Network Security: Application-Layer and Domain Name System

COMPUTER SECURITY

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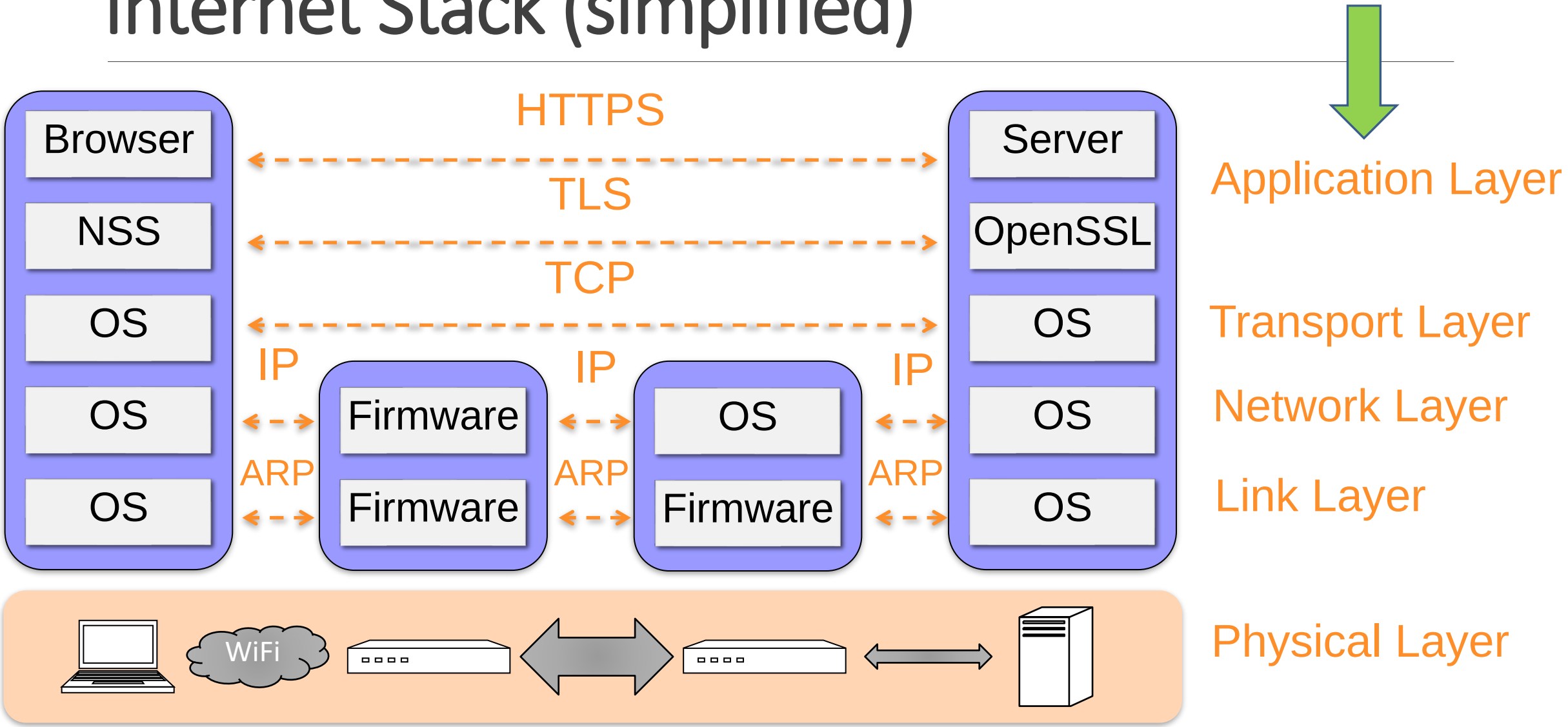
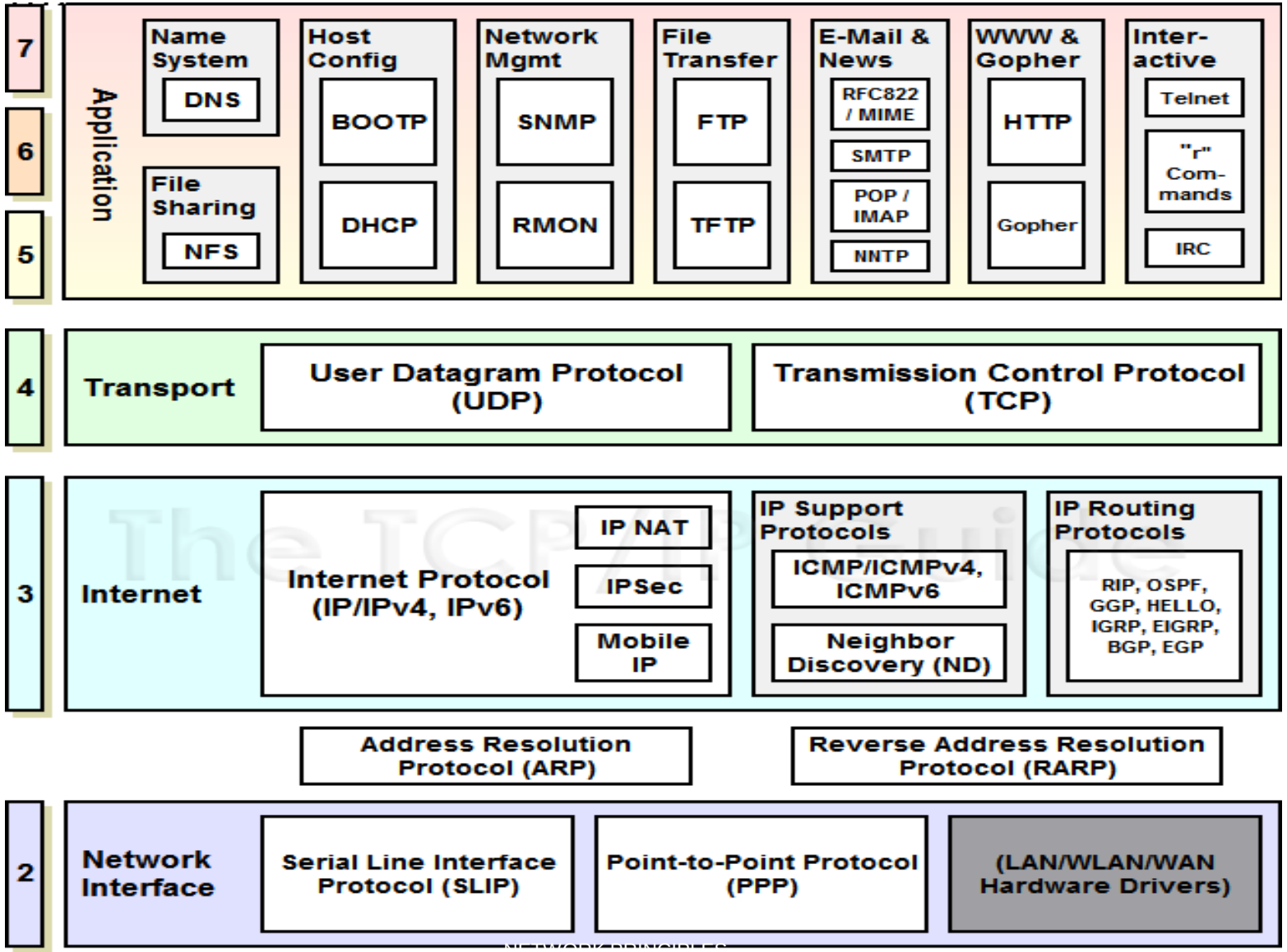
Some slides adapted from those by Markulf Kohlweiss, Myrto Arapinis, Kami Vaniea, and Roberto Tamassia

Internet Stack (simplified)



TCP/IP Model Mapped onto OSI



Sample Application-Layer Protocols

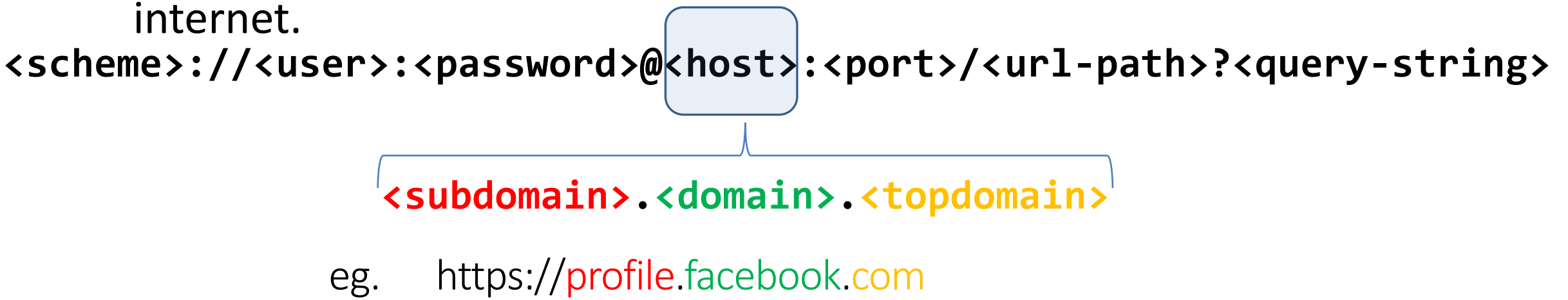
- Domain name system (DNS)
- Hypertext transfer protocol (HTTP)
- SSL/TLS. Protocol used for secure, encrypted browsing (HTTPS)
- IMAP/POP/SMTP. Internet email protocols
- File transfer protocol (FTP). An old but still used protocol for uploading and downloading files
- Telnet. Early remote access protocol
- SSH. More recent secure remote access protocol.

Other protocol examples [edit]

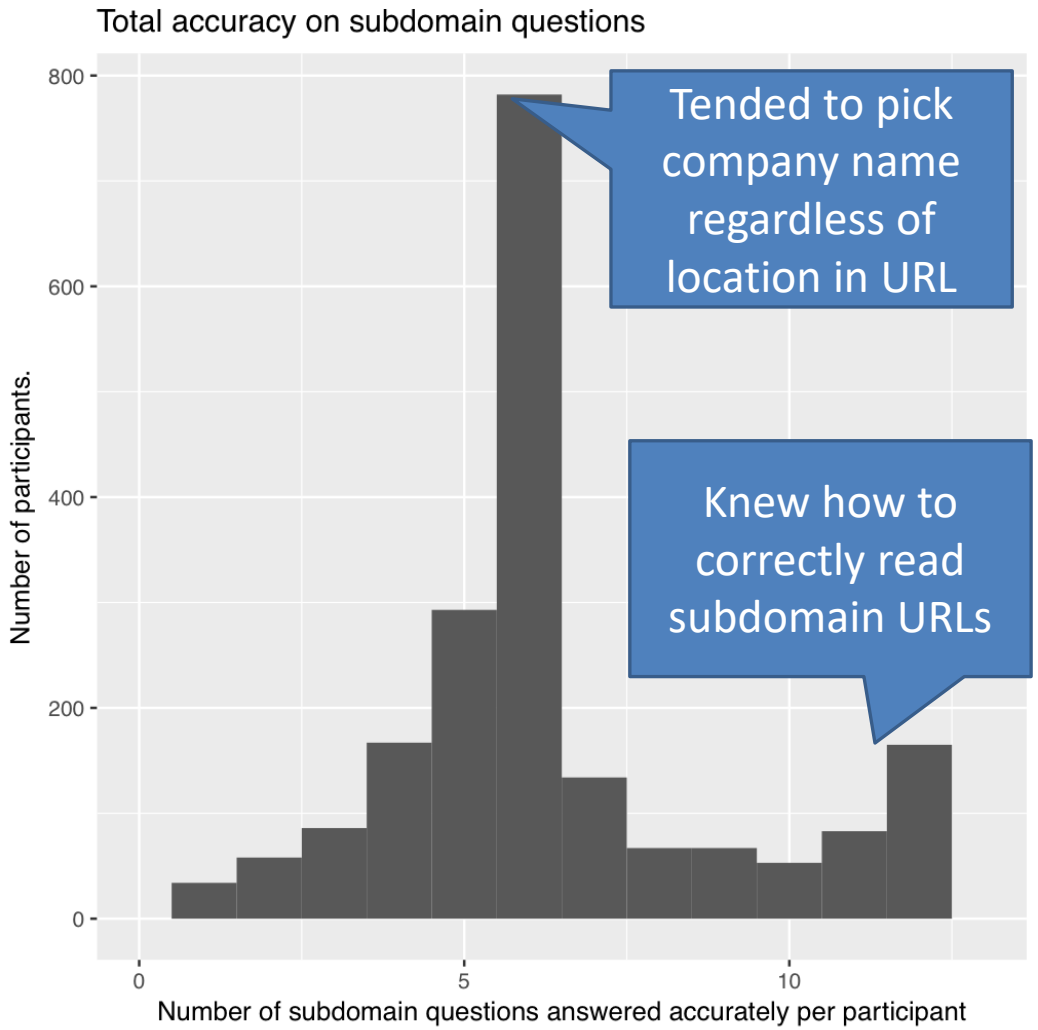
- 9P, Plan 9 from Bell Labs distributed file system protocol
- AFP, Apple Filing Protocol
- APPC, Advanced Program-to-Program Communication
- AMQP, Advanced Message Queuing Protocol
- Atom Publishing Protocol
- BEEP, Block Extensible Exchange Protocol
- Bitcoin
- BitTorrent
- CFDP, Coherent File Distribution Protocol
- CoAP, Constrained Application Protocol
- DDS, Data Distribution Service
- DeviceNet
- eDonkey
- ENRP, Endpoint Handlespace Redundancy Protocol
- FastTrack (KaZaa, Grokster, iMesh)
- Finger, User Information Protocol
- Freenet
- FTAM, File Transfer Access and Management
- Gopher, Gopher protocol
- HL7, Health Level Seven
- HTTP, HyperText Transfer Protocol
- H.323, Packet-Based Multimedia Communications System
- IMAP, Internet Message Access Protocol
- IRCP, Internet Relay Chat Protocol
- IPFS, InterPlanetary File System
- Kademlia
- LDAP, Lightweight Directory Access Protocol
- LPD, Line Printer Daemon Protocol
- MIME (S-MIME), Multipurpose Internet Mail Extensions and Secure MIME
- Modbus
- MQTT Protocol
- Netconf
- NFS, Network File System
- NIS, Network Information Service
- NNTP, Network News Transfer Protocol
- NTCIP, National Transportation Communications for Intelligent Transportation System Protocol
- NTP, Network Time Protocol
- OSCAR, AOL Instant Messenger Protocol
- POP, Post Office Protocol
- PNRP, Peer Name Resolution Protocol
- RDP, Remote Desktop Protocol
- RELP, Reliable Event Logging Protocol
- Rlogin, Remote Login in UNIX Systems
- RPC, Remote Procedure Call
- RTMP, Real Time Messaging Protocol
- RTP, Real-time Transport Protocol
- RTPS, Real Time Publish Subscribe
- RTSP, Real Time Streaming Protocol
- SAP, Session Announcement Protocol
- SDP, Session Description Protocol
- SIP, Session Initiation Protocol
- SLP, Service Location Protocol
- SMB, Server Message Block
- SMTP, Simple Mail Transfer Protocol
- SNTP, Simple Network Time Protocol
- SSH, Secure Shell
- SSMS, Secure SMS Messaging Protocol
- TCAP, Transaction Capabilities Application Part
- TDS, Tabular Data Stream
- Tor (anonymity network)
- Tox
- TSP, Time Stamp Protocol
- VTP, Virtual Terminal Protocol
- Whois (and RWhois), Remote Directory Access Protocol
- WebDAV
- X.400, Message Handling Service Protocol
- X.500, Directory Access Protocol (DAP)
- XMPP, Extensible Messaging and Presence Protocol

What is a URL?

- Uniform Resource Locators (URLs) are a standardized format for describing the location and access method of resources via the internet.



eg. https://profile.facebook.com

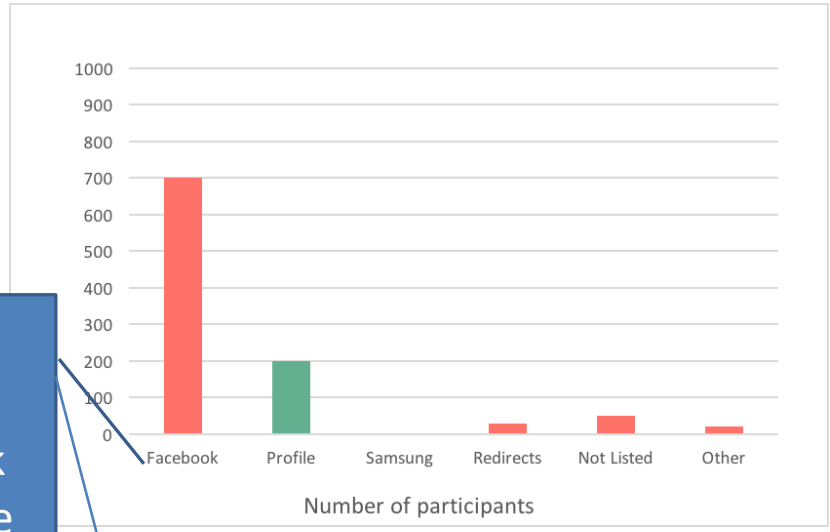


Tended to pick company name regardless of location in URL

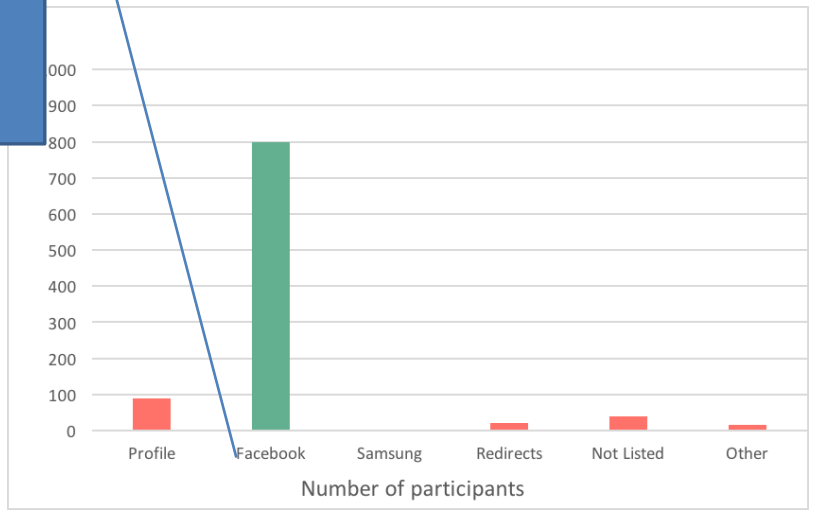
Knew how to correctly read subdomain URLs

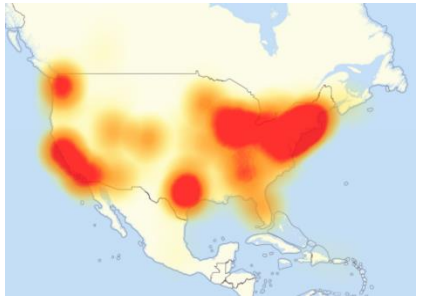
Tended to pick company name regardless of location in URL

https://facebook.profile.com



https://profile.facebook.com





DNS Servers are soft targets for attackers, take out the mapping and the website goes “offline”

DoS attack on major DNS provider brings Internet to morning crawl [Updated]

Dyn’s US East region hit hardest in attack that affected Twitter, Reddit.

SEAN GALLAGHER - OCT 21, 2016 1:59 PM UTC

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Update (12:04p ET): A second wave of DDoS attacks against Dyn is underway, as of noon Eastern Time today. Dyn is continuing to work on the issue. Our original story follows below; further updates will be added as information becomes available.

A distributed denial of service attack against Dyn, the dynamic DNS service, affected the availability of dozens of major websites and Internet services this morning, including Twitter and Reddit. The attack, which began this morning at 7:10am Eastern Time (12:10pm UK), is apparently focused on Dyn’s US East Coast name servers.

“This morning, Dyn received a global DDoS attack on our Managed DNS infrastructure in the east coast of the United States,” Doug Madory, Director of Internet Analysis at Dyn, said in an e-mail sent to Ars this morning. “DNS traffic resolved from east coast name server locations are experiencing a service interruption during this time.” By 9:20am ET this morning, Dyn had mitigated the attack and services returned to normal.

[Update, 1:20 PM ET] Less than three hours later, the attack began again, and is still in progress.

CNN Home International Edition +

Syrian group cited as New York Times outage continues

By Heather Kelly, CNN

Updated 1330 GMT (2130 HKT) August 29, 2013

The hackers gained access to a Melbourne IT reseller account using a phishing email and proceeded to change the DNS records of multiple domains, including NYTimes.com, according to the company.

The N

Stor

New
probl

Syria
York

The group is loyal to Syrian President Bashar Al-Assad

Twitter also experienced problems on Tuesday due to a similar attack

multiple attacks on media websites in recent months and, on Twitter, took credit for a sophisticated hack that had hobbled the Times' news site for roughly 20 hours.

"The @nytimes attack was going to deliver an anti-war message but our server couldn't last for 3 minutes," the group posted on its Twitter feed at about 9:40 Wednesday morning.

Domain Name System

The domain name system (DNS) is an application-layer protocol

Basic function of DNS

- Map domain names to IP addresses
- The mapping is many to many

Examples:

- www.ed.ac.uk and edwc.is.ed.ac.uk map to 129.215.228.101
- google.com maps to 216.58.213.110, 198.7.237.249, and other addresses

More generally, DNS is a distributed database that stores resource records

- Address (A) record: IP address associated with a host name
- Mail exchange (MX) record: mail server of a domain
- Name server (NS) record: authoritative server for a domain

Domains

Domain name

- Two or more labels, separated by dots (e.g., inf.ed.ac.uk)

Top-level domain (TLD)

- Generic (gTLD), e.g., .com, .org, .net
- Country-code (ccTLD), e.g., .ca, .it
- New top level domains, e.g., .scot, .tirol

ICANN

- (non-profit) Internet Corporation for Assigned Names and Numbers
- Keeps database of registered gTLDs (InterNIC)
- Accredits registrars for gTLDs

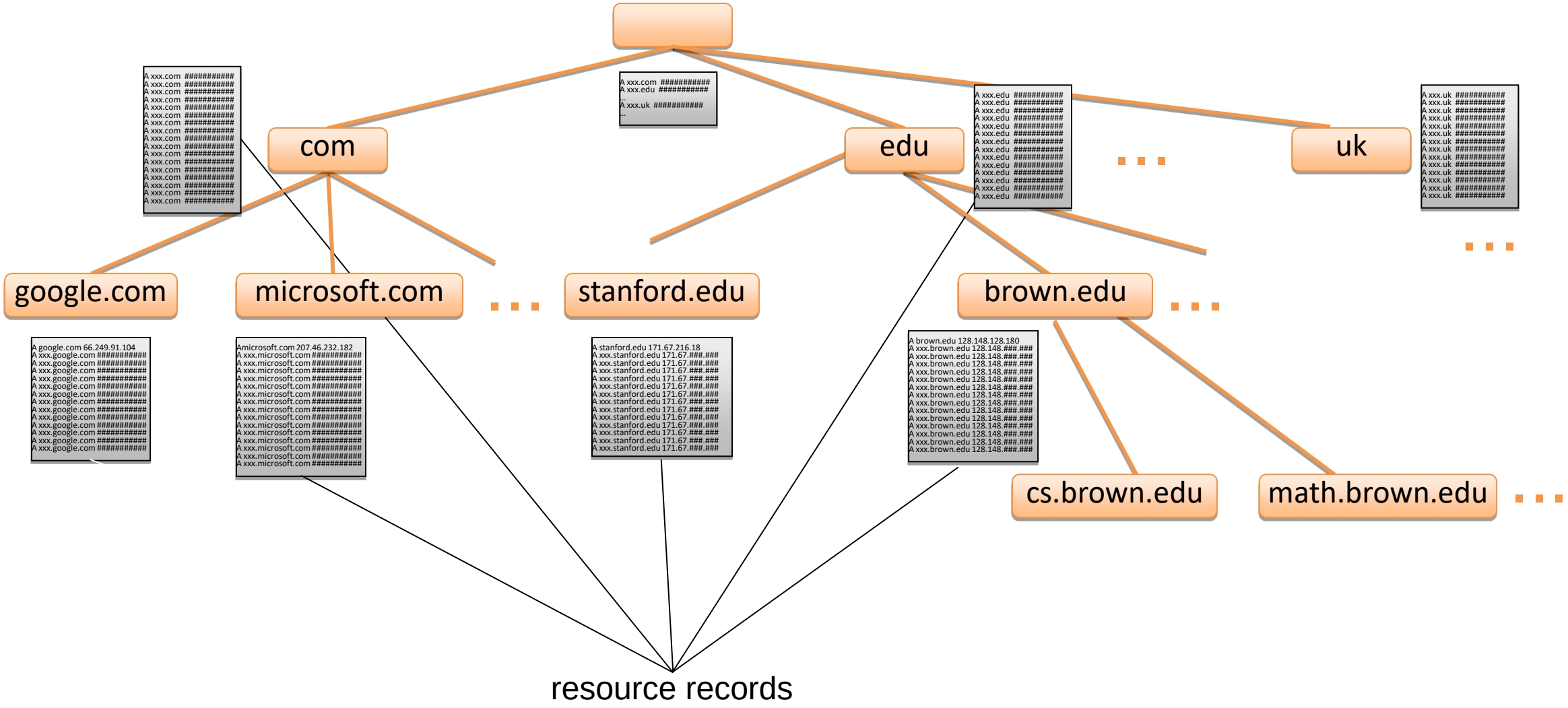
gTLDs

- Managed by ICANN

ccTLDs

- Managed by government organizations

DNS Tree


com
edu
uk
google.com
microsoft.com
stanford.edu
brown.edu
cs.brown.edu
math.brown.edu
resource records

Name Servers

- Name server
  - Keeps local database of DNS records
  - Answers DNS queries
  - Can ask other name servers if record not in local database
- Authoritative name server
  - Stores reference version of DNS records for a zone (partial tree)
- Examples
  - dns0.ed.ac.uk is authoritative for ed.ac.uk and dns0.inf.ed.ac.uk for inf.ed.ac.uk
- Root servers
  - Authoritative for the root zone (TLDs)
  - [a-m].root-servers.net
  - Supervised by ICANN

Name Resolution

- Resolver
  - Program that retrieves DNS records
  - Connects to a name server (default, root, or given)
  - E.g., dig in Linux and nslookup in Windows
  - Caches records received

Iterative resolution

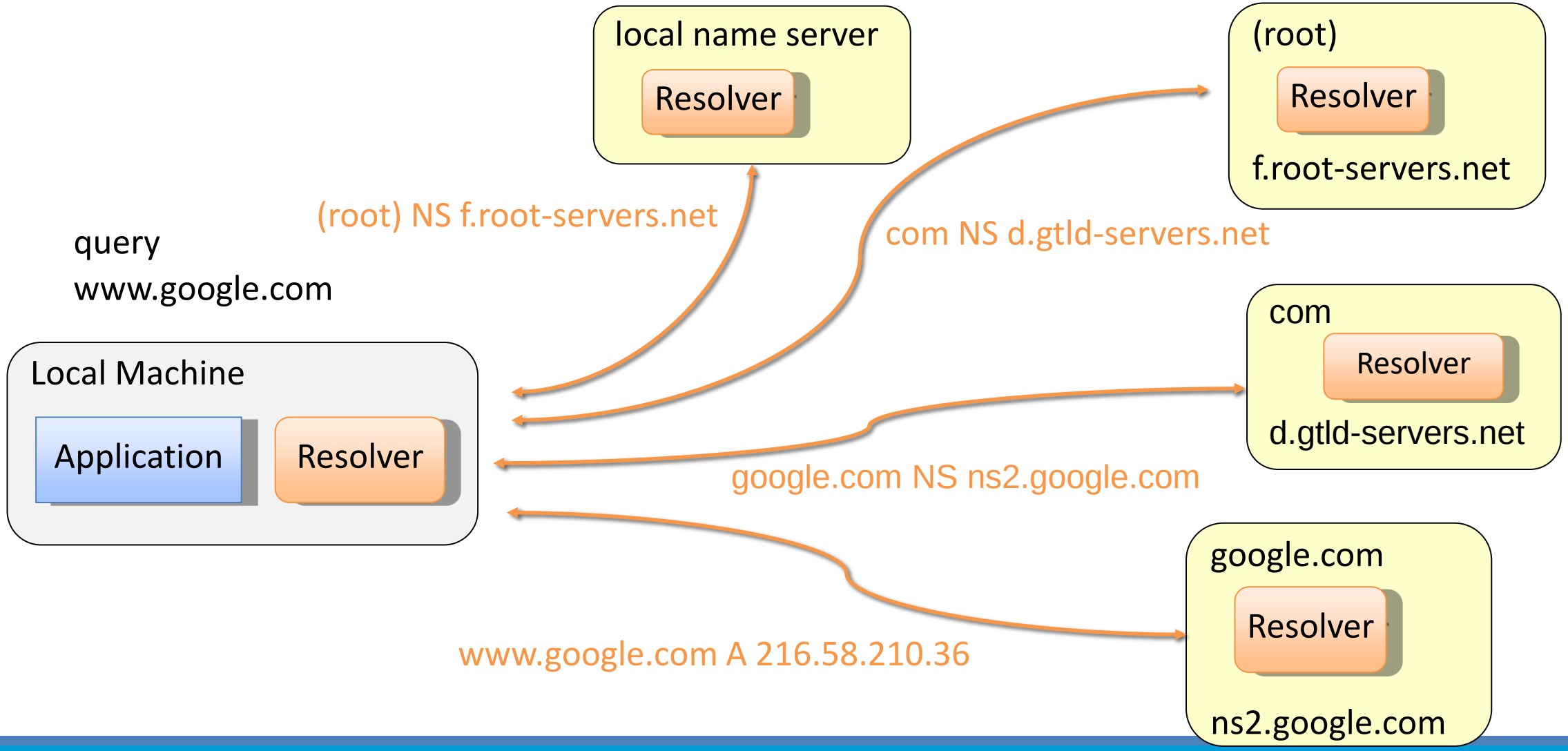
Name server refers client to authoritative server (e.g., a TLD server) via an NS record

Repeat

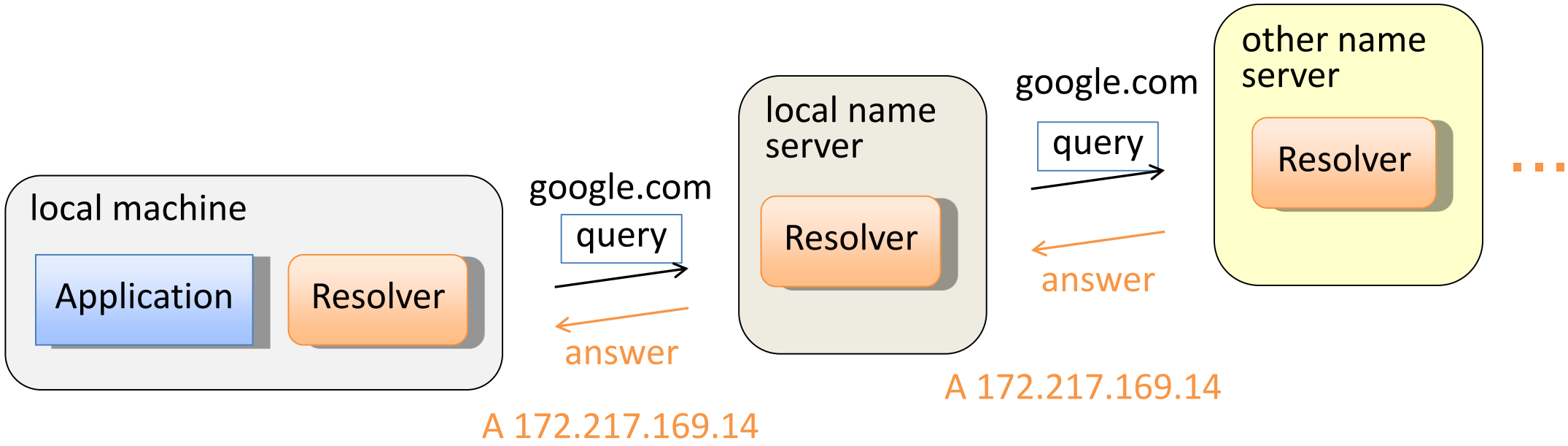
Recursive resolution

Name server queries another server and forwards the final answer (e.g., A record) to client

Iterative Name Resolution



Recursive Name Resolution



Glue Records

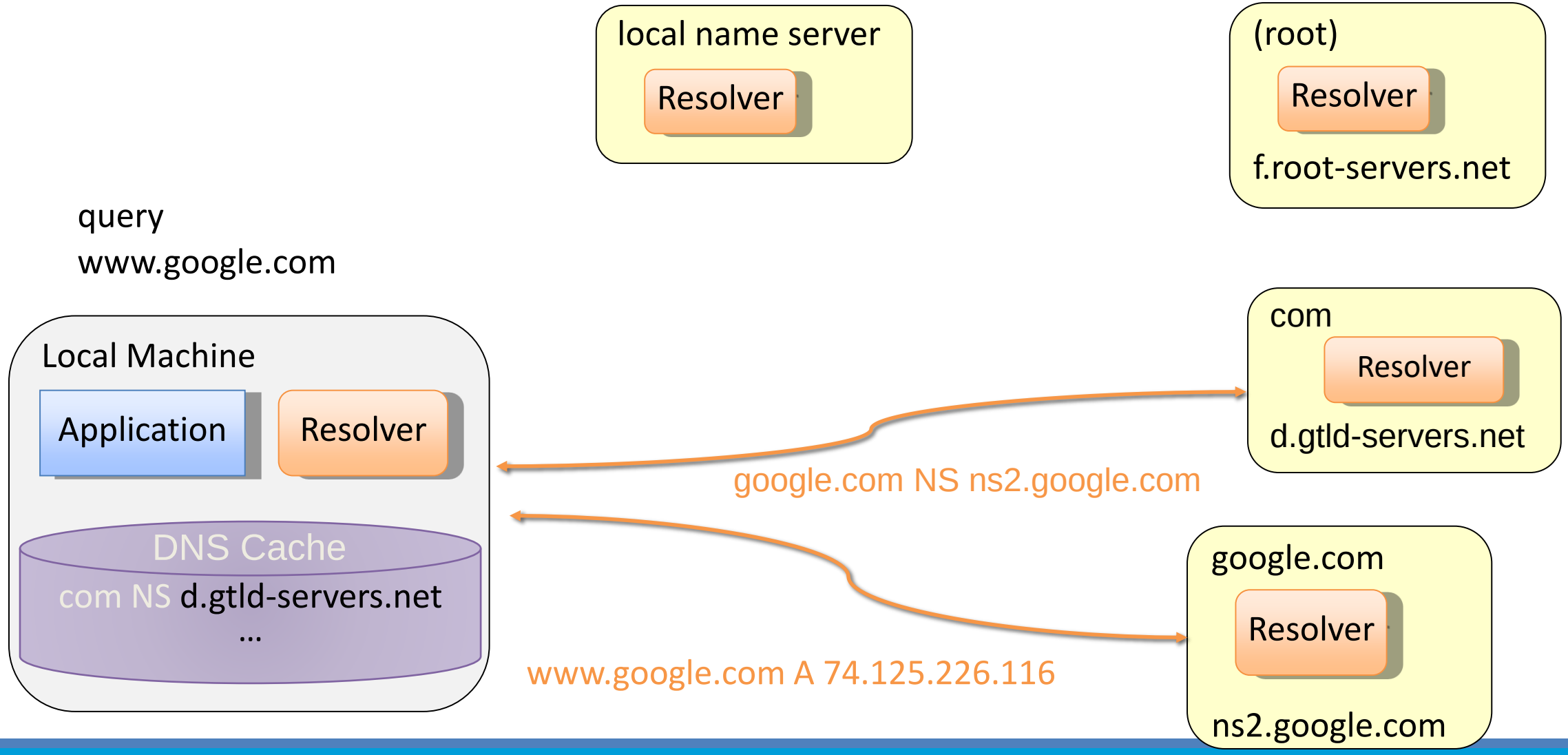
- Circular references
  - The authoritative name server for a domain may be within the same domain
  - E.g., dns0.inf.ed.ac.uk is authoritative for inf.ed.ac.uk
- Glue record
  - Record of type A (IP address) for a name server referred to NS record
  - Essential to break circular references
- Example

inf.ed.ac.uk.	NS	dns0.inf.ed.ac.uk.	
dns0.inf.ed.ac.uk.	A	129.215.160.240	[glue record]

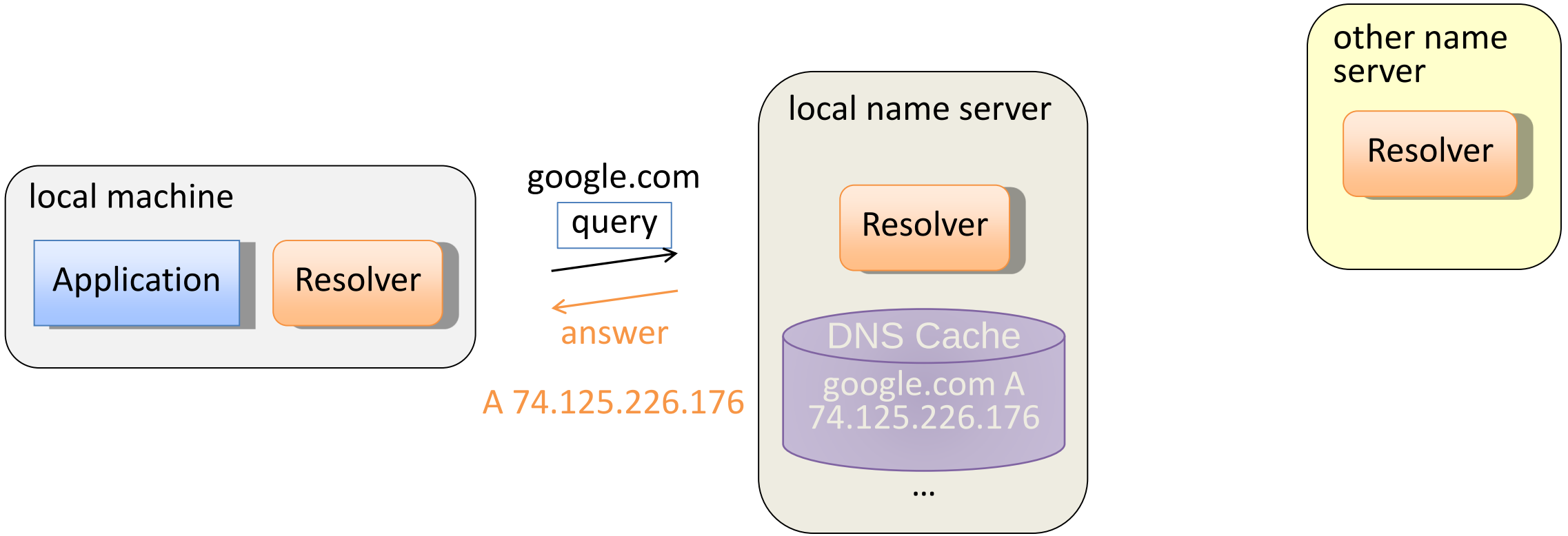
DNS Caching

- There would be too much network traffic if a path in the DNS tree would be traversed for each query
  - Root servers and TLD servers would be rapidly overloaded
- DNS servers cache records that are results of queries for a specified amount of time
  - Time-to-live field
- DNS queries with caching
  - First, resolver looks in cache for A record of query domain
  - Next , resolver looks in cache for NS record of longest suffix of query domain

Iterative Name Resolution with Caching



Recursive Name Resolution with Caching



Local DNS Cache

```
C:\Users\marku>ipconfig /displaydns

Windows IP Configuration

    arstechnica.com
    ----------------------------------------
    Record Name . . . . . : arstechnica.com
    Record Type . . . . . : 1
    Time To Live  . . . . : 128
    Data Length . . . . . : 4
    Section . . . . . . . : Answer
    A (Host) Record . . . : 50.31.169.131
```

- Operating system maintains DNS cache
  - Shared among all running applications
  - Can be displayed to all users
  - View DNS cache in Windows with command ipconfig /displaydns
  - Clear DNS cache in Windows with command ipconfig /flushdns
- Privacy issues
  - Browsing by other users can be monitored
  - Note that private/incognito browsing does not clear DNS cache

DNS Cache Poisoning

- Basic idea
  - Give a DNS server a false address record and get it cached
- DNS query mechanism
  - Queries issued over UDP on port 53
  - 16-bit request identifier in payload to match answers with queries
  - No authentication

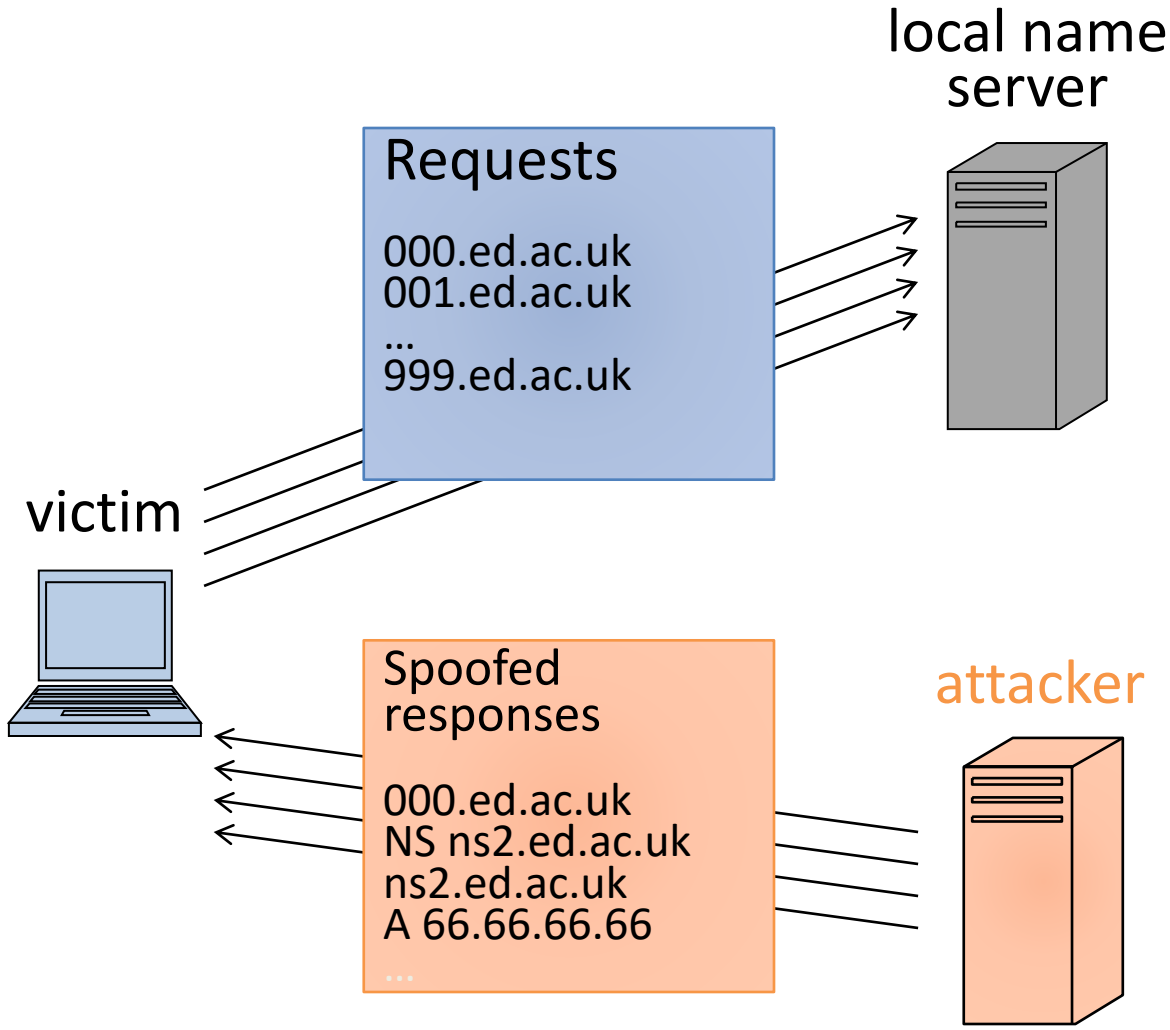
- Cache may be poisoned when a resolver
  - Query has predictable identifiers and return ports
  - Attacker answers before authoritative name server
  - Ignore identifier, accepts unsolicited DNS records
- Early versions of BIND (popular DNS software) vulnerable to cache poisoning

DNS Cache Poisoning Defenses

- Query randomization
  - Random request identifier (16 bits)
  - Random return port (16 bits)
  - Probability of guessing request ID or return port
    - $1 / 2^{16} = 0.0015\%$
  - Probability of guessing request ID and return port is
    - $1 / 2^{32}$ (less than one in four billion)
- Birthday Paradox

Subdomain DNS Cache Poisoning (Kaminsky)

- Attacker causes victim to send
  - Many DNS requests for nonexistent subdomains of target domain
- Attacker sends victim
  - Forged NS responses for the requests
- Format of forged response
  - Random ID
  - Correct NS record
  - Spoofed glue record pointing to the attacker's name server IP



Steve Friedl's Unixwiz.net Tech Tips

An Illustrated Guide to the Kaminsky DNS Vulnerability

The big security news of Summer 2008 has been Dan Kaminsky's discovery of a serious vulnerability in DNS. This vulnerability could allow an attacker to redirect network clients to alternate servers of his own choosing, presumably for ill ends.

Nice work, Dan

Table of Contents

This all led to a mad dash to patch DNS servers worldwide, and though there have been many writeups of just how the vulnerability manifests itself, we felt the need for one in far more detail. Hence, one of our Illustrated Guides.

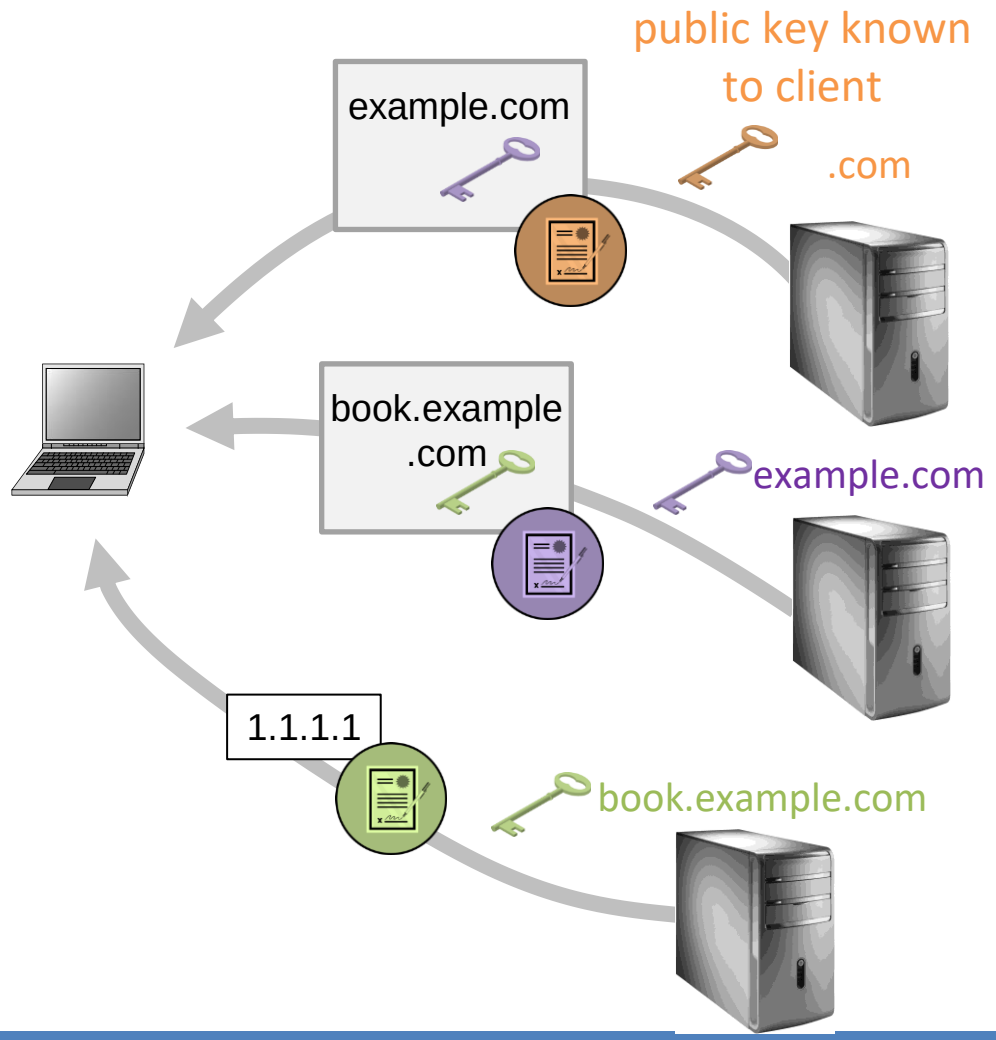
This paper covers how DNS works: first at a high level, then by picking apart an individual packet exchange field by field. Next, we'll use this knowledge to see how weaknesses in common implementations can lead to cache poisoning.

By fully understanding the issues at play, the reader may be better equipped to mitigate the risks in his or her own environment.

We hope everybody who runs a DNS server patches soon.

DNSSEC

- Goals
  - Authenticity of DNS answer origin
  - Integrity of reply
  - Authenticity of denial of existence
- Implementation
  - Signed DNS replies at each step
  - Public-key cryptography
- Slow deployment
  - Root servers support since 2010



What We Have Learned

- How DNS operates
  - Distributed database
  - Resolvers and name servers
  - Iterative vs. recursive resolution
  - Caching
- DNS cache poisoning attacks
- DNSSEC