Where Did the Web Archive Go?

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Abstract. To perform a longitudinal investigation of web archives and detecting variations and changes repleying individual archived pages, or mementos, we created a sample of 16,627 mementos from 17 public web archives. Over the course of our 14-month study (November, 2017 – January, 2019), we found that four web archives changed their base URIs and did not leave a machine-readable method of locating their new base URIs, necessitating manual rediscovery. Of the 1,981 mementos in our sample from these four web archives, 537 were impacted: 517 mementos were rediscovered but with changes in their time of archiving (or Memento-Datetime), HTTP status code, or the string comprising their original URI (or URI-R), and 20 of the mementos could not be found at all.

Keywords: Web Archives · Memento · Archive-It.

1 Introduction

Web archives are established with the objective of providing permanent access to archived web pages, or mementos. Mementos should be accessible in web archives even after the corresponding live web page is no longer available. The Uniform Resource Identifier (URI) of the archived web page should not change over time, otherwise this defeats the purpose of using archived URIs. When web archives change their infrastructure, resulting in new base URIs for mementos, there should be machine-readable breadcrumbs left so that the older mementos still work.

We wanted to study the fixity of archived web pages, so we gathered a diverse set of mementos from 17 web archives distributed over 1996-2017. Our longitudinal experiment involved replaying the same mementos over the course of 14 months [7,8,9,10]. During our study, we noticed that we were no longer able to access any mementos from four web archives (Library and Archives Canada, the National Library of Ireland, the Public Record Office of Northern Ireland, and

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Perma.cc) at certain points, and there was no machine-readable redirection to
the new URIs. This paper outlines our discovery of the disappearance of these
mementos and our efforts to find their new locations.

2 Background

Memento \cite{Memento} is an HTTP protocol extension that allows for content-negotiation
of web resources in the time dimension. The Memento protocol is supported by
most public web archives, including those included in this study. In the Memento
framework, the identifier of an original resource from the live Web is a \textit{URI-R},
and the identifier of an archived version of that resource at a particular point in
time is a \textit{URI-M}, or \textit{memento}.

When a request is made to a Memento-compatible web archive for a URI-M
that the archive holds, the archive will include Memento headers in the HTTP
response. In particular, the Memento-Datetime HTTP Response header (e.g.,
\textit{Memento-Datetime: Sun, 08 Jan 2017 09:15:41 GMT}) is sent by the archive
to indicate the datetime at which the resource was archived.

A request for a URI-M indicates both the URI-R and the Memento-Datetime
requested. If an archive does not have a memento for the requested URI-R at that
particular Memento-Datetime, the archive may return an HTTP \texttt{30x Redirect}
status with a Location response header indicating the temporally closest URI-M
that the archive does have available.

Many, though not all, Memento-compatible web archives construct URI-Ms
that contain both the URI-R and the Memento-Datetime. For example, for the
URI-M http://www.collectionscanada.gc.ca/webarchives/20060208075019/h
\texttt{ttp://www.cdc.gov/}, the URI-R is http://www.cdc.gov/ and the Memento-
DateTime is represented by the 14-digit date string \texttt{20060208075019}, which is
Wed, 08 Feb 2006 07:50:19 GMT.

Web archives can differ in how they handle URI-Ms that returned an HTTP
\texttt{404 Not Found} or \texttt{503 Service Unavailable} status code during capture. Some
archives will return an HTTP \texttt{200 OK} status code and include the archived
error page in the HTTP response body. Other archives, such as the Internet
Archive and Archive-It, will respond with the original status code; they return
an archived \texttt{404 Not Found} for URI-Ms that returned a \texttt{404 Not Found}
on capture.

When a new archive receives an archived collection from the original archive,
it may apply some post-crawling techniques to the received files (e.g., WARC
files) including deduplication, spam filtering, and indexing. This may result in
mementos in the new archive that have different values of the Memento-Datetime
compared to their corresponding values in the original archive.

3 Methodology

Our original study accessed 16,627 mementos from 17 public web archives 39
times over a period of 14 months (Nov 2017 - Jan 2019); the details of data
selection are described elsewhere [10]. For each URI-R chosen, we used the LANL Memento Aggregator [13] in November 2017 to discover URI-Ms in different web archives. The data set is available in GitHub [18]. Our goal was to study the fixity of mementos. We would expect that replaying the same memento over time should result in the same representation, but that is not always the case. During the time period of this study, we found instances where none of the mementos from particular archives were available. This led us to the investigations we report in this paper.

We used the Squidwarc headless crawler [11] to load each URI-M (including executing JavaScript to ensure loading all embedded resources) and download the contents into a WARC file [16]. Saving the data in WARC files allowed us to record all HTTP response headers and content for all of the resources that made up the composite memento [1].

In our analysis, we refer to the archive from which mementos have moved as the original archive and the archive to which the mementos have moved as the new archive. We are strict in our approach to determine if a memento in the new archive is the same as a corresponding memento in the original archive: we compare the Memento-Datetimes, the URI-Rs, and the final HTTP status codes, and if any of these values do not match, we declare that it is a missing memento.

4 Findings

Table 1 shows the original and new archives, if the Memento-Datetimes matched, if the HTTP status codes matched, and if the URI-Rs matched, along with the number of mementos in each category. The number of mementos we consider as missing are in bold. We studied a total of 1,981 mementos from these four archives (we only count the NLI mementos once), classified 537 as missing (i.e., different Memento-Datetimes, status codes, or URI-Rs), and were unable to rediscover any version of 20 mementos in their corresponding new archives (these have NO in all columns in the table).

4.1 Library and Archives Canada

In our study, we had 351 mementos from collectionscanada.gc.ca maintained by Library and Archives Canada (LAC). In July 2018 we discovered that all 351 URI-Ms from this archive were redirecting to http://www.bac-lac.gc.ca/eng/discover/archives-web-government/Pages/web-archives.aspx, the main webpage of the Government of Canada Web Archive. By viewing that live webpage, we discovered that the contents of this web archive had moved to webarchive.bac-lac.gc.ca. Additional details of our findings regarding LAC can be found in our blog post [4].

Because LAC still controls the domain of the original archive (collectionscanada.gc.ca), it would be possible for requests to the original archive to redirect
Table 1: Web archive changes based on how mementos changed. The number of missing mementos is shown in **bold**.

| Original archive      | Same Memento-Datetimes? | Same status codes? | Same URI-Rs? | URI-Ms |
|-----------------------|-------------------------|--------------------|--------------|-------|
| collectionscanada.gc.ca → bac-lac.gc.ca | Yes                     | Yes                | Yes          | 302   |
|                       | NO                      | Yes                | Yes          | **28** |
|                       | NO                      | Yes                | NO           | 18    |
|                       | NO                      | NO                 | Yes          | 1     |
|                       | NO                      | NO                 | NO           | 2     |
| europarchive.org/NLI → internetmemory.org/NLI | Yes                     | Yes                | Yes          | 979   |
|                       | Yes                     | NO                 | Yes          | 1     |
|                       | Yes                     | NO                 | NO           | 2     |
|                       | NO                      | Yes                | Yes          | 184   |
|                       | NO                      | Yes                | NO           | 5     |
| internetmemory.org/NLI → archive-it.org | Yes                     | Yes                | Yes          | 355   |
|                       | Yes                     | NO                 | Yes          | 2     |
|                       | NO                      | Yes                | Yes          | 106   |
|                       | NO                      | Yes                | NO           | 6     |
| proni.gov.uk → archive-it.org | No                      | Yes                | Yes          | 164   |
|                       | No                      | No                 | Yes          | 18    |

Fig. 1: An example of a memento moved from **collectionscanada.gc.ca** to **webarchive.bac-lac.gc.ca**.

This would maintain link integrity via “follow-your-nose” from the old URI-M to the new URI-M.
But since we found that every memento request to the original archive redirected to the home page of the new archive, we had to manually intervene to detect the corresponding URI-Ms of the mementos in the new archive. This was done by replacing www.collectionscanada.gc.ca/webarchives with webarchive.bac-lac.gc.ca:8080/wayback in the URI-Ms of the original archive. For instance, http://www.collectionscanada.gc.ca/webarchives/20051228174058/http://nationalatlas.gov/ is now available at http://webarchive.bac-lac.gc.ca:8080/wayback/20051228174058/http://nationalatlas.gov/

Many of the mementos from LAC have been archived by the Internet Archive, meaning that the URI-Ms are archived, not just the URI-Rs. For instance, http://web.archive.org/web/20160720232234/http://www.collectionscanada.gc.ca/webarchives/20071125005256/http://www.phac-aspc.gc.ca/publicat/ccdr-rmtc/95vol21/index.html is a URI-M captured in the Internet Archive in July 2016 of a URI-M captured by LAC in November 2007. Because of this, we were able to estimate when LAC made the change from www.collectionscanada.gc.ca to webarchive.bac-lac.gc.ca. It appears that LAC began using the new archive around Dec 2011, with http://web.archive.org/web/20111211144417/http://www.collectionscanada.gc.ca/linking to http://web.archive.org/web/2011120710200/http://www.bac-lac.gc.ca/eng/Pages/default.aspx. Starting in February 2017, the Internet Archive was capturing mementos from both webarchive.bac-lac.gc.ca:8080/wayback/ and collectionscanada.gc.ca/webarchives/, indicating that LAC had two separate archives operational concurrently, but only URI-Ms from collectionscanada.gc.ca were being returned to the Memento LANL Aggregator.

We classified 49 out of 351 mementos from www.collectionscanada.gc.ca as missing because they cannot be retrieved exactly from the new archive as they were in the old archive. Instead, the new archive responds with other mementos that have different Memento-Datetimes. For example, when we requested the URI-M http://www.collectionscanada.gc.ca/webarchives/20060208075019/http://www.cdc.gov/ from the original archive on February 27, 2018, we received the HTTP status 200 OK and a Memento-Datetime of Wed, 08 Feb 2006 07:50:19 GMT. Then, we requested the corresponding URI-M, http://webarchive.bac-lac.gc.ca:8080/wayback/20060208075019/http://www.cdc.gov/ from the new archive. This request is redirected to another URI-M, http://webarchive.bac-lac.gc.ca:8080/wayback/20061026060247/http://www.cdc.gov/, which has a

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```
# With mod_rewrite
RewriteEngine on
RewriteRule "^/webarchives/(\d{14})/(.+)" http://webarchive.bac-lac.gc.ca:8080/wayback/$1/$2 [L,R=301]
```

Fig. 2: The Apache mod_rewrite rules that can be used to handle redirects from www.collectionscanada.gc.ca to webarchive.bac-lac.gc.ca
different Memento-Datetime (Thu, 26 Oct 2006 06:02:47 GMT), resulting in a delta of about 260 days. In addition, the content of the memento in the new archive is different from the content of the memento from the original archive. Figure 3 shows the difference between the original Memento-Datetime and the new Memento-Datetime for each URI-M.

We also found that the HTTP status codes of URI-Ms in the new archive might not be identical to the HTTP status code of the corresponding URI-Ms in the original archive. For example, the HTTP request for the URI-M [http://www.collectionscanada.gc.ca/webarchives/20070220181041/http://www.berlin.gc.ca/] from the original archive resulted in the multiple HTTP 302 redirects before ending up with the HTTP status code 404 (Figure 4).

When we requested the corresponding URI-M from the new archive, it ended up with the HTTP status code 200 (Figure 5):

Additionally, as of this writing, it appears that all URI-Ms in the new archive are redirecting to [https://www.bac-lac.gc.ca/eng/discover/archives-web-government/Pages/web-archives.aspx] which states that “the Government of Canada Web Archive is currently not available”. This message has been displayed on the webpage since April 2020.

Although this is outside of our 14-month study, this effectively means that all 351 LAC mementos are currently missing.
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4.2 National Library of Ireland

In May 2018, we discovered that 979 mementos from the National Library of Ireland (NLI) collection that were originally hosted by The European Archive at [europarchive.org](http://europarchive.org) were moved to [internetmemory.org](http://internetmemory.org) hosted by the Internet Memory Foundation. This appears to have just been a domain name change, as The European Archive announced its name change to the Internet Memory Foundation in 2011 (Figure 6b), but had been still returning URI-Ms with the domain [europarchive.org](http://europarchive.org) to the LANL Memento Aggregator. Although there was a human-readable notice that the domain name would be changing, there was no machine-readable notice provided. In addition to using `mod_rewrite` to provide automatic redirects, another option would be to use the Sunset HTTP response header [20] on requests for URI-Ms from the original archive. In September 2018, we found that the collection of mementos had been moved to Archive-It ([archive-it.org](http://archive-it.org)) in collection [https://archive-it.org/collections/10702](https://archive-it.org/collections/10702) Figure 6.
shows a single memento represented in the three different archives. Additional

(a) In europarchive.org  (b) European Archive announcing their
name change to IMF

c) In internetmemory.org  (d) In archive-it.org

Fig. 6: An example of a memento moved from europarchive.org to internetmemory.org and then to archive-it.org

details of our findings regarding NLI can be found in our blog post [5].

There were no changes in the 979 mementos (other than their URIs) when they moved from europarchive.org to internetmemory.org thus our assumption that this was only a domain name change. As with LAC, the European Archive did not use URL rewriting to automatically redirect requests for URI-Ms with the collection.europarchive.org domain to collections.internetmemory.org we had to manually make the changes in our dataset. In addition after the changeover, the main webpage for europarchive.org itself was no longer main-
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The movement of mementos from these archives will affect link integrity across web resources that contain links to mementos from europarchive.org and internetmemory.org. In addition, as shown in Figure 6, the custom archive banners of the European Archive and IMF appear to be the same. Via these banners, the archives allow users to view the number of available mementos per year and the representation of a selected memento in the same page. Archive-It, on the other hand, uses a basic playback banner as shown in Figure 6.

We found that upon moving to Archive-It, 192 of the original 979 mementos were missing and cannot be retrieved from the new archive. For these missing mementos, the new archive responds with other mementos that have different values for the Memento-Datetime, the URI-R, or the HTTP status code. One example shows a memento that cannot be found in the new archive with the same Memento-Datetime as it was in the original archive. When requesting the URI-M http://collections.internetmemory.org/nli/20121221162201/http://bbc.co.uk/news/ from the original archive on September 3, 2018, the archive responded with 200 OK, and the Memento-Datetime was Fri, 21 Dec 2012 16:22:01 GMT. Then, we requested the corresponding URI-M, http://wayback.archive-it.org/10702/20121221162201/http://bbc.co.uk/news/ from the new archive. The request redirected to another URI-M http://wayback.archive-it.org/10702/20121221163248/http://www.bbc.co.uk/news/, as shown in Figure 7.

![Fig. 7: The HTTP status codes of the URI-M](http://wayback.archive-it.org/10702/20121221162201/http://bbc.co.uk/news/)

$ curl --head --location --silent http://wayback.archive-it.org/10702/20121221162201/http://bbc.co.uk/news/ | egrep -i "(HTTP/|^location:|^Memento-Datetime)"

HTTP/1.1 302 Found
Location: /10702/20121221163248/http://www.bbc.co.uk/news/
HTTP/1.1 200 OK
Memento-Datetime: Fri, 21 Dec 2012 16:32:48 GMT

![Fig. 7: The HTTP status codes of the URI-M](http://wayback.archive-it.org/10702/20121221163248/http://www.bbc.co.uk/news/)

Although the representations of both mementos are identical (except for the archival banners), we consider the memento from the original archive as missing because both mementos have different values for Memento-Datetime (i.e., Fri, 21 Dec 2012 16:32:48 GMT in the new archive) for a delta of about 10 minutes. Even though the 10-minute delta might not be semantically significant (apparently just a change in the canonicalization of the URI-R, with bbc.co.uk redirecting...
to [www.bbc.co.uk](http://www.bbc.co.uk), we do not consider it to be the same since the values of the Memento-Datetime are not identical. Figure 8 shows the difference between the original Memento-Datetime and the new Memento-Datetime for each URI-M.

![Graph showing the difference between the Memento-Datetimes for URI-Ms from internetmemory.org and the corresponding URI-Ms from archive-it.org.](image)

**Fig. 8:** Difference between the Memento-Datetimes for URI-Ms from internetmemory.org and the corresponding URI-Ms from archive-it.org.

The second example shows a memento that has different values for the Memento-Datetime and URI-R compared to the corresponding values from the original archive. When requesting the memento [http://collections.internetmemory.org/nli/20121223122758/http://www.whitehouse.gov/](http://collections.internetmemory.org/nli/20121223122758/http://www.whitehouse.gov/) on September 03, 2018, the original archive returned 200 OK for an archived 403 Forbidden. When requesting the corresponding memento from archive-it.org [http://wayback.archive-it.org/10702/20121223122758/http://www.whitehouse.gov/](http://wayback.archive-it.org/10702/20121223122758/http://www.whitehouse.gov/) the request redirected to another URI-M [http://wayback.archive-it.org/10702/201212222130/http://www.whitehouse.gov/administration/eop/nec/speeches/gene-sperling-remarks-economic-club-washington](http://wayback.archive-it.org/10702/201212222130/http://www.whitehouse.gov/administration/eop/nec/speeches/gene-sperling-remarks-economic-club-washington) which is 200 OK. Not only are the values of the Memento-Datetime different, but also the URI-Rs.

Another change we found was in the way the archives handled archived HTTP 4xx/5xx status codes. The replay tool in the original archive was configured so that it returned the status code 200 OK for archived 4xx/5xx. For example, when requesting the memento [http://collections.internetmemory.org/nli/20121021203647/http://www.amazon.com/](http://collections.internetmemory.org/nli/20121021203647/http://www.amazon.com/) on September 03, 2018, the original archive returned 200 OK for an archived 503 Service Unavailable. Even the HTTP
status code of the inner iframe in which the archived content is loaded returned 200 OK. When requesting the corresponding memento [http://wayback.archive-it.org/10702/2012012303647/http://www.amazon.com/] as described in Section 2, Archive-It properly returns the status code 503 Service Unavailable for an archived 503 response.

Finally, we found that some HTTP status codes of URI-Ms in the new archive might not be identical to the HTTP status code of the corresponding URI-Ms in the original archive. For example, the HTTP request of the URI-M [http://collections.internetmemory.org/nli/20121223031837/http://www2008.org/] to the original archive resulted in 200 OK (Figure 10). The request to the corresponding URI-M [http://wayback.archive-it.org/10702/20121223031837/http://www2008.org/] from Archive-It results in 404 Not Found as the cURL session in Figure 9 shows:

```
$ curl --head --silent http://wayback.archive-it.org/10702/20121223031837/http://www2008.org/
HTTP/1.1 404 Not Found
Server: Apache-Coyote/1.1
Content-Security-Policy-Report-Only: default-src "self"
[...]
Content-Type: text/html;charset=utf-8
Content-Length: 4902
Date: Thu, 05 Sep 2019 08:28:27 GMT
```

Fig. 9: The HTTP status codes of the URI-M [http://wayback.archive-it.org/10702/20121223031837/http://www2008.org/] from the new archive [archive-it.org].

We note that the move to Archive-It included a change of web archiving platform, which can affect the replay of mementos. Therefore, when the original WARC files were moved to the new platform, differences in indexing, replay, URI canonicalization, and handling of HTTP redirections may explain some of the differences in the values of Memento-Datetime, URI-R, and HTTP status code in the new archive.

### 4.3 Public Record Office of Northern Ireland (PRONI)

The Public Record Office of Northern Ireland (PRONI) Web Archive was also hosted by the European Archive/IMF, but using a custom domain, `webarchive.proni.gov.uk`. In October 2018, mementos in the PRONI archive were moved to Archive-It (`archive-it.org`) in the collection at [https://archive-it.org/collections/11112](https://archive-it.org/collections/11112) as shown in Figure 11. After the move, we found that 114 of the original 469 mementos in our study were missing. Additional details of our findings regarding PRONI can be found in our blog post [6].
As with LAC and NLI, requests for URI-Ms in PRONI do not automatically redirect to mementos at Archive-It. In fact, every request to a URI-M in the PRONI archive now returns a 404 Not Found status code, as the cURL session in Figure 12 shows.
However, users of the archive can indirectly find the corresponding URI-Ms because [https://webarchive.proni.gov.uk](https://webarchive.proni.gov.uk) provides a list of the URI-Rs for which mementos have been created. Let us consider finding the corresponding memento in Archive-It for the PRONI memento [http://webarchive.proni.gov.uk/20150318223351/http://www.afbini.gov.uk/](http://webarchive.proni.gov.uk/20150318223351/http://www.afbini.gov.uk/) which has a URI-R of [http://www.afbini.gov.uk/](http://www.afbini.gov.uk/) and a Memento-Datetime of Wed 18 Mar 2015 22:33:51 GMT. From the index at webarchive.proni.gov.uk, we can click on the URI-R [www.afbini.gov.uk](http://www.afbini.gov.uk) which will redirect to an Archive-It HTML page that contains all available mementos for the selected URI-R. Then, we choose 2015-03-18, the same Memento-Datetime as in the original archive. In addition, once the Archive-It collection ID (11112) is known, URI-Ms from PRONI can be transformed to corresponding Archive-It URI-Ms. For example, the memento [http://webarchive.proni.gov.uk/20100218151844/http://www.berr.gov.uk/](http://webarchive.proni.gov.uk/20100218151844/http://www.berr.gov.uk/) is now available at [http://wayback.archive-it.org/11112/20100218151844/http://www.berr.gov.uk/](http://wayback.archive-it.org/11112/20100218151844/http://www.berr.gov.uk/) The representations of both mementos are illustrated in Figure 13.

Even though the PRONI collection was hosted by the European Archive, its URI-Ms did not change when [europarchive.org](https://europarchive.org) became [internetmemory.org](https://internetmemory.org). It appears that PRONI served mementos under [proni.gov.uk](https://proni.gov.uk) while using the hosting services provided by the European Archive/IMF. Thus, the regular users of the PRONI archive did not notice any change in URI-Ms. We do not believe custom domains are available with Archive-It, so PRONI was unable to continue to host their mementos in their own URI namespace.

Unlike the European Archive and IMF, PRONI still owns the domain name of the original archive, [webarchive.proni.gov.uk](https://webarchive.proni.gov.uk). Therefore, to maintain link integrity via “follow-your-nose”, PRONI could issue redirects (even though it currently does not) to the corresponding URI-Ms in Archive-It. For example,
since PRONI uses the Apache web server, the mod rewrite rule could be used to perform automatic redirects as shown in Figure 14.

```apache
# With mod_rewrite
RewriteEngine on
RewriteRule "^/(\d{14})/(.+)$" http://wayback.archive-it.org/11112/$1/$2 [L,R=301]
```

Fig. 14: The Apache mod rewrite rules that can be used to handle redirects from webarchive.proni.gov.uk to archive-it.org.

For the 114 missing mementos, the new archive responds with other mementos that have different values for the Memento-Datetime, the URI-R, or the HTTP status code. For example, when requesting the URI-M http://webarchive.proni.gov.uk/20160901021637/https://www.flickr.com/ from the original archive on Dec 1, 2017, the archive responded with 200 OK, and a Memento-Datetime of Thu, 01 September 2016 02:16:37 GMT. When we requested the corresponding URI-M http://wayback.archive-it.org/11112/20160901021637/https://www.flickr.com/ from the new archive, the request was redirected to another URI-M http://wayback.archive-it.org/11112/20170401014520/https://www.flickr.com/ The representations of both mementos are identical (except for the archival banners). However, these mementos have different Memento-Datetime values (i.e., Fri, 21 Apr 2017 01:45:20 GMT in the new archive) for a delta of about 211 days. Figure 15 shows the difference between the original Memento-Datetime and the new Memento-Datetime for each URI-M.
We found that 63 of the 114 missing mementos have Memento-Datetime values with a delta of less than 11 seconds. For example, the request to the memento http://webarchive.proni.gov.uk/20170102004044/http://www.fws.gov/ from the original archive on November 18, 2017 returned a 302 redirect to http://webarchive.proni.gov.uk/20170102004044/https://fws.gov/. The request to the corresponding memento http://wayback.archive-it.org/11112/20170102004044/http://www.fws.gov/ from the new archive redirects to the memento http://wayback.archive-it.org/11112/20170102004051/https://www.fws.gov/. There is a 10-second difference between the values of the Memento-Datetimes, which might not be semantically significant, but we do not consider the mementos identical because of the difference in the Memento-Datetime values.

Since PRONI used the same replay engine as NLI (when both were hosted by the European Archive/IMF), it returned the status code 200 OK for archived 4xx/5xx responses. For example, when requesting the memento http://webarchive.proni.gov.uk/20160216154000/http://www.megalithic.co.uk/ on 2017-11-18, the original archive returned 200 OK for an archived 403 Forbidden. Even the HTTP status code of the inner iframe in which the archived content is loaded returned 200 OK. When requesting the corresponding memento http://wayback.archive-it.org/11112/20160216154000/http://www.megalithic.co.uk/ Archive-It properly returns the status code 403 for an archived 403 response.
Mementos may disappear when moving from the original archive to the new archive. For example, the request to the URI-M http://webarchive.proni.gov.uk/201404081855512/http://www.www126.com/ from the original archive resulted in 200 OK. The request to the corresponding URI-M http://wayback.archive-it.org/11112/20140408185512/http://www.www126.com/ from Archive-It results in 404 Not Found. Before transferring collections to the new archive, it is possible that the original archive reviews collections and removes URI-Rs/URI-Ms that are considered off-topic [2,17,3] or spam (e.g., the URI-R www.www126.com is about auto insurance).

4.4 Perma.cc

The Perma.cc archive [21] is maintained by the Harvard Law School Library and has the goal of providing permanent URIs for archived webpages for use in academic publications. When a user archives a webpage in Perma.cc, the user is provided a unique “Perma Link” as the URI-M (e.g., https://perma.cc/T8U2-994F). This is different than the URI-Ms from many other archives that include the 14-digit Memento-Datetime and URI-R in the URI-M.

Prior to 2020, mementos were accessible via long-form URI-Ms, for instance http://perma-archives.org/warc/20170731024959/https://www.tmall.com/. These long-form URI-Ms were what had been returned to the LANL Memento Aggregator and are the form we used in our longitudinal study.

On February 5, 2020, Perma.cc deployed new support for Memento, which involved changing the endpoints for Memento services and the URI-Ms provided [14]. Some of the changes included removing access to the URI-Ms of the form http://perma-archives.org/warc/... that we had been using and only returning mementos with the Perma Link URI-Ms, such as https://perma.cc/T8U2-994F. Another change removed embedded resources from Memento access and began only providing access to top-level pages that were public, user-initiated captures. Requests for mementos of non-top level pages would return 404 Not Found.

Our original study included 182 long-form URI-Ms from Perma.cc. After the change, we were able to find only 164 corresponding short-form URI-Ms, resulting in 18 mementos that could not be found at all. It is possible that these missing mementos were not top-level URI-Ms or that they were private Perma Links, both of which are no longer replayable. However, in all 164 cases, the corresponding mementos had different Memento-Datetime values, with delta ranging from one second to three years. Figure 16 shows each URI-M and the difference between the original Memento-Datetime and the new Memento-Datetime.

5 Conclusion

The main goal of web archives is to provide permanent access to web resources using consistent URIs. Links to such archived resources are used in academic publications so that the information cited remains available even if the resource on the live Web changes or disappears. Our study provides a cautionary tale for
archives that have to change domains or web archiving platforms. In a study of 16,627 mementos over 17 public web archives, we found that four archives changed their domains without providing a machine-readable notification, affecting 1,981 mementos from our study. Of these, we were not able to find 537 identical mementos in the new archives, 20 of which had disappeared completely. The data set is available in GitHub [18].

References

1. Ainsworth, S.G., Nelson, M.L., Van de Sompel, H.: A framework for evaluation of composite memento temporal coherence. Tech. Rep. arXiv:1402.0928, arXiv (2014)
2. AlNoamany, Y., Weigle, M.C., Nelson, M.L.: Detecting off-topic pages in web archives. In: Proceedings of Theory and Practice of Digital Libraries (TPDL). pp. 225–237 (2015). https://doi.org/10.1007/978-3-319-24592-8_17
3. AlNoamany, Y., Weigle, M.C., Nelson, M.L.: Detecting off-topic pages within timemaps in web archives. International Journal on Digital Libraries 17, 203–221 (Sep 2016). https://doi.org/10.1007/s00799-016-0183-5
4. Aturban, M.: Where did the archive go? Part 1: Library and Archives Canada. https://ws-dl.blogspot.com/2019/08/2019-08-30-where-did-archive-go-part1.html (2019)
5. Aturban, M.: Where did the archive go? Part 2: National Library of Ireland. [https://ws-dl.blogspot.com/2019/09/2019-09-10-where-did-archive-go-part-2.html] (2019)
6. Aturban, M.: Where did the archive go? Part 3: Public Record Office of Northern Ireland. [https://ws-dl.blogspot.com/2019/09/2019-09-25-where-did-archive-go-part-3.html] (2019)
7. Aturban, M.: A Framework for verifying the fixity of archived web resources. Ph.D. thesis, Old Dominion University (2020). [https://doi.org/10.25777/PCSD-Y213]
8. Aturban, M., Alam, S., Nelson, M.L., Weigle, M.C.: Archive assisted archival fixity verification framework. In: Proceedings of the 19th ACM/IEEE Joint Conference on Digital Libraries (JCDL). pp. 162–171 (2019). [https://doi.org/10.1109/JCDL.2019.00032]
9. Aturban, M., Nelson, M.L., Weigle, M.C.: It is hard to compute fixity on archived web pages. In: Proceedings of the Workshop on Web Archiving and Digital Libraries (WADL) held in conjunction with the 18th ACM/IEEE Joint Conference on Digital Libraries (JCDL) (2018). [https://vtechworks.lib.vt.edu/bitstream/handle/10919/97988/WADL2018.pdf]
10. Aturban, M., Nelson, M.L., Weigle, M.C., Klein, M., Van de Sompel, H.: Collecting 16K archived web pages from 17 public web archives. Tech. Rep. arXiv:1905.03836, arXiv (May 2019)
11. Berlin, J.: Squidwarc - A high fidelity archival crawler that uses Chrome or Chrome Headless. [https://github.com/N0taN3rd/Squidwarc] (July 2017)
12. Berners-Lee, T., Fielding, R., Massinter, L.: Uniform Resource Identifier (URI): Generic Syntax, Internet RFC-3986, [https://datatracker.ietf.org/doc/html/rfc3986] (January 2005)
13. Bornand, N.J., Balakireva, L., Van de Sompel, H.: Routing Memento requests using binary classifiers. In: Proceedings of the 16th ACM/IEEE Joint Conference on Digital Libraries (JCDL). pp. 63–72 (2016). [https://doi.org/10.1145/2910896.2910899]
14. Cremona, R.: New memento support at perma.cc, [https://groups.google.com/g/memento-dev/c/XHb4lezBiqA/m/BpB4m8DjBQAJ] (Feb 2020)
15. Fielding, R.T.: REST APIs must be hypertext-driven (2008). [https://roy.gbiv.com/untangled/2008/rest-apis-must-be-hypertext-driven]
16. International Organization for Standardization (ISO): WARC file format. ISO 28500:2017, [https://www.iso.org/standard/68004.html] (2017)
17. Jones, S.M., Weigle, M.C., Nelson, M.L.: The off-topic Memento toolkit. In: Proceedings of iPres (2018). [https://doi.org/https://doi.org/10.17605/OSF.IO/UBW87]
18. Mohamed Aturban: Mementos-Fixity. [https://github.com/oduwsdl/mementos-fixity/blob/master/final_urims.txt] (2019)
19. Van de Sompel, H., Nelson, M.L., Sanderson, R.: HTTP framework for time-based access to resource states – Memento, Internet RFC 7089. [http://tools.ietf.org/html/rfc7089] (2013)
20. Wilde, E.: The Sunset HTTP Header Field, Internet RFC 8594. [https://tools.ietf.org/html/rfc8594] (2019)
21. Zittrain, J., Albert, K., Lessig, L.: Perma: Scoping and addressing the problem of link and reference rot in legal citations. Legal Information Management 14(02), 88–99 (2014). [https://doi.org/10.1017/S1472669614000255]