Resilient Networking
Module 4: Name Resolution Security

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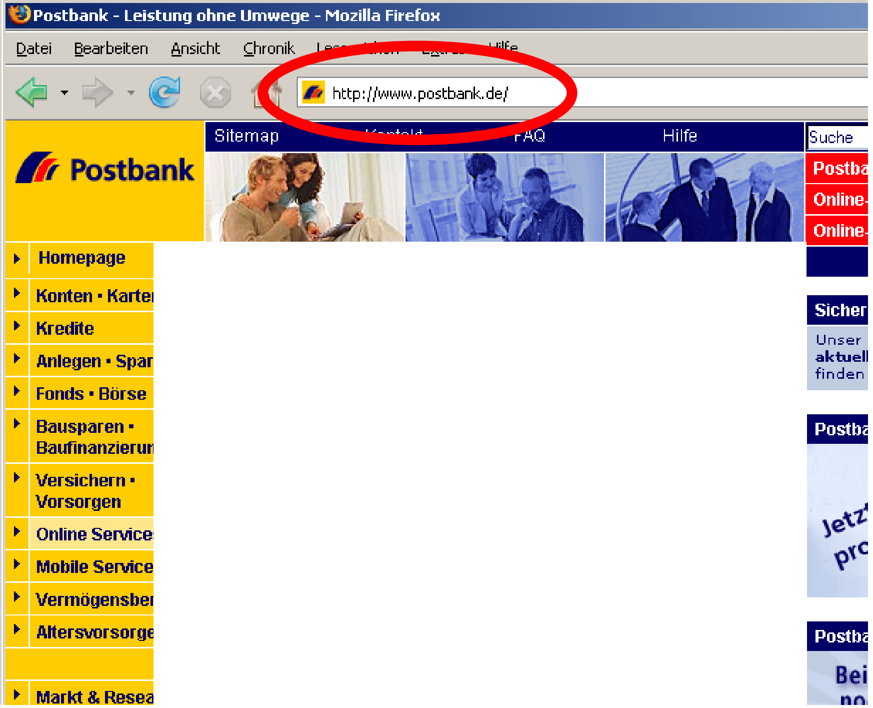
Competence Center for Applied Security Technology

Module Outline

- Overview of DNS
- Known attacks on DNS
  - Denial-of-Service
  - Cache Poisoning
- Securing DNS
  - Split-horizon DNS
  - DNS Cookies (RFC 7873)
  - DNSSEC
  - DNSCurve
  - PNRP
  - GNS

DNS – The Domain Name System

- What is DNS?
- Naming Service for (almost all) Internet traffic
- Lookup of (resolve)
  - Host-Addresses
  - Mail-Servers
  - Alias Names
  - Alternative Name Servers
  - …
- Distributed Database consisting of multitude of servers



DNS – what does it do?

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- ***DNS services***
- Hostname to IP address translation
- Host aliasing
  - Canonical and alias names
- Mail server aliasing
- Load distribution
  - Replicated Web servers: set of IP addresses for one canonical name

- ***Why not centralize DNS?***
- Single point of failure
- Traffic volume
- Distant centralized database
- Maintenance
- *does not scale!*

What does this „it scales“ mean anyways!?

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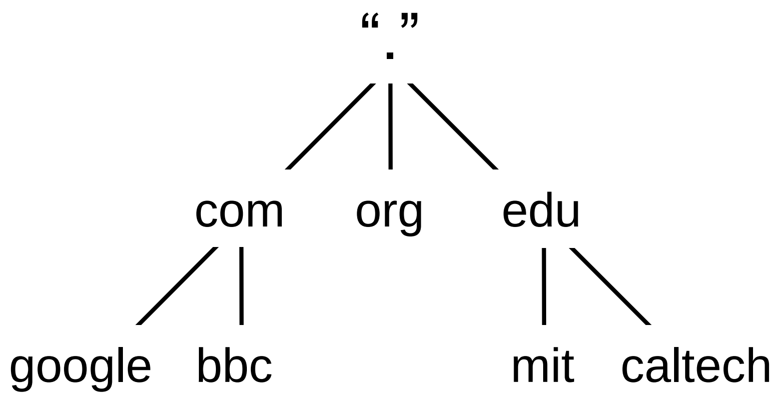
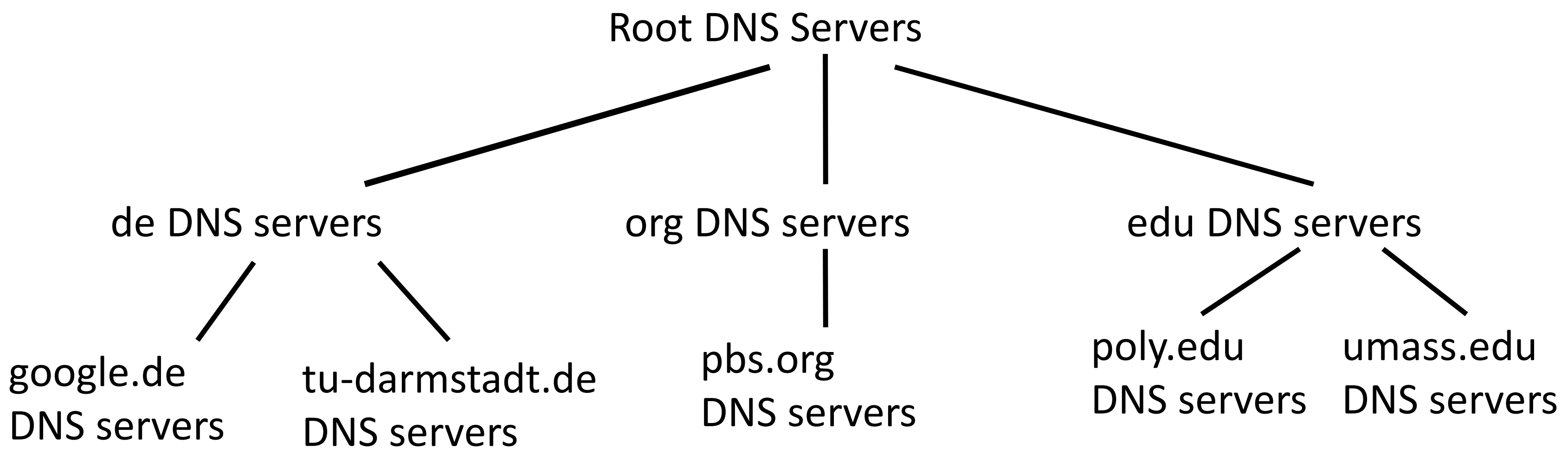
DNS – Data Organization: Domains / Zones

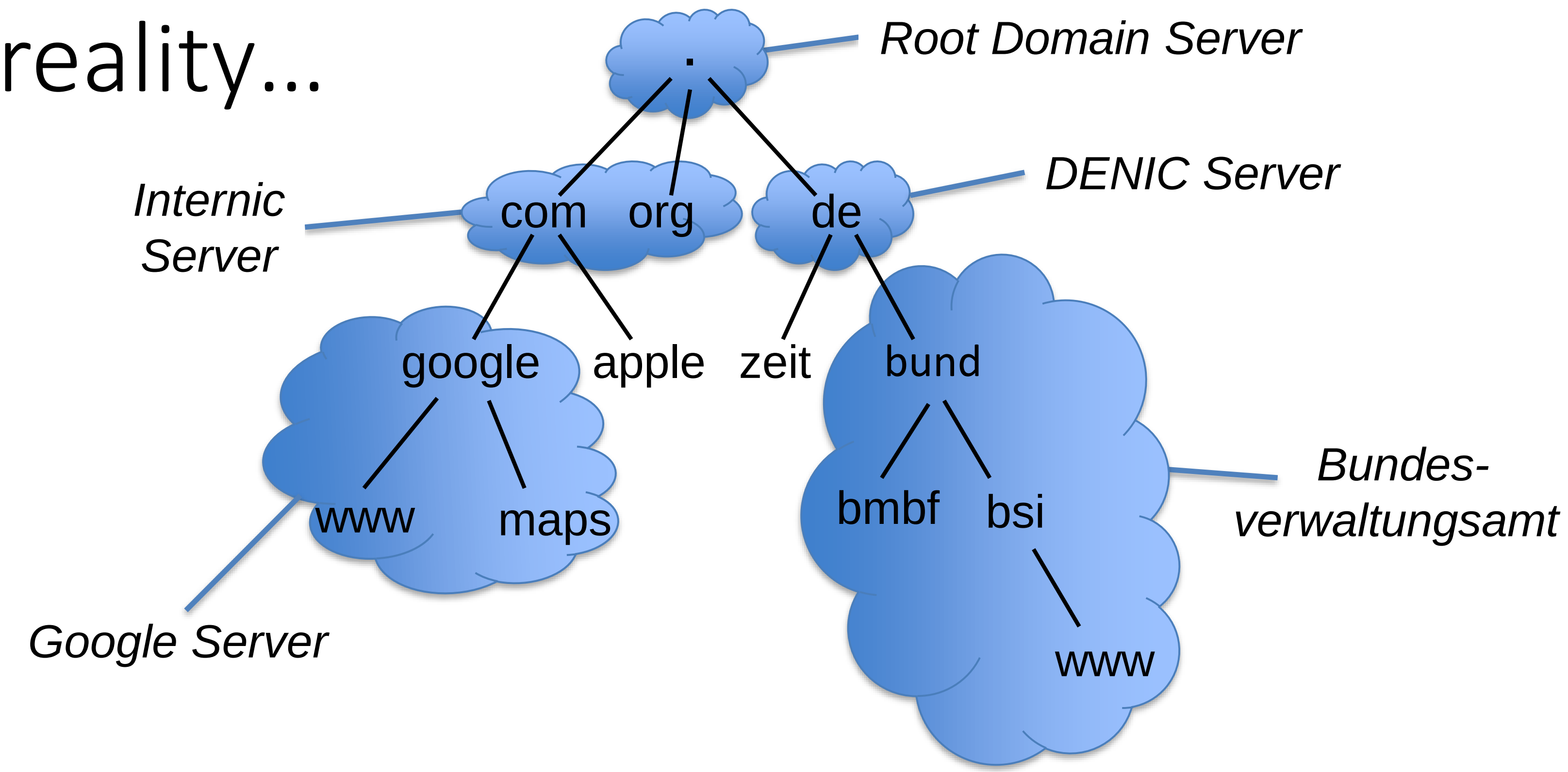


- Structured Namespace
- Hierarchical organization in sub domains/zones
- Sourced at “root zone” (“.”)
- Parent zones maintain pointers to child zones (*“zone cuts”*)
- Zone data is stored as “Resource Records” (RR)

Distributed, Hierarchical Database



…and in reality…



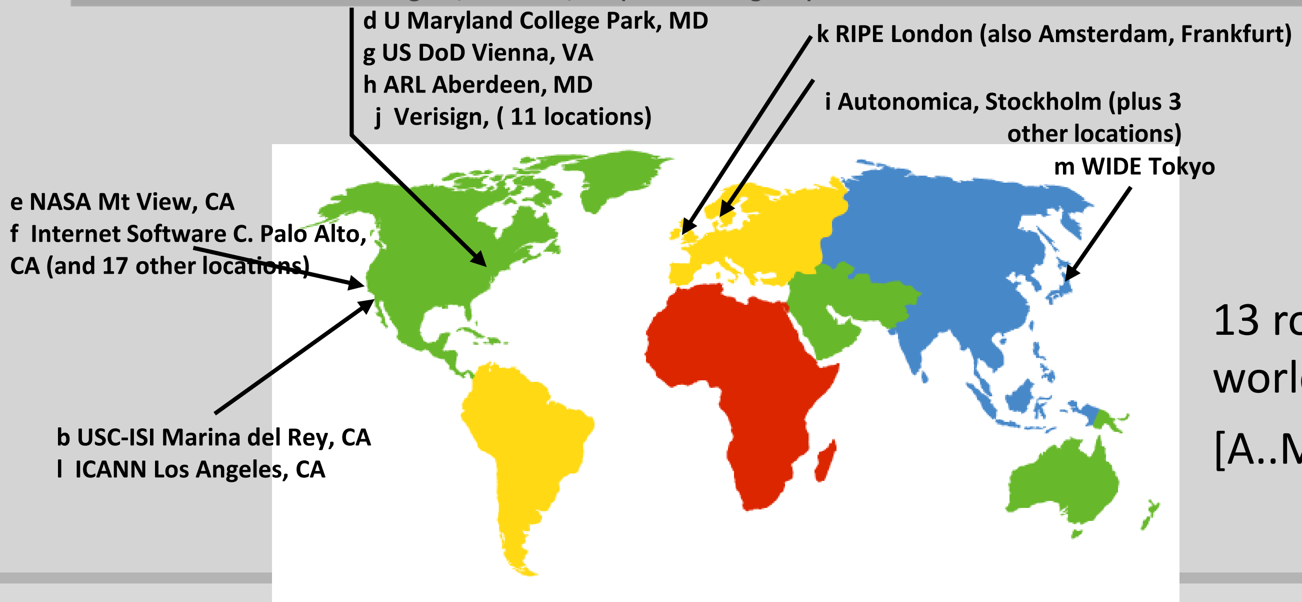
Client wants IP for www.dud.inf.tu-dresden.de; 1st approx:

- Client queries a root server to find **de** DNS server
- Client queries de DNS server to get **tu-dresden.de** DNS server
- Client queries tu-dresden.de DNS server to get IP address for www.dud.inf.tu-dresden.de

DNS: Root Name Servers

- Contacted by local name server that can not resolve name
- Root name server:
  - Contacts authoritative name server if name mapping not known
  - Gets mapping
  - Returns mapping to local name server

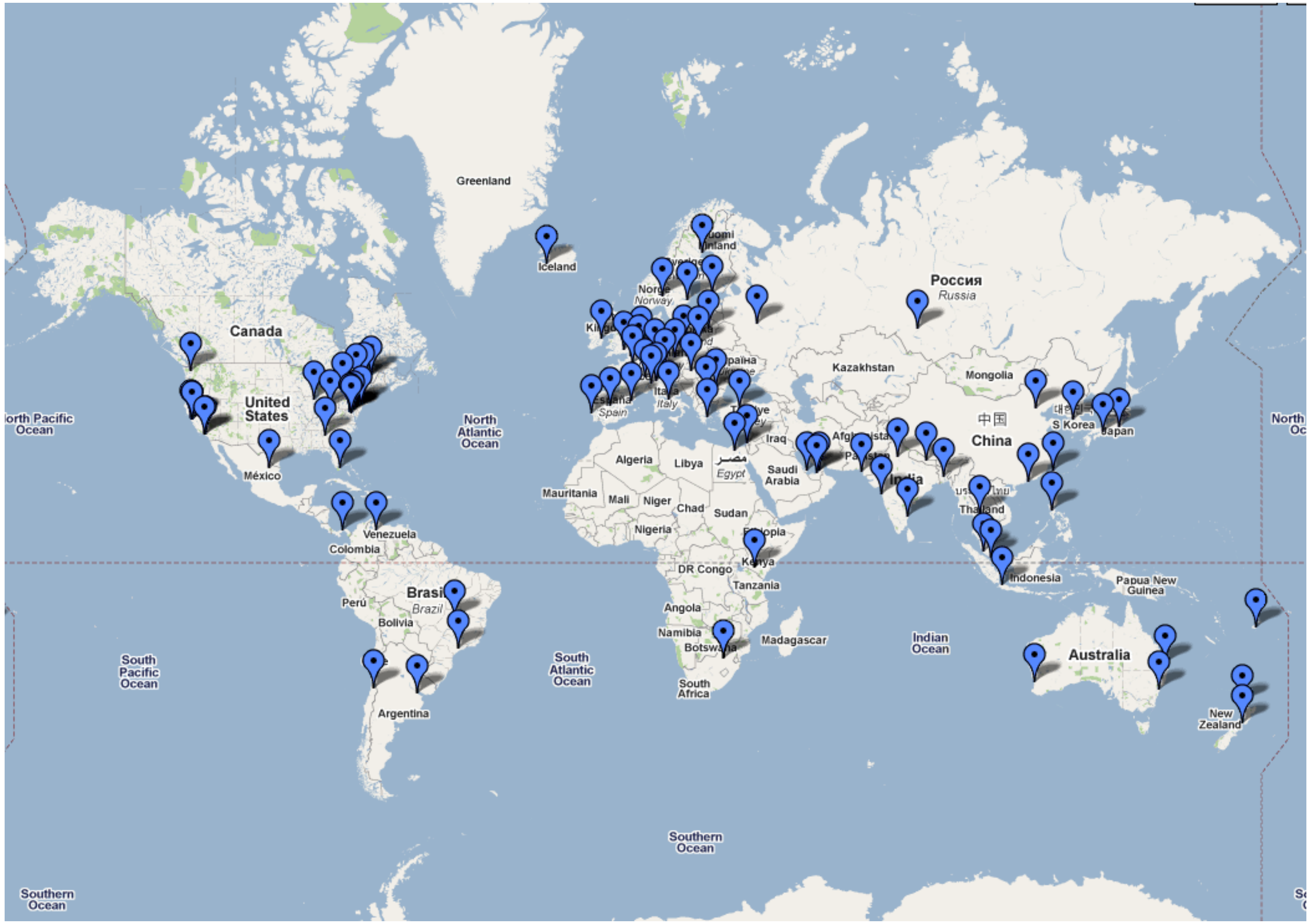
So, how many root nameservers are there actually? (physically)



13 root name servers worldwide

[A..M].ROOT-SERVERS.NET

DNS: Root Name Servers



http://www.root-servers.org/

DNS – Components

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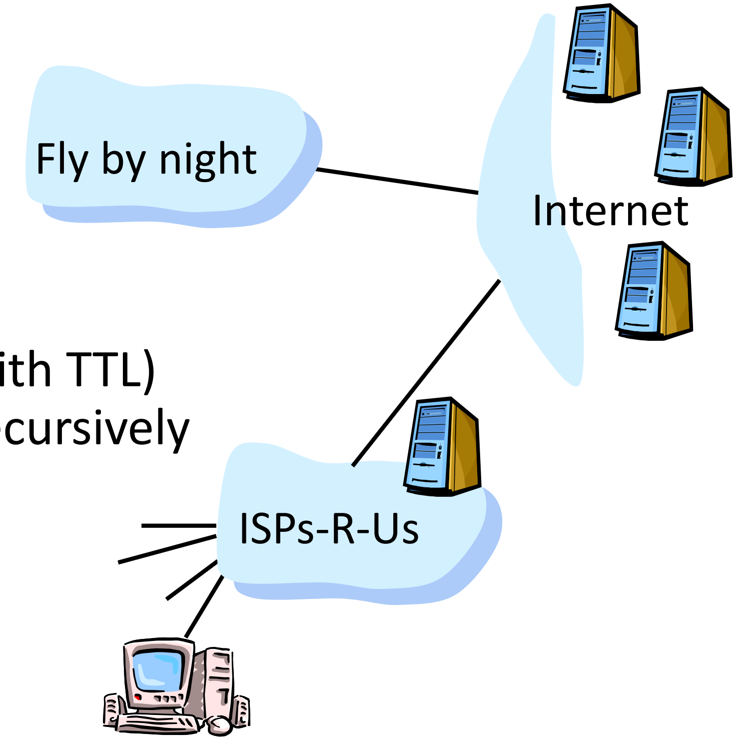
- **Authoritative Server**
  - Server maintaining authoritative content of a complete DNS zone
  - Top-Level-Domain (TLD) servers & auth servers of organization's domains
  - Pointed to in parent zone as authoritative
  - Possible load balancing: master/slaves
- **Recursive (Caching) Server**
  - Local proxy for DNS requests
  - Caches content for specified period of time (soft-state with TTL)
  - If data not available in the cache, request is processed recursively
- **Resolver**
  - Software on client's machines (part of the OS)
  - Windows-* and *nix: Stub resolvers
    - Delegate request to local server
    - Recursive requests only, no support for iterative requests



DNS – Resource Record Type

- Atomic entries in DNS are called “Resource Records” (RR)
- Format: <name> [<ttl>] [<class>] <type> <rdata>

  - `name` (domain name of resource)
  - `ttl` (Time-to-live)
  - `class` (used protocol): IN (Internet), CH (Chaosnet)…
  - `type` (record type): A (Host-Address), NS (Name Server), MX (Mail Exchange), CNAME (Canonical Name), AAAA (IPv6-Host-Address), DNAME (CNAME, IPv6)
  - `rdata` (resource data): ***Content!*** *(What did we want to look up?)*

Specific DNS Records

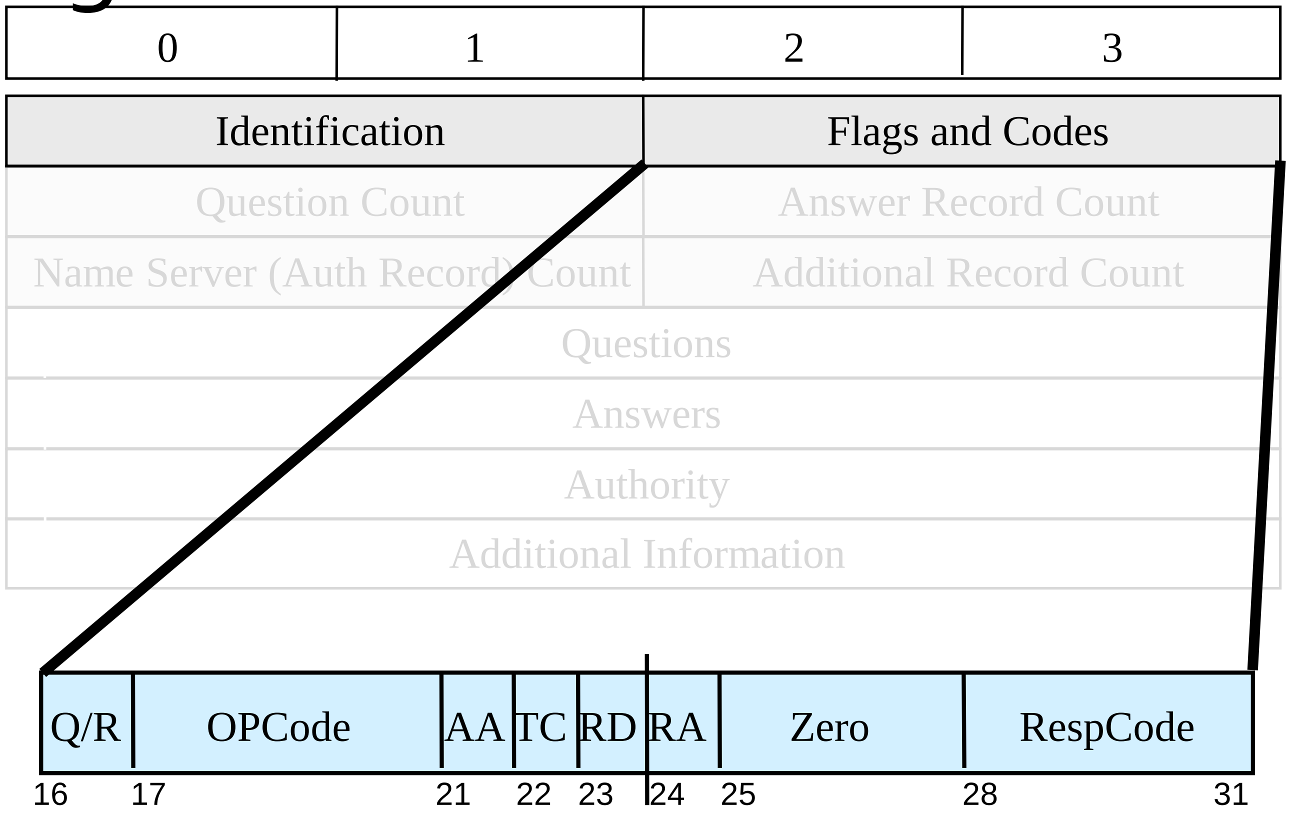
RR Format: **(name, ttl, class, type, value)**

- Type=A
  - **`name`** is hostname
  - **`value`** is IP address
- Type=NS
  - **`name`** is domain (e.g. foo.com)
  - **`value`** is IP address of authoritative name server for this domain
- Type=MX
  - **`value`** is name of mailserver associated with **`name`**
- Type=CNAME
  - **`name`** is alias name for some “canonical” (the real) name

    `www.ibm.com` is really

    `servereast.backup2.ibm.com`
  - **`value`** is canonical name

DNS – Message Format



- Q/R *Query/Response Flag*
- *Operation Code*
- AA *Auth. Answer Flag*
- TC *Truncation Flag*
- RD *Recursion Desired Flag*
- RA *Recursion Available Flag*
- Zero (three resv. bits)
- *Response Code*

DNS: Caching and Updating Records

- Once (any) name server learns mapping, it caches mapping
  - Stored as “soft state”: Cache entries timeout (disappear) after some time
  - TLD servers typically cached in local name servers
  - Thus, root name servers not often visited

- Updating records, independent of TTL
  - RFC 2136 defines dynamic updates
  - BIND (>8) implements nsupdate (upon TSIG, see below)

Inserting Records Into DNS

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- Example: just created startup “Fireblog”
- Register name `fireblog.de` at a registrar (e.g., denic)
  - Need to provide registrar with names and IP addresses of your authoritative name server (***primary*** and ***secondary***)
  - Registrar inserts two RRs into the de TLD server:

  - **`(fireblog.de, dns1.fireblog.de, NS)`**
  - **`(dns1.fireblog.de, 212.212.212.1, A)`**

- Add authoritative server Type A record for `www.fireblog.de` and Type MX record for `fireblog.de`

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DNS – Recursive and Iterative Queries

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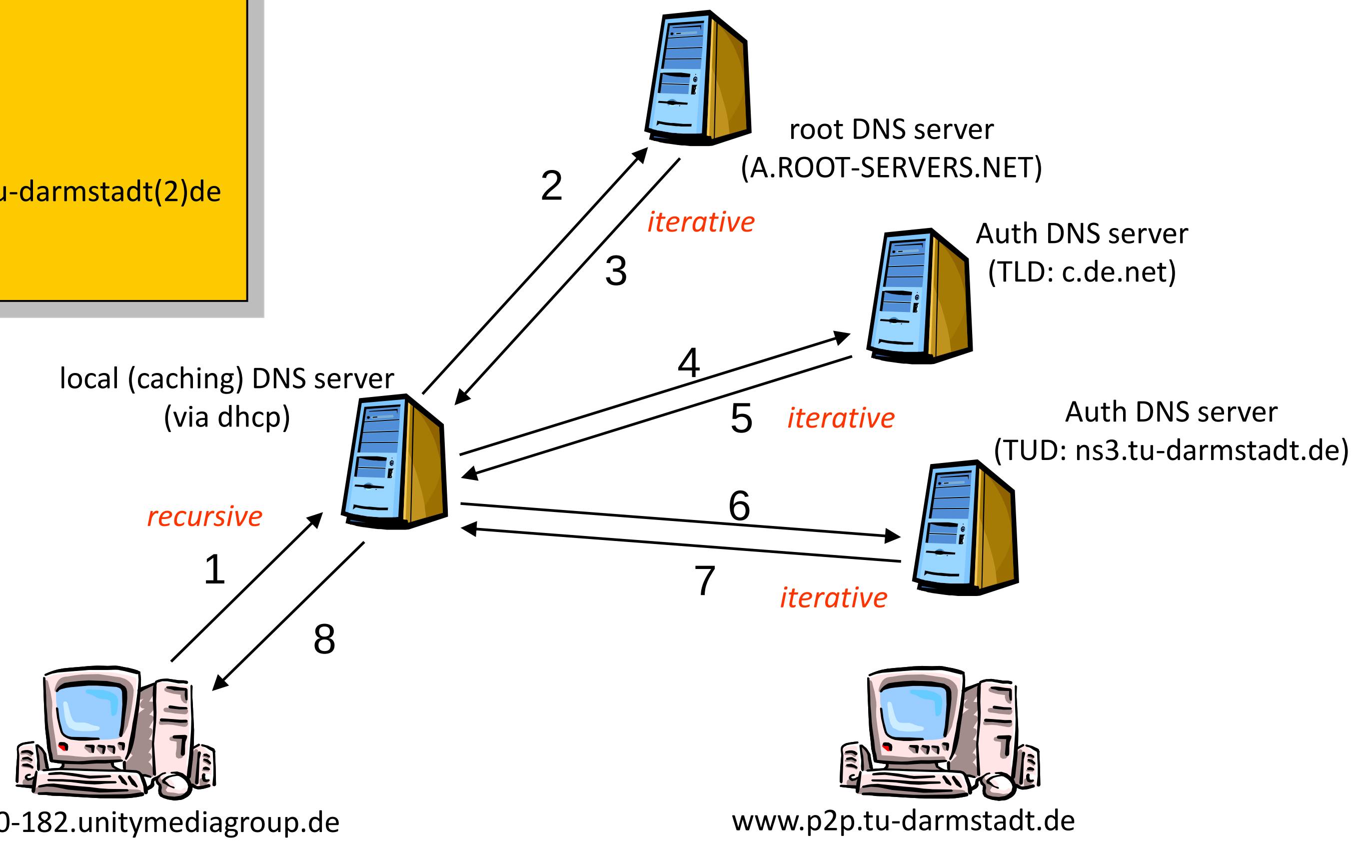
DNS HEADER (send)
- Identifier: 0x3116
- Flags: 0x00 (Q)
- Opcode: 0 (Standard query)
- Return code: 0 (No error)
- Number questions: 1
- Number answer RR: 0
- Number authority RR: 0
- Number additional RR: 0

QUESTIONS (send)
- Queryname: (3)www(3)p2p(12)tu-darmstadt(2)de
- Type: 1 (A)
- Class: 1 (Internet)



A Quick Example…

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```
strufe@eris:~$ dnstracer -v www.p2p.tu-darmstadt.de
Tracing to informatik.tu-darmstadt.de[a] via 130.83.163.141, maximum of 3 retries
130.83.163.141 (130.83.163.141) IP HEADER
-Destination address:  130.83.163.141
-DNS HEADER (send)
-- Identifier:         0x3116
-- Flags:              0x00 (Q )
-- Opcode:             0 (Standard query)
-- Return code:        0 (No error)
-- Number questions:   1
-- Number answer RR:   0
-- Number authority RR: 0
-- Number additional RR: 0
-QUESTIONS (send)
-- Queryname:          (3)www(3)p2p(12)tu-darmstad
-- Type:               1 (A)
-- Class:              1 (Internet)
-DNS HEADER (recv)
-- Identifier:         0x3116
-- Flags:              0x8080 (R RA )
-- Opcode:             0 (Standard query)
-- Return code:        0 (No error)
-- Number questions:   1
-- Number answer RR:   2
-- Number authority RR: 0
-- Number additional RR: 0
-.......
```

```
QUESTIONS (recv)
- Queryname:        (3)www(3)p2p(12)tu-darmstadt(2)de
- Type:             1 (A)
- Class:            1 (Internet)
ANSWER RR
- Domainname:       (6)charon(7)dekanat(10)informatik(12)tu-darmstadt(2)de
- Type:             1 (A)
- Class:            1 (Internet)
- TTL:              1592 (26m32s)
- Resource length:  4
- Resource data:    130.83.162.6
ANSWER RR
- Domainname:       (3)www(3)p2p(12)tu-darmstadt(2)de
- Type:             5 (CNAME)
- Class:            1 (Internet)
- TTL:              49817 (13h50m17s)
- Resource length:  28
- Resource data:    (6)charon(7)dekanat(10)informatik(12)tu-darmstadt(2)de
Got answer [received type is cname]
```

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So where is the Info?

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```
strufe@eris:~$  dnstracer -v -qns tu-darmstadt.de
Tracing to tu-darmstadt.de[ns] via 130.83.163.130
130.83.163.130 (130.83.163.130) IP HEADER
- Destination address:  130.83.163.130
DNS HEADER (send)
- Identifier:          0x4C45
- Flags:               0x00 (Q )
- Opcode:              0 (Standard query)
- Return code:         0 (No error)
- Number questions:    1
- Number answer RR:    0
- Number authority RR: 0
- Number additional RR: 0
QUESTIONS (send)
- Queryname:           (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
DNS HEADER (recv)
- Identifier:          0x4C45
- Flags:               0x8080 (R RA )
- Opcode:              0 (Standard query)
- Return code:         0 (No error)
- Number questions:    1
- Number answer RR:    5
- Number authority RR: 0
- Number additional RR: 9

…….
```

```
QUESTIONS (recv)
- Queryname:           (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
ANSWER RR
- Domainname:          (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
- TTL:                 70523 (19h35m23s)
- Resource length:     6
- Resource data:       (3)ns1(3)hrz(12)tu-darmstadt(2)de
ANSWER RR
- Domainname:          (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
- TTL:                 70523 (19h35m23s)
- Resource length:     5
- Resource data:       (2)ns(6)man-da(2)de
ANSWER RR
- Domainname:          (12)tu-darmstadt(2)de
- Type:                2 (NS)
- Class:               1 (Internet)
- TTL:                 70523 (19h35m23s)
- Resource length:     6
- Resource data:       (3)ns2(3)hrz(12)tu-darmstadt(2)de

…….
```

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Answer ctd…

```
…….
ADDITIONAL RR
- Domainname:        (3)ns1(3)hrz(12)tu-darmstadt(2)de
- Type:              1 (A)
- Class:             1 (Internet)
- TTL:               17335 (4h48m55s)
- Resource length:   4
- Resource data:     130.83.22.63
ADDITIONAL RR
- Domainname:        (2)ns(6)man-da(2)de
- Type:              28 (unknown)
- Class:             1 (Internet)
- TTL:               38386 (10h39m46s)
- Resource length:   16
- Resource data:     2001:41b8:0000:0001:0000:0000:0000:0053
ADDITIONAL RR
- Domainname:        (2)ns(6)man-da(2)de
- Type:              1 (A)
- Class:             1 (Internet)
- TTL:               38386 (10h39m46s)
- Resource length:   4
- Resource data:     82.195.66.249
ADDITIONAL RR
- Domainname:        (3)ns2(3)hrz(12)tu-darmstadt(2)de
- Type:              28 (unknown)
- Class:             1 (Internet)
- TTL:               17335 (4h48m55s)
- Resource length:   16
- Resource data:     2001:41b8:083f:0022:0000:0000:0000:0063
…….
```

```
…….
ADDITIONAL RR
- Domainname:        (3)ns2(3)hrz(12)tu-darmstadt(2)de
- Type:              1 (A)
- Class:             1 (Internet)
- TTL:               17335 (4h48m55s)
- Resource length:   4
- Resource data:     130.83.22.60
ADDITIONAL RR
- Domainname:        (3)ns2(6)man-da(2)de
- Type:              1 (A)
- Class:             1 (Internet)
- TTL:               38386 (10h39m46s)
- Resource length:   4
- Resource data:     217.198.242.225
ADDITIONAL RR
- Domainname:        (3)ns3(3)hrz(12)tu-darmstadt(2)de
- Type:              28 (unknown)
- Class:             1 (Internet)
- TTL:               17335 (4h48m55s)
- Resource length:   16
- Resource data:     2001:41b8:083f:0056:0000:0000:0000:0060
ADDITIONAL RR
- Domainname:        (3)ns3(3)hrz(12)tu-darmstadt(2)de
- Type:              1 (A)
- Class:             1 (Internet)
- TTL:               17335 (4h48m55s)
- Resource length:   4
- Resource data:     130.83.56.60
Got answer
```

DNS – Lessons Learned

- Structure name space (divide et impera)
- Simple „routing“ b/c of structured (hierarchical) namespace

- Store information at multiple locations
- Maintain multiple connections

- → Be redundant! (Replicate…)
  - primary and secondary server, multiple TLD servers

- Delegation using iterative or recursive forwarding
  - (Btw: what are the pros and cons of each?)

Security of the Domain Name System

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- Vital service for the Internet
  - “Do you know the IP-Address of your mail server?”
  - “You know you shouldn’t follow the link

    `http://malicio.us/phishing/yourbank.html`

    but what about

    `http://www.yourbank.de` ??”
- But: DNS does not support
  - Data integrity
  - Data origin authentication
- Threats:
  - Denial of Service
  - Data Authenticity/Integrity

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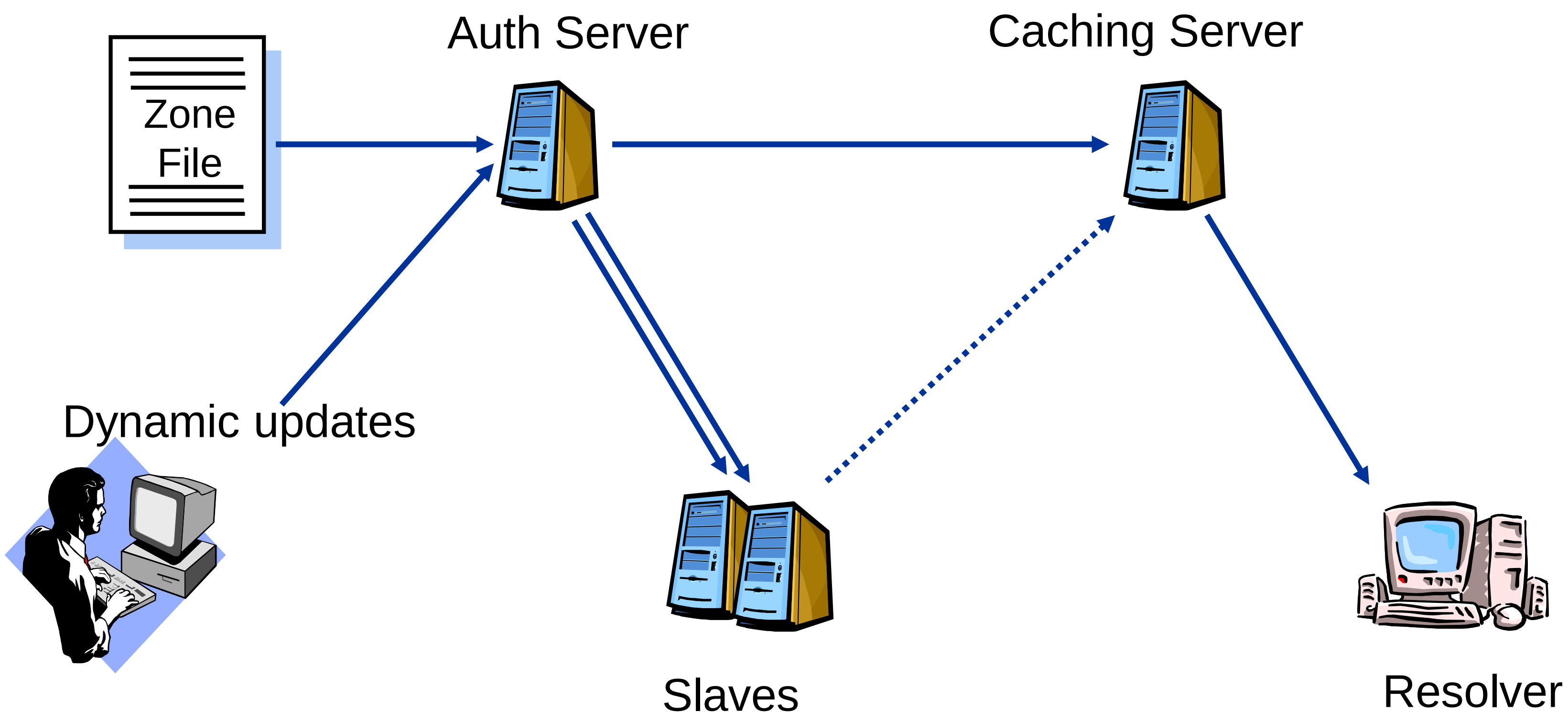
DNS – Data Flow



[http://www.ripe.net/training/dnssec/]

DNS Security Issues Outlined

- Robustness towards DDoS
  - General issues
  - Redundancy

- Robustness towards data corruption
  - Cache Poisoning and simple countermeasures

  - More complex countermeasures:
    - Split-Split DNS / Split-horizon DNS
  - Cryptographic countermeasures
    - DNS Cookies
    - DNSSEC
    - DNSCurve

How does this relate to security of routing?

Threats to DNS: Denial of Service

- DNS as vital service a “worthy” target
  - Without DNS most Internet services will not work
    (usage of names rather than IP-Addresses for numerous reasons!)

- DDoS Attacks on root servers: via notorious “typos” in TLDs

- DNS Amplification Attack (15.02.2006)
  - Spoofed queries (60 Bytes) may generate potentially large responses (4KBytes)
  - Exploit open recursive servers to generate load on other DNS servers
  - Exploit open servers as reflectors when flooding a victim with traffic
    (via source IP Address spoofing in request)

Robustness towards DDoS

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- General issues
  - Secure DNS server
    - OS selection and updates
    - Firewalls
    - Server software selection and updates
  - Redundancy and over-provisioning
    - Root “.”: 13 name server “names” ({a..m}.root-servers.net)
    - “com”, “net”, “de”: several name servers each
  - Anycast
    - Announcement of an IP prefix from multiple locations
    - Requests from different parts of the internet are routed to different machines with the same IP address
    - Done with several DNS servers

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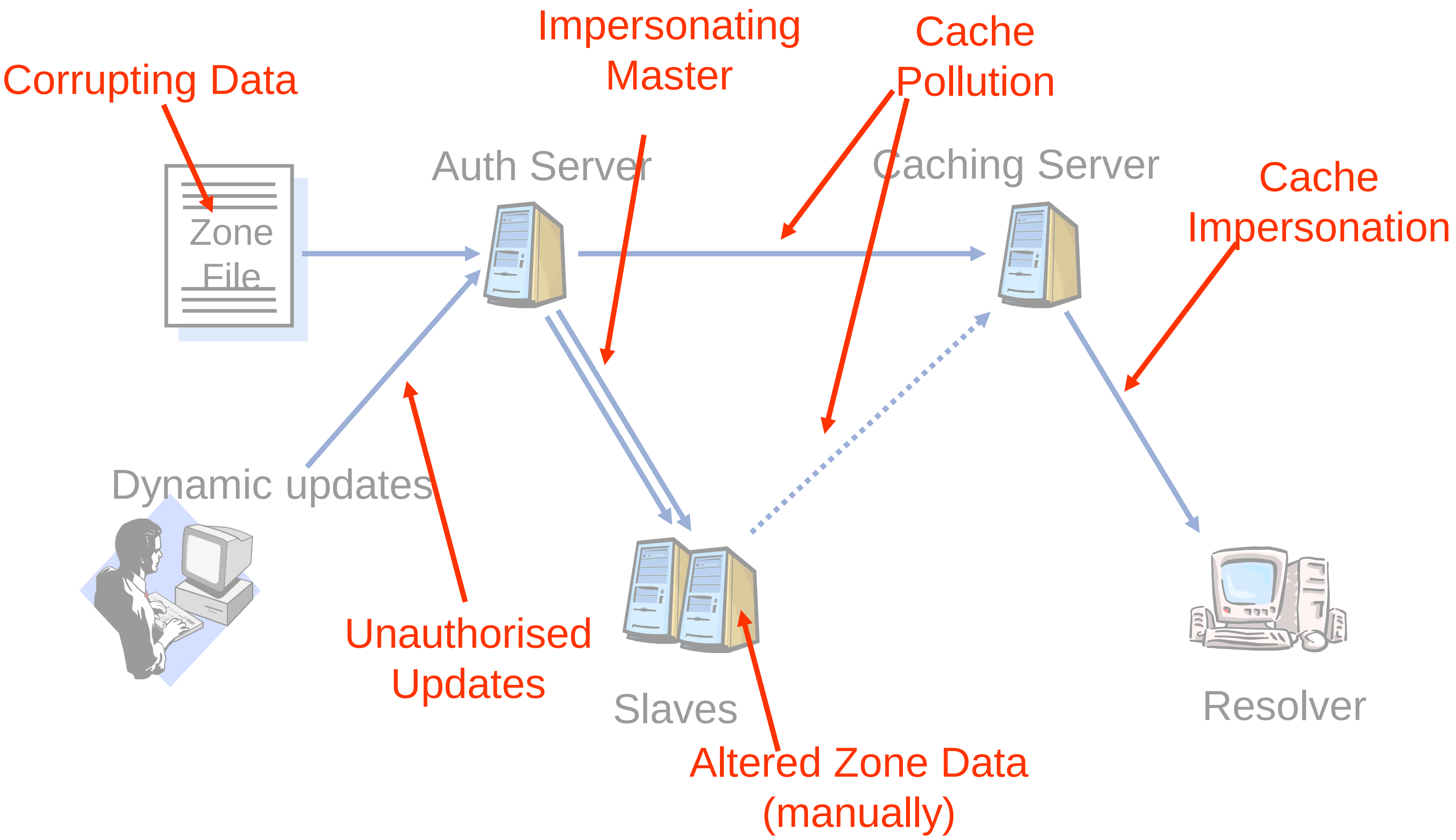
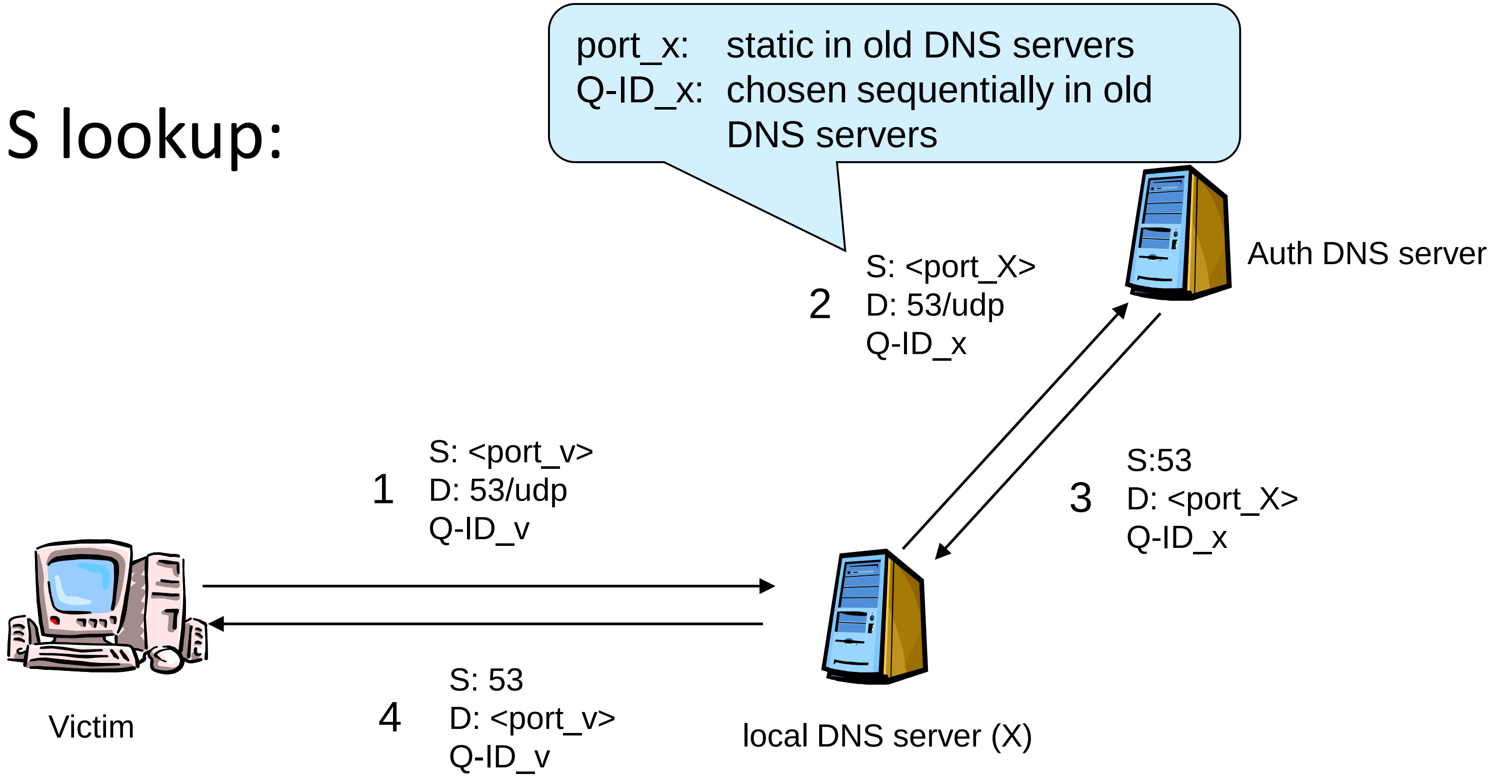
DNS – Threats to Data Integrity



Threats to DNS: Data Corruption / Cache Poisoning

- All resolved RRs are cached at local DNS servers
- DNS slave servers replicate zone data from master
- Normal DNS lookup:



DNS Threats – Cache Poisoning: Simple Poisoning(1)

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- ***Attack***: plant fake data in slaves / caching servers
  (and nobody will realize the redirection from
  `www.yourbank.de to    malicio.us/phishing/yourbank.html` …)

- DNS via UDP/IP, no handshakes for connection establishment
- Transactions in DNS only identified by tuple of
  <auth server(ip-address), auth server(port), transaction id>

- With knowledge about transactions: distribute malicious data

- **IP Address** of authoritative name servers are well known
- In many implementations same **port** for all transactions
- **Q-ID** unknown, but: BIND used to choose them sequentially…

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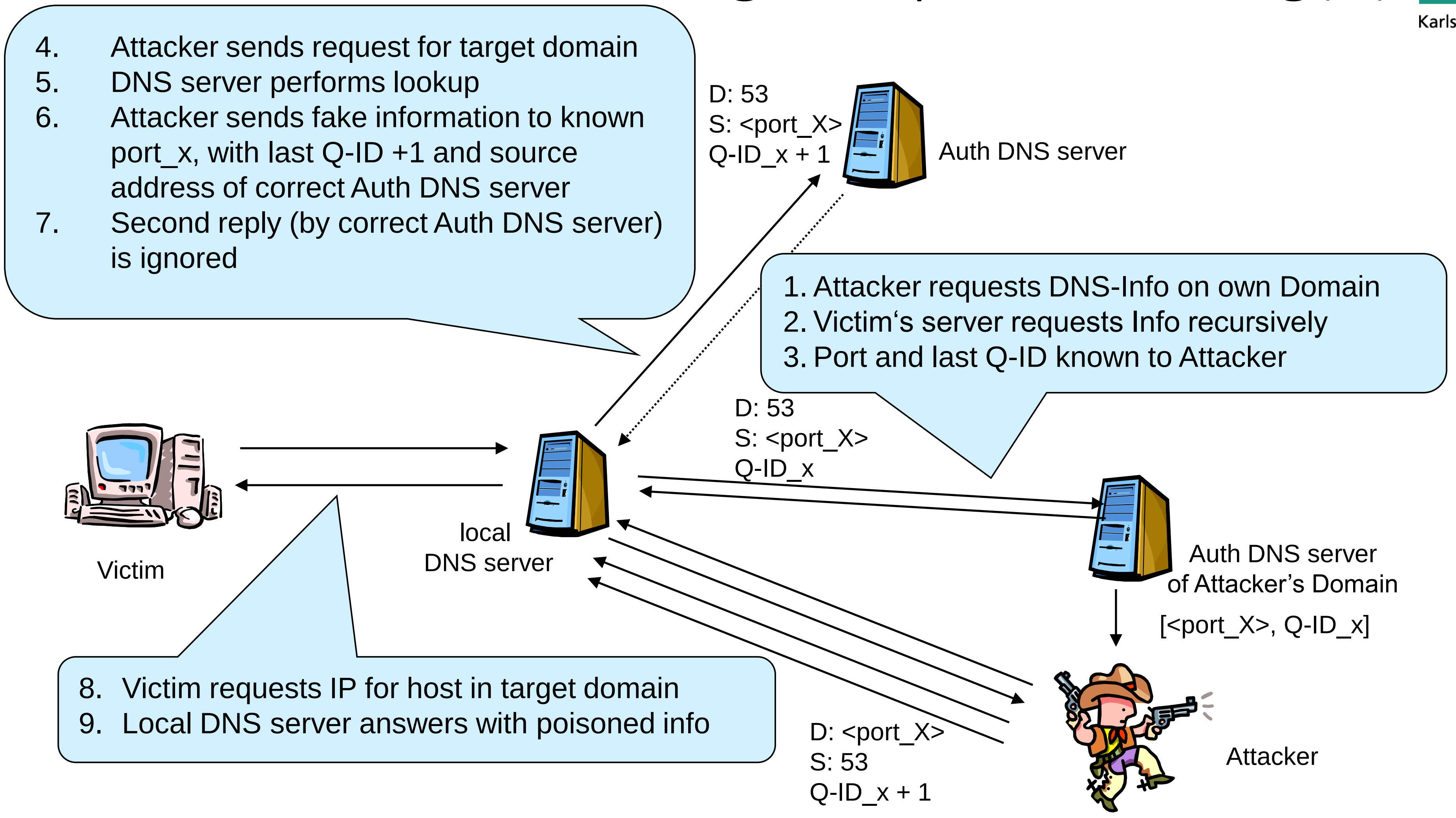
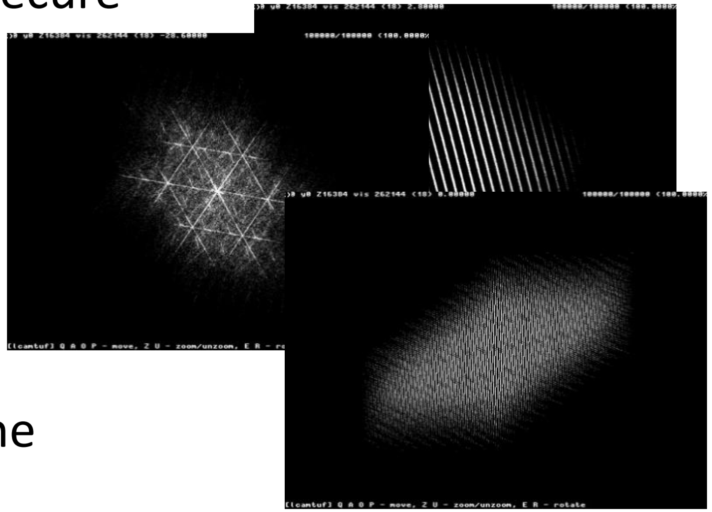
DNS Threats – Cache Poisoning: Simple Poisoning(2)



Mitigation of Cache Poisoning

- Random ports for each transaction (BIND8)
  - Since Version 8 BIND uses PRNG for port number and query id selection
  - However PRNG == **Pseudo** Random Number Generator, with knowledge about previous port numbers future port numbers can be guessed if PRNG not cryptographically secure



- More random ports for each transaction (BIND9)
  - New and better PRNG since BIND9, random numbers are harder to guess
- Cache Poisoning only after aging of entry in local DNS server
  - Only if attacker attacks at the right moment, he can poison the cache
  - Typical TTL:
    - 172800 (2d) for most name servers
    - Seconds to hours for A-Entries of organizations (tu-ilmenau.de 24h, deutschebank.de:60mins, commerzbank.de 30mins, postbank.de 30s, microsoft.com:60mins (*where do you get your sec-updates today*?))
- Nevertheless: cache poisoning is still not solved…

Cache Poisoning with "Brute Force"

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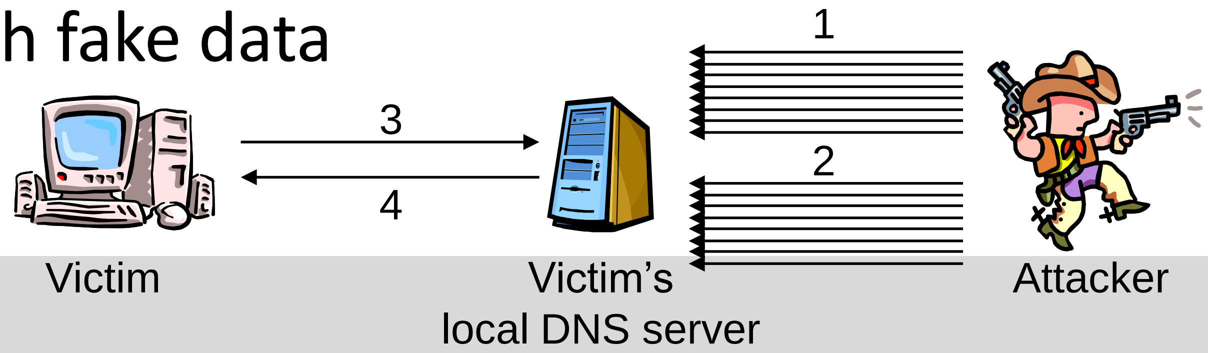
1. Attacker sends ***multitude of requests*** for targeted domain to local DNS server of victim and
2. Attacker sends ***multitude of fake replies*** with IP and port from auth server of targeted domain, guessing transaction id for one of the recursive requests from local caching server to auth server (2^{16} x 2^{16} = 2^{32} ≈ 4 Billion possible combinations)
3. Victim requests data about targeted domain
4. Local caching server responds with fake data



More Sophisticated Cache Poisoning

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- Usually not a high number of chances ***when TTL high***, e.g., 1 day
- Imagine the attacker M:
  - M → Cache: Give me `kslkskdf.bank.com` (w/ random “kslkskdf”)
    - The cache server must now ask the Authoritative Server at bank.com
  - M → Cache: Not responsible for `kslkskdf.bank.com`, but `www.bank.com` is. You may reach `www.bank.com` at `A.B.C.D` (`A.B.C.D` being the address of the attacking host)
    - The cache will then ask A.B.C.D for kslkskdf.bank.com and will also remember the “name server” www.bank.com
-

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More Sophisticated Cache Poisoning - Defense

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- How can we increase the entropy of DNS queries?

- ***Idea:*** DNS does not distinguish between upper and lower case, encode more bits in the name
- Now the same attack:
  - M → Cache: Give me `kslkskdf.bank.com`
    - The Cache Server must now ask the Authoritative Server at bank.com
      Cache → Auth Server: Give me `kSLkSkdF.bAnK.COM`
  - M → Cache: Not responsible for `kslkskdf.bank.com`, but `www.bank.com` is. You may reach `www.bank.com` at 141.24.212.114. (Ignored as kslkskdf.bank.com does not match the case of the query)
  - Auth Server → Cache: `kSLkSkdF.bAnK.COM` is unknown

- Entropy is increased to 2^{32+n} for n being the letters in a domain name
- Helps for `www.tu-dresden.de` but not much for `tud.de`

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Most Sophisticated Cache Poisoning

- DNS is usually transported over UDP, which may fragment

- What happens when a DNS reply gets fragmented?
  - Random port numbers, Query ID and perhaps the original question (e.g. `kSLkSkdF.bAnK.COM`) are in the first fragment
  - Depending on the query and the MTU the actual answer may be in the second fragment
  - Fragments are matched by a 16 bit identification field…

- Attackers thus can try to
  - Find queries leading to large answers
  - Spoof PMTU related ICMP messages to set the fragmentation boundary
  - Send a “second” fragment with different identifications to the cache
  - Send the query to the cache
  - Wait for the cache to reassemble the reply and the crafted second fragment…

- DNS server should avoid large answers and PMTU discovery...

Prevent Data Corruption: Split-Split DNS

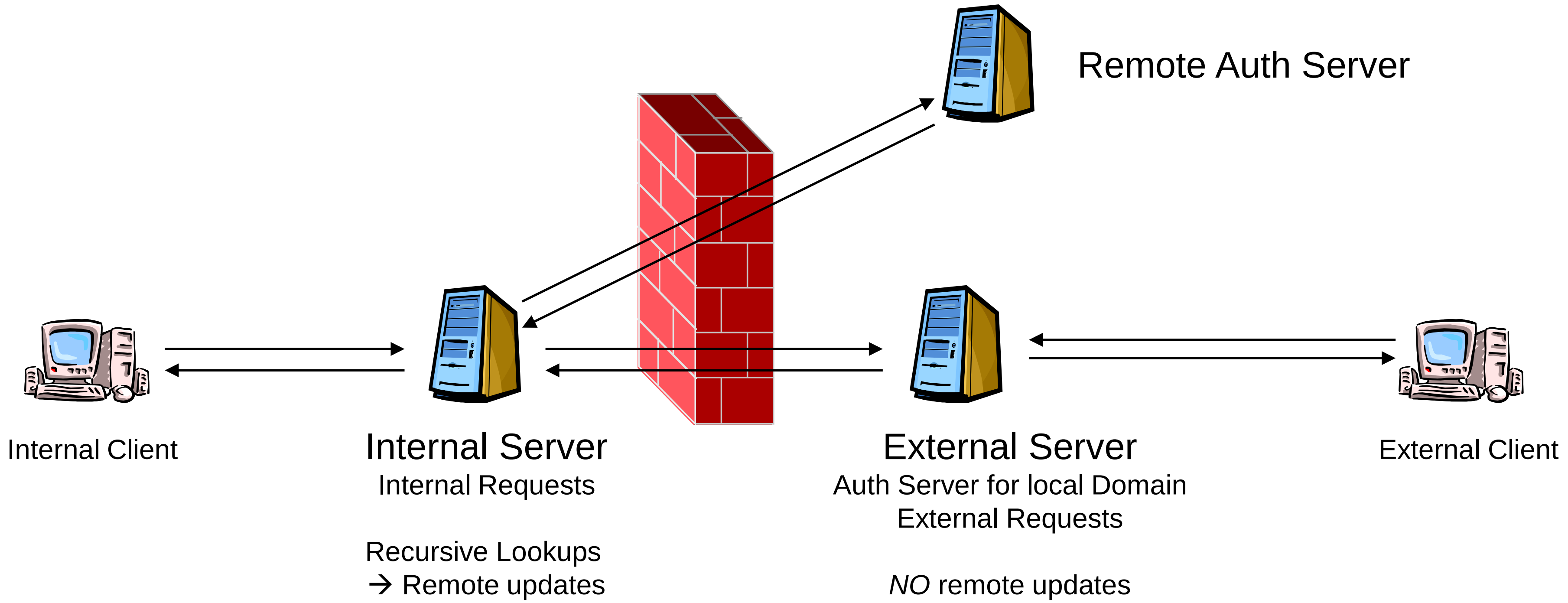
- **Goal**: Avoid cache poisoning from external machines
- **Idea**: Split the name service functions
  - Name resolution (look up of DNS info)
  - Domain information (Auth service of local DNS info)

- Internal server
  - Implements name resolution
  - Performs recursive look-ups at remote DNS servers
  - Located behind firewall and only accepts requests from local LAN

- External server
  - Authoritative server of domain
  - Accepts remote requests but **never accepts** remote updates

- Zone transfer from external to internal server allowed

Split-Split DNS/ Split-Horizon DNS



DNS Cookies

- Goals
  - DNS transaction security
    - Prevent off-path attacks (poisoning)
    - Limit spoofing, DoS

- Core ideas:
  - „Authenticate“ query in DNS response
  - Establish semi-state between clients and servers

- Approach:
  - EDNS option
  - Include client/server cookies (extending query ID)

[Eastlake, Andrews: „RFC 7873: Domain Name System Cookies “]

DNS Cookies – States and Behavior

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- States of communication

1. „Unauthenticated“: Client contacts server for the first time
2. „Authenticated“: Client and server share some state

- Server behavior:

1. Provide service at low priority, offer server cookie
2. Provide normal DNS service (return server cookie)

- Client behavior:

1.
   a. Send DNS query, client cookie and ask for server cookie, OR
   b. Query for server cookie, then (2)
2. Send server cookie, DNS query, client cookie

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DNS Cookies – Cookies and OPT RR

- Generating DNS cookies:
- `cookie <- PRNG(Client IP, Server IP, k)`
- *with temporary secret k at server/client*

- Message format:

0	1	2	3
Option Code = 10		Option Length	
Client Cookie ([0-3])			
Client Cookie ctd. ([4-7])			
Server Cookie			
Server Cookie ctd.			

- Option length: [8 (only client cookie), {>=16, <=40} (client/server cookies)]
- Client cookie: fixed size 8 octets
- Server cookie: variable size, 8-32 bytes

DNS Cookies - Protection

- So what do DNS cookies actually achieve?

- Protects transactions between resolvers/caches and caches/servers

- Validation of cookies:
  - Valid client cookie for server (probably no off-path poisoning)
  - Valid server cookie for client (previous transactions with same IP address, probably no IP address spoofing)

- Critical assessment:
  - Very low overhead, no protocol changes, little software adaptation
  - Currently rolled out
  - However: very weak protection *(on-path adversaries? Leaked cookies?)*
  - Unclear how servers should behave in phase 1

Securing DNS Cryptographically

- Securing DNS has different goals:

- DNS transaction security
  - Peer/message authentication

- DNS data security
  - Data origin authentication
  - Authenticated denial of existence

Transaction Authentication (TSIG)

- ***Idea***:
- Use signatures to secure data at zone transfer **master → slave**
- Pre shared symmetric key at each entity
- MD5 Hash used as signature

- **TSIG Resource Record:**
  `(Name, Type ("TSIG"), Class ("ANY"), TTL("0"), Length, Data(<signature>))`

- Possibility to authenticate, but very complex to administrate in large domains (manual pre-sharing of keys)
  - amount of keys required: $\frac{n(n-1)}{2}$

- Main application areas:
  - Secure communication between stub resolvers and security aware caching servers *(?)*
  - Zone transfers (master → slave)
  - Combined with nsupdate in data centers, to update stale information in caches

[Vixie et. al: „RFC 2845: Secret Key Transaction Authentication for DNS"]

DNS Security (DNSSEC) – Objectives

- DNS security ***objectives***:
  - End-to-end zone data *origin authentication* and integrity
  - *Detection* of data corruption and spoofing

- DNSSEC ***does not*** (want to) provide:
  - DoS-Protection *(in fact, it facilitates DoS Attacks on DNS servers)*
  - Data delivery guarantees (availability)
  - Guarantee for correctness of data (only that it has been signed by some authoritative entity)

[Eastlake: „RFC 2535: Domain Name System Security Extensions“ (obsolete)]
[Arends et. al: „RFC 4033: DNS Security Introduction and Requirements“]
[RFCs:4033,4034,4035,4310,4641]

DNSSEC

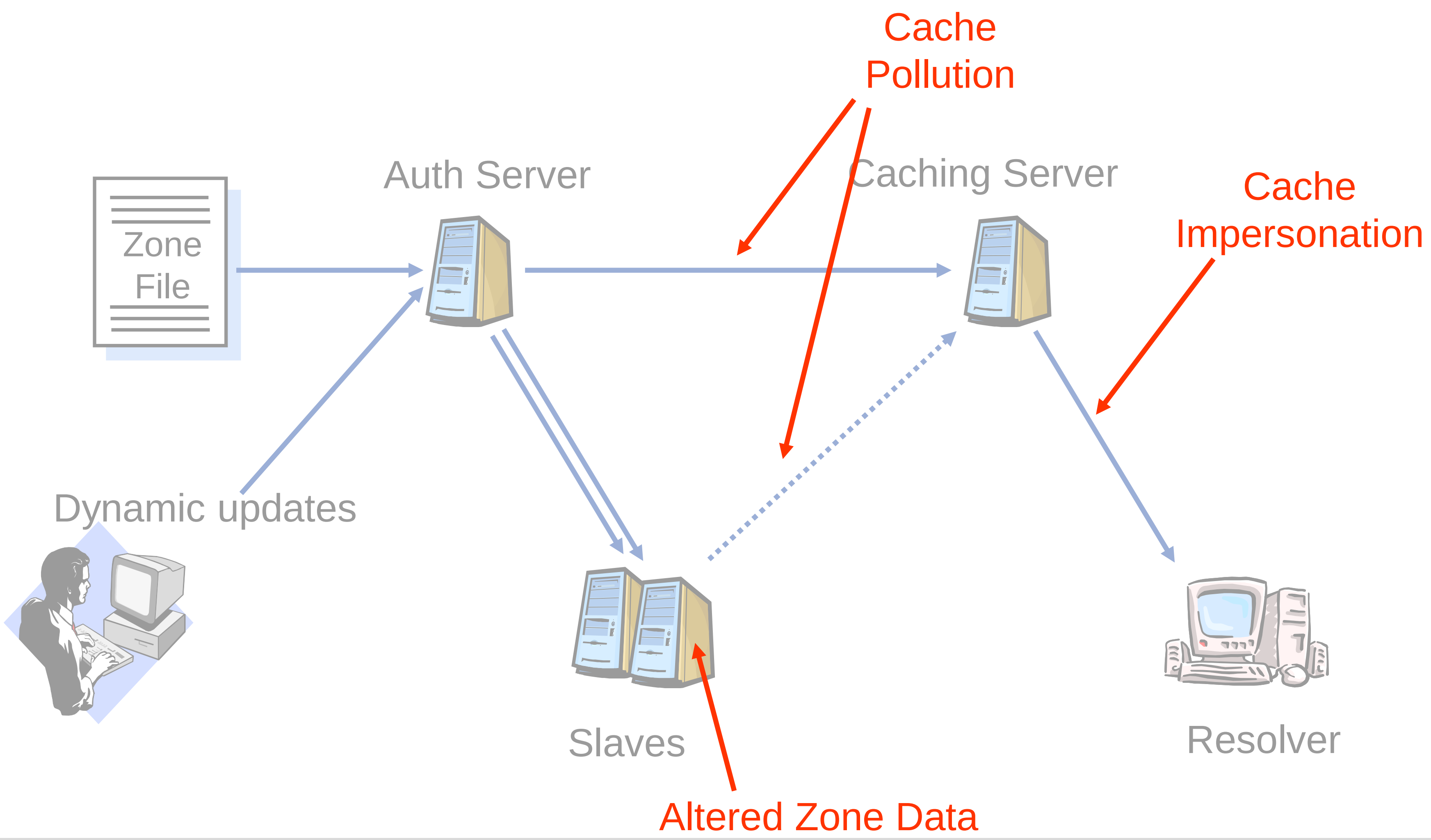
- Usage of *public key cryptography* to allow for ***data origin authentication*** on a world wide scale

- **RRSets** (groups of RRs) signed with private key of authoritative entities
- **Public keys** (DNSKEYs) published using DNS

- Distinguish *zone signing key* (**ZSK**) and *key signing key* (**KSK**)
- Child zone keys are authenticated by parents (according to the zone hierarchy) and hence anchored trust chains established
- Only root zone key signing key (KSK) needed (manual distribution) to create complete trust hierarchy (in theory)

- Until then: islands of trust with manually shared anchor keys
- No key revocation → DNSSEC keys should have short expiration date (quick rollover)

DNSSEC – Targeted Threats



DNSSEC – Means of Securing RRSets

- Goal: authenticity and integrity of Resource Record Sets
- Means:
  - Public Key Cryptography (with Trust Chains)
  - Security integrated in DNS (new RRs)

- New Resource Record Types:
  - `RRSig`: RR for signatures to transmitted RRs
  - `DNSKEY`: RR for transmission of public keys
  - `DS`: RR for trust chaining (trust anchor signs key of child zone)
  - `NSEC`: RR for next secure zone in canonical order (authenticated denial for requested zone)

DNSSEC – New Resource Records: RRSIG

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- Resource Record for transmission of ***signatures***

- `RRSIG:`

  (Name, Type, Algorithm, Labels, TTL, Sig Expiration, Sig Inception, Key Tag, Signer's Name, Signature)

  - `Name` – name of the signed RR
  - `Type` – RRSIG (46)
  - `Algorithm` – MD5(1), Diffie-Hellman(2), DSA (3)
  - `Labels` – number of labels in original RR (wildcard indication)
  - `TTL` – TTL at time of signature inception
  - `Signature Expiration` – End of validity period of signature
  - `Signature Inception` – Beginning of validity period of signature
  - `Key Tag` – ID of used key if signer owns multiple keys
  - `Signer's Name` – Name of the signer
  - `Signature` – Actual Signature

DNSSEC – New Resource Records: DNSKEY

- Resource Record containing ***public keys*** for distribution
- `DNSKEY:` (Label, Class, Type, Flags, Protocol, Algorithm, Key)

  - `Label` – Name of key owner
  - `Class` – Always: IN (3)
  - `Type` – DNSKEY
  - `Flags` – key types: Key Signing Key (257) or Zone Signing Key (256)
  - `Protocol` – Always DNSSEC (3)
  - `Algorithm` – RSA/MD5(1), Diffie-Hellman(2), DSA/SHA-1(3), elliptic curves(4), RSA/SHA-1(5)
  - `Key` – Actual key

DNSSEC – New RRs: Delegation Signer (DS)

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- DS contains ***hash-value of DNSKEY*** of the name server of a sub zone

- Together with NS Resource Record, DS is used for trust chaining

- `DS`: (Name, Type, Key Tag, Algorithm, Digest Type, Digest)
  - `Name` – Name of the chained sub zone
  - `Type` – DS
  - `Key Tag` – Identification of the hashed key
  - `Algorithm` – RSA/MD5(1), Diffie-Hellman(2), DSA(3) (of referred DNSKEY)
  - `Digest Type` – SHA-1(1), SHA-256(2)
  - `Digest` – Actual value of hashed DNSKEY

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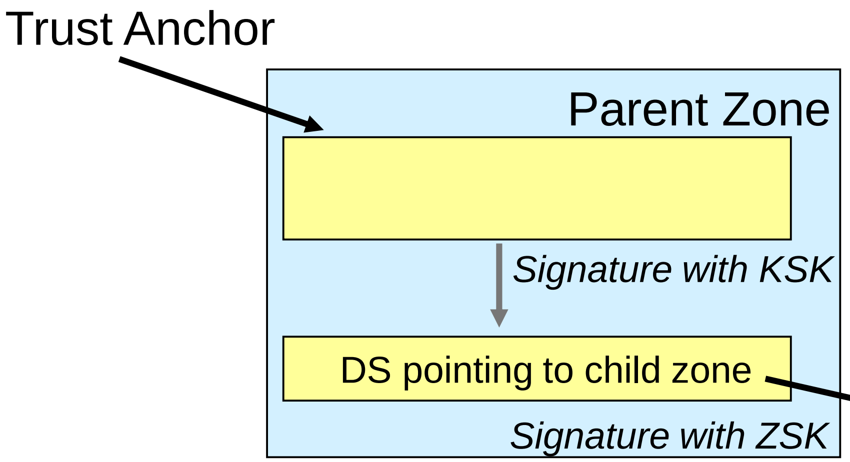
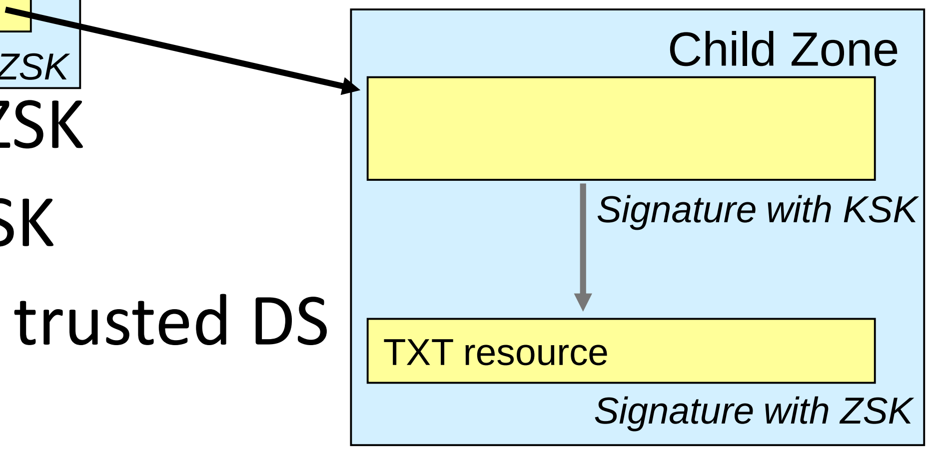
DNS – Authority Delegation and Trust Chaining





- Data can be trusted if signed by a ZSK
- ZSK can be trusted if signed by a KSK
- KSK can be trusted if pointed to by trusted DS
- DS record can be trusted if
  - Signed by parents ZSK
  - Signed by locally configured trusted key

DNSSEC – New Resource Records: NSEC

- Next Secure (NSEC) gives information about the next zone / sub domain in canonical order (last entry points to first entry for the construction of a closed ring)
- Gives the ability to prove the non-existence of a DNS entry: *Authenticated Denial*

- `NSEC` (Name, Type, Next Domain)
  - `Name` – Name of the signed RR
  - `Type` – NSEC (47)
  - `Next Domain` – Name of the next domain in alphabetical order

- *Allows adversary to crawl entire name zone ("zone walking")*

DNSSEC – New RRs: NSEC3 (1)

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- Successor to NSEC: NSEC3 and NSEC3PARAM
- Uses hashed domain names to make zone walking more difficult
- Hashing based on salt and multiple iterations to make dictionary attacks more difficult

- NSEC3
  - `Name` – Name of the signed RR
  - `Type` – NSEC3 (50)
  - `Hash Algorithm` – SHA-1 (1)
  - `Flags` – To Opt-Out unsigned names
  - `Iterations` – Number of iterations of Hash Algorithm
  - `Salt Length` – Length of the salt value
  - `Salt` – Actual salt value
  - `Hash Length` – Output length of hash function
  - `Next Hashed Owner Name` – Next Hash of domain name in alphabetical order

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DNSSEC – New RRs: NSEC3 (2)

- Potential advantage: Salting and hashing does not allow for easily deducting hostnames from zone walks

- Problem:
  - Hostnames usually have very low entropy (to remember them)
  - Easy dictionary attacks - despite the usage of salts & iterations
  - But not used heavily anyways:
    - .: Uses NSEC
    - .com: No salt, No iterations
    - .de: Static salt BA5EBA11, 15 Iterations

DNSSEC: NSEC5 / Record Type Denial

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- Provide authenticated denial of existence without leaking names requires online signing.
- Providers do not want to trust the DNS servers with keys…

- Cloudflare Record Type Denial
- Send positive response but deny requested record type

[Goldberg et al.: NSEC5: Provably Preventing DNSSEC Zone Enumeration]

DNSSEC Issues

- Pro's:
  - DNSSEC allows to prevent unauthorized/spoofed DNS records

- Con's:
  - Added complexity (signing, checking, key distribution) **eases DoS attacks** on DNS servers
  - Zones need to be signed completely (performance challenge for large companies or registries)
  - Authenticated denial with NSEC gives the possibility to "walk" the chain of NSEC and to gain knowledge on the **full zone content** (all zones/ sub domains) in O(N) ==> NSEC3, …
  - Distribution of anchor keys still a **manual task** (allows for human error, social engineering)

Deployment:

- https://www.internetsociety.org/deploy360/dnssec/maps/

Summary

- DNS a central service of the Internet, implemented on layer 7
- Vital for secure operations
- Vulnerabilities:
  - DoS
  - Poisoning
- Countermeasures
  - Better PRNG
  - Split/Split DNS
  - TSIG
  - DNSSEC
  - DNS Cookies
  - *DNSCurve, PNRG, GNS*