Naming & DNS

CS 475, Spring 2019
Concurrent & Distributed Systems
Review: Recurring Problem: Replication

- Replication solves some problems, but creates a huge new one: consistency

OK, we obviously need to actually do something here to replicate the data… but what?
Review: CAP Theorem

• Pick two of three:
  • Consistency: All nodes see the same data at the same time (sequential consistency)
  • Availability: Individual node failures do not prevent survivors from continuing to operate
  • Partition tolerance: The system continues to operate despite message loss (from network and/or node failure)
• You can not have all three, ever
Review: CAP Theorem

- C+A: Provide strong consistency and availability, assuming there are no network partitions
- C+P: Provide strong consistency in the presence of network partitions; minority partition is unavailable
- A+P: Provide availability even in presence of partitions; no sequential consistency guarantee, *maybe can guarantee something else*
Review: Relaxing Consistency

• We can relax two design principles:
  • How stale reads can be
  • The ordering of writes across the replicas
Review: Choosing a consistency model

- Sequential consistency
  - All over - it’s the most intuitive

- Causal consistency
  - “Increasingly useful” but not really widely used - still pay coordination cost, unclear what the performance benefits are

- Eventual consistency
  - Very popular in industry and academia
  - File synchronizers, Amazon’s Bayou and more
Example: Facebook

• Problem: >1 billion active users
• Solutions: Thousands of servers across the world
• What kind of consistency guarantees are reasonable? Need 100% availability!
• If I post a story on my news feed, is it OK if it doesn’t immediately show up on yours?
  • Two users might not see the same data at the same time
  • Now this is “solved” anyway because there is no “sort by most recent first” option anyway
Example: Airline Reservations

• Reservations and flight inventory are managed by a GDS (Global Distribution System), who acts as a middle broker between airlines, ticket agencies and consumers [Except for Southwest and Air New Zealand and other oddballs]
• GDS needs to sell as many seats as possible within given constraints
• If I have 100 seats for sale on a flight, does it matter if reservations for flights are reconciled immediately?
• If I have 5 seats for sale on a flight, does it matter if reservations are reconciled immediately?
Example: Airline Reservations

• Result: Reservations can be made using either a strong consistency model or a weak, eventual one
• Most reservations are made under the normal strong model (reservation is confirmed immediately)
• GDS also supports “Long Sell” - issue a reservation without confirmed availability, need to eventually reconcile it
• Long sells require the seller to make clear to the customer that even though there’s a confirmation number it’s not confirmed!
What consistency guarantees do a filesystem provide?
- read, write, sync, close
- On sync, guarantee writes are persisted to disk
- Readers see most recent
- What does a network file system do?
Network Filesystem Consistency

• How do you maintain these same semantics?
• (Cheat answer): Very, very expensive
  • EVERY write needs to propagate out
  • EVERY read needs to make sure it sees the most recent write
  • Oof. Just like Ivy.
Consistency Takeaways

• Strong consistency (sequential or strict) comes at a tradeoff: performance, availability

• Weaker consistency also has a tradeoff (weaker consistency)

• But: applications can make these design choices clear to end-users
  • Facebook
  • Dropbox

• This week: examples of two systems that involve replication and handle consistency differently: DNS, NFS
This week - case studies in replication
- Today: DNS and naming (partially explaining how the internet works)
- Reminder:
  - HW4 is due 4/15!
How do we find data?

- DNS - Domain Name System - responsible for mapping IP address to human-readable domain names
- DNS is a distributed system
- Not immediately obvious how to scale: how do we maintain replication, some measure of consistency?
Partitioning + Replication

How do clients know where to ask for data?
Partitioning + Replication

• If input is structured, can possibly leverage that structure to build these buckets (*name spaces*)

• Example: File system
  • Map from: /home/bellj/teaching/swe622 to file contents
  • Could have different machines responsible for each tier?

• Example: DNS system
  • Maps from: www.jonbell.net TO: 104.24.122.171
  • Different machines for each tier?
Idea: break apart responsibility for each part of a domain name (zone) to a different group of servers

Each zone is a continuous section of name space
Each zone has an associate set of name servers
DNS

- Can have more/less servers replicating each zone based on popularity
- DNS responses are cached at clients
  - Caches periodically time out; bigger zones tend to have longer timeouts
  - Quick response for the same request, also for similar requests
DNS: Example

Local DNS Server

129.174.126.40

home.cs.gmu.edu

129.174.126.40

gmu.edu

cs.gmu.edu

Root

.edu

ns.edu

home.cs.gmu.edu

ns1.gmu.edu

home.cs.gmu.edu

ns1.cs.gmu.edu

home.cs.gmu.edu

129.174.126.40

129.174.126.40
DNS: Example

- Body Level One
- Body Level Two
- Body Level Three
- Body Level Four
- Body Level Five

Local DNS Server

Local server has cached the server for *.cs.gmu.edu!
Domain Name System

- Obvious solution: Local file
  - Keep local copy of mapping from all hosts to all IPs (e.g., /etc/hosts)
  - Hosts change IPs regularly: Download file frequently
  - IPv4 space is now full
    - 32-bits: 4,294,967,296 addresses
    - At 1 byte per address, file would be 4GB
    - Not a lot of disk space (now, DNS introduced in the late 80s)
Domain Name System

- Obvious solution: Local file
  - Keep local copy of mapping from all hosts to all IPs (e.g., `~/etc/hosts`)
  - Hosts change IPs regularly: Download file frequently
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We need 200x of these to hold 4GB: $270K+$
Domain Name System

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    • At 1 byte per address, file would be 4GB
    • Not a lot of disk space (now, DNS introduced in the late 80s)
    • But a lot of constant internet bandwidth
  • More names than IPs
    • Aliases
  • Not scalable!
Domain Name System

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    - But a lot of constant internet bandwidth
  - More names than IPs
    - Aliases
    - Not scalable!
- Obvious solution: Well known centralized server
  - Single point of failure
  - Traffic volume
  - Access time
  - Not scalable!

http://a.root-servers.org/static/index.html
Domain Name System

• Goals
  • Scalable
  • Robust
    • High availability
  • Decentralized maintenance
  • Global scope
    • Names mean the same thing everywhere

• Non-goals
  • Atomicity
  • Strong consistency
Domain Name System - Root Servers

• 13 root servers
  • [a-m].root-servers.org
  • E.g., d.root-servers.org

• Handled by 12 entities

• How many physical servers?
  • a) Less than 13
  • b) 13
  • c) Tens
  • d) Hundreds
  • e) Thousands
  • f) Millions

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Domain Name System - Root Servers

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  - [a-m].root-servers.org
  - E.g., d.root-servers.org
- Handled by 12 entities
- How many physical servers?
  - a) Less than 13
  - b) 13
  - c) Tens
  - d) Hundreds
    - 980
  - e) Thousands
  - f) Millions

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Domain Name System - Root servers

www.root-servers.net
Domain Name System - Root servers

www.root-servers.net
Domain Name System - Root servers

www.root-servers.net
Domain Name System - Root servers

Operator: U.S. Army Research Lab

Locations: Sites: 2

- Aberdeen Proving Ground, US
- San Diego, US

www.root-servers.net
Domain Name System - Root servers

![Image of root servers locations](www.root-servers.net)
Domain Name System - Scale

Global Layer
- net
- org
- edu
- com
- gov
- uk

Administrational Layer
- root-servers
- gmu

Managerial Layer
- www
- www
- cs
- www

980 physical servers
Domain Name System - Scale

Global Layer

Administrational Layer

Managerial Layer

980 physical servers

net 13 org 6 edu 6 com 13 gov 4 uk 8

root-servers 3 gmu 4

www 1 www 1** cs 3*

www 1**
Domain Name System - Zones

DNS zones are managed by the same entity
Domain Name System - Questions/Answers

- DNS message format is the same for questions and answers
  - Header
    - ID
      - Question/Answer have the same ID
    - Flags
      - 1 bit for question/answer, etc.
    - Number of questions
    - Number of answers
    - Number of authority RRs (Resource Records)
    - Number of additional RRs
  - Questions
  - Answers
  - Authority
  - Additional Info
Domain Name System - Resource Records (RRs)

- RR format: (class, name, value, type, ttl)
  - Class: Internet (IN)
  - Type
    - A (AAAA for IPv6)
      - name is hostname
      - value is IP address
    - NS
      - name is domain
      - value is authoritative server for domain
    - CNAME
      - name is alias for some canonical (real) name
      - value is canonical name
    - And more...
Domain Name System - Example Query

dig(1) - Linux man page

Name
dig - DNS lookup utility

Synopsis
dig [@server] [-b address] [-c class] [-f filename] [-k filename] [-m] [-p port#] [-q name] [-t type] [-x addr] [-y hmac:]name:key] [-4] [-6] [name] [type] [class] [queryopt...]
dig [-h]
dig [global-queryopt...] [query...]
> dig www.gmu.edu a

;; Got answer:

;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 20159

;; flags: qr rd ra; QUERY: 1, ANSWER: 2, AUTHORITY: 3, ADDITIONAL: 3

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096

;; QUESTION SECTION:

www.gmu.edu.                   IN      A

;; ANSWER SECTION:


jiju3.gmu.edu.          46534   IN      A       129.174.1.59

;; AUTHORITY SECTION:

gmu.edu.                86013   IN      NS      eve.gmu.edu.
gmu.edu.                86013   IN      NS      uvaarpa.virginia.edu.
gmu.edu.                86013   IN      NS      magda.gmu.edu.

;; ADDITIONAL SECTION:

eve.gmu.edu.            3219    IN      A       129.174.253.66
magda.gmu.edu.          1993    IN      A       129.174.18.18

uvaarpa.virginia.edu.   84640   IN      A       128.143.2.7

;; Query time: 2 msec

;; SERVER: 192.168.1.1#53(192.168.1.1)

;; WHEN: Thu Feb 15 10:19:24 EST 2018

;; MSG SIZE  rcvd: 212
Domain Name System - Example Query

> dig www.ic.ac.uk a

;; Got answer:

;; ->>>HEADER<<- opcode: QUERY, status: NOERROR, id: 28622

;; flags: qr rd ra; QUERY: 1, ANSWER: 2, AUTHORITY: 0, ADDITIONAL: 1

;; OPT PSEUDOSECTION:

;; EDNS: version: 0, flags:; udp: 4096

;; QUESTION SECTION:

;www.ic.ac.uk.  IN  A

;; ANSWER SECTION:

www.ic.ac.uk. 271 IN CNAME wrp.cc.gslb.ic.ac.uk.

wrlp.cc.gslb.ic.ac.uk. 1 IN A 146.179.40.24

;; Query time: 1 msec

;; SERVER: 192.168.1.1#53(192.168.1.1)

;; WHEN: Thu Feb 15 10:23:52 EST 2018

;; MSG SIZE  rcvd: 83
Domain Name System - Resolution

- **edu**
- **gmu**
- **Local NS (e.g., 192.168.1.1)**
- **root-server.net**
- **dns1.nic.uk**
- **ns0.ja.net**
- **ns0.ic.ac.uk**
- **uk**
- **ac**
- **ic**
- **www.ic.ac.uk?**
- 155.198.64.24
- 146.179.40.24
Domain Name System - (Recursive) Resolution

root-server.net

edu
gmu

Local NS (e.g., 192.168.1.1)

www.ic.ac.uk? A: 155.198.64.24 A: 146.179.40.24

dns1.nic.uk

ns0.ja.net

ns0.ic.ac.uk

155.198.64.24 146.179.40.24

uk

ac

ic

www
Domain Name System - Iterative Resolution

Local NS (e.g., 192.168.1.1)

- A: -
- NS: dns1.nic.uk

- A: 155.198.64.24
- A: 146.179.40.24
- NS: ns0.ja.net

- A: 155.198.64.24
- A: 146.179.40.24
- NS: ns0.ic.ac.uk

- A: 155.198.64.24
- A: 146.179.40.24

- A: -
- NS: ns0.ic.ac.uk

www.ic.ac.uk?
Domain Name System - Iterative Resolution

- **edu**
  - **gmu**
    - **root-server.net**
      - **A:** -
      - **NS:** dns1.nic.uk
    - **Local NS** (e.g., 192.168.1.1)
      - **A:** -
      - **NS:** ns0.ja.net
      - **NS:** ns0.ic.ac.uk
    - **www.ic.ac.uk?**
      - **A:** 155.198.64.24
      - **A:** 146.179.40.24
  - **uk**
    - **dns1.nic.uk**
      - **A:** -
      - **NS:** ns0.ja.net
    - **ac**
      - **ns0.ja.net**
      - **A:** -
      - **NS:** ns0.ic.ac.uk
    - **ic**
      - **ns0.ic.ac.uk**
      - **A:** 155.198.64.24
      - **A:** 146.179.40.24
      - **A:** 155.198.64.24
      - **A:** 146.179.40.24
    - **www**
> cat /etc/resolv.conf #which DNS server am I using
# Generated by resolvconf
search fios-router.home
nameserver 192.168.1.1
> dig @192.168.1.1 www.ic.ac.uk a #recursive query
...
> dig +norecurse @192.168.1.1 www.ic.ac.uk a
# same answer, why?
# what if I had tried this first?

https://xkcd.com/908/
Domain Name System - Caching

Some gamers steamed over alleged Valve anti-cheat DNS spying - CSO
https://www.csoonline.com/.../some-gamers-steamed-over-alleged-valve-anti-cheat-dns... ▼
Feb 16, 2014 - Goes through all your DNS Cache entries (ipconfig /displaydns); Hashes each one with MDS; Reports back to VAC Servers. Valve is not the only company that uses an anti-cheat system, but it is perhaps one of the most highly regarded companies as countless millions of gamers have Steam.
Various ...

Reddit user claims Valve Anti-Cheat scans your DNS cache - PC ...
https://gamefaqs.gamespot.com/boards/916573-pc/68593356 ▼
For PC on the PC, a GameFAQs message board topic titled "Reddit user claims Valve Anti-Cheat scans your DNS cache".

Valve Anti-Cheat seems to scan your DNS cache, but probably doesn ...
https://www.neogaf.com › Discussions › Gaming Discussion ▼
Feb 16, 2014 - Trust is a critical part of a multiplayer game community - trust in the developer, trust in the system, and trust in the other players. Cheats are a negative sum game, where a minority benefits less than the majority is harmed. There are a bunch of different ways to attack a trust-based system including writing a ...

Report: Valve anti-cheat scans your DNS history - Player Attack
Feb 17, 2014 - Even if you've never actively visited a cheat website, there may be traces of them in your DNS, and that's what VAC is reportedly now looking for. The news was first posted to the Counter-Strike: Global Offensive Reddit, explaining that VAC now: Goes through all your DNS Cache entries (ipconfig ...

IS IT OK THAT VAC SCANS YOUR DNS CACHE? :: VAC Discussion - Steam...
steamcommunity.com › Steam Forums › VAC Discussion ▼
Feb 15, 2014 - 16 posts - 7 authors
Valve ANSWER THIS! http://www.ghacks.net/2014/02/16/steams-vac-protection-now-scans-ans-transfers-dns-cache/ What Is going on with this DNS spying? We all know that various anti-cheat programs do check your DNS, some of them don't really collect data though. It has been proven that VAC collects ...
There are a number of kernel-level paid cheats that relate to this Reddit thread. Cheat developers have a problem in getting cheaters to actually pay them for all the obvious reasons, so they start creating DRM and anti-cheat code for their cheats. These cheats phone home to a DRM server that confirms that a cheater has actually paid to use the cheat.

VAC checked for the presence of these cheats. If they were detected VAC then checked to see which cheat DRM server was being contacted. This second check was done by looking for a partial match to those (non-web) cheat DRM servers in the DNS cache. If found, then hashes of the matching DNS entries were sent to the VAC servers. The match was double checked on our servers and then that client was marked for a future ban. Less than a tenth of one percent of clients triggered the second check. 570 cheaters are being banned as a result.

Gabe Newell, Valve’s CEO

https://www.reddit.com/r/gaming/comments/1y70ej/valve_vac_and_trust/
> dig ic.ac.uk a
;; ANSWER SECTION:
ic.ac.uk.    86363 IN A 155.198.63.21
ic.ac.uk.    86363 IN A 155.198.30.71
ic.ac.uk.    86363 IN A 129.31.100.150
ic.ac.uk.    86363 IN A 155.198.30.55
ic.ac.uk.    86363 IN A 146.179.32.12
ic.ac.uk.    86363 IN A 129.31.47.2
ic.ac.uk.    86363 IN A 155.198.30.98
ic.ac.uk.    86363 IN A 146.179.32.37
ic.ac.uk.    86363 IN A 129.31.22.11

> dig ic.ac.uk a
;; ANSWER SECTION:
ic.ac.uk.    86340 IN A 129.31.47.2
ic.ac.uk.    86340 IN A 155.198.30.55
ic.ac.uk.    86340 IN A 129.31.22.11
ic.ac.uk.    86340 IN A 155.198.30.71
ic.ac.uk.    86340 IN A 146.179.32.37
ic.ac.uk.    86340 IN A 155.198.63.21
ic.ac.uk.    86340 IN A 146.179.32.12
ic.ac.uk.    86340 IN A 129.31.100.150
ic.ac.uk.    86340 IN A 155.198.30.98

Different order: Load balancing requests among all available servers
Domain Name System

Name Discovery
Name Discovery

- No configuration
- Automatic discovery of other hosts on the same network
- Does this use DNS?
  - Global/Local

How does this work?
Name Discovery
Name Discovery

• DNS requires knowing the address of the root servers
• Also requires names to be centrally registered and globally available
• Useful, but not for every scenario
  • Hosts on an LAN
    • Typically router provides
      • Dynamic Host Configuration Protocol (DHCP) server
      • Local DNS server
    • What about unmanaged LANs?
  • IOT devices
    • “Just work” without any manual configuration
    • I.e., automatically discovered
  • In both cases, names should be local to their LAN and available after joining the LAN
    • DNS is global and takes some time to react to changes (e.g., up to 24h)
Name Discovery - Broadcasting

• Broadcast the ID, requesting the entity to answer with its address
  • “Is Jon Doe here?”
Name Discovery - Broadcasting

- Broadcast the ID, requesting the entity to answer with its address
  - "Is Jon Doe here?"

```plaintext
Yes          No

Alice    Bob    Charlie    Jon Doe
          Nope    Nope        Yup
```

Are you “Jon Doe”?*
Name Discovery - Broadcasting

- Broadcast the ID, requesting the entity to answer with its address
  - “Is Jon Doe here?”
Name Discovery - Broadcasting

- Broadcast the ID, requesting the entity to answer with its address
  - “Is Jon Doe here?”
- Simple
- Requires all entities to listen to incoming requests
- Not very scalable, network traffic wasted by name requests
  - But LAN is relatively small, so that’s OK
Name Discovery - Broadcasting

• Unmanaged networks (i.e., no router)
  • The Address Resolution Protocol (ARP), used to map IP addresses (e.g., 127.0.0.1) to MAC addresses (e.g., 00:00:00:00:00:00), uses this approach

• Managed networks
  • The Dynamic Host Configuration Protocol (DHCP) allows a router to assign IP addresses to all hosts
    • And set up the local name server
  • Newly connected host broadcast a DHCP discover message on the network to discover if there’s any DHCP server
  • DHCP server replies, and host now knows its IP and how to use DNS
  • Service discovery (iTunes, etc.) does not require a router
Broadcast - Multicast

- Unicast connections are one-to-one (or point-to-point)
  - One sender, one receiver
  - E.g., HTTP traffic, server sends pages to the clients
- Multicast connections are **one-to-many**
  - One sender, many receivers
  - E.g., Address Resolution Protocol (ARP) shown earlier
Multicast in practice - Multicast DNS (mDNS)

- Resolve DNS records without any DNS server
- All hosts on a local network listen to IPv4 address 224.0.0.251 on port 5353
  - Address FF02::FB for IPv6
- DNS query sent to this address is broadcast among all hosts
  - Host with the correct name answers the query
DNS Service Discovery

- DNS Service Discovery (DNS-SD)
  - Service discovery based on mDNS
- Discover a service on the network (e.g., scanner)
  - Send a query for a PTR Record for the domain: <service>.<transport>.local
    - E.g., _scanner._tcp.local
  - Receive list of PTR RRs if service exists on the network
    - <instance>.<service>.<transport>.local
    - E.g., Deskjet\0323520\032series\032[5C41EC]._scanner._tcp.local
  - `dig @224.0.0.251 -p 5353 _scanner._tcp.local ptr`
> dig @224.0.0.251 -p 5353 _scanner._tcp.local ptr
> ; <<>> DIG 9.11.2 <<>> @224.0.0.251 -p 5353 _scanner._tcp.local ptr
> ; (1 server found)
> ;; global options: +cmd
> ;; Got answer:
> ;; WARNING: .local is reserved for Multicast DNS
> ;; You are currently testing what happens when an mDNS query is leaked to DNS
> ;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 10754
> ;; flags: qr aa; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 4
> ;; QUESTION SECTION:
> _scanner._tcp.local. IN PTR
> ;; ANSWER SECTION:
> _scanner._tcp.local. 10 IN PTR Deskjet\0323520\032series\032[5C41EC]._scanner._tcp.local.
> ;; ADDITIONAL SECTION:
> Deskjet\0323520\032series\032[5C41EC]._scanner._tcp.local. 10 IN SRV 0 0 8080 HP28924A5C41EC.local.
> Deskjet\0323520\032series\032[5C41EC]._scanner._tcp.local. 10 IN TXT "txtvers=1" "ty=Deskjet 3520 series" "mfg=HP" "mdl=Deskjet 3520 series" "adminurl=http://HP28924A5C41EC.local." "note=" "UUID=1c852a4d-b800-1f08-abcd-28924a5c41ec" "button=T" "flatbed=T"
> HP28924A5C41EC.local. 10 IN A 192.168.1.160
> HP28924A5C41EC.local. 10 IN AAAA fe80::2a92:4aff:fe5c:41ec
> ;; Query time: 185 msec
> ;; SERVER: 192.168.1.160#5353(224.0.0.251)
> ;; WHEN: Thu Feb 22 11:23:58 EST 2018
> ;; MSG SIZE  rcvd: 340

mDNS - Example with dig

MDSN ON THE INTERNET?

I ALSO LIKE TO LIVE DANGEROUSLY

mDNS - Example with dig
DNS-SD in practice - Zeroconf

• Modern Operating Systems all have a zeroconf daemon
  • Apple: *Bonjour* protocol
    • mDNSResponder released as open source, used by Android
  • Microsoft:
    • *Netbios* (not mDNS)
      • Until Windows XP (at least?)
    • *Link-Local Multicast Name Resolution* (LLMNR)
      • From Windows Vista
  • GNU/Linux
    • *Avahi* service
• Building block of modern IOT devices
Conclusion

• Resolving names requires a large scale distributed system
  • Domain Name System (DNS)
  • Distributed between several entities and among all continents
  • World-wide scale
  • High availability

• Sometimes we need local names
  • Peer-to-peer protocol based on DNS and on local network multicast
  • mDNS: Each host is responsible for its own records
  • Distributed, small scale, high availability zeroconf services
    • Bonjour, Avahi, mDNS responder, LLMNR
    • Building block of IOT
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