CS-340 Introduction to Computer Networking

Lecture 4: Domain Name Service

Steve Tarzia

Many diagrams & slides are adapted from those by J.F Kurose and K.W. Ross

Last Lecture

- Application-layer protocols are usually built on top of TCP
  - Don't have to worry about network itself, just connect with other hosts
- Most applications use a *client-server* architecture: request-response.
- A *peer-to-peer* architecture is more scalable, but difficult to organize.
- *HTTP* was invented for fetching documents from web servers.
  - It's now used as the basis for many request-response interactions.
  - URLs, request method, response status, human-readable headers, body
  - REST APIs are built on top of HTTP, so it's a layer in its own right.
- *SMTP* is an earlier application-layer protocol, for sending email
  - Unlike HTTP, it's *stateful* (server has to remember what you previously said).

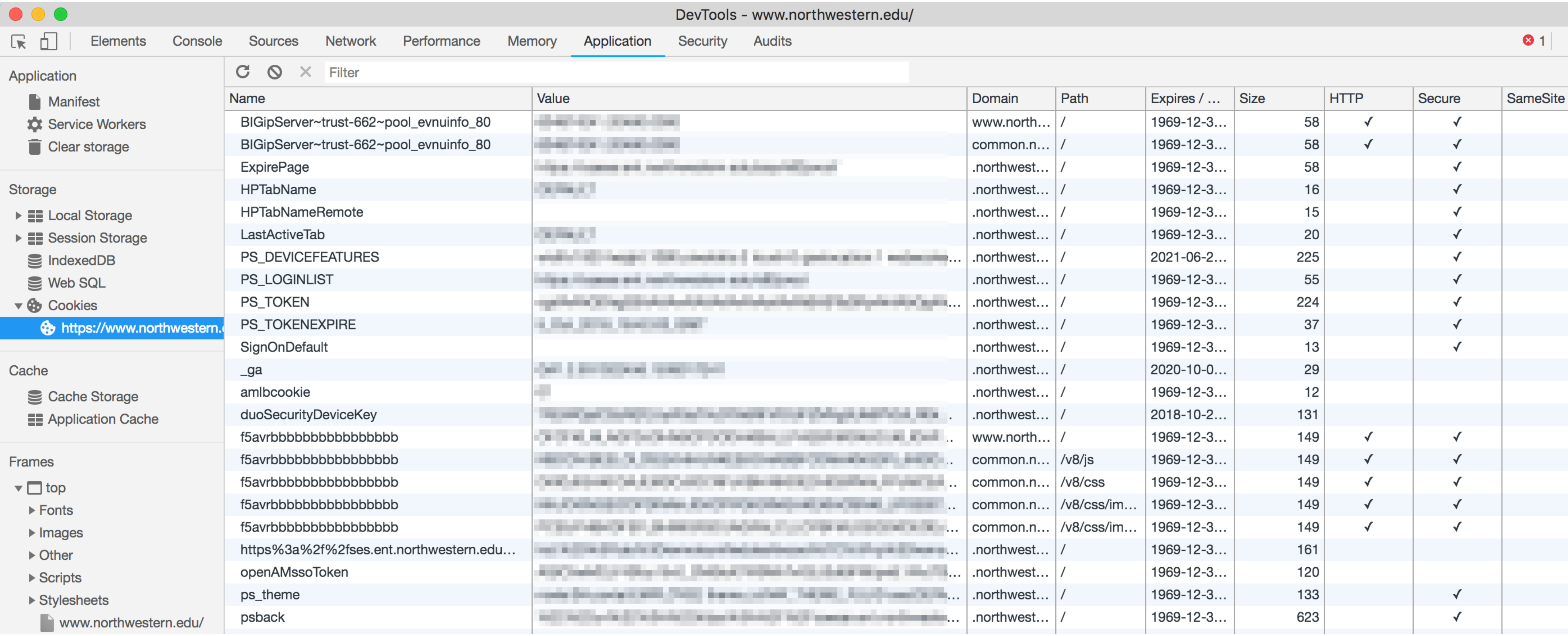
Third party cookies, pixels, and tags

- Recall, that an HTTP response may include a **cookie**.
  - Cookies are random strings stored by your browser and included in every request to the same domain.
  - Cookies are a way for the browser to remind a website of your identity.
- **Third party cookies** are cookies from a domain different that the currently viewed web page.
  - Often enabled with a one-pixel GIF image included in the page:

```
<img src="https://facebook.com/tracker/pix.gif">
```

  - Causes browser to send a request to facebook.com (including your Facebook cookie) even though I'm visiting a page unrelated to Facebook.
  - The request has a "Referer:" header listing the current URL.
  - Thus, Facebook (for example) learns about much of your web activity.

Visiting Northwestern's webpage (w/Ghostery plugin)



Name	Value	Domain	Path	Expires / …	Size	HTTP	Secure	SameSite
BIGipServer~trust-662~pool_evnuinfo_80	[illegible]	www.north…	/	1969-12-3…	58	✓	✓	
BIGipServer~trust-662~pool_evnuinfo_80	[illegible]	common.n…	/	1969-12-3…	58	✓	✓	
ExpirePage	[illegible]	.northwest…	/	1969-12-3…	58		✓	
HPTabName	[illegible]	.northwest…	/	1969-12-3…	16		✓	
HPTabNameRemote		.northwest…	/	1969-12-3…	15		✓	
LastActiveTab	[illegible]	.northwest…	/	1969-12-3…	20		✓	
PS_DEVICEFEATURES	[illegible]	.northwest…	/	2021-06-2…	225		✓	
PS_LOGINLIST	[illegible]	.northwest…	/	1969-12-3…	55		✓	
PS_TOKEN	[illegible]	.northwest…	/	1969-12-3…	224		✓	
PS_TOKENEXPIRE	[illegible]	.northwest…	/	1969-12-3…	37		✓	
SignOnDefault		.northwest…	/	1969-12-3…	13		✓	
_ga	[illegible]	.northwest…	/	2020-10-0…	29			
amlbcookie	[illegible]	.northwest…	/	1969-12-3…	12			
duoSecurityDeviceKey	[illegible]	.northwest…	/	2018-10-2…	131			
f5avrbbbbbbbbbbbbbbbb	[illegible]	www.north…	/	1969-12-3…	149	✓	✓	
f5avrbbbbbbbbbbbbbbbb	[illegible]	common.n…	/v8/js	1969-12-3…	149	✓	✓	
f5avrbbbbbbbbbbbbbbbb	[illegible]	common.n…	/v8/css	1969-12-3…	149	✓	✓	
f5avrbbbbbbbbbbbbbbbb	[illegible]	common.n…	/v8/css/im…	1969-12-3…	149	✓	✓	
f5avrbbbbbbbbbbbbbbbb	[illegible]	common.n…	/v8/css/im…	1969-12-3…	149	✓	✓	
https%3a%2f%2fses.ent.northwestern.edu…	[illegible]	.northwest…	/	1969-12-3…	161			
openAMssoToken	[illegible]	.northwest…	/	1969-12-3…	120			
ps_theme	[illegible]	.northwest…	/	1969-12-3…	133		✓	
psback	[illegible]	.northwest…	/	1969-12-3…	623		✓	

New York Times homepage (allowing all cookies)

DevTools - www.nytimes.com/

Elements Console Sources Network Performance Memory Application Security Audits 3 6

Application
- Manifest
- Service Workers
- Clear storage

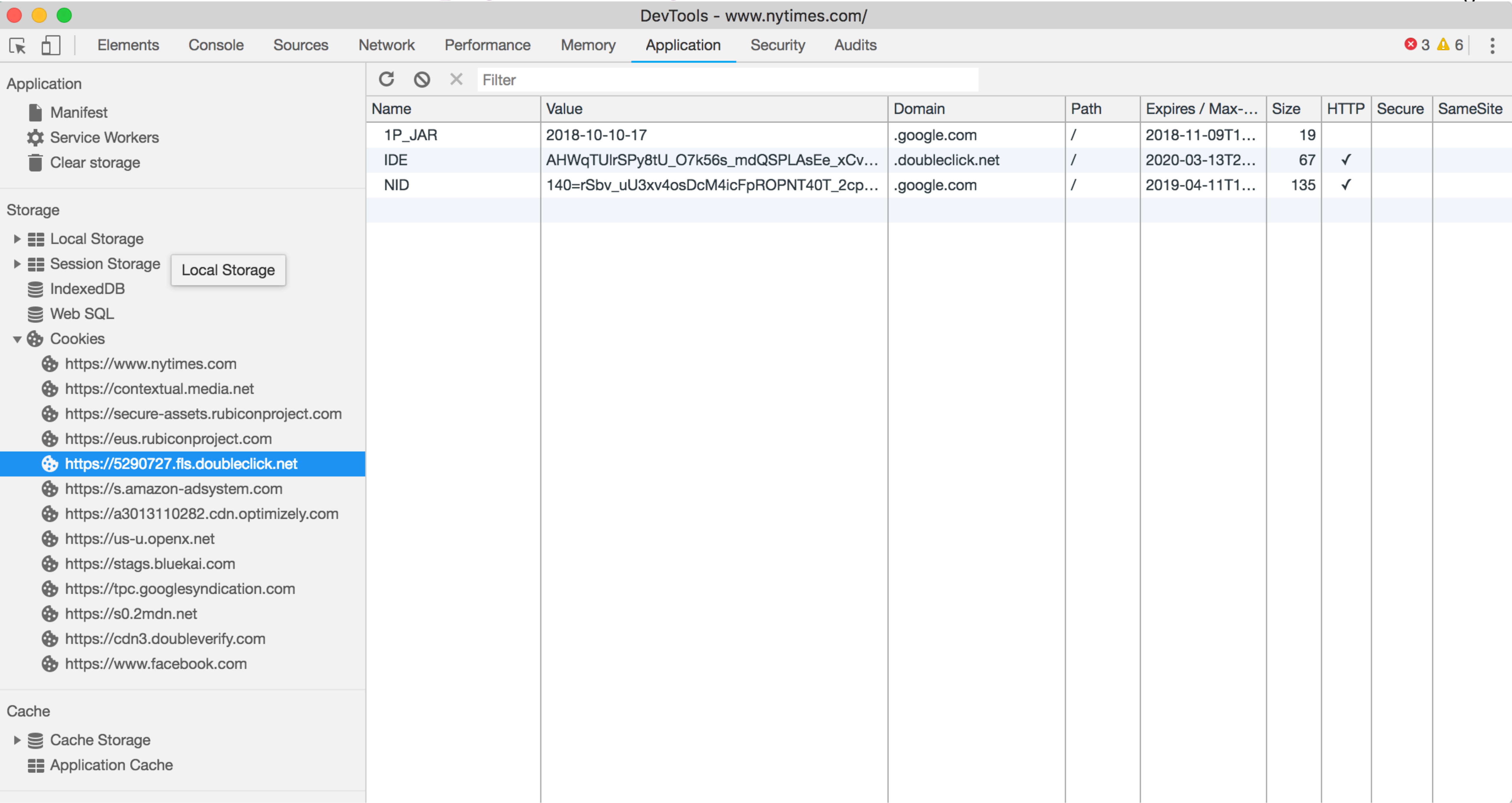
Storage
- Local Storage
- Session Storage
- IndexedDB
- Web SQL
- Cookies
  - https://www.nytimes.com
  - https://contextual.media.net
  - https://secure-assets.rubiconproject.com
  - https://eus.rubiconproject.com
  - https://5290727.fls.doubleclick.net
  - https://s.amazon-adsystem.com
  - https://a3013110282.cdn.optimizely.com
  - https://us-u.openx.net
  - https://stags.bluekai.com
  - https://tpc.googlesyndication.com
  - https://s0.2mdn.net
  - https://cdn3.doubleverify.com
  - https://www.facebook.com

Cache
- Cache Storage
- Application Cache

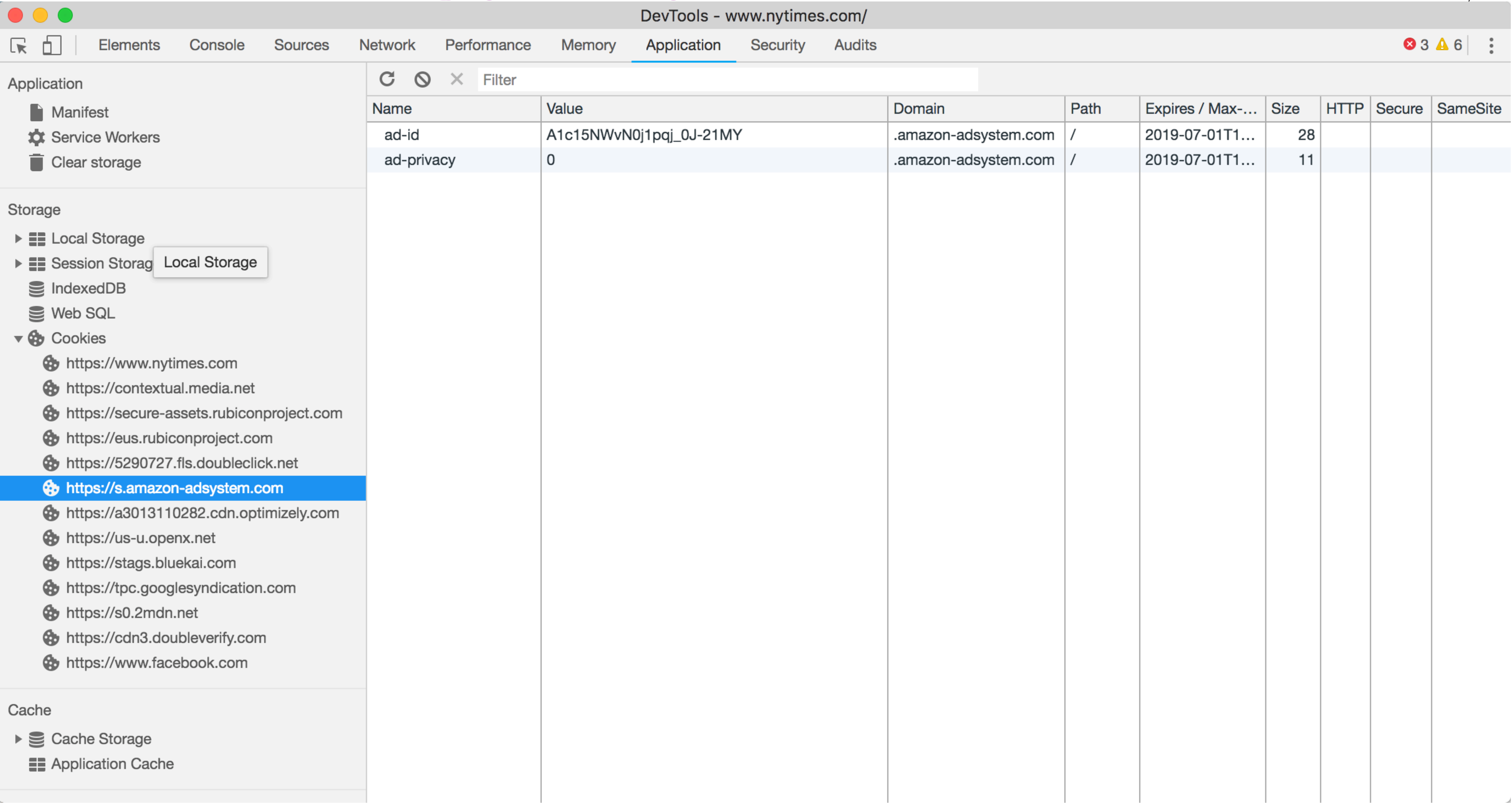
Filter

Name	Value	Domain	Path	Expires / Max-...	Size	HTTP	Secure	SameSite
1P_JAR	2018-10-10-17	.google.com	/	2018-11-09T1...	19			
B	ddr1ohddaj1iv&b=3&s=ve	.yahoo.com	/	2019-10-10T1...	23			
IDE	AHWqTUlrSPy8tU_O7k56s_mdQSPLAsEe_xCv...	.doubleclick.net	/	2020-03-13T2...	67	✓		
NID	140=rSbv_uU3xv4osDcM4icFpROPNT40T_2cp...	.google.com	/	2019-04-11T1...	135	✓		
UID	1E423a43a16412a20b8a0e31521059421	.scorecardresearch.com	/	2020-03-03T2...	36			
UIDR	1521059421	.scorecardresearch.com	/	2020-03-03T2...	14			
__gads	ID=6e101206618230e6:T=1539191150:S=ALNI...	.nytimes.com	/	2020-10-09T1...	75			
_cb	CjGfbSBySCCXD49eid	www.nytimes.com	/	2019-11-09T1...	21			
_cb_ls	1	www.nytimes.com	/	2019-11-09T1...	7			
_cb_svref	null	www.nytimes.com	/	2018-10-10T1...	13			
_chartbeat2	.1539191149429.1539191149429.1.zmaYPrN4t...	www.nytimes.com	/	2019-11-09T1...	72			
_fbp	fb.1.1539191209422.1576464936	.nytimes.com	/	2018-10-10T1...	33			
_gcl_au	1.1.776137764.1539191148	.nytimes.com	/	2019-01-08T1...	31			
ad-id	A1c15NWvN0j1pqj_0J-21MY	.amazon-adsystem.com	/	2019-07-01T1...	28			
ad-privacy	0	.amazon-adsystem.com	/	2019-07-01T1...	11			
b2b_cig_opt	%7B%22isCorpUser%22%3Afalse%7D	.nytimes.com	/	2018-10-11T1...	41			
bkdc	phx	.bluekai.com	/	2019-04-08T1...	7			
bku	jzA99/KW0Noro6zf	.bluekai.com	/	2019-04-08T1...	19			
data	||||||||||||||||||||||||||||||||||||||||||	.media.net	/	2019-10-10T1...	43			
data-a	6251294085577535347~~1	.media.net	/	2019-01-07T1...	28			
data-o	117fb9b7-8125-08a3-1b3a-4719baeae860~~3	.media.net	/	2019-06-26T1...	45			
data-r	JERJIA06-1A-BEJB~~1	.media.net	/	2019-04-08T1...	25			
edu_cig_opt	%7B%22isEduUser%22%3Atrue%2C%22nick...	.nytimes.com	/	2018-10-11T1...	77			
et-a1	%257B%2522agentId%2522%253A%2522aSfl...	.et.nytimes.com	/	2019-10-10T1...	282			
fr	0fP3kKNAcFunxs7iE..BbvjGp...1.0.BbvjGp.	.facebook.com	/	2019-01-08T1...	41	✓	✓	
jkidd-l	uid=0&sessionIndex=1&sessionStart=15391911...	.a.nytimes.com	/	2019-10-10T1...	410	✓		
jkidd-p	prevPage=&currPage=	.a.nytimes.com	/	2019-10-10T1...	26	✓		

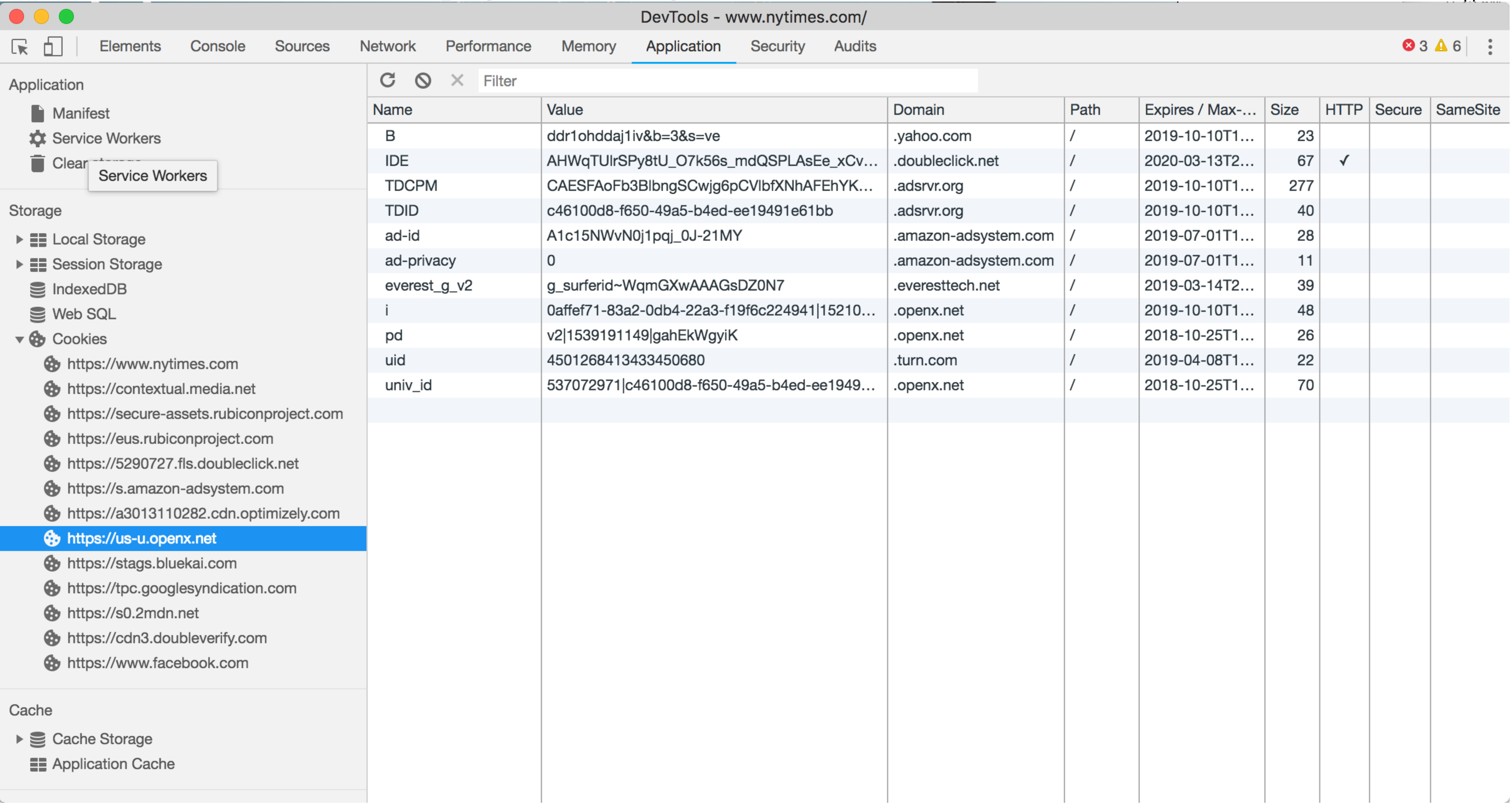
New York Times homepage (allowing all cookies)



New York Times homepage (allowing all cookies)



New York Times homepage (allowing all cookies)



Name	Value	Domain	Path	Expires / Max-...	Size	HTTP	Secure	SameSite
B	ddr1ohddaj1iv&b=3&s=ve	.yahoo.com	/	2019-10-10T1...	23			
IDE	AHWqTUlrSPy8tU_O7k56s_mdQSPLAsEe_xCv...	.doubleclick.net	/	2020-03-13T2...	67	✓		
TDCPM	CAESFAoFb3BlbngSCwjg6pCVlbfXNhAFEhYK...	.adsrvr.org	/	2019-10-10T1...	277			
TDID	c46100d8-f650-49a5-b4ed-ee19491e61bb	.adsrvr.org	/	2019-10-10T1...	40			
ad-id	A1c15NWvN0j1pqj_0J-21MY	.amazon-adsystem.com	/	2019-07-01T1...	28			
ad-privacy	0	.amazon-adsystem.com	/	2019-07-01T1...	11			
everest_g_v2	g_surferid~WqmGXwAAAGsDZ0N7	.everesttech.net	/	2019-03-14T2...	39			
i	0affef71-83a2-0db4-22a3-f19f6c224941|15210...	.openx.net	/	2019-10-10T1...	48			
pd	v2|1539191149|gahEkWgyiK	.openx.net	/	2018-10-25T1...	26			
uid	4501268413433450680	.turn.com	/	2019-04-08T1...	22			
univ_id	537072971|c46100d8-f650-49a5-b4ed-ee1949...	.openx.net	/	2018-10-25T1...	70			

New York Times homepage (allowing all cookies)

DevTools - www.nytimes.com/

Elements Console Sources Network Performance Memory Application Security Audits

3 6

Application
- Manifest
- Service Workers
- Clear storage

Clear storage

Storage
- Local Storage
- Session Storage
- IndexedDB
- Web SQL
- Cookies
  - https://www.nytimes.com
  - https://contextual.media.net
  - https://secure-assets.rubiconproject.com
  - https://eus.rubiconproject.com
  - https://5290727.fls.doubleclick.net
  - https://s.amazon-adsystem.com
  - https://a3013110282.cdn.optimizely.com
  - https://us-u.openx.net
  - https://stags.bluekai.com
  - https://tpc.googlesyndication.com
  - https://s0.2mdn.net
  - https://cdn3.doubleverify.com
  - https://www.facebook.com

Cache
- Cache Storage
- Application Cache

Filter

Name	Value	Domain	Path	Expires / Max-…	Size	HTTP	Secure	SameSite
1P_JAR	2018-10-10-17	.google.com	/	2018-11-09T1…	19			
ANONCHK	1	.c.bing.com	/	2018-10-10T1…	8			
IDE	AHWqTUlrSPy8tU_O7k56s_mdQSPLAsEe_xCv…	.doubleclick.net	/	2020-03-13T2…	67	✓		
MR	0	.c.bing.com	/	2018-12-24T1…	3			
MUID	09743DC4CA4E6C002DD031DFCE4E6FF8	.bing.com	/	2019-07-22T1…	36			
MUIDB	09743DC4CA4E6C002DD031DFCE4E6FF8	c.bing.com	/	2019-11-04T1…	37	✓		
NID	140=rSbv_uU3xv4osDcM4icFpROPNT40T_2cp…	.google.com	/	2019-04-11T1…	135	✓		
bkdc	phx	.bluekai.com	/	2019-04-08T1…	7			
bku	jzA99/KW0Noro6zf	.bluekai.com	/	2019-04-08T1…	19			
everest_g_v2	g_surferid~WqmGXwAAAGsDZ0N7	.everesttech.net	/	2019-03-14T2…	39			
personalization_id	"v1_4MshLYPvGXpSib+h7NRe8g=="	.twitter.com	/	2020-10-09T1…	47			

Cookies are secrets!

- Remember that web servers use cookies to *authenticate* (identify) users.
- If I steal your browser's cookies and copy them to my browser, then any websites I visit recognize me as you.
- Web browsers isolate cookies by domain.

- Cookies have expiration dates.
- This is why you have to re-sign-in to websites occasionally, even if you did not sign out.
- Signing out involves clearing your browser's cookies *and* removing the cookies from a server-side database.

Cross-Site Request Forgery (CSRF) attack

- Cookies must be carefully configured to prevent attacks.
- Eg., I can place the following code in my website to trigger an authenticated request to another website:

```
<img src="https://mybank.com/transfer?
account=bob&amount=1000000&to=mallory">
```

- The browser will include that domain's cookies in the request, and those cookies authenticate the request.
- There is also a variation of this attack that uses a hidden HTML form to generate a POST request.
- Cookies can be stored with "SameSite" attribute to prevent CSRF, and many other protection strategies are possible.

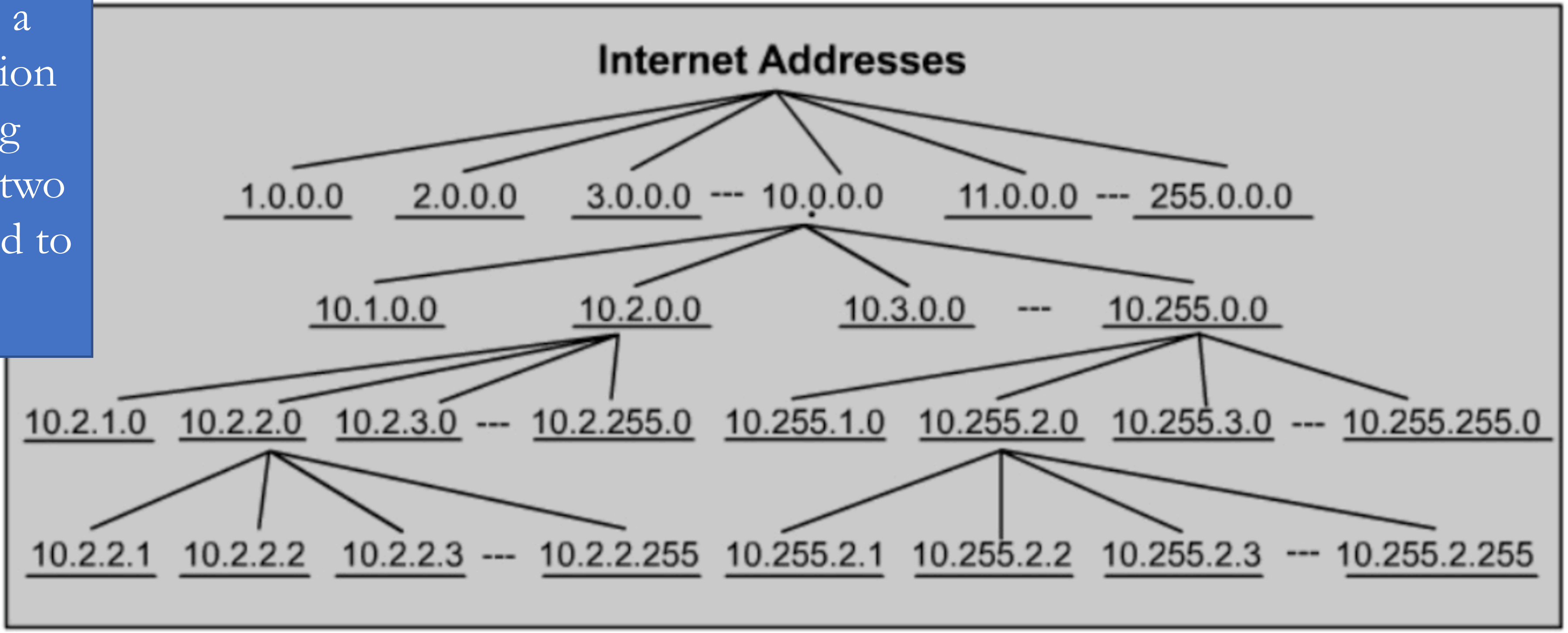
Domain Name Service (DNS)

- Internet hosts are reachable by IP address:
  - eg.: **129.105.136.70** (IPv4) or **2001:db8::ff00:42:8329** (IPv6)
- But we need some way to find these addresses.
- DNS maps from human-friendly ***hostnames*** to IP addresses
  - Eg., “northwestern.edu” → 129.105.136.70
- *IP addresses* are bound to *machines.*
- *Hostnames* are associated with *services.*
  - More permanent than IP addresses (allows machines to move).

- DNS provides a **layer of indirection** in addressing, useful in many ways.
- Defined in RFCs [1034]() and [1035]()

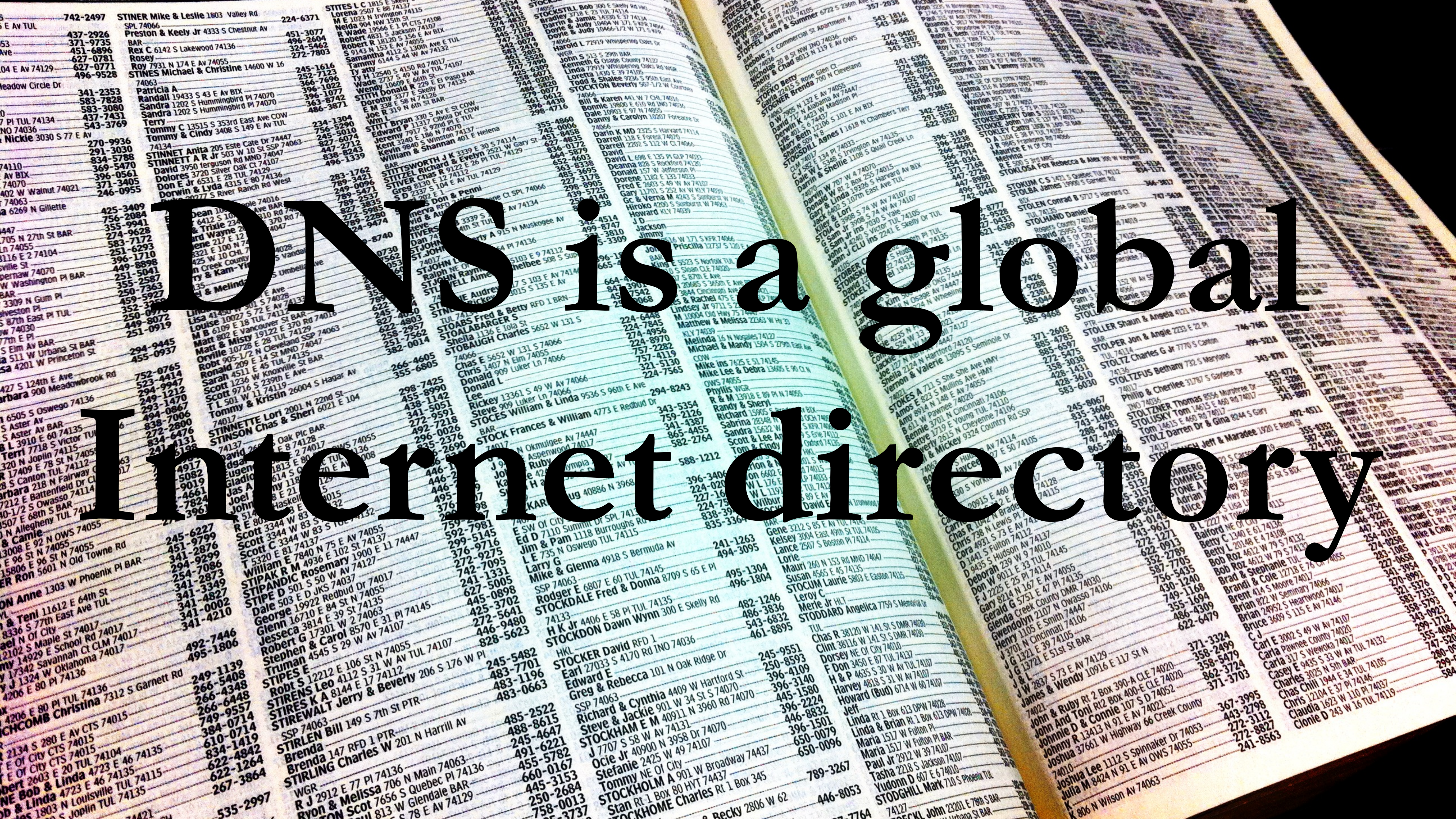
IP Addresses are for *routing*

Actually, this is a gross simplification of how routing works. We have two chapters dedicated to IP routing.



- Nearby IP addresses are *usually* physically closer together in the network.
- Left-most bits are for global location, right-most bits are local.
- Similar to telephone numbers: **1-847-491-7069**

USA, NE Illinois, Northwestern campus, Steve's phone


DNS is a global
Internet directory

925-0635
925-4633
328-0817
337-1883
471-0684
749-1098
696-2725
28-4212
8-7872
-2288
4899
028
13
3

CASEY Robt L 32 Scott Cir Ded....................
Robt & Lauren 8 Otis Av Ded.................... 326-2370
Robt W 71 Herbert Rd Bra.................... 326-0635
Rose 617 Broad Wey.................... 848-5137
Ruth B 208 Atlntc Av Hul.................... 331-6948
Sean 141 Carroll Av Wswd.................... 925-2525
Stacie 30 Chapman Wey.................... 329-9412
Stephen & Katherine
590 Middle Wey.................... 331-3652
Stephen R 17 Draper Can.................... 340-6658
Theresa 17 Binnacle Ln Qui.................... 828-1108
Thos 65 Dickens Qui.................... 479-4923
Thos A Jr 194 School Wswd.................... 328-6078
Thos R 1 Wentworth Rd Can.................... 326-2474
Thos W 20 Westchester Dr Wswd.................... 828-6
Timothy P 30 French Qui....................
Timothy P 637 Pleasant
Tom & Judy 63
V 9 Fore Ri
Walt

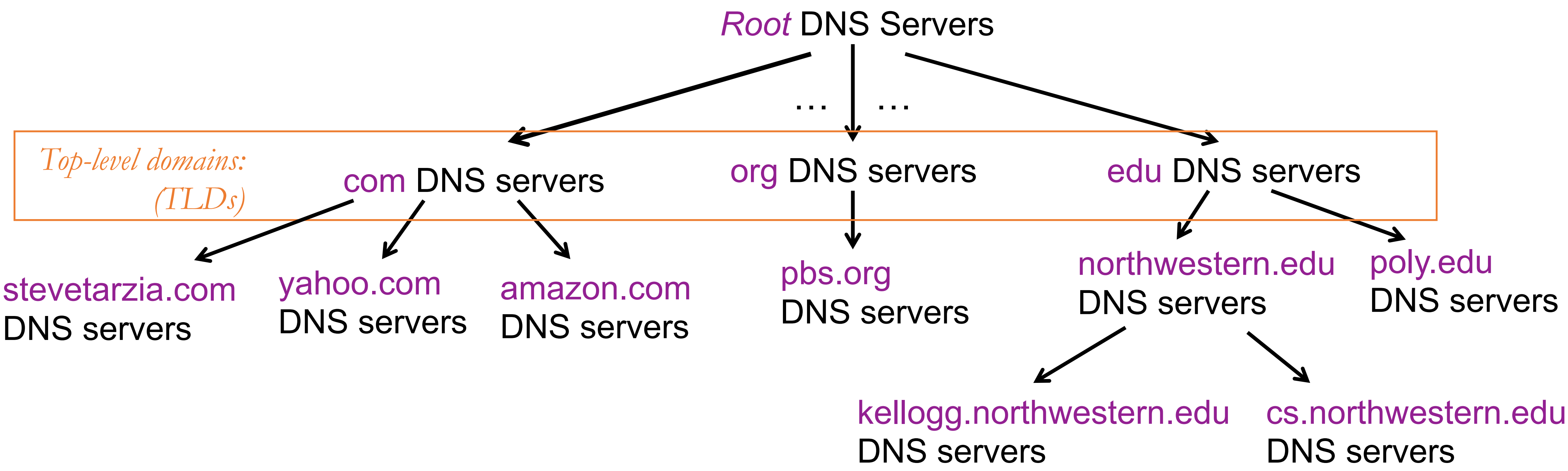
DNS scaling

- A single directory machine would not scale
  - Many web requests require a DNS lookup first.
  - One server cannot handle all the Internet's directory requests!
  - Plus, you want to do this lookup at a nearby server.

- How would you make DNS scalable, to provide IP address lookups for all machines on the Internet?

- Two basic solutions:
  - **Distribute** the database across many machines.
  - **Cache** DNS lookups locally on the client and in nearby caching proxies.

DNS is distributed and *hierarchical*



- Each DNS server only knows about the records in its own subdomain
- These are the authoritative ***nameservers*** for the various ***subdomains.***
  - If I want to own and operate "stevetarzia.com" I must pay someone to add a record to the "com" top-level-domain nameservers.
  - I then can run my own nameserver on my subdomain, defining:
    - **www**.stevetarzia.com, **mail**.stevetarzia.com, and even **citibank**.stevetarzia.com (for phishing purposes).

13 Root DNS servers (run by ICANN)

- These store IP addresses of the nameservers for all the top-level-domains (TLDs): com, net, uk, edu, cn, *etc.*

Each Root DNS Server is actually redundant across many physical locations using *IP anycast*. More on this later!

c. Cogent, Herndon, VA (5 other sites)
d. U Maryland College Park, MD
h. ARL Aberdeen, MD
j. Verisign, Dulles VA (69 other sites)

k. RIPE London (17 other sites)

i. Netnod, Stockholm (37 other sites)

e. NASA Mt View, CA
f. Internet Software C.
Palo Alto, CA (and 48 other sites)

m. WIDE Tokyo
(5 other sites)

a. Verisign, Los Angeles CA
(5 other sites)
b. USC-ISI Marina del Rey, CA
l. ICANN Los Angeles, CA
(41 other sites)

g. US DoD Columbus, OH (5 other sites)

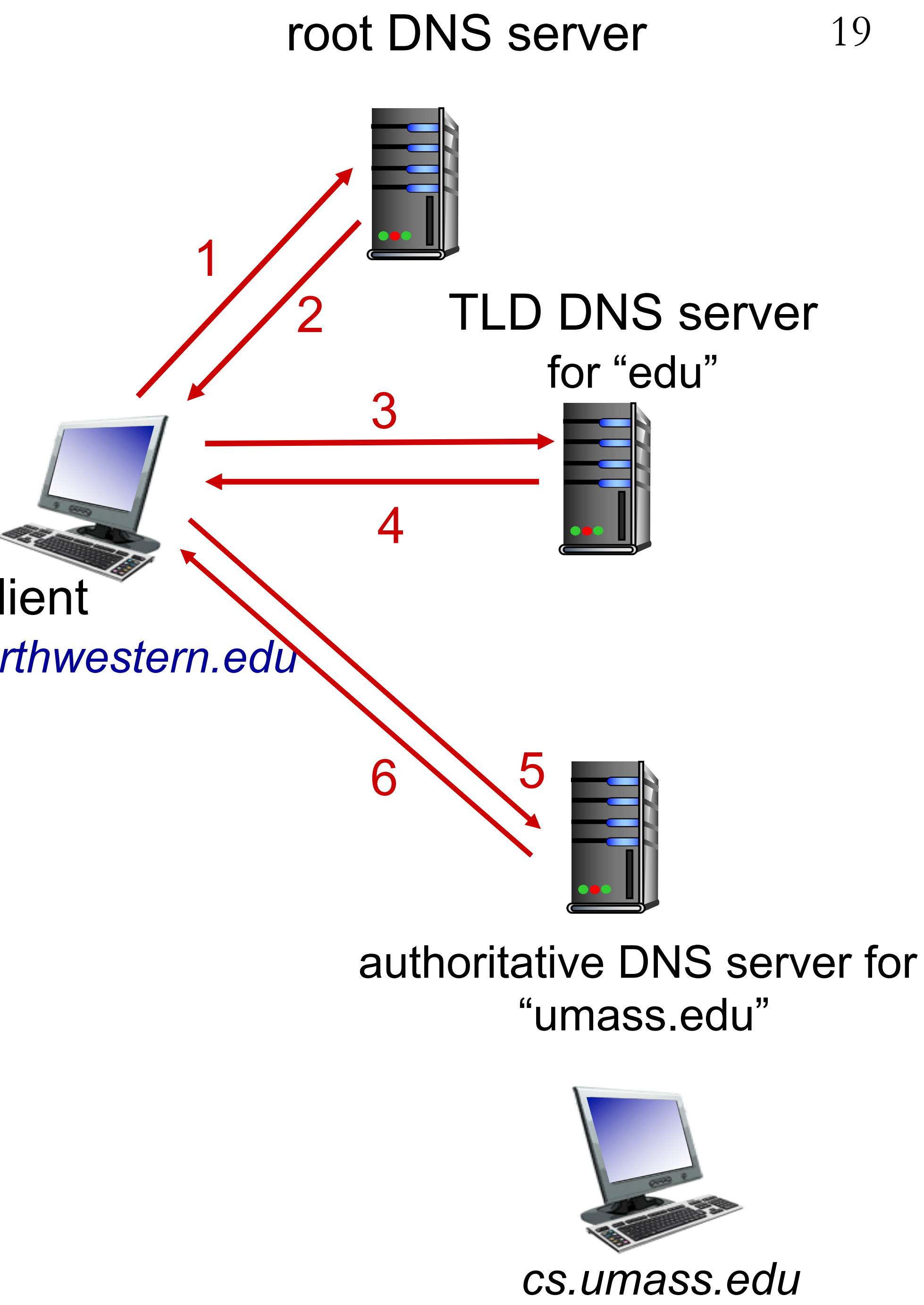
Querying the DNS hierarchy

Client wants IP address of **cs.umass.edu**

- Query *iteratively*, starting with the root server:
  - Each server replies with an answer or the name of server to contact:
  - "I don't know this name, but ask this server."

Performance problems?

- Every request hits the root server.
- Common domains, like google.com are queried billions of times per day!



Local **DNS Resolver**

Key observation:

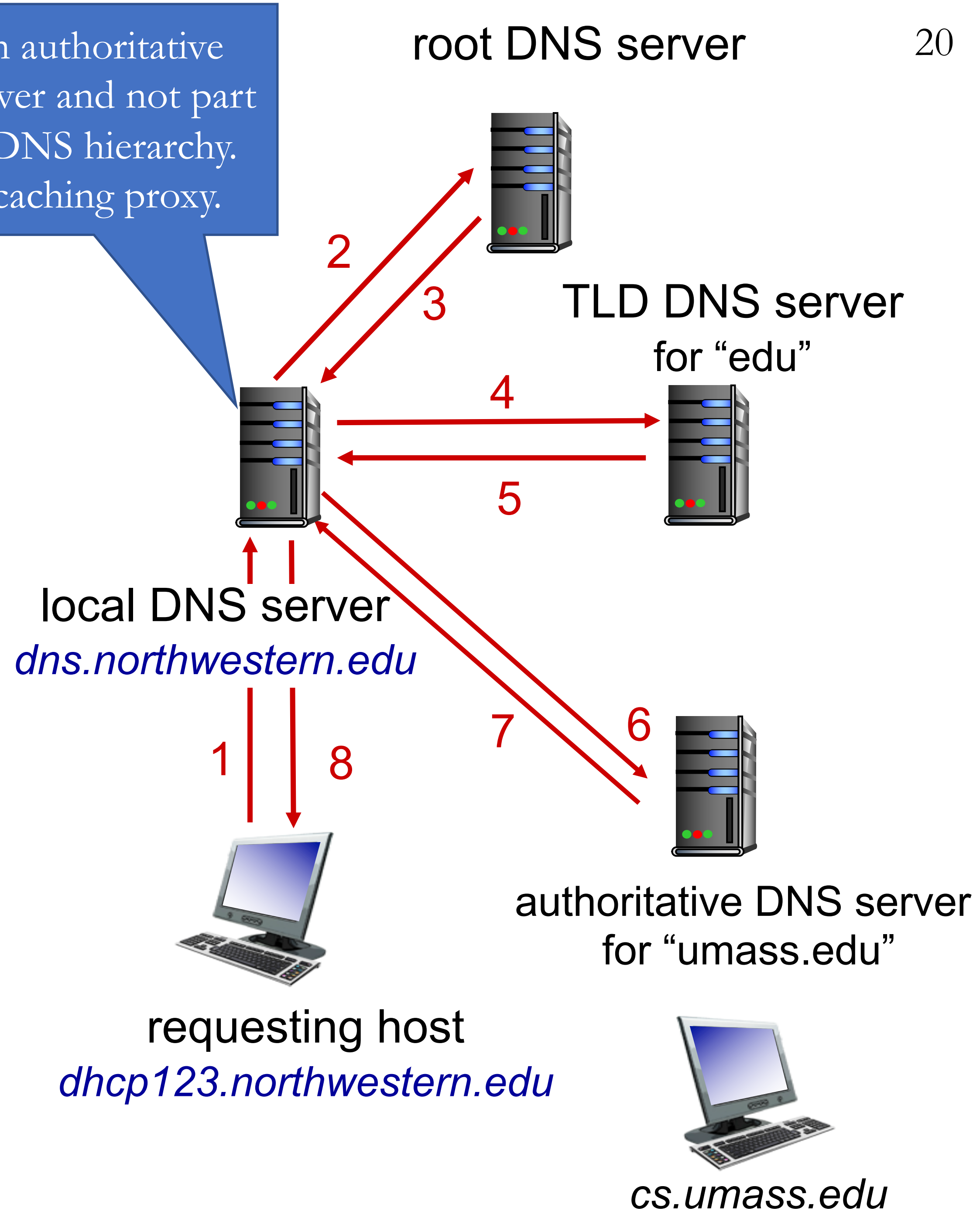
- A few domains are very popular, and your neighbors are probably accessing the same set of services.

Local DNS resolver is a caching proxy:

- A **proxy** is just an intermediary or "middleman" for a request.
- **Caching** is saving recent responses so they can be reused without doing all the work to generate them again.

ISPs operate DNS resolvers for their customer.

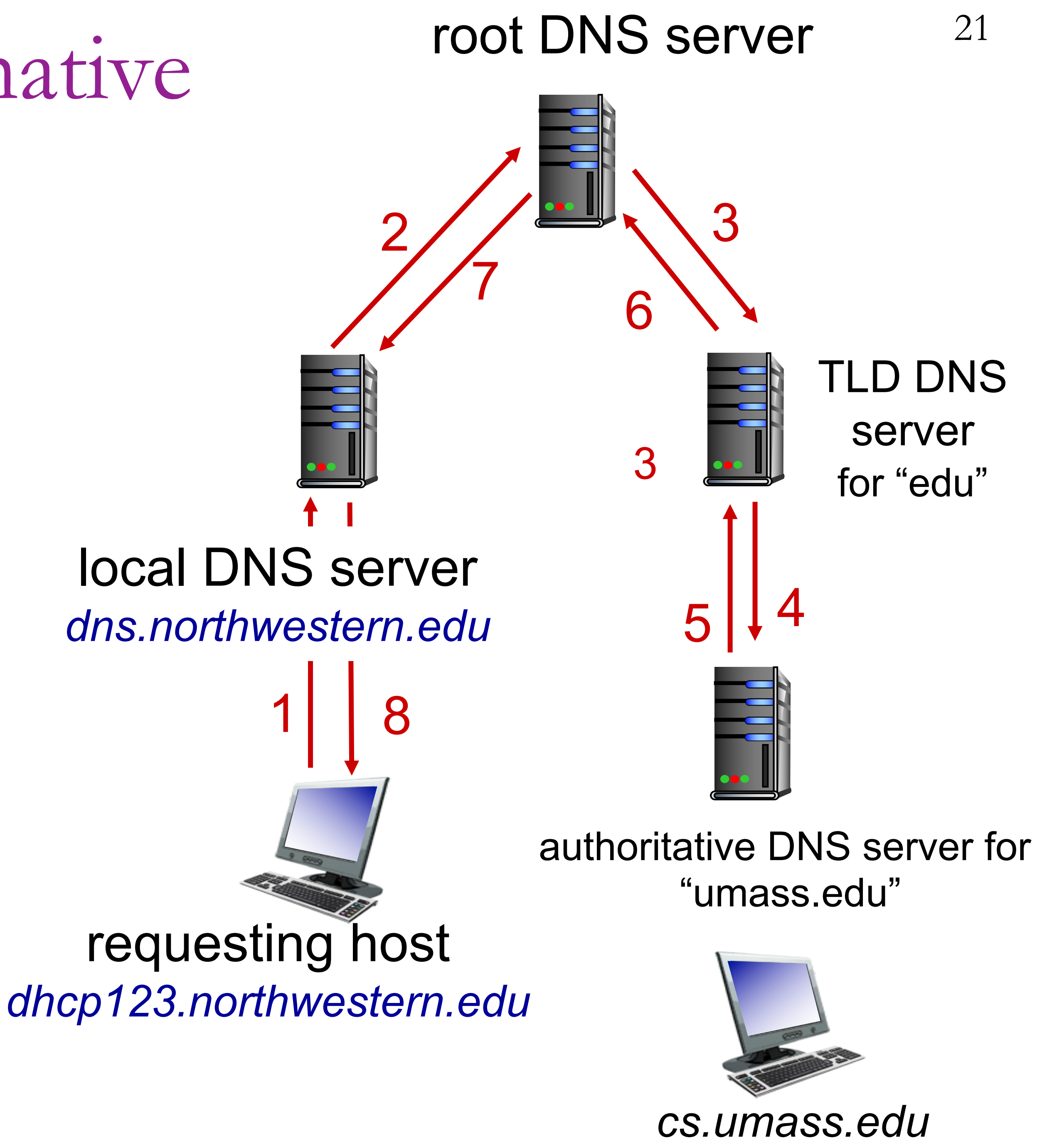
Not an authoritative nameserver and not part of the DNS hierarchy. Just a caching proxy.



Side note: an unlikely alternative

A very polite DNS server may actually *recursively* look up the answer to our query, even if it is not the authoritative server for that domain.

- DNS servers are rarely so kind.
- This does not happen in practice.



DNS Record Time to Live (TTL)

Why not always set the TTL to a very low value?

- DNS is a distributed system, and query responses are ***cached*** (remembered) at the "edge" of the network.
  - This allows repeated and common queries to be answered quickly, without asking the authoritative nameserver.
  - Eg., if I ask my local nameserver the IP address of *google.com*, I will likely get a cached answer immediately, because someone probably queried it recently.
- However, records cannot be cached forever – this would make the system *static*. Changes in the authoritative server would never be seen.
- DNS records have a **Time to Live (TTL)** indicating when they expire.
  - After expiry, must ask the authoritative nameserver for the updated value
  - TTL typically = 300 to 86400 seconds (5 minutes to 24 hours)

DNS contents

- Records:
  - Name
  - Value
  - Type
  - TTL

Name	Type	Value	TTL
stevetarzia.com.	A	54.245.121.172	3600
stevetarzia.com.	MX	10 mail.stevetarzia.com	3600
stevetarzia.com.	NS	ns-1856.awsdns-40.co.uk. ns-1199.awsdns-21.org. ns-938.awsdns-53.net. ns-91.awsdns-11.com.	172800
stevetarzia.com.	SOA	ns-938.awsdns-53.net. awsdns-hostmaster.amazon.	900
grits.stevetarzia.com.	A	54.245.121.172	3600
ireland.stevetarzia.com.	A	52.19.15.31	300
mail.stevetarzia.com.	A	54.245.121.172	3600
vortex.stevetarzia.com.	CNAME	vortex.epsilondeltalabs.org.	300
www.stevetarzia.com.	CNAME	stevetarzia.com	3600

DNS has different *types* of records, for different uses

- **A records**: map hostnames to IP addresses
  - grits.stevetarzia.com → 54.245.121.172
  - **AAAA records** do the same for IPv6
- **NS records**: lists the nameservers for a given domain
  - These records are present in the parent domain's nameserver.
    - Authoritative nameservers for "com" store the NS records for "stevetarzia.com"
- **MX records**: list the email servers
  - To whom should I send mail addressed to strongbad**@stevetarzia.com**?
  - Several servers can be listed, with numbers indicating the priority of each one.
- **CNAME records**: list aliases
  - www.stevetarzia.com → stevetarzia.com

Advanced DNS records

- **SOA records** store information about who created the DNS records and how they should be cached.
- **SRV records** list server for a specified service (generalization of MX):
  - _sip._udp.columbia.edu → laurel.cc.columbia.edu:5060
  - Tells us which server handles VoIP phone calls to user@columbia.edu.
  - _minecraft._tcp.stevetarzia.com → …
- **TXT records** are a generic key-value store
  - DKIM records (stored in a TXT record) store email signature public key:
    - key1._domainkey.example.com → k=rsa;p=J8eTBu224i086iK
- **SPF records** list valid outbound mail servers for the domain
- **PTR records** store reverse DNS records, IP address → hostname

GoDaddy™ EN

(480) 505-8877 Help Blog Sign In

Domains Websites WordPress Hosting Web Security Online Marketing Email & Office Phone Numbers Promos

eecs340.com

Continue to Cart

Yes! Your domain is available. Buy it before someone else does.

eecs340.com

~~$14.99*~~ $11.99* Add to Cart

eecs340.us Add this: $1.00
when you register for 2 years or more, 1st year price $1.00 Additional years $19.99

Buy 3 and Save 69%

~~$58.97*~~ $18.00* Add to Cart

eecs340.net
eecs340.org
eecs340.info

STOP and THINK

Technically, what is the result of my buying a domain? Where is domain ownership defined?

Protect your name with these domains:

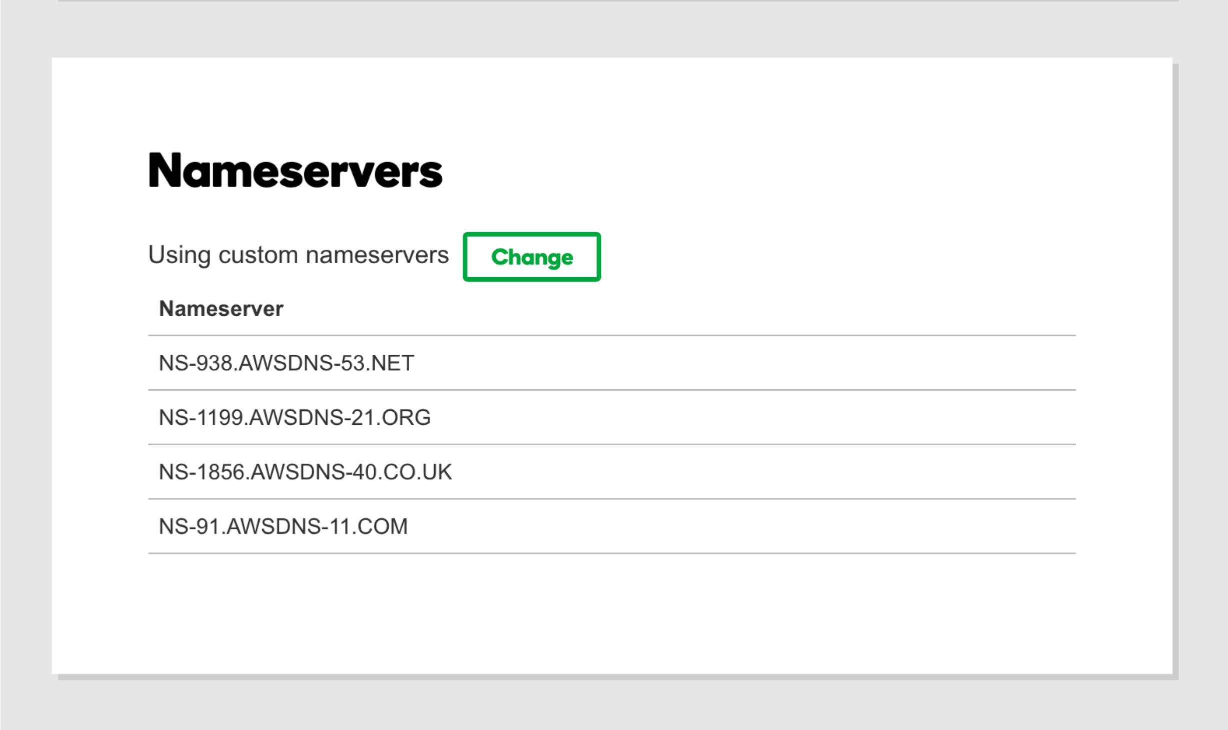
Extensions

All extensions

eecs340.**org** ~~$19.99*~~ $7.99* Add to Cart

Domain Name **Registrars** sell domain names

- Eg., GoDaddy, Namecheap, AWS.
- Must be accredited (approved) by the TLD registry:
  - ICANN appoints an organization to manage each TLD.
  - Eg., **.com** TLD is managed by Verisign, Inc.
  - 100 million **.com** domains (in 2011).
- Registrar collects your money and your **nameserver list**, and causes it to be stored by the TLD.
- ICANN collects an 18 cent fee.



Advanced DNS

- Modern DNS is much more than just a directory.
- It's is a valuable tool for managing delivery of Internet services:
  - Decides how to connect clients and servers
  - DNS records may change over time (allowing services to move)
  - Nameservers may give different answers to different clients!
- Simple nameservers are *static* (always return the same answer), but **dynamic nameservers** may be more clever

Round Robin DNS

- DNS can return **multiple records** for a given query.
- A domain like *www.ebay.com* can map to many different IP addresses (machines)
- This allows many machines to share the responsibility of answering requests (**load balancing**).
  - This works well for web traffic because HTTP is stateless.
- For very large services, dynamic nameserver may return a *random subset* of IP addresses capable of handling a request.
- Load-balancing nameserver may also monitor the **health** of servers to exclude IP addresses that are not responding.
  - TTL must be very short for this to work well.

Global Internet performance

- Recall that packet delivery time is influenced by number of network hops (nodal delays) and length of links (propagation delay).
  - **Latency** is high for distant servers.
- It is much faster to access a nearby server, especially for applications like the web, that involve dozens of small requests.

Sending a packet to China

```
$ nslookup www.tsinghua.edu.cn
Server:     192.168.0.1
Address:    192.168.0.1#53

Non-authoritative answer:
www.tsinghua.edu.cn   canonical name = www.d.tsinghua.edu.cn.
Name: www.d.tsinghua.edu.cn
Address: 166.111.4.100

$ ping 166.111.4.100
PING 166.111.4.100 (166.111.4.100): 56 data bytes
64 bytes from 166.111.4.100: icmp_seq=0 ttl=233 time=401.758 ms
64 bytes from 166.111.4.100: icmp_seq=1 ttl=233 time=219.958 ms
64 bytes from 166.111.4.100: icmp_seq=2 ttl=233 time=220.512 ms
64 bytes from 166.111.4.100: icmp_seq=3 ttl=233 time=223.185 ms
```

Sending a packet to Lemont, Illinois

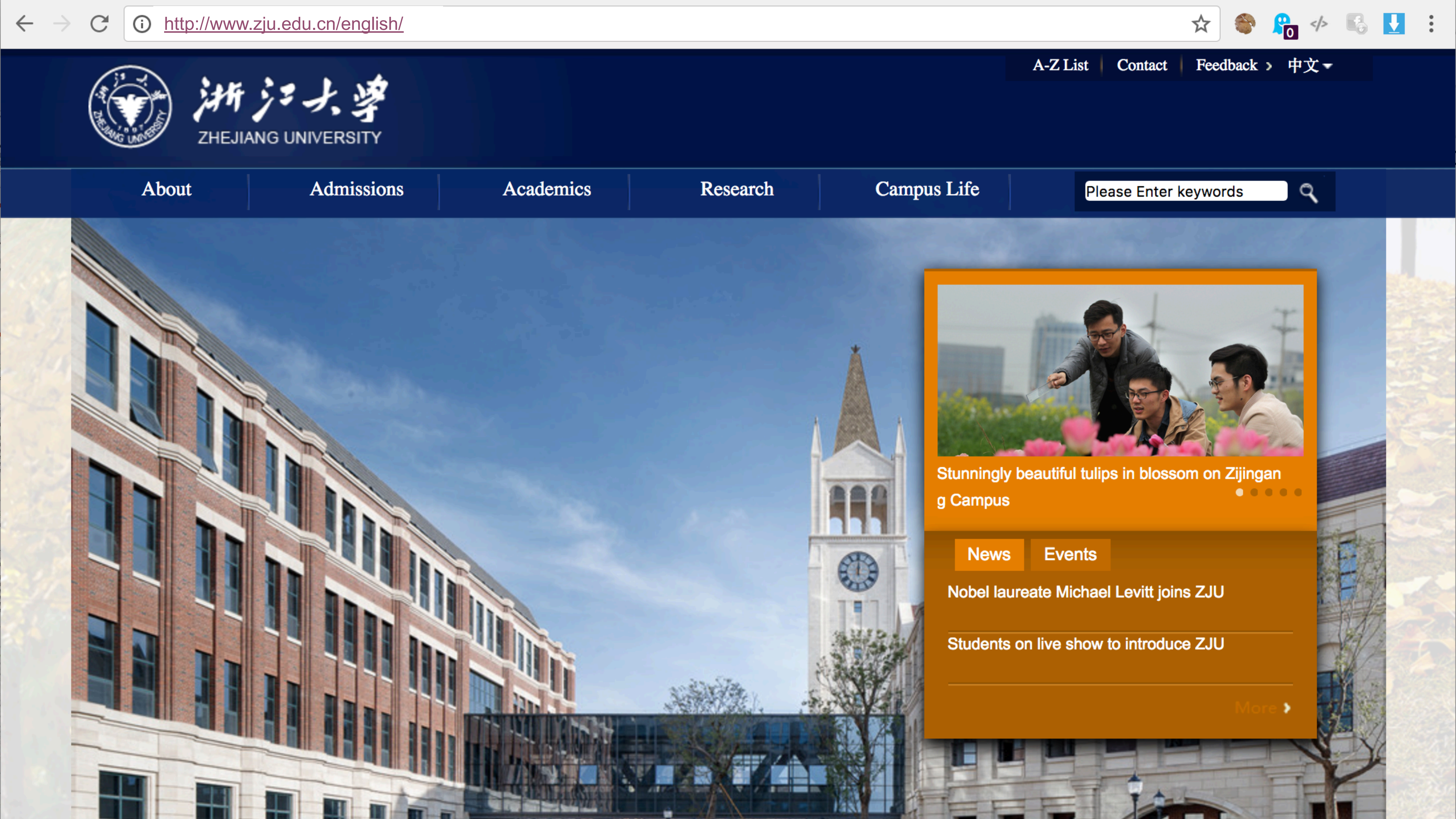
```
$ nslookup www.anl.gov
Server:     192.168.0.1
Address:    192.168.0.1#53

Non-authoritative answer:
Name: www.anl.gov
Address: 146.137.23.18

$ ping 146.137.23.18
PING 146.137.23.18 (146.137.23.18): 56 data bytes
64 bytes from 146.137.23.18: icmp_seq=0 ttl=242 time=27.578 ms
64 bytes from 146.137.23.18: icmp_seq=1 ttl=242 time=22.076 ms
64 bytes from 146.137.23.18: icmp_seq=2 ttl=242 time=15.406 ms
64 bytes from 146.137.23.18: icmp_seq=3 ttl=242 time=15.370 ms
```

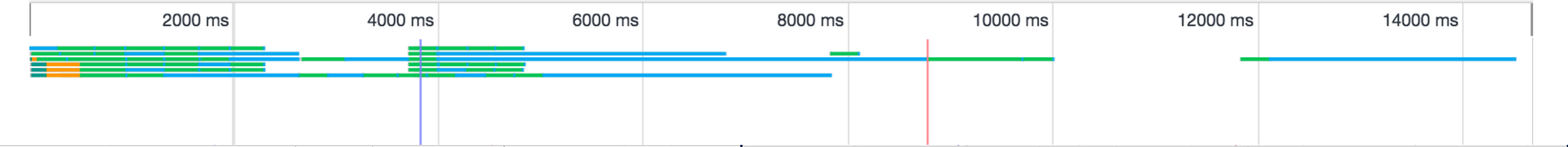
Evanston apartment to Beijing route


```
$ traceroute 166.111.4.100
traceroute to 166.111.4.100 (166.111.4.100), 64 hops max, 52 byte packets
 1   (192.168.0.1)  3.981 ms  2.138 ms  1.804 ms
 2  96.120.29.37 (96.120.29.37)  10.648 ms  10.112 ms  9.856 ms
 3  te-0-7-0-11-sur03.mortongrove.il.chicago.comcast.net (68.87.209.245)  9.87
 4  162.151.36.238 (162.151.36.238)  10.365 ms  10.320 ms  10.812 ms
 5  be-141-ar01.area4.il.chicago.comcast.net (162.151.36.241)  12.360 ms  15.8
 6  be-33491-cr02.350ecermak.il.ibone.comcast.net (68.86.91.165)  12.240 ms  2
 7  ix-xe-8-0-0-2-0.tcore1.ct8-chicago.as6453.net (64.86.137.45)  11.884 ms  1
 8  if-ae-29-2.tcore2.sqn-san-jose.as6453.net (64.86.21.104)  88.461 ms  73.92
 9  if-ae-1-2.tcore1.sqn-san-jose.as6453.net (63.243.205.1)  73.931 ms  74.063
10  if-ae-38-2.tcore2.sv1-santa-clara.as6453.net (63.243.205.75)  73.271 ms
11  if-ae-0-2.tcore1.sv1-santa-clara.as6453.net (63.243.251.1)  73.662 ms  74.
12  if-ae-8-2.tcore1.lvw-los-angeles.as6453.net (66.110.59.8)  74.468 ms  93.9
13  66.110.59.182 (66.110.59.182)  75.365 ms  77.409 ms  77.519 ms
14  101.4.117.213 (101.4.117.213)  300.917 ms  261.717 ms  312.424 ms
15  101.4.117.101 (101.4.117.101)  307.725 ms  328.299 ms  311.348 ms
16  101.4.115.254 (101.4.115.254)  306.925 ms  378.022 ms  293.795 ms
17  101.4.112.197 (101.4.112.197)  219.399 ms  240.069 ms  306.198 ms
18  * * *
```

Northwestern Campus to Beijing route


```
$ traceroute 166.111.4.100
traceroute to 166.111.4.100 (166.111.4.100), 64 hops max, 52 byte packets
 1  tech-6-vln-498.northwestern.edu (129.105.5.5)  9.108 ms
    tech-5-vln-498.northwestern.edu (129.105.5.4)  0.584 ms
    tech-6-vln-498.northwestern.edu (129.105.5.5)  0.592 ms
 2  2020rdg-4-prt-242.northwestern.edu (129.105.247.94)  0.737 ms
    lev-5-po242.northwestern.edu (129.105.247.92)  0.648 ms
    lev-5-po243.northwestern.edu (129.105.247.14)  0.634 ms
 3  abbt-2-vln-2341.northwestern.edu (129.105.253.94)  1.109 ms  1.520 ms  0.975 ms
 4  abbt-5-xe-1-0-3.northwestern.edu (129.105.247.231)  1.506 ms
    abbt-5-xe-2-0-3.northwestern.edu (129.105.247.225)  1.583 ms
    abbt-5-xe-1-0-3.northwestern.edu (129.105.247.231)  1.527 ms
 5  starlight-lsd6509.northwestern.edu (199.249.169.6)  1.528 ms  2.268 ms  1.567 ms
 6  et-7-0-0.1136.rtsw.star.net.internet2.edu (198.71.46.206)  1.696 ms  1.542 ms  1.464 ms
 7  et-2-1-0.4079.rtsw.chic.net.internet2.edu (162.252.70.116)  3.450 ms  2.114 ms  1.778 ms
 8  ae-3.4079.rtsw.kans.net.internet2.edu (162.252.70.141)  13.860 ms *  13.021 ms
 9  ae-5.4079.rtsw.salt.net.internet2.edu (162.252.70.145)  32.994 ms  33.189 ms  34.230 ms
10  * ae-1.4079.rtsw.losa.net.internet2.edu (162.252.70.114)  45.478 ms  45.611 ms
11  210.25.189.133 (210.25.189.133)  51.453 ms  48.035 ms  47.858 m
12  * * *
13  210.25.187.42 (210.25.187.42)  200.646 ms  200.820 ms  201.288 ms
14  210.25.187.45 (210.25.187.45)  200.391 ms  202.337 ms  200.467 ms
15  210.25.189.69 (210.25.189.69)  202.314 ms  200.980 ms  203.745 ms
16  101.4.115.254 (101.4.115.254)  199.979 ms  199.829 ms  202.220 ms
17  101.4.113.234 (101.4.113.234)  200.503 ms  200.646 ms  201.140 ms
18  * * *
```


http://www.zju.edu.cn/english/
A-Z List
Contact
Feedback ›
中文
浙江大學
ZHEJIANG UNIVERSITY
About
Admissions
Academics
Research
Campus Life
Please Enter keywords
Stunningly beautiful tulips in blossom on Zijingang Campus
News
Events
Nobel laureate Michael Levitt joins ZJU
Students on live show to introduce ZJU
More ›



Name	Size	Time	Waterfall 10.00 s
english/	22.9 KB	1.34 s	
system.css	281 B	285 ms	
1.css	249 B	351 ms	
58.css	249 B	620 ms	
dtjt9.css	1.4 KB	621 ms	
system.css	420 B	930 ms	
default.css	6.5 KB	929 ms	
simplenews.css	17.3 KB	1.29 s	
datepicker.css	5.7 KB	931 ms	
sudyNav.css	1.8 KB	919 ms	
jquery.min.js	91.9 KB	2.60 s	
jquery.sudy.wp.visitcount.js	6.6 KB	1.64 s	
jquery.datepicker.js	26.7 KB	1.93 s	
datepicker_lang_US.js	1.2 KB	1.64 s	
jquery.sudyNav.js	6.2 KB	1.64 s	
common.css	18.5 KB	1.29 s	
default.css	7.5 KB	1.30 s	
menu.css	2.0 KB	1.29 s	
extends.css	7.0 KB	1.30 s	
uaredirect.js	1.1 KB	1.93 s	
ImageSwitch.js	8.7 KB	1.94 s	
plugin.js	18.5 KB	2.60 s	
jMenu.js	7.5 KB	2.27 s	
zju-edu.js	3.3 KB	2.27 s	
extends.js	1.7 KB	2.27 s	

Name	Size	Time	Waterfall 10.00 s ▲15
system_editor.css	60.4 KB	2.32 s	
logo.png	11.1 KB	627 ms	
jquery.sudy.js	15.4 KB	1.03 s	
loading.gif	1.3 KB	339 ms	
more.png	1.6 KB	287 ms	
0192aba5-f380-445d-a96b-c4b2e41e…	198 KB	5.06 s	
01-1352270229-2160306.png	1.1 MB	3.09 s	
background.png	23.0 KB	549 ms	
list_ss_03.png	1.6 KB	291 ms	
e_07.png	1.3 KB	276 ms	
logobg.png	22.7 KB	695 ms	
zy_02.png	1.2 KB	524 ms	
zy_03.png	1.2 KB	525 ms	
zy_01.png	1.2 KB	787 ms	
news_bg_1.jpg	1.5 KB	776 ms	
subnav_left.png	1.3 KB	772 ms	
subnav_bg.png	1.2 KB	950 ms	
subnav_right.png	16.7 KB	1.03 s	
bd.png	16.2 KB	1.04 s	
_visitcount?siteId=77&type=1&colum…	216 B	279 ms	
aca00e73-13bb-4ff0-bfce-985a30529…	214 KB	3.09 s	
d34f55a3-b526-498e-ad84-0358d39f…	40.6 KB	276 ms	
favicon.ico	1.7 KB	916 ms	
favicon.ico	1.7 KB	301 ms	
bce58689-cc64-4c7d-83da-198900b…	75.3 KB	2.67 s	

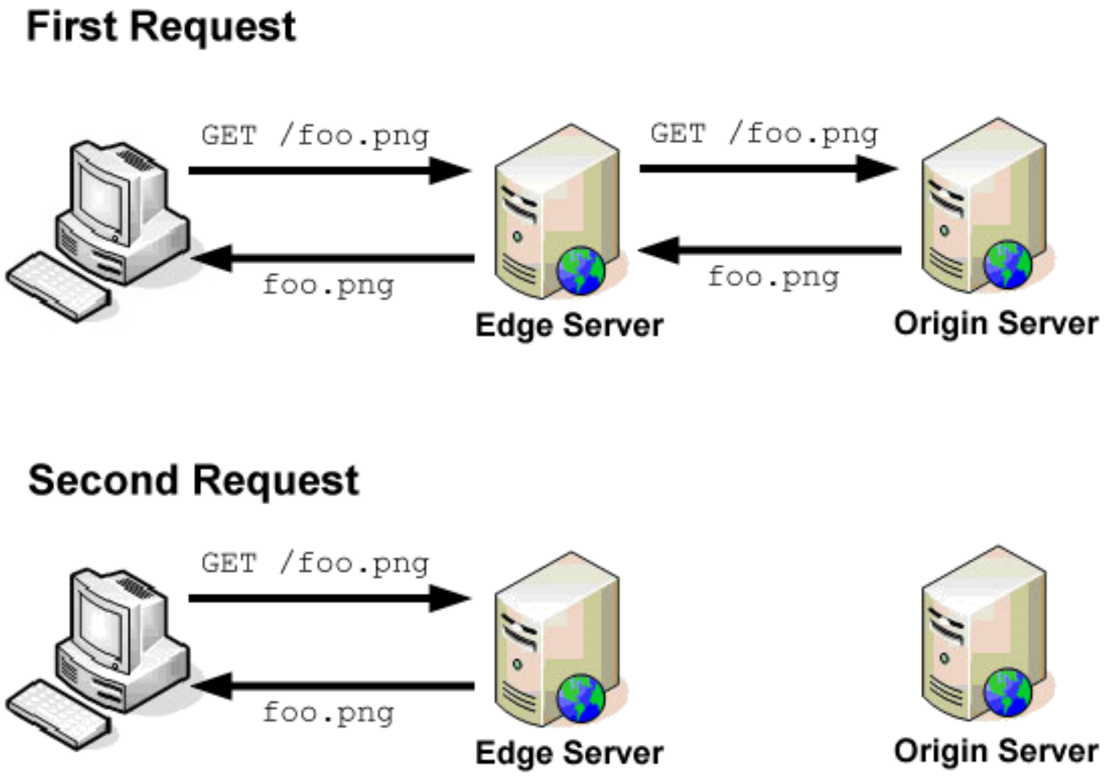
50 requests | 2.1 MB transferred | Finish: 15.57 s | DOMContentLoaded: 4.90 s | Load: 9.84 s

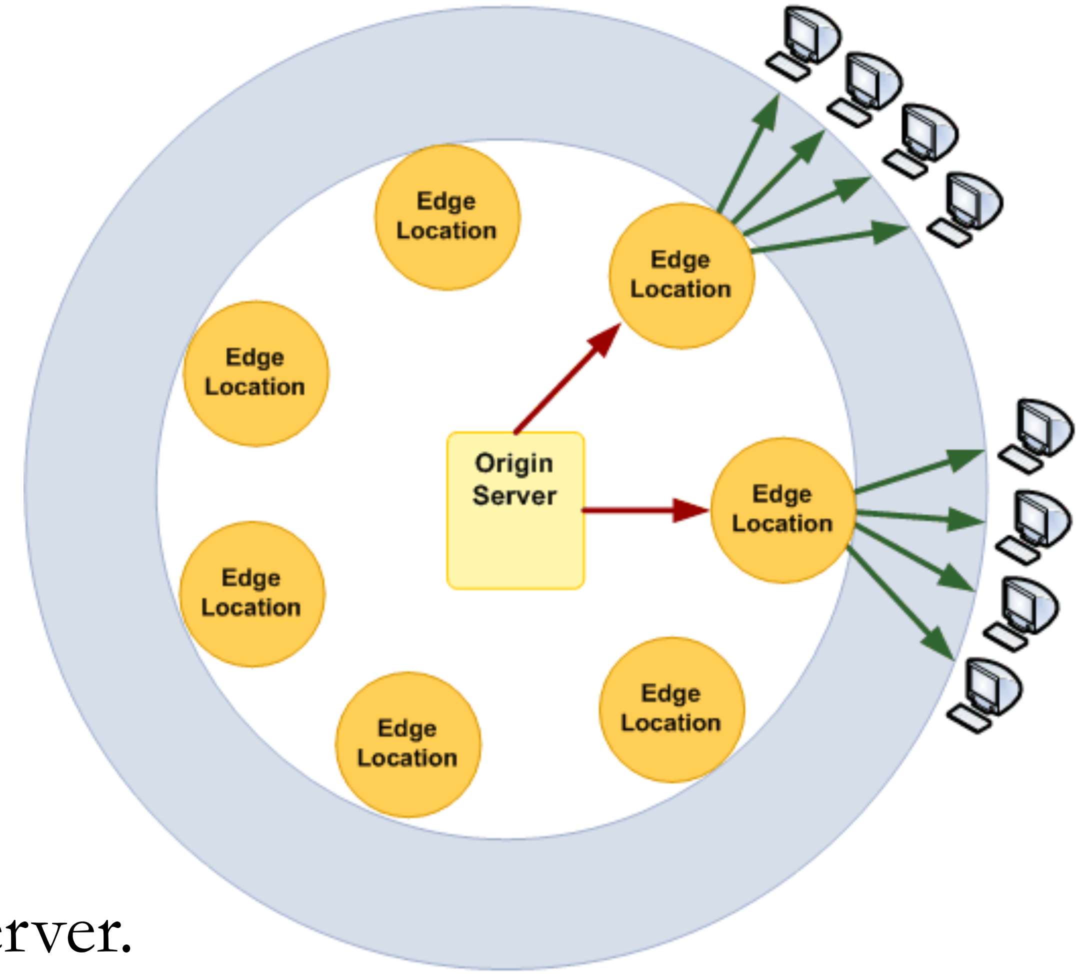
Content Delivery Network (CDN)

- Globally distributed servers that *cache* HTTP responses for local clients.
- Special DNS server examines **IP address of requester** and resolves to the server that it thinks is closest to the client (IP address *geolocation*).
- Eg., Akamai, Cloudflare, Cloudfront

Distributed "edge" servers

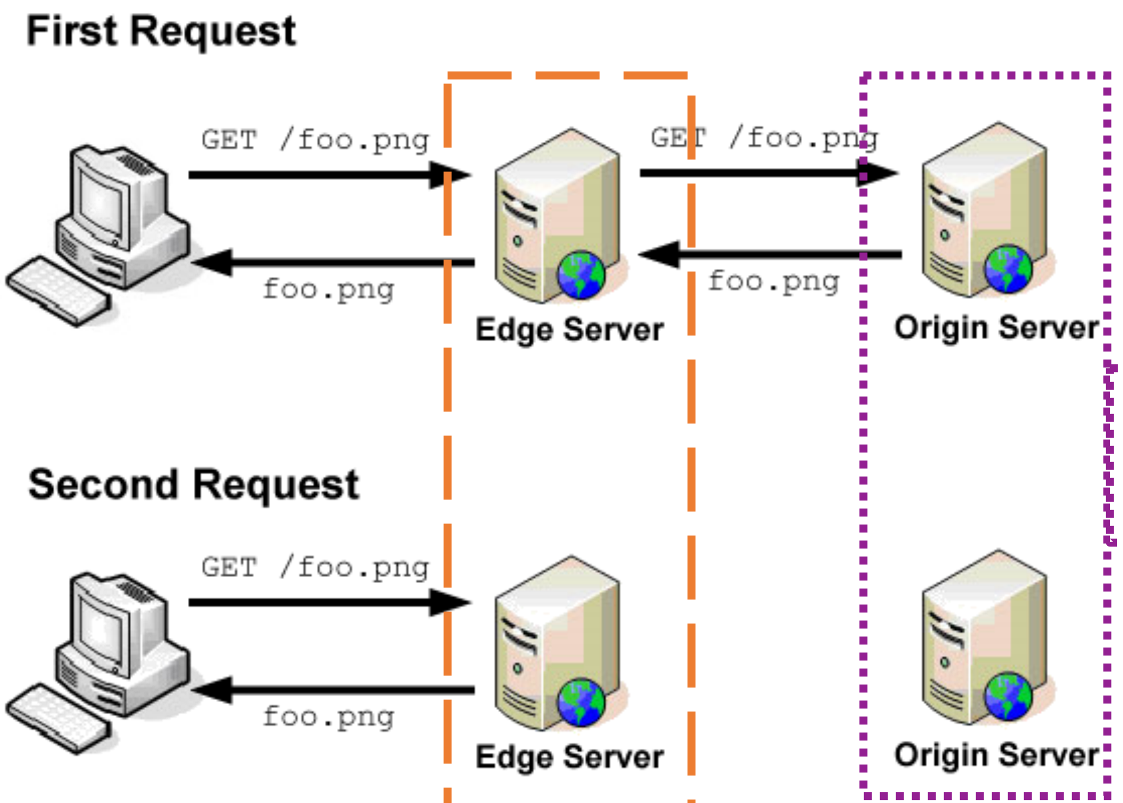
CDN uses HTTP caching proxies



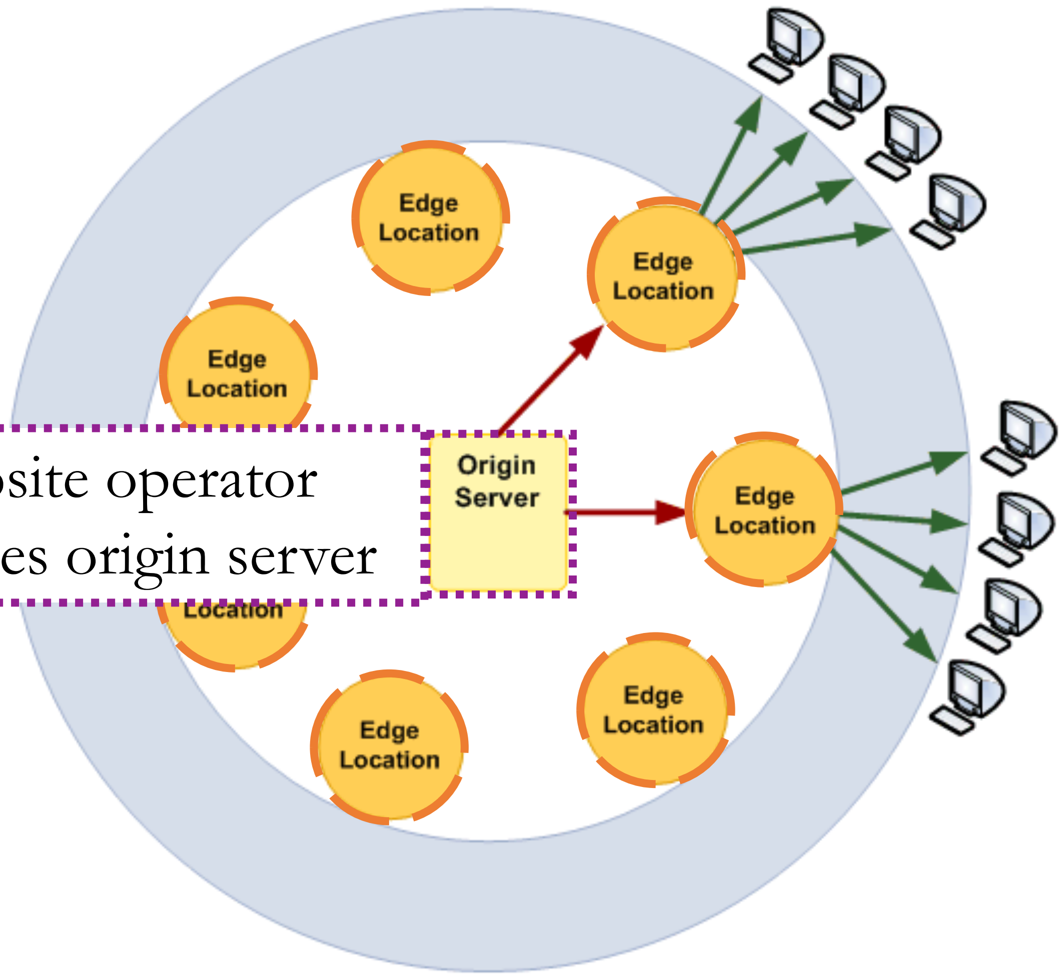


- **Origin Server** is the original, central web server. (Sets *cache-control* HTTP headers in responses).
- Edge Servers are **caching proxies**. Like DNS, ask origin server if don't have a cached response.

CDNs are *add-on* services



Website operator manages origin server



CDN operator manages edge servers (Cloudflare, Akamai, Cloudfront)

Google public DNS

- DNS is critical for most Internet applications.
- Failure of your local nameserver is very often the source of "Internet outages" you may experience.
- Google provides free public DNS servers at 8.8.8.8 and 8.8.4.4.
  - It's a useful backup option if your local DNS resolver is not working.
- Why does Google provide this service for free?
  - DNS requests tell them even more about your web surfing habits, and this helps their advertising business.

Captive portals also use DNS in a clever way

Recap

- DNS is the Internet’s directory service
- It’s distributed and hierarchical
- Caching proxies are request intermediaries that store and reuse recent responses. Examples include DNS resolvers and CDNs.
- Dynamic DNS server can cleverly craft their responses to provide:
  - *Load balancing* and fault tolerance in a cluster of servers
  - *Content Delivery Networks*, that direct you to the closest service “mirror”
  - *Captive portals*, that can hijack the entire Internet
    - But TLS encryption and PKI prevent spoofing of secure (https) sites.