

A First Look at the Consolidation of DNS and Web Hosting Providers

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Abstract. Although the Internet continues to grow, it increasingly depends on a small set of dominant service providers for Domain Name System (DNS) hosting and web hosting providers. This consolidation of Internet resources poses a variety of potential threats to the Internet, including susceptibility to outages, failures, and even overt censorship from platforms. Increasingly, an outage from a single organization can create widespread disruption across a large number of sites and services. Consolidation trends have been noted for several years, yet these trends have not been quantified. Towards this end, this paper aims to quantify these trends, in particular, the reliance of the most popular domains on a small set of organizations for DNS and web hosting. We highlight the extent to which the hosting of authoritative name servers and web hosting for the top 10,000 websites are consolidated on relatively few platforms. The statistics are surprising and somewhat alarming. We find that over 75% of the top 10,000 domains rely on only a single organization for hosting authoritative DNS resolution. Furthermore, two organizations, Cloudflare and Amazon, are the sole host of DNS name servers for over 40% of these popular domains. In terms of web hosting, we find that 62% of index pages and many external page resources for the top 10,000 websites are hosted by only five organizations: Cloudflare, Amazon, Akamai, Fastly, and Google.

1 Introduction

The success of the Internet can be partially attributed to its distributed design. Indeed, distributing services over infrastructures across many parties has contributed to the relative security, resiliency, and accessibility of the Internet. Over the past several years, however, control of Internet infrastructure is becoming consolidated in fewer organizations and entities. In particular, two critical aspects of Internet service—DNS hosting and web hosting—were once naturally distributed but are now increasingly operated by relatively few providers. Various organizations, including the Internet Society, have expressed concern over the potentially negative ramifications of this so-called Internet consolidation: *“The fact that a few corporations dominate large parts of the Internet is not news. Today, a handful of actors play a significant role in our increasingly-connected*

societies. In this context it's important to consider what the implications of those trends are, not only from an economic perspective but also in terms of how they may shape the Internet in coming years." [28]

These concerns over consolidation are more than a curiosity or idle concern; rather, they have concrete, and potentially wide-ranging, consequences and ramifications. One consequence is reduced resilience: Over the past several years, many websites have suffered considerable outages. For example, in October 2016, a distributed denial of service (DDoS) attack on Dyn, a major Domain Name System (DNS) provider, resulted in outages to more than 60 major Internet sites and services, including CNN, Etsy, GitHub, Netflix, the *New York Times*, Reddit, Slack, the *Wall Street Journal*, Yelp, and many others [12]. Last month, September 2021, alone saw several major outages. Notably, Facebook, Whatsapp, and Instagram were unreachable for five hours after an erroneous BGP update withdrew routing advertisements to the authoritative DNS name servers for these services [20]. In late September, a large portion of Amazon Web Services experienced a degradation that took Signal and Nest offline [29]. These incidents were caused by a failure within a single organization, yet the magnitude of the disruptions was so pronounced precisely because many Internet services depended on the functionality of that organization. As people become more dependent on the availability of Internet websites and services for work, entertainment, and communication, the social and economic costs of these incidents increases.

The risks of consolidation also go beyond simply reliability, to issues of Internet censorship and platform control over online speech, as well as control over marketplaces. Large content hosts such as Amazon and Cloudflare have, in the past, exercised discretion with shutting down websites [19, 26]; Cloudflare has also prevented certain web clients from reaching websites hosted on its platform [14]. The consolidation of hosting on a smaller number of platforms, particularly when any given site is hosted on *only one* of the platforms, thus poses grave risks along a number of dimensions.

This process of increasing control over Internet infrastructure and services by a small set of organizations has been defined as *Internet consolidation*, and has been defined with a relatively broad scope: "*The most visible aspects of this involve well-recognized Internet services, but it is important to recognize that the Internet is a complex ecosystem. There are many underlying services whose diversity, or lack thereof, are as important as that of, say, consumer-visible social networks. For instance, the diversity of cloud services, operating systems, browser engines is as important as that of application stores or the browsers themselves.*" [8] This expansive definition of Internet consolidation raises questions about the *extent* and *evolution* of this phenomenon from a variety of facets. While some previous work has considered consolidation through the lens of DNS traffic [16, 21], others have examined the economic and political implications of a few powerful companies dominating markets on the Internet [28].

Despite some attention to this topic, however, little is still known about how consolidation trends are affecting the resiliency of Internet services. Specifically,

we do not have precise measures about the websites and services that could be vulnerable to an outage of a single, particular DNS service provider, content delivery network, or web hosting service. Of course, answering that “what if” question is challenging, due to the dynamic nature of Internet services and the nature of dependencies in complex systems such as the Internet; yet, we can begin to get some understanding of these vulnerabilities by studying how critical aspects of content delivery—namely, DNS hosting and web hosting—are consolidated for popular websites and services.

We study consolidation from several aspects. We first explore the extent to which a relatively small number of organizations control DNS hosting for popular websites (Section 4.1). We find that two organizations, Amazon and Cloudflare, are responsible for exclusively hosting the name servers for over 40% of domains in the Tranco top 10K (i.e., 40% of domains exclusively host their DNS on one of these sites). Additionally, we found that over 75% of popular websites use a single organization to host their name servers. We also study these phenomena for web hosting (Section 4.2) and find similar trends: in particular, five organizations—Cloudflare, Amazon, Akamai, Fastly, and Google—host about 62% of index pages in the Tranco top 10K, as well as the majority of external page resources for these sites.

These findings have significant implications for the design of current and future Internet services that are resilient to both accidental misconfiguration and overt shutdown. As others have noted, these consolidation trends also have economic implications, particularly as they relate to issues such as competition, barriers to entry, and permissionless innovation [8, 11]. It is thus important not only to report on consolidation at a particular moment in time, as we have done in this paper, but also to track how consolidation evolves over time. To facilitate ongoing measurements of consolidation, we have released all of our data and measurement metrics.¹

2 Background and Related Work

This section provides background on Internet consolidation, as well as on DNS and web hosting. We highlight particular previous work that has explored various aspects of consolidation in these two areas.

2.1 The Domain Name System (DNS)

DNS is responsible for translating domain names into the Internet Protocol (IP) addresses needed to communicate with the desired network endpoint, such as a website, service, or device. Assuming the DNS record is not cached at a recursive resolver, the client translates the domain by querying an authoritative name server for the domain’s DNS A record. If a domain name’s authoritative name servers are unreachable (and the A record is not cached), the client cannot

¹ The project website will be made public upon publication of the paper.

communicate with the network endpoint. It is common for organizations other than the operator of the domain to host that domain’s name servers, a trend we discuss in Section 4.1. As discussed in the next section, past work has observed that increasing centralization of third-party service providers and other aspects of the DNS can have consequences on the robustness and security of various Internet services.

DNS Consolidation. Previous work has studied both the extent and effects of increased DNS centralization. Zembruzki et al. [30] found that up to 12,000 name servers used by websites in the Alexa top 1 million shared the same third-party infrastructure. As for public resolvers, Radu et al. [27] found that the popularity of Google’s public DNS resolver has increased tremendously over time, serving as the default resolver for over 35% of studied clients. The popularity of public DNS resolvers might be explained by their lower response times in comparison to that of local resolvers, despite the advantage being dependent on client location [13]. To further investigate the centralized usage of cloud providers, Moura et al. [22] found that more than 30% of DNS queries to two country-code top-level domains were sent from five large U.S. cloud providers: Google, Amazon, Microsoft, Cloudflare, and Facebook. From the centralization perspective, Bates et al. [11] propose a metric for measuring the market share of organizations that provide DNS resolvers. However, since the metric is designed based on antitrust economics literature, which is not widely used in computer science literature, we do not apply it to our measurements.

2.2 Web Hosting and Content Delivery Networks

Content delivery networks (CDNs) can provide faster delivery of content (e.g., websites) to a global population of users. Many companies who operate CDNs also help to enhance security by providing services such as DDoS mitigation. Websites and services who do not rely on a CDN are subject to a variety of risks, including performance degradation during traffic surges (“flash crowds”), weak protection against DDoS attacks, higher Internet transit costs, and slower content delivery. These providers not only provide sophisticated infrastructure, but also make it easy for users to quickly establish hosting: whereas a decade ago, hosting a website entailed a significant amount of system administration on the part of the publisher, these CDNs also provide web hosting services that now make this process turnkey.

Web Hosting Consolidation. The consolidation of CDNs has not been systematically studied, so our work attempts to fill in the gap. While we do not explicitly measure CDNs for our dataset of domains, we measure the hosting of page content and index pages. In many cases, especially among the top 10K domains, CDNs are used to host the website. Thus, by measuring content hosting, we can capture the consolidation of CDNs in addition to other hosting options. In a preliminary, concurrent unpublished technical report, Moura et al. [23] used the resource records in DNS zone files to identify up to 200 million domains and

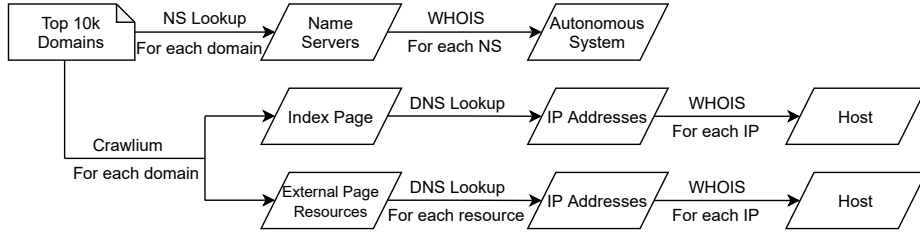


Fig. 1: The measurement pipeline used to study each domain.

the owners of the autonomous systems that the domains belong to. They found that one-third of the domains they studied were hosted by Google, GoDaddy, Cloudflare, and Amazon. Our work complements and extends this study, considering both popular domains, as well as both the DNS infrastructure (i.e., authoritative name servers) and the infrastructure that hosts external resources on websites.

3 Methods

In this section, we describe the methods that we used to measure two facets of Internet consolidation: DNS hosting and web hosting.

Overview. We study the authoritative name servers and hosting providers used by the 10,000 most popular domains from the October 2021 Tranco rankings. Tranco aggregates the results of several other top sites rankings to create an accurate and resilient list [18]. For each domain, we determine (1) the organization hosting each of its name servers, (2) the organization hosting its index page, and (3) the organization hosting its external page resources. We define *organization* as the company or entity that owns the autonomous system in which the server is found. In addition, we discuss the limitations of our approach.

3.1 DNS Consolidation

We identify the organization responsible for hosting the authoritative name servers using the pipeline illustrated in Figure 1. For each domain in the top 10,000, we query both Google and Cloudflare’s public resolver, 8.8.8.8 and 1.1.1.1, respectively. We query multiple resolvers to increase the likelihood of discovering all the IPs associated with a given domain. Next, we determine the AS of each IP using Team Cymru’s [3] IP-to-AS database. We consider the organization name for each AS as a distinct organization when analyzing consolidation, so that multiple AS numbers that share the same organization are considered as a single organization if the organization names match.

3.2 Web Hosting Consolidation

We determine the organizations responsible for hosting web content on each domain by examining the index page and all external page resources on the domain’s homepage. We consider both the index page and other resources because a domain may use different hosting providers for each. For example, Github (<https://github.com>) hosts its own index page but uses Fastly (<https://www.fastly.com>) to host other assets. We scrape the homepage of each domain using Crawlium [9], an open-source web crawler used in prior works [10,15], and extract information about each resource loaded on the page.

Index pages. We determine the host of each domain’s index page using the pipeline illustrated in Figure 1. We cannot perform a DNS lookup directly on the domain because the domain may be different from the URL of the index page. This can occur when an HTTP request to the domain returns a 301 or 302 response, which means that the page has been permanently, or temporarily moved to another URL that it redirects to. For example, making a request to `nytimes.com` will respond with a redirect to `www.nytimes.com`, and `www.nytimes.com` and `nytimes.com` are translated to different IP addresses. To account for this, we use Crawlium to determine the URL of the index page by extracting the URL of the first HTTP request to return a 200 response, which means that the request has succeeded. We can then resolve the URL of the index page and determine the organization from which it was loaded using Team Cymru’s IP-to-AS database.

External page resources. Most modern websites rely on dynamic content fetched from third parties. Thus, in addition to the index page, we use Crawlium to collect information about every resource that is loaded by each domain. However, many of these resources may not be critical to the functioning of the page. Because we are interested in only the resources that are absolutely required by the page, we filter out ads, trackers, cookies, and certain social media elements using EasyList’s block lists [5]. We then perform the same lookup process as we did for name servers to determine the organization from which each resource was loaded.

3.3 Data Analysis

A domain can become suddenly unavailable due to incidents such as attacks [4] and outages [17] that compromise Internet services that the domain depends on. In order to quantify the effect of such incidents, we introduce the notion of domains being *affected* or *unreachable*. For our DNS analysis, if a domain uses a single AS to host all of its name servers, then the domain would be *unreachable* if that AS becomes unavailable. If a domain uses an AS for at least one of its name servers, then the domain would be *affected* if the AS becomes unavailable. Similarly, for web hosting, we consider a domain to be *unreachable* when the AS that hosts its index page becomes unavailable. Finally, if the domain has external page resources hosted by an AS, then the domain is only *affected* if that AS becomes unavailable.

3.4 Limitations

We determine the name servers for domains but do not identify the name servers for all subdomains. While these name servers are likely the same, it is possible that they are different. If they are different, a subdomain may be reachable even if the domain is not. For example, if `nytimes.com` and `www.nytimes.com` have different name servers, the website may still be accessible even if the name servers for `nytimes.com` are unreachable.

Furthermore, modern websites, especially highly-trafficked ones, may use DNS redirection to direct the client to a nearby data center serving their content. As a result, a website may employ several organizations to host web content. Our measurements, however, only observe content delivered from a single organization that we happen to be close to. This limitation can be better avoided by measuring from several geographically distributed vantage points. Additionally, it is possible that a website uses a different host as a backup in case the primary host is unreachable. In this case, we may underestimate resilience because we can not observe or identify the back up host.

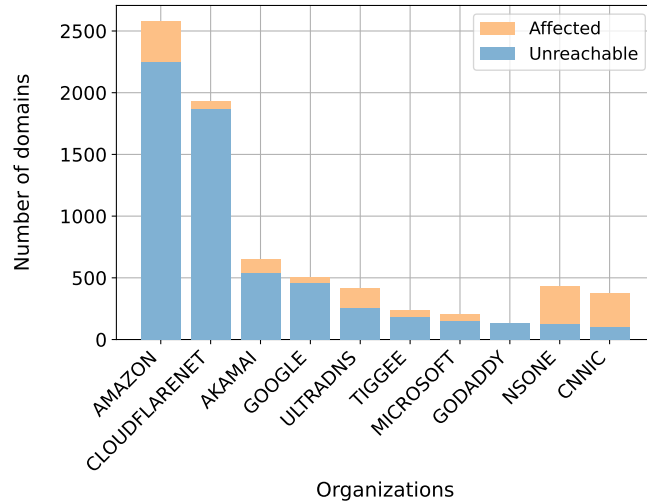


Fig. 2: Number of domains that use exclusively one AS to host their name servers (unreachable) and use that AS at least partially (affected).

4 Findings

In this section, we present the results of our analysis. We address the following questions: (1) Which organizations host each domain’s name servers? and (2) Which organizations host web content (including index pages and external page resources)? Our results show in both cases, hosting is dominated by a few large companies.

4.1 Which Organizations Provide Name Servers?

We first analyze which organizations host each domains' name servers. Of the 10,000 domains, we found a valid A record for the name servers of 9,957 domains. We characterize the potential consequences of organization outages on each domain in terms of two metrics: (1) unreachable and (2) affected. In terms of our analysis of authoritative DNS name servers, a domain is unreachable if all of its name servers are hosted by the same organization and said organization is down. On the other hand, a domain is affected if at least one of the domain's name servers is hosted by an organization and that organization is down. Based on these definitions, the set of unreachable domains is a subset of the set of affected domains in the case of an organization outage.

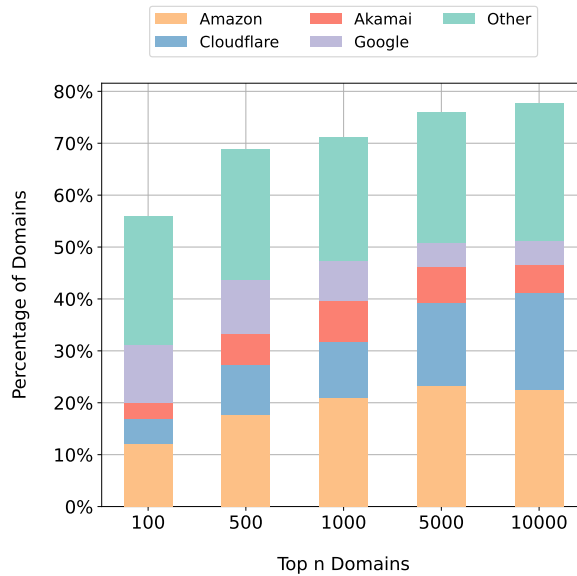


Fig. 3: *Percentage of domains that use exclusively one AS to host their name servers (unreachable).*

A majority of domains use a single organization to host its name servers. We find that 75.8% of domains use only one organization to host its name servers. For example, `netflix.com` uses four authoritative name servers each of which belong to autonomous systems controlled by Amazon Web Services. The remaining 24.2% of domains have name servers hosted across multiple organizations. For example, `twitter.com` uses ten authoritative name servers, out of which four belong to autonomous systems operated by Amazon and six operated by Dyn. If either of these AS organizations went down, the associated domains would be affected but still reachable via the name servers hosted by the other AS organization. As shown in Figure 2 and Table 1, the number of domains affected by an AS going down is only slightly larger than the number of domains that would be completely unreachable. Furthermore, the distribution for affected domains does not follow the same distribution for unreachable

| | % Unreachable | % Affected |
|------------|---------------|------------|
| Cloudflare | 22.6 | 25.8 |
| Amazon | 18.7 | 19.4 |
| Akamai | 5.4 | 6.5 |
| Google | 4.6 | 5.1 |
| UltraDNS | 2.6 | 4.1 |
| TIGEE | 1.9 | 2.4 |
| Microsoft | 1.5 | 2.1 |
| GoDaddy | 1.3 | 1.4 |
| NSONE | 1.3 | 4.3 |
| CNNIC | 1.0 | 3.7 |
| Total | 60.9 | - |

Table 1: Percentage of domains that use exclusively one AS to host their name servers (unreachable) and use that AS at least partially (affected).

| | % Unreachable | % Affected |
|------------|---------------|------------|
| Cloudflare | 18.9 | 45.7 |
| Amazon | 17.4 | 43.6 |
| Akamai | 14.0 | 16.9 |
| Fastly | 7.2 | 24.1 |
| Google | 5.4 | 6.3 |
| Total | 62.9 | - |

Table 2: Percentage of domains that use exclusively one AS to host their index page (unreachable) and use that AS at least partially (affected).

domains. For example, NSONE, the ninth most popular AS to be used solely, is the second most popular AS to be used in conjunction with another AS. Perhaps the difference indicates some AS organizations like NSONE are more commonly used as supplementary or even backup NS providers than sole primary providers.

Two organizations are responsible for hosting the name servers for over 40% of domains. Amazon and Cloudflare exclusively host the name servers for 22.5% and 18.7% of domains, respectively. Table 1 shows the top ten most popular name server hosting providers by the percentage of domains that would be unreachable if that provider experienced an outage. Although these ten providers serve for over 60% of domains, there is a significant decline from Cloudflare to the next most common organization, Akamai. This trend likely results from the fact that Amazon and Cloudflare both offer lower-tier instant services [2] and enterprise level support, whereas Akamai does not offer the lower-tier hosting options [1].

The use of a single organization to host all name servers is prevalent however we define the top N domains. Figure 3 shows that the percentage of domains that use only a given organization to host its name servers in the top n domains is greater than 50% for a wide range of possible n . In other words, both popular and less popular domains rely on a single organization for DNS hosting. However, the proportion of domains that rely on a single organization for DNS name server hosting increases by over 20% between the top 100 domains and the top 10,000 domains. Additionally, the popularity of each major organization peaks in different ranges of domains. For example, the proportions of domains using Google peaks in the top 100 and decreases with n . This is likely because Google hosts its own domains but does not provide hosting services for other domains to the same degree as traditional hosting providers such

| | Threshold | | | |
|------------|-----------|------|------|------|
| | 0% | 50% | 75% | 90% |
| Cloudflare | 37.6 | 18.5 | 16.5 | 13.1 |
| Amazon | 46.2 | 18.1 | 15.0 | 11.2 |
| Akamai | 35.7 | 14.7 | 12.6 | 9.7 |
| Fastly | 17.8 | 8.0 | 6.3 | 4.4 |
| Google | 37.9 | 4.9 | 4.5 | 4.2 |
| Total | - | 64.2 | 54.9 | 42.6 |

Table 3: Percentage of domains that fetch greater than the indicated threshold of external page resources from a given organization. The 0% threshold is used to count domains that load any resources from a given organization.

as Cloudflare and Akamai. Cloudflare exhibits the opposite trend, hosting the lowest proportion of domains in the top 100 and increasing with n . The reason for this phenomenon is unclear, although one possibility is that Cloudflare is a less expensive option for hosting, and therefore more accessible, especially for the less popular domains [24].

4.2 Which Organizations Host Web Content?

We next study which organizations host the index page and the external page resources for the Tranco 10K domains. Of these domains, we were able to load the index page for only 9,320; only 8,611 of these domains loaded external resources that were not filtered out by our block list (e.g., trackers). All of the percentages in this section are computed with respect to the appropriate number of responsive domains.

Five organizations exclusively host the index page for a majority of domains. Table 2 shows the percentage of index pages that are hosted exclusively by one organization and the percentage of index pages that each AS at least partially hosts. We find that Cloudflare, Amazon, Akamai, Fastly, and Google exclusively host over 62% of index pages of the domains. In addition, both Cloudflare and Amazon host the index page for more than 43% of domains. With the exception of Fastly, the most popular index page hosts are the same as the most popular name server hosts, as presented in Section 4.1. Figure 4 further details the distribution of index page hosting. As with name server hosting, Google’s representation peaks in the top 100 domains; Akamai in the top 1,000; and Cloudflare in the top 10,000, indicating that each of the dominant organizations may offer service packages that are attractive to or even catered towards domains of similar popularity.

Five organizations host the majority of external page resources. A website may load external page resources from many organizations, yet in many cases there is a single dominant organization that hosts the majority of external resources for a given webpage. We identify the websites that fetch a majority of

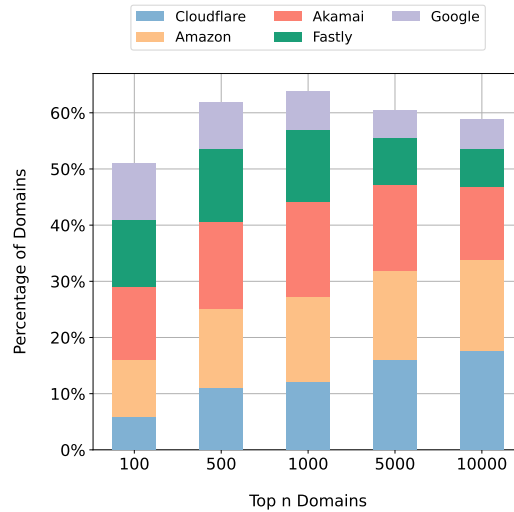


Fig. 4: *Percentage of domains that use exclusively one AS to host their index page (unreachable).*

resources from a single organization. To do so, we count both the total number of resources and the number of resources loaded from each organization. Table 3 shows the five most popular sources of externally loaded content on each website’s homepage using several thresholds. For example, 18.5% of domains loaded more than 50% of external page resources from Cloudflare.

More than 64% of websites fetch a majority of their external page resources from one of the five hosting providers, namely Cloudflare, Amazon, Akamai, Fastly, and Google. Furthermore, over 42% of domains load over 90% of external page resources from these five organizations. These findings are similar to our study of index page hosts, in that most websites rely heavily on these five organizations for content hosting.

5 Discussion

Our results suggest that the market for DNS and web hosting is concentrated around a small set of providers, affecting the resiliency and security of the domains. In addition, this type of concentration carries economic and legal implications.

Resiliency and Security While some degree of consolidation in infrastructure can be beneficial for efficient security upgrades and protocol implementation, domains relying on a single organization introduces a single point of failure. As exhibited during the Dyn and AWS outages, a large-scale DDoS attack on a single organization can lead to many website outages. With this in mind, it is important to strike a balance between distributing reliance across many organizations and limiting redundancy.

Internet consolidation can also introduce the notion of “attractive surveillance targets” [7], where too much information or traffic is controlled by a single entity. Companies like Cloudflare, Amazon, and Akamai, who host content for a large amount of domains, have access to the network traffic to the domains, and therefore can collect more information, not only from the domains themselves, but also from users visiting those domains. Large amounts of user information concentrated within one system intensifies concerns of surveillance by both the controlling company and potential attackers.

Content Moderation Market concentration can give companies the power to selectively moderate content on platforms that they service, sometimes enforcing stricter restrictions than are currently legally required [6]. As regulation continues to lag, these companies will have greater ability to both control online content and influence future policy. These implications are especially pertinent in light of ongoing debate on free speech online. Multi-national companies play an even greater role in content moderation, as they may mediate speech differentially across geo-political lines. In this work, we explain the critical role that name server and web hosts play in the content delivery process. Future work may continue to study how companies can exert control at other points of this process, including at DNS resolvers [25].

6 Conclusion

The consolidation of the hosting of various Internet infrastructure and services is an ongoing trend that potentially threatens Internet resilience, security, competition, and free and open communication. Although many organizations, from the Internet Society to the Internet Engineering Task Force, have expressed concern over this ongoing and evolving trend, we have, to date, only had a limited understanding of the extent and evolution of such consolidation. This paper aims to quantify two aspects of Internet consolidation—authoritative DNS name server hosting and web hosting. To do so, we analyzed the extent of consolidation of DNS authoritative name server providers and web content hosting providers for the most popular 10,000 Internet domains, as enumerated in the Tranco 10K.

Our analysis revealed that two organizations, Amazon and Cloudflare, are responsible for exclusively hosting the name servers for over 40% of domains in the Tranco top 10K, and that only five organizations—Cloudflare, Amazon, Akamai, Fastly, and Google—host about 62% of index pages in the Tranco top 10K, as well as the majority of external page resources for these sites. We also found that more than 75% of domains use only one AS organization for all of its name servers. These results suggest that, in the areas of DNS name server hosting and web hosting, consolidation is indeed significant. Our results nonetheless represent a single snapshot of the current state of affairs. Given the potential consequences of increasing consolidation, continual measurements could shed more light on these trends over time and provide insights into potential dependencies or points of vulnerability for modern Internet services. To facilitate such measurements, we will publicly release both our current measurements and

measurement framework, and we will continue to perform and release updated measurements periodically.

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