

WHOIS Lost in Translation: (Mis)Understanding Domain Name Expiration and Re-Registration

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ABSTRACT

Internet domain names expire when not renewed and may be claimed by a new owner. To date, despite existing work on abuses of residual trust after domain ownership changes, it is not well understood how often and how fast re-registrations occur, and the underlying processes are often over-simplified in scientific literature, leading to a potential bias in those studies. While in principle registration data is available in WHOIS databases, scalability issues and data ambiguities make re-registrations a challenging subject of study in practice. By focusing on domains about to be deleted, we were able to track 7.4 M `com`, `net`, `org`, `biz` and `name` domains over up to ten months to gather data for a survival analysis of re-registrations. Our results show that expiration processes may vary, and that many re-registrations happen soon after deletion, especially for older domains. We also discuss intricacies of WHOIS data to aid in avoiding potential pitfalls, as fast domain ownership changes combined with hidden domain states may pose challenges to operational and research communities.

1. INTRODUCTION

Internet domain names are typically assigned on a first-come, first-served basis. Registrations are valid for a limited time period and must be renewed regularly in order to remain active. When an owner fails to do so, they can still rescue their domain during a short *redemption period*, but ultimately it will be deleted and can be re-registered by any interested party.

In this paper, we aim to quantify the phenomenon of Internet domain expiration and re-registration. While it is known that re-registrations are sometimes done for malicious purposes [8, 13, 15, 17], in general it is not well understood what fraction of expired domains is eventually re-registered, and what the temporal aspects of re-registrations look like. Furthermore, the expiration process of domains is often over-simplified in the literature; registrars have a considerable degree of freedom for their implementations. We aim to shed light on how the process varies in practice, and how it could potentially bias studies that do not account for these subtleties.

An important challenge to answering these questions is that historical domain registration data is difficult to obtain in a scalable way. Information about currently registered domains is publicly available through the WHOIS protocol, but there is no complete archive of prior registrations. Furthermore, as researchers previously pointed out [16], WHOIS is designed for occasional manual use rather than bulk access. The data format of the text-based protocol can be inconsistent, and rate limits restrict the number of possible lookups. Even worse, we show in this paper that there are various ambiguities in WHOIS data that can make it quite complex to correctly infer the state of a domain.

We built a system that discovers domains about to be deleted in DNS zone files and tracks their WHOIS records through the various states of expiration and potentially re-registration. Overall, we track 7.4 M `com`, `net`, `org`, `biz` and `name` domains from August 2015 to June 2016. We carefully filter the collected data to account for various WHOIS intricacies and perform a survival analysis of 6.5 M expired domains with about 16.5 % observed re-registrations.

Our findings show higher rates of re-registration for larger zones and older domains; for instance, around 20 % of expired `com` domains are re-registered within 300 days. Furthermore, there appears to be significant competition over re-registrations since many of them occur in spikes around the earliest availability. The latter

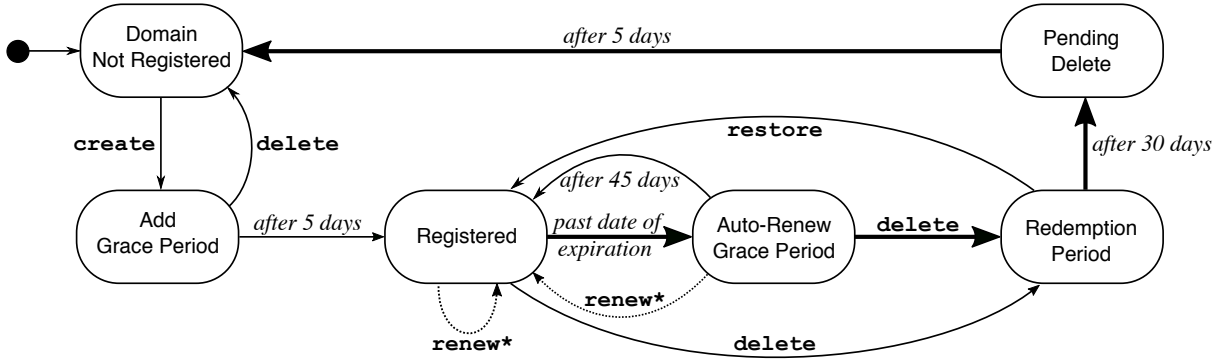


Figure 1: Domain states with transitions due to EPP commands issued by the registrar, or *automatic* transitions if none is issued before the deadline. If a domain is not **deleted** or **renewed** by the registrar before the expiration date, the registry automatically renews it for a year. *Additional states for **renew** and domain transfers omitted.

date does not follow the same pattern for all domains, which contradicts the common misconception of a fixed deletion delay. On a different level, our results also include several lessons about working with WHOIS data that we learned the hard way. Fast domain ownership changes combined with the difficulty of distinguishing the WHOIS records of a recently renewed domain from one that is about to be deleted, for instance, are potential pitfalls when identifying origins of malicious behaviour or surveying the domain ecosystem. We hope that this work will raise awareness for these issues.

2. BACKGROUND & RELATED WORK

Names in the Domain Name System (DNS) are structured hierarchically. Top-level domains (TLDs) such as **com** or **net** are created by the Internet Corporation for Assigned Names and Numbers (ICANN) and then delegated for day-to-day operation to a *registry* such as Verisign. Each registry maintains a directory of the registered second-level names and their authoritative name servers, called a *DNS zone*. Registries delegate billing and customer support to ICANN-accredited *registrars*, companies such as GoDaddy or Gandi, which sell domain names to *registrants* or domain owners.

Domain Lifecycle: Domains are registered for a period of one or more years. If a domain is not renewed before its expiration date, it goes through a series of phases that permit late renewals before the domain is ultimately deleted. Registrars manage the state of the domains they sponsor by connecting to the registries’ systems using the Extensible Provisioning Protocol (EPP) [7]. Figure 1 shows a subset of possible domain states [3], and how EPP commands cause transitions between them [1, 2, 4, 5, 6]. The most common case for domain expiration, and typically the only case mentioned in related work, is a 45-day *auto-renew grace period* followed by a 30-day *redemption period* and a 5-day *pending delete* state [13, 15] – a total of 80 days between the expiration date and the earliest opportunity for re-registration. The corresponding path in the figure is highlighted with bold arrows. In practice, how-

ever, registrars have a considerable degree of freedom when implementing this state machine.

In fact, a domain enters the *auto-renew* state only if it is not renewed or deleted by the registrar before its expiration date. The registry automatically renews domains past their expiration date for one year and grants the registrar up to 45 days to cancel the renewal without becoming liable for the renewal fee. During this time, at the discretion of the registrar, the domain may still be active in the DNS zone and continue to resolve.

When a domain is marked for deletion by the registrar, it is deactivated in the zone and stops resolving. The *redemption period* gives the registrant a final 30 day chance to restore the domain. If not restored, the domain is moved into *pending delete*, and after 5 days, it can be re-registered on a first-come, first-served basis.

The Whois Protocol: Registries maintain databases of registration information for currently registered domains, including creation and expiration dates, the ID of the respective registrar, and currently active EPP status code flags [3]. These databases are accessible to the public via the WHOIS protocol, e.g. to look up the owner of a domain or check availability for registration. WHOIS servers are optimised for manual investigations; they allow lookups of one domain at a time, are heavily rate limited, and contain data about only the current registration in a semi-structured, textual format that is not always consistent [16]. While commercial archives of WHOIS data do exist, the available granularity of data can vary from domain to domain, and the companies do not disclose when and how they collect the data, which all makes these archives ill suited for a systematic study of domain expiration and re-registration.

Related Work: Prior research in the area of domain registrations includes the work on registration intent by Halvorson et al. [10, 11, 12], and a study of registration abuses such as domain tasting [9]. Schlamp et al. [17] describe an attack to take over protected resources by re-registering the expired domains of email addresses. Attackers have also been reported to re-register expired domains that built up a good reputation [8, 13, 15].

Zone	com	net	org	biz	name
Size	123.0 M	15.6 M	10.9 M	2.3 M	168.5 k
Added	111.2 k 0.09 %	11.4 k 0.07 %	7.4 k 0.07 %	1.2 k 0.05 %	77 0.05 %
Removed	84.0 k 0.07 %	10.6 k 0.07 %	6.7 k 0.06 %	1.8 k 0.08 %	121 0.07 %
Sample, max.	25 k 29.6 %	6 k 56.7 %	2 k 30 %	2 k 100 %	200 100 %

Table 1: Median zone size with additions/removals per day (08/2015 – 05/2016) and max. daily sample size.

Two works present a more systematic examination of domain re-registrations: Hao et al. [13] investigate characteristic registration patterns of spam domains and find that among re-registered domains, those later used for spamming tend to be registered faster than non-malicious domains. Lever et al. [15] analyse the maliciousness of domains before and after re-registration with a focus on when malicious behaviour occurs, not when or why a domain is re-registered.

Liu et al. [16] propose a machine learning approach to parse the responses of registrar-level WHOIS servers, which do not have a standardised format. Our work is orthogonal in the sense that we describe how certain domain states may not be visible in a single observation.

3. METHODOLOGY

To measure the re-registration behaviour of domains, we need to know which domains are about to expire, and we need to track how they progress through the expiration states, are deleted, and possibly re-registered.

3.1 Expiring Domain Discovery

It is important to find domain expiration candidates early so that we can extract their original creation and expiration dates before they are deleted. Since some DNS zones are very large, it is inefficient to discover domains approaching their expiration date through exhaustive crawling of WHOIS records; e.g., it took Liu et al. multiple months to crawl the `com` zone [16].

As a more targeted approach, and similar to prior work [15], we consider as expiration candidates the domains removed from the DNS zone. Under their ICANN agreements, registries grant researchers access to daily snapshots of their DNS zone files, that is, the data used to run the zone’s name servers—a list of all second-level domain names that have at least one authoritative name server configured. We download these zone files daily from the registries of `com`, `net`, `org`, `biz` and `name`; Table 1 shows the median of the overall zone size as well as the entries added and removed relative to the previous day. As discussed in Section 2, expiring names are removed from the DNS zone when they enter *redemption period* (or earlier); however, they can also be removed for various other reasons, such as misconfiguration. Since WHOIS records remain active throughout

the 35 days of the *redemption* and *pending delete* periods until the final deletion of the domain, we can extract all required metadata and verify the domain’s status.

3.2 Domain Tracking

To keep track of domains as they evolve through various states of expiration and potentially re-registration, we built a system that schedules periodic WHOIS queries for domains removed from the DNS zone. After a first lookup immediately upon removal, future lookups are scheduled regularly until the results of the lookup indicate either that the domain will not expire in the near future (e.g., it was renewed), or when a re-registration is observed. We stop tracking such domains to reduce the number of lookups needed to run our measurement.

For domains found to be re-registered, if the query date was only five days or less after the creation date, as a precaution we schedule them for another query six days later to rule out the possibility of *domain tasting*: Some registries allow registrars to delete a new domain up to five days after creation (the *add grace period* in Figure 1) and do not charge for the domain. Domain tasting was found to be responsible for 76 % of `com` registrations in 2008, with each registration lasting for an average of 3.4 days, and is said to be used by domain speculators to test for free how much traffic a domain receives [9]. Since we cannot reliably observe all instances of domain tasting at a reasonable query frequency, we remove the cases that we do observe from our data set. That is, we consider only re-registrations that were active for at least six days.

Our experiment lasted a total of 10 months. We inserted domains removed from the zone file each day during the first seven months and kept tracking these domains for three more months, giving us between three and ten months of history for each domain. To keep the number of WHOIS lookups manageable, we performed random sampling of the domains removed from the zone files up to the daily limits outlined in Table 1. This allowed us to handle all domains removed from smaller zones and almost 30 % of even the largest `com` zone. We scheduled WHOIS lookups at a bi-weekly frequency so that we could observe each domains’ records in different expiration states while not overburdening our system. Overall, we collected nearly 86.2 M Whois records from 7.4 M domains in the five zones (Table 2). Since most registries did not publish any query rate limits, we conservatively performed one lookup every 2 s per IP address (20 s for `org`, below the published limit of 15 s). Our crawlers always received valid WHOIS responses without being slowed down or banned.

Unfortunately, when starting our measurement, we were not aware of the many intricacies and hidden domain states of the WHOIS protocol that we describe in Section 3.3. Our analysis revealed that the scheduler had sometimes incorrectly inferred domain states, not the least because some states can be inferred correctly only in retrospect but not at the time of the observation.

To account for this, at the end of our measurement we looked up every domain name ever tracked by our system so that we have at least two WHOIS observations for each domain. While two lookups are sufficient to measure re-registrations, the intermediate data points were necessary in many cases to understand in detail how domain expiration works, and how to filter and post-process the dataset as described in Section 3.4. For future measurement studies, we recommend looking up each domain only twice several months apart, or using periodic but unconditional lookups.

3.3 Whois Data Intricacies

When we first looked at the collected data, we noticed a number of unexpected scenarios, such as decreasing expiration dates and seemingly overlapping registrations for the same domain. Upon further investigation, we found that these cases resulted from domain states that were not explicit in the WHOIS records. We provide an overview of frequent issues that may be of interest to other researchers working with WHOIS data.

Increasing and Decreasing Expiration Dates:

When a registrar does not renew or delete a domain before its expiration date, the registry automatically extends the registration by one year by moving the domain into the *auto-renew* state. However, since intended renewals typically occur before the expiration date, most automatically renewed domains will in fact be deleted during the 45-day grace period and enter *redemption period*, during which the expiration date may or may not decrease by one year to the previous value.

Inconsistent and Incomplete Flag Use: While EPP defines status codes [3] corresponding to the domain states in Figure 1, not all of these possible flags are used in practice, and their use varies by registry and registrar. Out of the five registries in our dataset, only **org** had the *autoRenewPeriod* flag set. For the other registries, it is not possible to tell whether the expiration date shown in the WHOIS record is the actual expiration date or the provisionally extended one—see, e.g., the 2003 discussion on DNSO’s *registrars* mailing list.¹ Note that even for **org**, a single observation during the *redemption* or *pending delete* periods does not reveal whether the year of the expiration date is correct since it often remains at the increased value and only a prior observation of the *autoRenewPeriod* flag could help in disambiguating the data. As another example for the inconsistent use of flags, **com** and **net** use *redemptionPeriod* and *pendingDelete* in a mutually exclusive way, whereas **org** sets both flags simultaneously during *redemption period*.

Delayed Updates: We sometimes observed brief delays between events that we expected to co-occur, such as the beginning of the *auto-renew* period and the increase of the expiration date. This might be due to

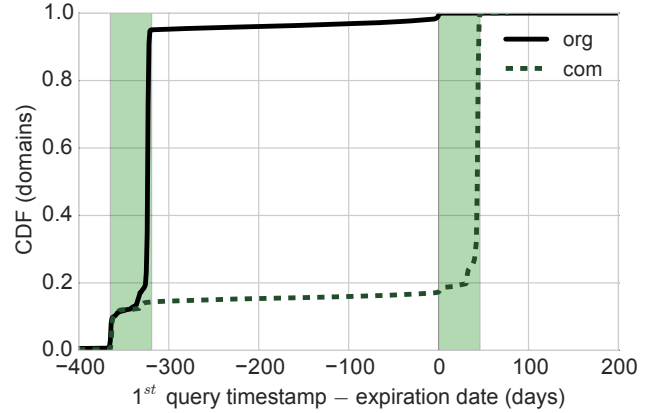


Figure 2: Removal of **com/org** domains from the DNS zone relative to their expiration date. The shaded areas correspond to removals 0 – 46 days after expiration; the left area appears shifted one year due to “auto-renew.”

some changes being made by the registrar while others are done by the registry, as alluded to in the mailing list discussion above. Due to these ambiguities, the state of a domain can often be inferred only in retrospect by making use of multiple WHOIS observations.

3.4 Data Filtering and Post-Processing

Our data encompasses 7.4 M domains from five zones, all with at least two WHOIS observations between three and ten months apart (see Table 2). Although all instances of domain tasting re-registrations were already detected and removed during the scheduling phase, we still need to account for several other artefacts of the data before we can measure re-registration delays.

As the first step, we remove domains that did not expire during our measurement (or were renewed), that is, domains for which all WHOIS observations contain the same creation date and no observation of a “domain not found” response—these domains were likely removed from the DNS zone for reasons other than expiration. Next, we remove domains having a “domain not found” response as the first lookup result. In all likelihood, these are not expirations, but deletions during the *add grace period* (i.e., domain tasting registrations) because they do not go through the *redemption period* and WHOIS records become unavailable immediately.

Our next set of filters is based on the time difference between the first WHOIS lookup, that is, the time the domain was removed from the DNS zone, and the expiration date found in the corresponding WHOIS record. Since we are interested in expiring domains, they should not disappear from the DNS zone before the expiration date, and they should not be removed more than 45 + 1 days after their expiration date, which is the maximum duration of grace periods before the *redemption period* (we add one day to account for possible delays in our pipeline). Since registries may automatically increase the expiration date of expired domains by

¹<http://www.dnsso.org/clubpublic/registrars/Arc02/msg00143.html>

Zone	com	net	org	biz	name
All Domains	5,342,999	1,268,722	425,994	377,299	25,251
No Expiration Observed (unrelated removal from zone)	323,542	71,689	22,180	22,559	2,226
Not Found in 1 st Lookup (domain already deleted)	168,593	26,598	4,074	9,569	5,091
Manually Deleted (>1 y before expiration date)	16,139	3,621	3,181	1,046	326
Atypically Late Removal from Zone File	12,414	2,537	9	277	1
Manually Del. (<1 y)/Late Removal (auto-renew/+1 y)	140,520	40,198	15,219	11,789	1,877
Expired Domains (regular)	4,001,538	973,735	4,716	330,594	10,176
Expired Domains (auto-renew/+1 y)	680,253	150,344	376,615	1,465	5,554
Domains with Observed Re-Registration	845,210	159,876	46,233	28,010	798
Domains without Re-Registration (censored)	3,836,581	964,203	335,098	304,049	14,932

Table 2: Domains in our sample: Subset removed for lack of (typical) expiration, and data used in survival analysis.

one year (Section 3.3), the aforementioned interval can also occur shifted by 365 days. Figure 2 visualises the removal/expiration date time difference for our **org** domains; we retain the domains in the right shaded interval as “regular” expirations, and those in the left shaded interval as “auto-renew” expirations. The vast majority of expiring **org** domains already have their expiration date increased by one year, whereas the opposite is true for first observations of **com**, **net** and **biz** domains.

We remove the domains in the three remaining intervals. The leftmost interval corresponds to domains that were deleted more than one year before their expiration date; these are likely domains that were manually and purposefully deleted. We remove these domains since their deletion time appears unrelated to their expiration date, and because our analysis of re-registration delays is based on the assumption that domains remain active until the expiration date. The rightmost interval contains domains that remained in the DNS zone for longer than expected (one example entered *redemption period* more than 2.5 months after the expiration date). We exclude these atypical cases since they may correspond to registrar errors or special handling of domains under dispute or suspicion of maliciousness. The middle interval is a combination of the two aforementioned cases, that is, domains manually deleted less than one year before the expiration date, and “auto-renew” domains removed from the DNS zone later than expected.

After filtering, we are left with between 15.7k (**name**) and 4.68M domains (**com**). For the re-registration analysis, we subtract one year from the expiration date of domains in the “auto-renew” expiration interval, and we use only the first and last observed WHOIS response per domain. The result of the last lookup is either “domain not found,” in which case no re-registration has been observed, or it is a valid record containing the creation date of the new re-registration instance.

3.5 Limitations

Since we seed our system with domains that are removed from zone files, our study does not include domains that are registered but do not appear in a DNS zone, such as when the domain is not meant to resolve.

Our study excludes manually deleted domains since the deletion may be unrelated to the expiration date, which in turn is the basis for our re-registration analysis.

Similarly, we analyse only domains that go through the *redemption* and *pending delete* periods, which guarantees that they are removed from the DNS zone. We cannot characterise private domain sales or auctions that result in ownership transfers rather than expiration, deletion and re-registration cycles because such transfers may keep the domain active in the DNS zone and retain the original creation date in the WHOIS data. Note however that we can quantify re-registrations no matter if a domain re-appears in the DNS zone or not since we use WHOIS signals for detection.

4. RE-REGISTRATION ANALYSIS

In our measurement, we added samples of domains removed from DNS zones each day for seven months and tracked them until the end of our measurement after ten months. From a statistical point of view, our re-registration data is *right-censored* because the observation period is not the same for all domains. A common way to deal with such data is *survival analysis*, for which we use the Kaplan-Meier (KM) estimator [14].

The survival function $S(t)$ corresponds to the probability that an expired domain has not yet been re-registered after time t . We define the random variable T to represent the time between a domain’s expiration date and the next creation date. Note that under this definition, the re-registration delay T includes a time span during which the domain has already expired but is not yet available for re-registration because it is still in the *auto-renew*, *redemption* or *pending delete* state. We include expiration delays in our definition because it is difficult to predict when a domain will be available for re-registration, as we will show below. With $F(t)$ the cumulative distribution function (CDF) of T , the survival function is defined as follows:

$$S(t) = Pr[T > t] = 1 - F(t)$$

The KM estimator makes no assumption about the distribution of re-registration delays. Its input is the set of observed re-registration delays as defined above and, for

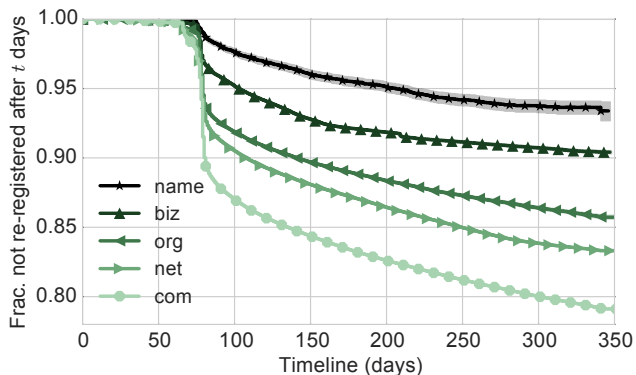


Figure 3: Survival plot for domains not re-registered (95% confidence intervals). Smaller zones also have a smaller *fraction* of re-registrations.

the censored part of our data, the set of non-registration time spans (i.e., expiration date until the most recent “domain not found” WHOIS observation). Our survival analysis is based on observed re-registrations of over 1 M domains in five zones, and almost 5.5 M domains not re-registered during the measurement (Table 2).

Overall Re-Registration Delay: Figure 3 shows the survival functions for the five zones. Those with a smaller size (see Table 1) also exhibit a smaller *rate* of re-registrations for expired domains. The most popular zone, *com*, has a re-registration rate of about 20% after 300 days. An interesting observation is that on our time scale, domains that are re-registered tend to be re-registered early. All zones exhibit a spike of re-registrations just before day 80; for *com*, days 0 – 80 see about as many re-registrations as days 80 – 350. Eighty days correspond to the maximum deletion delay after expiration (45 days in *auto-renew*, 30 in *redemption period* and 5 in *pending delete*). Therefore, we hypothesise that these re-registrations illustrate registrants taking over expired domains as soon as possible.

Earliest Re-Registrations: Immediate re-registration of deleted domains is the core business of so-called *drop-catch* services. For a fee, they attempt to “catch” a domain automatically as soon as it “drops.” Being fully automated, and with multiple companies in direct competition, we assume that domain registrations by drop-catch services happen as early as possible, and we can use those registrations to gain better insights into the expiration behaviour of domains.

Many online explanations of domain expiration behaviour would mislead the reader into believing that the delay is always 80 days after the expiration date. However, the steepest increase in re-registrations we observe in our data is on days 78 and 79. The reason is that the *auto-renew* grace period has a *maximum* duration of 45 days, after which the registrar becomes liable for a year’s worth of domain renewal fees. To avoid the fee, registrars can delete a domain at any point during the 45 days, and they appear to do so a few days early.

In fact, the first clearly visible increase of domain re-registrations begins around day 35. Although these represent only a tiny fraction overall (0.1% of *com* domains are re-registered before day 40), they again contradict the common misconception of an 80-day deletion delay. Based on our understanding of domain states (Figure 1), domains re-registered around day 35 likely never entered the *auto-renew* grace period but were instead deleted by the registrar on the expiration date, which made them go directly into *redemption period*. This seems to be a matter of how registrars implement EPP state transitions on their end. When looking at the prior registrars of domains re-registered before 50 days, we find that there are only relatively few of them, and around half or more of the re-registrations of their prior domains occur within 50 days, which suggests that those state transitions are regular behaviour for these registrars. Taken together, our findings indicate that there is no general pattern to predict domain deletion delays on a per-zone basis; if at all, it may exist on a per-registrar basis at best. (Our data counts over 2,000 registrars).

Re-Registrations by Prior Age: As a first step toward predicting which expired domains are more likely to be re-registered than others, we break down the survival function for *com* by the age of the domain before it expired. Figure 4 illustrates that domains that were previously registered for longer time spans are more likely to be re-registered than short-lived domains. A prior registration period of nine or more years, for instance, makes a domain about three times more likely to be re-registered than a domain that was not renewed after its initial year. Longer prior registration periods may indicate that such a domain was more desirable to keep, and it may have established a good online reputation that could be valuable not only to regular businesses or Internet users looking to establish a presence under a newly available, coveted name, but also to spammers [13] or other miscreants aiming to exploit residual trust [15, 17], and more generally to domain speculators hoping to resell for a profit, or to monetise the domain not with content, but advertising [18]. Note however that age does not necessarily mean popularity; fewer than 200 domains in our sample appear on lists of popular Internet hosts such as the Alexa Top 1 M.

5. DISCUSSION & CONCLUSIONS

When we initially set out to quantify re-registration probabilities and delays, we expected this to be a relatively straight-forward measurement task, with WHOIS data collection at scale being the biggest anticipated challenge. As we found out, however, domain names can and do expire in various different ways that are not fully explored in relevant literature; variations in how sponsoring registrars implement expiration flows make it challenging to predict the time between expiration date and deletion. Furthermore, some domain states are not visible in WHOIS data, and it is easy to draw incor-

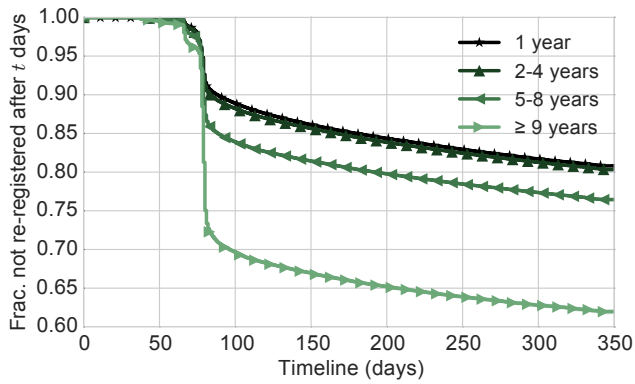


Figure 4: Survival plot for com domains not re-registered, based on prior registration length (95 % confidence intervals invisible). Older domains are more likely to be re-registered.

rect conclusions from a single observation. For instance, a domain with an expiration date months ahead may very well cease to exist a few weeks after the observation due to domain tasting or a retroactively canceled automatic renewal. These very common patterns can cause statistics about the remaining lifetime of domains to be overestimated, or make a distribution showing the age of registered domains in a zone include domains that, strictly speaking, do not exist at observation time.

Ambiguities in WHOIS responses make the data difficult to work with not only in large-scale studies like ours, but also for manual, one-time investigations. We believe that any successor to the WHOIS protocol should aim to enforce a well-defined, common format that is consistently used across registries and registrars, and make domain states more explicit. A public audit trail of domain state modifications, for instance, could satisfy this requirement and would also better support investigations of past (mis)behaviour of domains.

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