CSE508 Network Security

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Core Protocols: DNS

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Domain Name System

DNS maps domain names to IP addresses

"Phonebook" for the internet

Client: *I want to connect to:* `www.cs.stonybrook.edu`

DNS server: *here is its IP address:* `130.245.27.2`

Distributed, hierarchical, reliable database

Replaced the manually maintained `/etc/hosts` file

Domain names are assigned by *registrars* accredited by ICANN

Not always a one-to-one mapping

Virtual hosting: *many* names hosted on a *single* IP address

Load balancing/fault tolerance: *single* name hosted on *many* IP addresses

DNS Server Hierarchy

Hierarchically divided name space

`.edu` → `stonybrook.edu` → `cs.stonybrook.edu` → `www.cs.stonybrook.edu`

Root name servers

Responsible for top-level domains (TLDs): `.com`, `.edu`, `.net`, …

Point to the *authoritative name server* of each TLD → managed by governments or commercial organizations

```
$ curl http://data.iana.org/TLD/tlds-alpha-by-domain.txt |wc -l
1451
```

Authoritative name servers are responsible for a set of names belonging into a *zone*

A leaf node in the DNS hierarchy manages the zone of a single domain

Domain Name

A string that identifies a realm of administrative autonomy, authority, or control

The part of a URL after the protocol (e.g., `https://`) and before the next slash

The text that a user types into a browser window to reach a particular website

Fully Qualified Domain Name (FQDN)

A specific and complete name that provides an absolute path in the DNS hierarchy

Host name + subdomain + domain name (e.g., `www.cs.stonybrook.edu`)

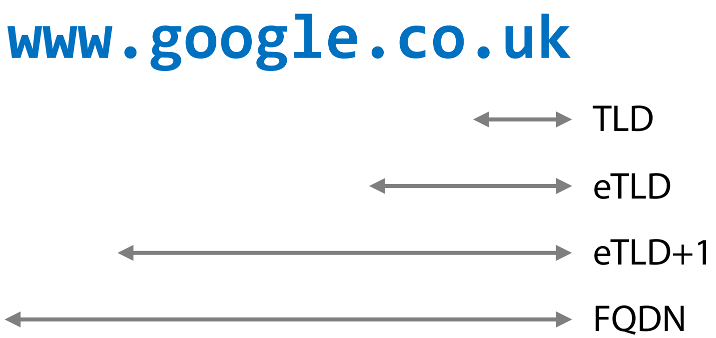
Effective Top-level Domain (eTLD)

Depending on the TLD, not all second-level domains can be registered

Example: the `.uk` name space is sub-divided into different categories controlled by the registrar (`.ac.uk` for colleges, `.co.uk` for companies, etc.)

Not only country level: .github.io, .dyndns.org, …

AKA *public suffix*: a suffix under which users can register names



eTLD+1

eTLD + next level: indicative of the actual domain registrant

Example: stonybrook.edu, bbc.co.uk

DNS Resolvers

Query DNS servers and resolve the requested resource

Main query types:

Recursive: query a single server, which may then query (as a client itself) other DNS servers on behalf of the requester

Has to reply with the requested response or "doesn't exist" (cannot refer the client to a different DNS server)

Iterative: query a chain of one or more DNS servers

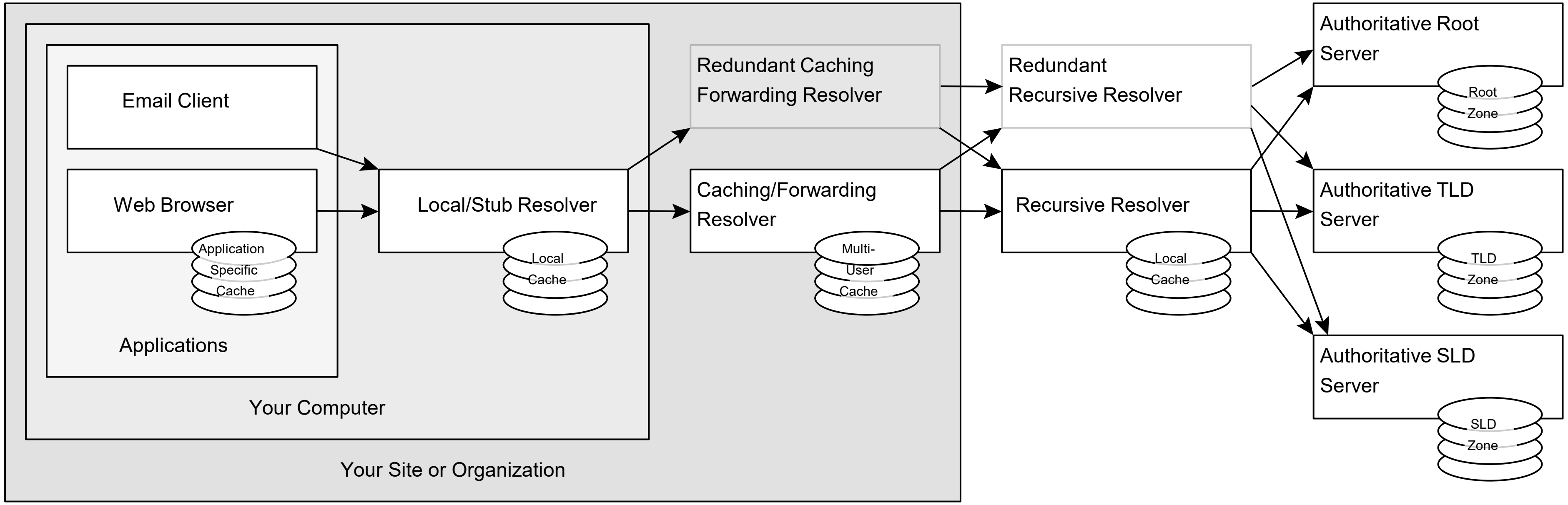
Each server returns the best answer it has

If the server cannot find an exact match, it returns a *referral:* a pointer to a server authoritative for a lower level of the domain namespace

Walking the Tree: End User

Applications place resolution requests to the *stub resolver* of the OS

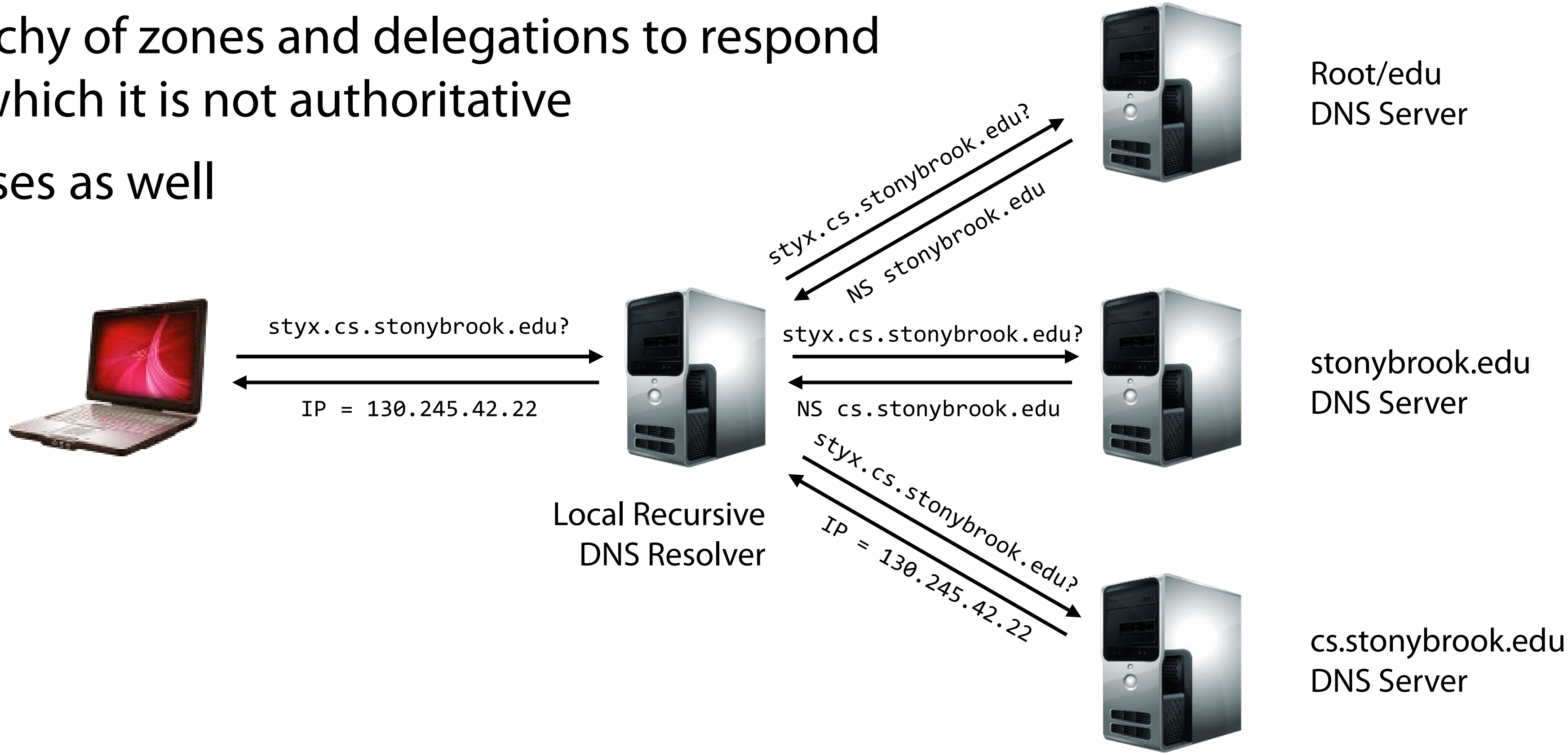
- The stub resolver then typically sends DNS queries to a *recursive resolver*
- Caches responses for future queries (TTL specified by the domain owner)
- Negative responses are cached as well → save time (e.g., misspellings, expired domains)



Walking the Tree: Recursive Resolver

Hosts know at least one local DNS *recursive resolver*

- Usually specified by the ISP or organization through DHCP – users can manually override it
- Uses the hierarchy of zones and delegations to respond to queries for which it is not authoritative
- Caches responses as well



DNS message

```
+---------------------+
|        Header       |
+---------------------+
|       Question      | the question for the name server
+---------------------+
|        Answer       | RRs answering the question
+---------------------+
|      Authority      | RRs pointing toward an authority
+---------------------+
|      Additional     | RRs holding additional information
+---------------------+
```

DNS header

```
                                1  1  1  1  1  1
  0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                      ID                       |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|QR|   Opcode  |AA|TC|RD|RA|   Z    |   RCODE   |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    QDCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    ANCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    NSCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    ARCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

Mostly uses UDP (port 53); TCP sometimes is used for long responses and zone transfers

Recent developments: DNS over TLS (port 853) and DNS over HTTPS (port 443)

DNS resource record

```
                                1  1  1  1  1  1
  0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                                               |
/                                               /
/                      NAME                     /
|                                               |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                      TYPE                     |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                     CLASS                     |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                      TTL                      |
|                                               |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                   RDLENGTH                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--|
/                     RDATA                     /
/                                               /
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

NAME: Name of the node to which this record pertains

TYPE: RR type in numeric form (e.g., 15 for MX RRs)

CLASS: Class code

TTL: Count of seconds the RR stays valid

RDLENGTH: Length of RDATA field

RDATA: Additional RR-specific data

Types of Resource Records

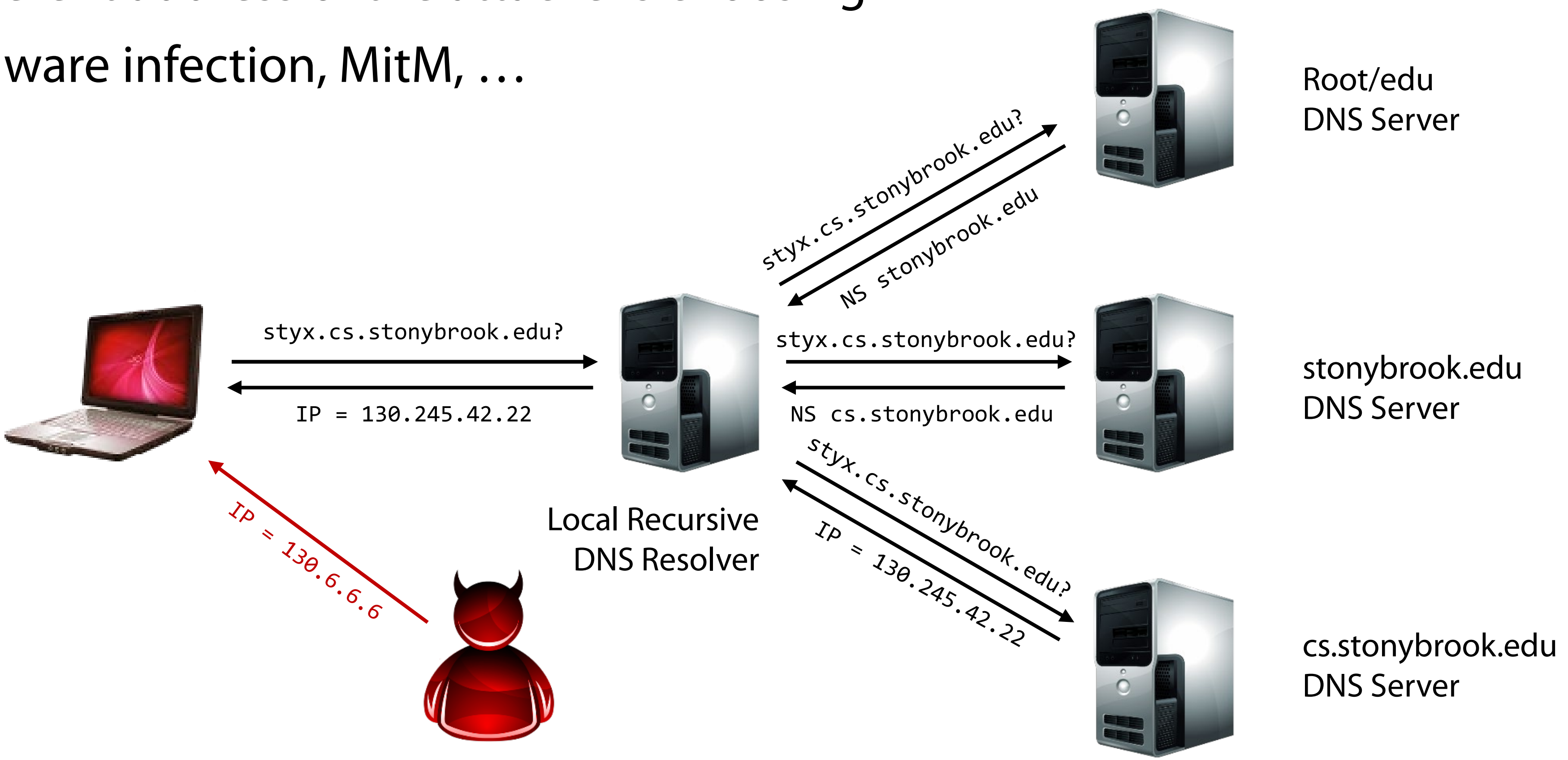
Besides translating host addresses, DNS is in essence a generic "directory" service for other host-related information

`A`	host IPv4 address
`AAAA`	host IPv6 address
`NS`	authoritative name server
`MX`	mail server of domain
`CNAME`	aliases for other names (not IP addresses)
`PTR`	map IP addresses to names (reverse lookup)
`TXT`	arbitrary data associated with the domain
`HINFO`	host information

DNS Spoofing/Cache Poisoning

No authentication: responses can be spoofed!

- Point to a different address of the attacker's choosing
- Phishing, malware infection, MitM, …



Subverting Name-based Authentication [Bellovin 1990]

Trusted access based on host names *(not a good idea)*

- Server performs reverse DNS lookup to check if a client's host name is contained in a list of authorized host names
- Example: "r-utilities" perform name-based authentication (e.g., permit all hosts in `.rhosts` to `rsh`/`rlogin` on the server)

Attack: fake a PTR record for an attacker-controlled IP address to return a trusted hostname

- When `rsh`/`rlogin` receives the connection, the reverse lookup using the attacker's originating IP will return a trusted name…

Fix: cross-check the returned name by performing a name lookup

- The returned IP address will not match the attacker's IP address ($IP_1 \rightarrow$ name $\rightarrow IP_2$)

DNS Poisoning: Different Vantage Points

Off-path: attackers cannot observe the victim's DNS messages *(blind)*

- **Blind injection:** must *guess* the proper values in the forged response fields according to the victim's query
- **Race condition:** forged response must arrive before the real one

On-path: attackers can passively observe the victim's traffic (DNS queries) and inject properly forged responses *(MotS)*

- Easy to mount in WiFi networks, by ISPs, …
- Race condition: forged response must arrive before the real one

In-path: attackers can block responses from reaching the victim, and inject forged ones instead *(MitM)*

- But at this point the attacker can do so much more…

Countering Blind Injection: DNS TXID

Synchronization mechanism between clients and servers

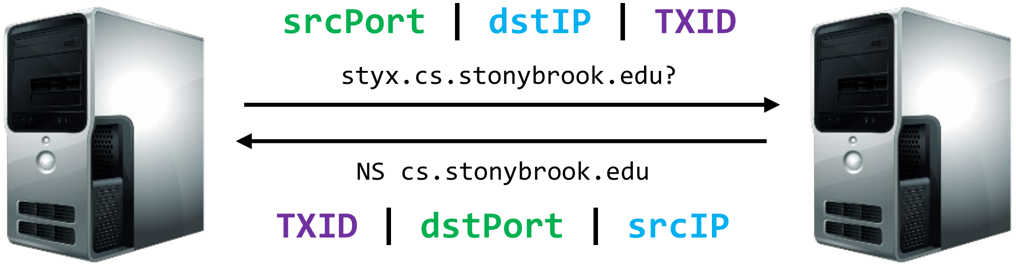
16-bit transaction identifier

- Randomly chosen for each query*
- Response accepted only if its TXID matches the one used in the request

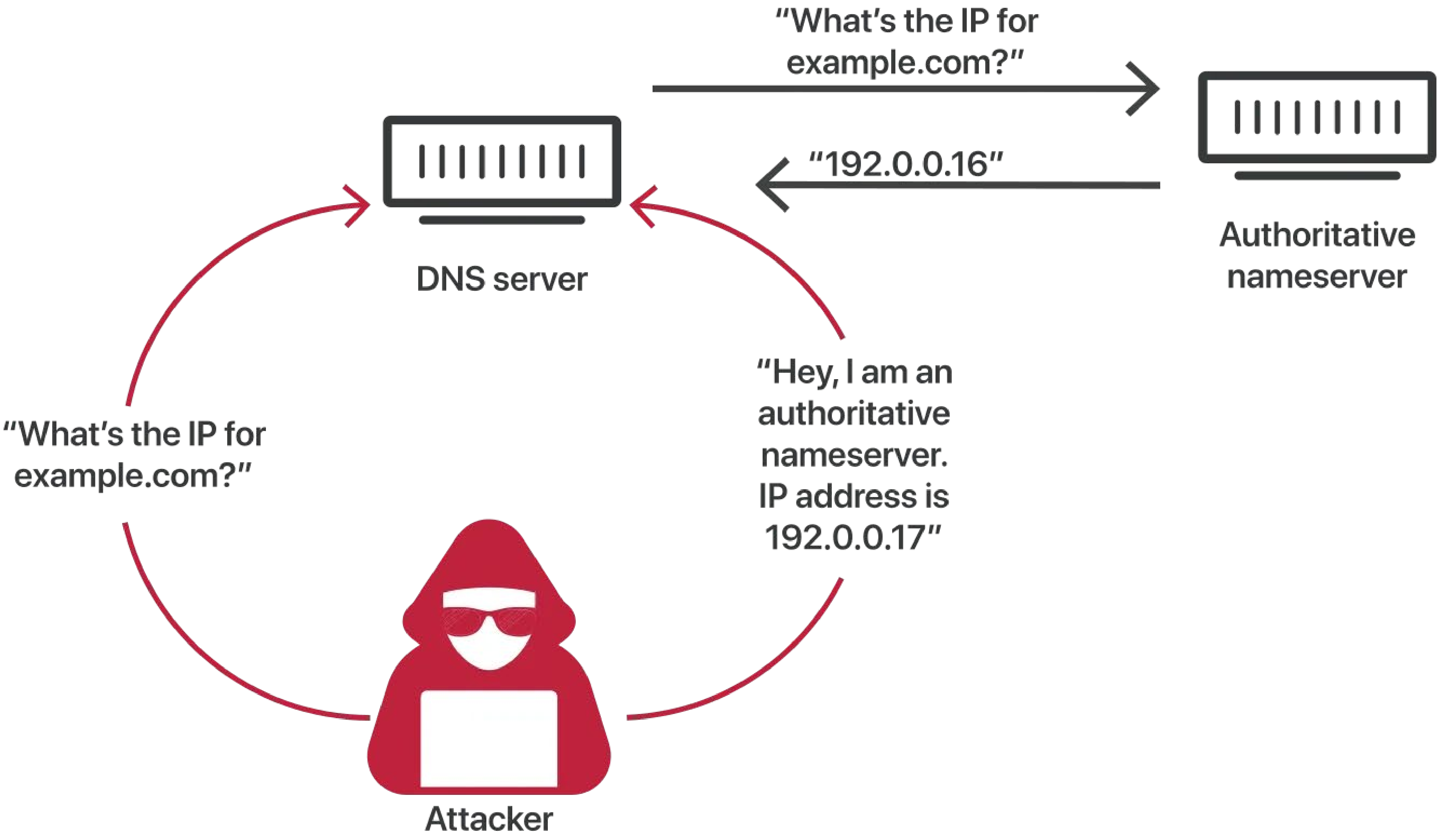
Attacker has to guess right and win a race

- Guess the correct TXID
- Response *src IP* and *dst port* should match query *dst IP* and *src port*

It's possible! Kaminsky attack



(*) Initial implementations would simply increment the TXID for each new request, which quickly led to successful attacks.



https://www.cloudflare.com/learning/dns/dns-cache-poisoning/

Kaminsky Attack (Dan Kaminsky, 2008)

Goal: poison a DNS server's cache entry for `example.com`

- The victim server will only accept responses to *pending* queries it has previously sent itself
- Unsolicited responses will be rejected

Requirements for a successful forged response:

- Matching question section ➔ *trivial:* attacker queries the victim server for an A record, which forces the victim to send a *controlled* query to the respective authoritative server
- Matching source and destination IP address ➔ *trivial:* IP address of the authoritative is known
- Matching source and destination UDP port ➔ *trivial:* pre-Kaminsky, DNS servers would use 53 for *source* port too (even if different, can be easily inferred if it changes predictably)
- Matching TXID ➔ *tough:* 16 bits of randomness

Additional issue: `www.example.com` may already be in the recursive's cache

- In that case the recursive will not ask the authoritative ➔ no opportunity for poisoning

Kaminsky Attack (Dan Kaminsky, 2008)

The attacker queries the recursive with a subdomain not in the cache

- Non-existent subdomains are fine! `foo1.example.com`
- Sidesteps the caching TTL issue (e.g., as would be the case for `www.example.com`)
- Causes the victim resolver to in turn query the authoritative server for the requested subdomain ➔ *the race begins!*

The attacker then floods the resolver with forged responses

- Each containing a different guess of the query's TXID

Fake referral as "glue" record →

```
;; ANSWER SECTION:
foo1.example.com.       120   IN A   10.0.0.10
;; AUTHORITY SECTION:
example.com.          86400   IN NS
ns1.example.com.
;; ADDITIONAL SECTION:
ns1.example.com.     604800   IN A   10.6.6.6
```

If the race is lost, just repeat with a different subdomain!

Kaminsky Attack: Key Insights

The recursive will always contact the authoritative of `example.com` for any lookup of a non-existent domain

- `foo1.example.com`, `foo2.example.com`, …

DNS responses may contain more than a single answer

- Additional responses can contain any type of record (AKA "glue" records)
- The attacker can poison the cache with values in the additional RR field

Today's internet speeds allow flooding the server with thousands of packets before the real response arrives

- Allows for more than enough TXID guesses

Fix: source UDP port randomization

- Orders of magnitude higher entropy by combining TXID + source port number

Even More Entropy: 0x20 Randomization

Domain names are case-insensitive

The request's question section is always copied verbatim into the response

Opportunity: use the 0x20 bit of ASCII letters to encode an additional value

```
A–Z: 0x41–0x5A, a–z: 0x61–0x7A
  A: 01000001 (0x41)
  a: 01100001 (0x61)
```

Example: the following names will be treated as equal by a responder (for cache matching), but can be treated as unique by a requestor

```
www.example.com   1111111111111
WWW.EXAMPLE.COM   0000000000000
WwW.eXaMpLe.CoM   0101010101010
wWw.ExAmPlE.cOm   1010101010101
```

Encoded value

				$b_7 b_6 b_5$ →	0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
b_4	b_3	b_2	b_1	Row ↓ / Column →	0	1	2	3	4	5	6	7
0	0	0	0	0	NUL	DLE	SP	0	@	P	`	p
0	0	0	1	1	SOH	DC1	!	1	A	Q	a	q
0	0	1	0	2	STX	DC2	"	2	B	R	b	r
0	0	1	1	3	ETX	DC3	#	3	C	S	c	s
0	1	0	0	4	EOT	DC4	$	4	D	T	d	t
0	1	0	1	5	ENQ	NAK	%	5	E	U	e	u
0	1	1	0	6	ACK	SYN	&	6	F	V	f	v
0	1	1	1	7	BEL	ETB	´	7	G	W	g	w
1	0	0	0	8	BS	CAN	(	8	H	X	h	x
1	0	0	1	9	HT	EM	)	9	I	Y	i	y
1	0	1	0	10	LF	SUB	*	:	J	Z	j	z
1	0	1	1	11	VT	ESC	+	;	K	[	k	{
1	1	0	0	12	FF	FS	,	<	L	\	l	¦
1	1	0	1	13	CR	GS	—	=	M	]	m	}
1	1	1	0	14	SO	RS	.	>	N	^	n	~
1	1	1	1	15	SI	US	/	?	O	_	o	DEL

ASCII chart from MIL-STD-188-100 (1972) | https://en.wikipedia.org/wiki/ASCII

Pharming

Traffic redirection at the client side by malware that alters DNS settings

- Change the system's (or the local router's) DNS server entry
- Add or override entries in `/etc/hosts`
- Example: DNSChanger: estimated 4M infected computers, US$14M profit (FBI's "Operation Ghost Click")

Drive-by pharming

- A malicious web page contains JavaScript code that alters the local router's DNS server *from inside the LAN*

Dynamic pharming (aka DNS rebinding)

- Quickly switch mapping of `bank.com` between a malicious and a real IP
- Serve malicious script, then switch to the real site ➔ same origin policy is bypassed

More Ways to Intercept Traffic using DNS

Hijacking of existing names by going after registrars

- Using social engineering, stolen credentials, insider attacks, exploits, …

Typosquatting, combosquatting, re-registering expired domains, …

- www.paypa1.com | www.goolge.com | www.google.co | www.goolge.secureapi.com
- www.paypal-secure.com | www.a.mazon.com | www.bankofamerca.com

Various attack goals

- Phishing
- Hijack scripts hosted on expired domains still in use by other web pages
- Hijack third-party libraries/modules of popular language repositories (NPM, PyPI, …)


PyPI Python repository h

https://nakedsecurity.sophos.com/2017/09/19/pypi-python-repository-hit-by-typosquatting-sneak-attack/

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PyPI Python repository hit by typosquatting sneak attack

19 SEP 2017 1

Security threats, Vulnerability

Previous: DOJ lets itself off the privacy hook

Next: Apple's new tracking protection is "sabotage", clai...

by John E Dunn

Somebody with time on their hands has tested out a devious new form of typosquatting targeting developers installing Python packages from the PyPI (Python Package Index) repository.

According to an advisory posted to the Slovak National Security Office (NBU), ten packages for Python 2.x were removed from the site after their setup.py files were found to contain malicious code. The bad code was hiding in plain site in the repository, using filenames either nearly identical to, or which could be mistaken for, legitimate ones.

`crossenv` malware on the npm registry

On August 1, a user notified us via Twitter that a package with a name very similar to the popular `cross-env` package was sending environment variables from its installation context out to npm.hacktask.net. We investigated this report immediately and took action to remove the package. Further investigation led us to remove about 40 packages in total.

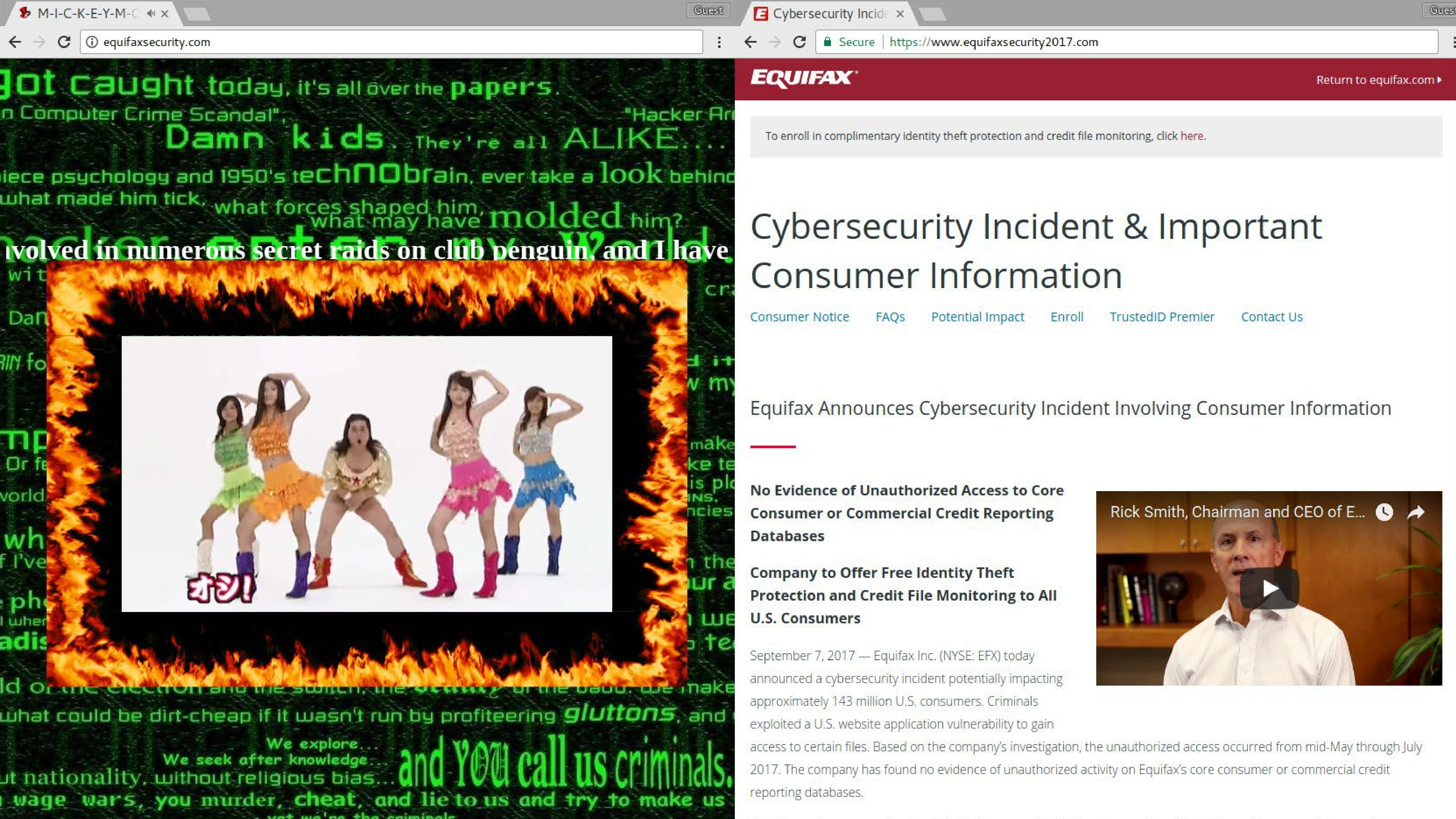
On July 19 a user named `hacktask` published a number of packages with names very similar to some popular npm packages. We refer to this practice as "typo-squatting". In the past, it's been mostly accidental. In a few cases we've seen deliberate typo-squatting by authors of libraries that compete with existing packages. This time, the package naming was both deliberate and malicious—the intent was to collect useful data from tricked users.

All of `hacktask`'s packages have been removed from the npm registry.

Adam Baldwin of Lift Security also looked into this incident to see if there were any other packages, not owned by `hacktask`, with the same package setup code. He has every file in the public registry indexed by content hash to make scans like this possible. He did not find any other instances of that specific file with those contents.

exposure

Following is a list of `hacktask`'s packages, with a count of total downloads from 7/19 to 7/31.


M-I-C-K-E-Y-M-C
Guest
equifaxsecurity.com
got caught today, it's all over the papers.
n Computer Crime Scandal",
"Hacker Ar
Damn kids. They're all ALIKE....
iece psychology and 1950's techNObrain, ever take a look behind
what made him tick, what forces shaped him, what may have molded him?
volved in numerous secret raids on club penguin, and I have
what could be dirt-cheap if it wasn't run by profiteering gluttons, and
We explore...
We seek after knowledge...
ut nationality, without religious bias...
and you call us criminals.
wage wars, you murder, cheat, and lie to us and try to make us
オシ!
Cybersecurity Incid
Guest
Secure
https://www.equifaxsecurity2017.com
EQUIFAX
Return to equifax.com
To enroll in complimentary identity theft protection and credit file monitoring, click here.
Cybersecurity Incident & Important Consumer Information
Consumer Notice
FAQs
Potential Impact
Enroll
TrustedID Premier
Contact Us
Equifax Announces Cybersecurity Incident Involving Consumer Information
No Evidence of Unauthorized Access to Core Consumer or Commercial Credit Reporting Databases
Company to Offer Free Identity Theft Protection and Credit File Monitoring to All U.S. Consumers
Rick Smith, Chairman and CEO of E...
September 7, 2017 — Equifax Inc. (NYSE: EFX) today announced a cybersecurity incident potentially impacting approximately 143 million U.S. consumers. Criminals exploited a U.S. website application vulnerability to gain access to certain files. Based on the company's investigation, the unauthorized access occurred from mid-May through July 2017. The company has found no evidence of unauthorized activity on Equifax's core consumer or commercial credit reporting databases.

Equifax Seized 138 Scammy Lookalike Domains Instead of Just Changing Its Dumb 'Security' Site

Dell Cameron
11/14/17 6:25PM

Late last month, Equifax secured control over 138 domains mimicking a website that the company launched in September in the wake of its massive data breach.

Subject to a cybersquatting complaint, the domains were originally purchased through GoDaddy by a Hong Kong company called China Capital Investment Limited. Even now, the domains redirect to placeholder pages full of ads labeled “Identity Theft Protection” and “Protect My Credit” that link to commercial products such as Lifelock.

This summer, after learning that criminal hackers had pilfered the personal and

Someone Made a Fake Equifax Site. Then Equifax Linked to It.

By Maggie Astor

Sept. 20, 2017

People create fake versions of big companies' websites all the time, usually for phishing purposes. But the companies do not usually link to them by mistake.

Equifax, however, did just that after Nick Sweeting, a software engineer, created an imitation of equifaxsecurity2017.com, Equifax's page about the security breach that may have exposed 143 million Americans' personal information. Several posts from the company's Twitter account directed consumers to Mr. Sweeting's version, securityequifax2017.com. They were deleted after the mistake was publicized.

By Wednesday evening, the Chrome, Firefox and Safari browsers

Other DNS Attacks

DoS on root/critical servers

- Or other targets ➔ DNS amplification attacks

Covert DNS communication

- Data exfiltration, C&C, …

Zone transfers

- Reconnaissance

Server bugs

- System compromise

Censorship

- Block websites at the domain level

DNSSEC

Goal: authenticate and ensure the integrity of DNS requests and responses

- Non-goals: availability, **confidentiality**

Cryptographically signed resource records: resolvers can verify the signature

Two new resource types:

DNSKEY: creates a hierarchy of trust within each zone

- Name = Zone domain name; Value = Public key for the zone

RRSIG: Prevents hijacking and spoofing

- Name = (type, name) tuple (the query itself); Value = Signature of the results

Not a complete solution

- Enables DoS amplification/CPU exhaustion attacks
- Forgery of delegation records still possible
- No "last mile" protection (between the DNS client and its local DNS server)

DoH/DoT (DNS over HTTPS/TLS)

Both protocols use end-to-end encryption between the client and the DoH/DoT-based DNS resolver

- Privacy: DNS requests cannot be monitored (e.g., nosy ISPs, censorship)
- Security: DNS responses cannot be manipulated (e.g., MitM/MotS)

DoH: queries and responses are transferred over HTTPS (RFC8484)

DoT: queries and responses are transferred over TLS (RFC7858)

- Main difference: DoT uses its own standard port (853) ➔ can be trivially blocked
- Better for corporate environments where administrators need to maintain control

Since February 2020, Firefox uses DoH by default for users in the USA

- With Cloudflare as the default provider (NextDNS or a custom server can be selected)

DoH/DoT Privacy Concerns

Trust is shifted to a different entity

The ISP cannot monitor the traffic, but the DoH server provider now can

Mozilla's Trusted Recursive Resolver program: Cloudflare has committed to

i) throwing away all PII after 24 hours

ii) never provide that data to third parties

iii) regular audits

Mitigation

Spread requests across multiple DoH vendors (K-resolver)

Introduce intermediate proxies (Oblivious DoH)

DoH/DoT Security Concerns

Reduced visibility and control

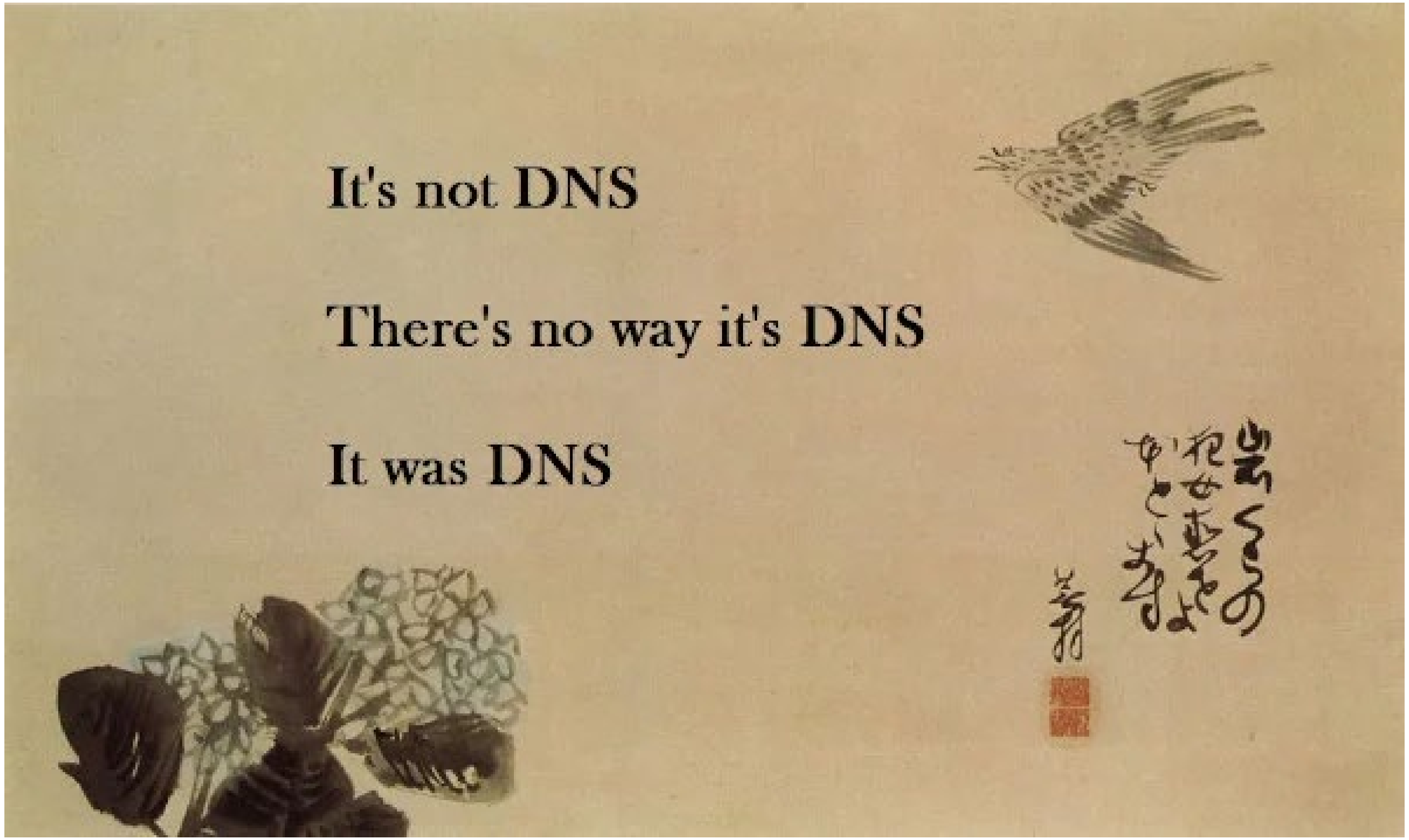
- Real-time DNS monitoring is invaluable for threat detection
- Analysis of logged DNS data is invaluable for incident response and forensics

DNS-level enterprise policies (filtering) becomes challenging

- The local DNS resolver is sidestepped: the web browser itself securely connects to the remote DoH server

Mitigation

- Use endpoint monitoring software (attackers can still tamper with it, not possible for BYOD environments)
- Intercept HTTPS (some organizations do that anyway)


It's not DNS
There's no way it's DNS
It was DNS