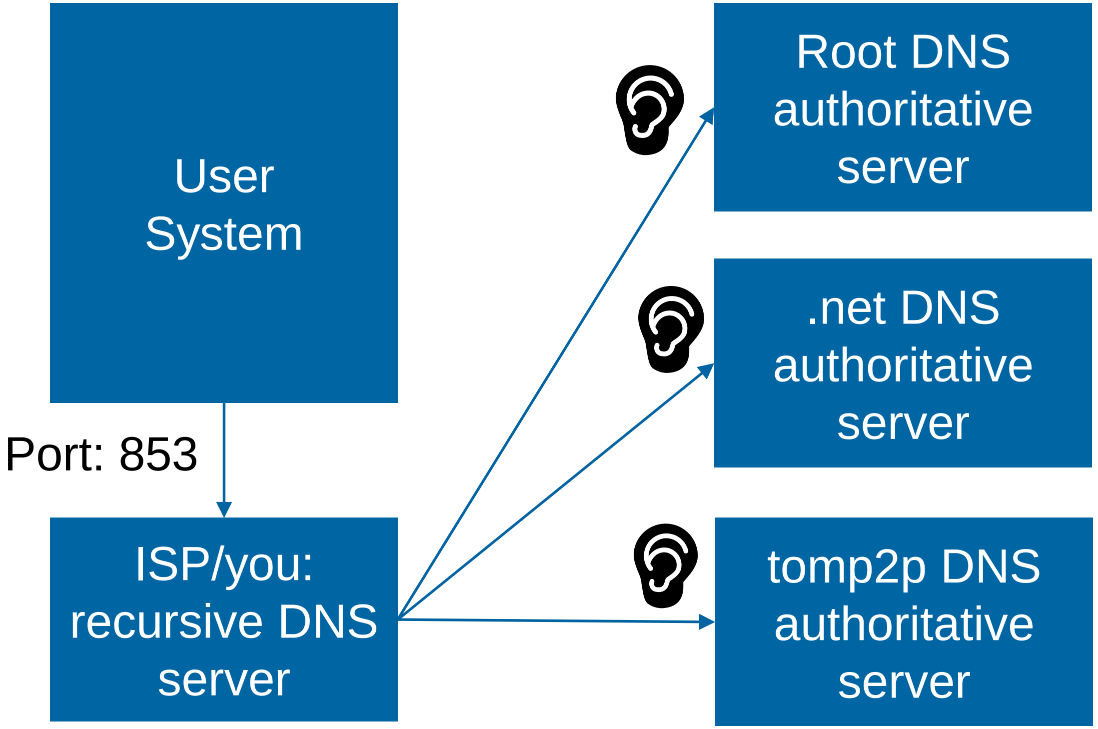
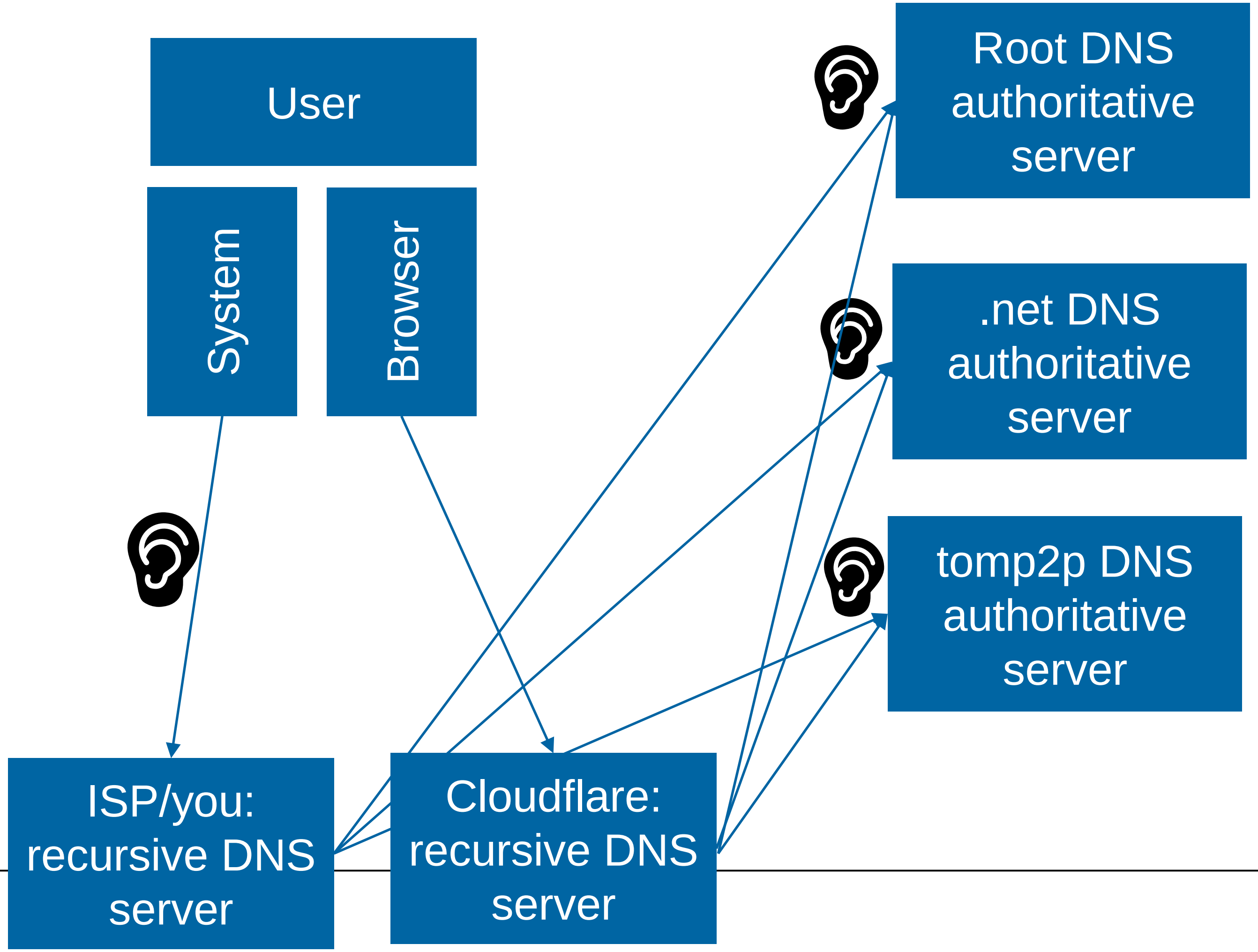
ISP/you: recursive DNS server
tomp2p DNS authoritative server

Application Protocol: DNS

- **DoT (assuming DNSSEC)**



- **DoH (assuming DNSSEC)**



The DNS war

DoH

- provides confidentiality of lookups in transit
- Uses standard HTTP/2, on the standard port (443)
  - Cannot distinguish between traffic/DNS
- Trivially deployed , DNS response are served like simple web pages
- Performance: TCP+TLS handshake → 2/3 RTT
  - But: Cloudflare is close to you
- Difficult upgrade path for clients: per-application installation
- Browsers can perform DNS queries using Javascript

DoT

- provides confidentiality of lookups in transit
- DNS over TLS, separate port (853)
  - Can be blocked
- Widely supported by serving software (Bind, PowerDNS, Unbound) and public resolvers (Cloudflare, Quad9, Google)
- Performance: TCP+TLS handshake → 2/3 RTT
  - But: ISP is close to you
- Easy upgrade path for clients: clients can test if the configured resolver supports DoT on port 853, fall back to DoU53 otherwise)

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Questions?

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