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Recommended Citation

White, Justin, "Link Rot, Reference Rot, and Link Resolvers" (2019). *University Library Publications and Presentations*. 1.

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Link Rot, Reference Rot, and Link Resolvers

Justin M. White

From the earliest days of the web, users have been aware of the fickleness of linking to content. In some ways, 1998 was a simpler time for the Internet. In other ways, like basic website design principles, everything old is new again. Jakob Nielsen, writing “Fighting Linkrot” in 1998, reported on a then-recent survey that suggested 6% of links on the web were broken. The advice then hasn’t changed: run a link validator on your site regularly, and update or remove broken links. Also set up redirects for links that do change. The mantra for Nielsen was “you are not allowed to break any old links.”¹ Several years later, partly in response to Nielsen, John S. Rhodes wrote a very interesting piece called “Web Sites That Heal.” Rhodes was interested in the causes of link rot and listed several technological and habitual causes. These included the growing use of Content Management Systems (CMSs), which relied on back-end databases and server-side scripting that generated unreliable URLs, and the growing complexity of websites which was leading to sloppy information architecture. On the behavioral side, website owners were satisfied to tell their users to “update their bookmarks,” websites were not tested for usability, content was seen as temporary, and many website owners were simply apathetic about link rot. Rhodes also noted the issue of government censorship and filtering, though he did not foresee the major way in which government would obfuscate old web pages, which will be discussed below. Rhodes made a pitch for a web server tool that would rely on the Semantic Web and allow websites to talk to each other automatically to resolve broken links on their own.² Although that approach hasn’t taken off, there are other solutions to the problem of link rot that are gaining traction.

What is link rot? Link rot is the process of hyperlinks no longer pointing to the most current or available web page. However, this isn't the only problem facing users: content on web pages isn't static. As authors and editors update and edit web pages over time, the original URL may stay the same but the page at that URL may be about something very different. This evolution of a page's function has been termed "content drift," and when combined with link rot, creates "reference rot." In general, when linking to a resource as a reference, the author is faced with a twofold problem: the link may no longer work, and even if it does, the material being referenced may no longer exist in the same context.³

Luckily, the technological solution for reference rot is already at hand. Rather than relying on link checkers, website owners can use link resolvers and decentralized web preservation through software like the Amber project (<http://amberlink.org>). The Amber project, out of the Berkman Klein Center for Internet and Society, works from a simple enough premise. When a web page is published, the software goes through it, takes a snapshot of each linked page, and saves it locally or to a centralized web archiving platform, such as the Internet Archive or Perma.cc. When it detects a link is broken or misbehaving, Amber suggests the archived version to the user. Amber emphasizes decentralized web archiving as a philosophical commitment to the need to avoid centralized responsibility of a few organizations for preserving the web. There are also link checkers that have begun to integrate web archiving into their workflows, but still tend to function in the same "scan for issues, change broken links" paradigm that Nielson described back in 1998.

The scope of the problem is extremely wide. The average lifespan of a URL is 44 days, according to the Internet Archive's Brewster Kahle.⁴ This number is hard to estimate, and will vary widely depending on who is asked and what context the links exist in. As it stands, there is

too much dependence on platforms that have no mandate to do the work of preservation.

Consider the third-party vendors libraries and their institutions rely on for data management.

Where will they be by five years? And if they find data to be objectionable in some way, what is to stop them from deleting it? This is part of the problem that the Amber project responded to by creating independent snapshots of web pages, rather than relying on the Internet Archive and Perma.cc. Clifford Lynch gave a speech in 2016 about the shift from print news media to broadcast and web news, in which the preservation systems previously put in place began to break down. Now that news organizations rely on links to underlying evidence, rather than utilizing extensive summaries, their context relies on information not controlled by them.⁵ It's easy to imagine a situation in which a website owner realizes their work has been linked to in a way they disapprove of, and changes the context as a "response" to the linked work.

Link and reference rot have a particular history in scholarly communication. In 2014, a group of researchers found that one in five articles suffers from reference rot.⁶ A 2016 study found that three out of four URI references led to content that had been changed since the study cited it, leading to the possibility of malicious changes to undermine a citation (particularly in legal decisions). Most preservation is concerned with the long term preservation of journal articles themselves, not the content referenced in them.⁷ Much like in the news world, there is a reliance on the publishers of data to preserve information, not libraries or other "faithful guardians of immortal works."⁸ The larger trend of citing web sources means that scholarly communication will have to focus its priorities on larger web preservation.⁹ In 2017, the Coalition for Networked Information's Clifford Lynch gave an opening plenary on "Resilience and Engagement in an Era of Uncertainty." Lynch emphasized that the crisis was not in the preservation of scholarly literature itself, but of information that scholars will use in the future.

Lynch also covered difficulties in our current preservation assumptions and questioned whether the government was a reliable steward of research data.¹⁰

Legal scholars have been particularly prominent in the discussion over reference rot, particularly as it affects the citations in legal decisions. The most prominent paper is that by Zittrain, Albert, and Lessig in 2014, but a year before their landmark paper, Raizel Liebler and June Liebert had surveyed the life span of web links in United States Supreme Court decisions from 1996-2010. They found that 29% of websites cited in these decisions were no longer working, with no discernible pattern of which links were most likely to rot.¹¹ Zittrain, Albert, and Lessig in 2014 looked at the legal implications for link rot and found reasons for alarm. The authors determined that approximately 50% of the URLs in Supreme Court opinions no longer linked to the original information, and that a selection of articles in legal journals, including *The Harvard Law Review*, published between 1999 and 2011 had a link rot rate of 70%. The authors of the 2014 study suggest that libraries be involved in the publishing process and take on the “*distributed, long-term preservation of link contents*” [emphasis added].¹²

How Link Rot and Web Archiving Apply to Libraries

Apart from the mentions above that call for libraries to take a part in the preservation process for scholarly and legal literature, what does link rot mean for libraries? Many libraries are not involved in academic or legal publishing but rely extensively on web resources for their users. Approaching the issue from a basic educational approach, a 2003 study found that link rot seriously limited the usefulness of web-based educational materials in biochemistry and molecular biology.¹³ It is not much of a stretch to imagine this issue is broader than the biological sciences.

The Chesapeake Project is a collaborative digital preservation initiative undertaken to preserve legal references. In exploring the materials preserved by the Project, Sarah Rhodes measured rates of link rot over a three-year period. Rhodes found that links most libraries would consider stable — government and state websites — degraded at an increasing rate over time.¹⁴ With the Whitehouse.gov reset at the beginning of the Trump administration, approximately 1,935 links on Wikipedia broke at the flip of a switch, as detailed in *The Outline*.¹⁵ Librarians who maintain LibGuides and Pathfinders to government information know the value of link checkers to their guides, as any government shakeup can mean many of their resources now live somewhere else, even in another government agency, with no overriding link routing system. While it is best practice to link to the most up-to-date information, a regime change can mean valuable studies and data can be deliberately or unintentionally obscured. For example, IRS tax statistics recently moved from <https://www.irs.gov/taxstats/index.html> to <https://www.irs.gov/statistics> with no redirect, even though this change was within the same domain. As the author is responsible for government information at his library, he would also note the fickleness of presidential libraries' websites, despite the preservation role of the libraries they represent online.

The Environmental Data & Governance Initiative (EDGI) sprang up in the face of new hostility from the incoming Trump administration to climate science and other scientific fields that rely on open government data. From its earliest days, EDGI attempted to “preserve publicly accessible and potentially vulnerable scientific data and archive web pages from EPA, DOE, NOAA, OSHA, NASA, USDA, DOI, and USGS,” utilizing the Internet Archive and DataRefuge. Visitors to the page can find a task in the preservation workflow that suits their skill sets (for example, general librarians might be tasked with checking metadata).¹⁶

Libraries should also keep in mind the growth of Open Access (OA) journals and their reliance on these journals to supplement their traditional, paid, subscriptions. While very large OA journals like the Public Library of Science (PLOS) have the scale and thus the notice of archival organizations, small OA journals are often run with shoestring budgets and few faculty supporters. Clifford Lynch pointed out that libraries are unlikely to advocate or financially support OA journal preservation when they are already relying on the fact that OA journals are free to access.¹⁷

Audrey Watters warned in a recent article that copyright enforcement also stands in the way of preservation efforts.¹⁸ This is particularly a problem in preservation efforts in new mediums and platforms, which may have DRM-protected content that prevents copying and access. Librarians will also have to deal with the various data and information generated by their library systems, such as internal communication, statistics, and customer management, that rely exclusively (at the moment) on the stability of the vendor.

Solutions on Hand

The technology for avoiding and repairing link rot is already on hand, just waiting for individuals and institutions to adopt it. The previously mentioned Internet Archive and Perma.cc are available for widespread use. These two particular services even have browser add-ons that can make archiving for scholarly reference as simple as a single click. Even more effective is software that can be built to utilize these systems for automatic web preservation and link routing. A content management system (CMS) like WordPress have many plugins that allow for automatic preservation of links that are in a post. These addons can scan new posts for links, submit them to the IA for preservation (creating a new snapshot that represents that page at the moment it was preserved), and can automatically route broken links to archived copies. The

Amber Project's WordPress plugin can utilize the IA, Perma.cc, or local copies to automatically preserve and reroute broken links.¹⁹ It seems reasonable to assume that link checkers in more CMSs will begin to follow this pattern of preservation and link routing, and librarians should engage with their vendors to ensure their web content remains accessible.

However, it is a dangerous assumption that these technologies, particularly the Internet Archive, are truly archiving the web. The IA can only archive the "surface" of the web, referring to the largely static web pages that the IA can capture, as opposed to the PDFs, videos, Adobe Flash objects, etc. that make up the web's content. The IA and Perma.cc have to be considered within the limits that they exist, and other approaches to preservation are required for a true solution to link and reference rot.²⁰

Studying legal citations, particularly those of the U.S. Supreme Court, has been a growing field since the first comparative analysis of citations of secondary sources by Sirico and Margulies in 1986. With the added stakes of being the highest court in the land, the accessibility of citations by the Supreme Court has garnered more attention than academic reference rot generally. As mentioned above, it is nearly impossible to predict with any certainty what links will break, whether gauging them by source or by format. Independent and decentralized digital archiving is extremely important to insuring the long-term viability of access to digital materials. For example, Liebler and Liebert's 2013 study of Supreme Court citations generated a list of invalid URLs: they found that only 68% of those broken citations could be found on the Internet Archive. A partnership between the Court and the IA or another digital archiving group would improve this number tremendously. Creating digital backups on already-existing systems such as PACER (Public Access to Court Electronic Resources) does improve digital archiving, but hinders access in a way that more open-access preservation doesn't.²¹

One common approach to preventing link rot is to create permanent URLs. In its most basic form, a permanent URL is an address that remains consistent while it can point to new homes where the content it represents lives. This requires a lot of upkeep, but also lacks the advantage of preservation approaches. A permanent URL can be updated when the content moves, but merely updating the URL does not track when the content itself has been changed in some way. Permanent links help address link rot, but not reference rot.

Memento links, in their most basic definition, are snapshots of a website with time/date information. Mementos have the advantage of including human and machine-readable information on what version of a preserved site is being viewed within the link URI itself.

This temporal context information has, so far, been included in a way that is helpful for human consumption. Despite the many variations in expressing the information that is relevant for a web citation, a user can interpret it and connect the dots. Also, temporal context information has so far only been included in formal web citations. However, since all links are subject to reference rot, addition of such information should not be limited to formal citations of web resources, but should rather be applicable to all links to web resources.²²

Thus, rather than saying “(link) was accessed on 10-11-2015,” the link itself contains temporal information within the HTML element `<a>`, using the `versionurl` and `versiondate` attributes.²³ A Memento with machine-readable information as an in-line link would look something like this HTML code:

```
<p>It allows writers and editors to capture and fix transient  
information on the web with a <a href =  
"http://blogs.law.harvard.edu/futureoftheinternet/2013/09/22/perma/"
```

```
versionurl = "http://perma.cc/0Hg62eLdZ3T" versiondate = "2013-10-02">new, permanent link</a>.</p>
```

The words “new, permanent link” would thus become a clickable link to a new resource, but the information in that link is more than a typical URL provides.

With all of the tools mentioned, from centralized platforms for preservation like the Internet Archive and Perma.cc, to decentralized projects like the Amber project and Memento protocols, it is possible right now to build platforms that incorporate best practices to prevent reference rot. Perma.cc, for instance, has recently received an IMLS grant to help scale up its operations, and could become a major player in concert with the Internet Archive as a first option for web archiving.²⁴ Specific examples of how these approaches will look will be discussed in the next section. In general, we can expect that all digital platforms will begin to incorporate solutions that scan and preserve web links, and create backups either on the Internet Archive, Perma.cc, or locally, and automatically re-route users to the archived copies when the platform’s link checker detects that the link is no longer functioning. We can also expect that institutional repositories will be scanned for web links, and those will be automatically preserved in a similar manner, though reading through references in scholarly papers is a bit trickier. Utilizing the Memento protocols for linking, with machine readable dates, might be the solution to ensuring that the same version of the web page is presented for various versions of a paper, such as a pre-print compared to a post-print. All of these efforts will inevitably come up against issues in copyright, which is why it is imperative that librarians are on hand to advocate for Fair Use defenses and technological adaptations that allow for preservation and access to be maintained when copyright law creates a barrier.

What Will Reference Rot Prevention Look Like?

Ultimately, changes in habits are required in the many ways we think about linking and citing web resources. In citations, it is tempting to follow current style guides and have only one URL, which a reference-rot-conscious writer would prefer to use. However, it's important to maintain the original context of the page cited. For the moment, we can focus on the Internet Archive and Perma.cc, which create new URLs for archived web pages, and set aside the machine-readable versioning approaches that the Hiberlink project utilizes. Original URLs serve as a reference that archived versions of web pages use as their ultimate context. If these are removed in citations, and the archived link no longer works, there is no opportunity to find another archived version. While waiting for citation manuals to catch up, or come up with new standards for Mementos and computer-readable Memento links, the best option for now is including both the original URL and the archived version's URL (see endnotes for examples).²⁵ In the realm of citation, authors are largely self-reliant in creating archival versions of their web sources, though institutions can support this role by hosting and promoting Perma.cc and its browser extension, or create a web archive with the Internet Archive.

On the topic of institutions supporting their authors, the rise of institutional repositories and small-scale journals has moved many libraries into the unfamiliar territory of acting as publisher. As in the publishing world, library-hosted and supported journals will rely on the library's efforts at preventing link rot. For example, Perma.cc has specifically marketed itself as compliant with the requirements for the Bluebook uniform system of citation for library-hosted journals. With the wide and growing variety of content management systems for hosting scholarly work, libraries will also want to consider what kind of automated web archiving processes are built into their platforms to make the task of preservation manageable.

Because a lot of cited materials are news-related, news preservation is another area of focus for memory organizations. For those news organizations, particularly those that do not self-archive, there is a need for digital as well as physical preservation. However, many news organizations are not geographically localized, and so the issue of who should preserve them remains an open question.²⁶ Social media presents a similar challenge, magnified by the ephemerality of most social media posts and the variety of formats presented.

Although it's possible that learning management systems (LMS) will adopt some form of link preservation in the near future, it will probably be after libraries start tackling this problem. Librarians who are involved in course design and support will be a useful resource for teaching faculty about reference rot and helping with the preservation of web materials used in courses. For those courses that eschew LMSs, other content management systems like WordPress already have link resolvers built in that utilize the Internet Archive and Perma.cc, along with server storage space for local copies (see the Amber project mentioned above).

Conclusions

So far, we've covered a wide range of applications for web archiving, some more specialized than others. This is because web archiving, and link rot prevention in general, is going to become a fundamental aspect in dealing with online resources of almost every kind. The areas in which most librarians will come into contact with web archiving can be broken down into a few categories. Library websites, with their Pathfinders/LibGuides, often link out to web resources that change with regular frequency (particularly things like government web resources, which change with every administration or agency restructuring). The CMSs that libraries use should begin to, or should be pressured to adopt web archiving technologies that automatically preserve links that are added to the library website, and like current link checkers, note when a

website is being non-responsive, and give the user the option to view a (preferably locally) archived version. With the falling costs of virtual server space thanks to competition between Amazon Web Services and its competitors, there is no reason librarians cannot expect their CMSs to make space available for locally archived copies of web resources.

Another area librarians at larger institutions can expect to interact with web archiving is through their institutional repository or other CMSs that handle publications. This is particularly true of those libraries that are acting as the homes of academic journals. When papers with web references are submitted to the journal's repository software, librarians should have every expectation that their vendor can provide a link checking and archiving tool that will make copies of all linked materials, either locally or in Perma.cc or even the university's web archiving tool (for example, the Internet Archive's paid service Archive-It). The legal profession has led the way in looking at how to provide snapshots (Mementos) of web resources that are properly timestamped in a machine-readable way, and although that might be too much for most journals to take on at once, there are plenty of institutions that libraries can partner with to learn about these new approaches while instituting their own procedures for preventing reference rot.

There are other possibilities for preventing link rot that will be even more challenging to approach but still should be considered. This includes vendor links to e-resources that the library subscribes to. Although this creates copyright issues, there is a strong argument to be made that libraries should have redundant copies available for when links break or are not redirected properly, as those libraries have made significant payments to have access to these materials and lack the first sale rights they enjoy with printed materials. Making e-resources more reliable could rely on coming to agreements about creating archives of subscription materials.

The difficulties facing libraries in web archiving are often not technological in nature, but legal. Copyright and anti-circumvention laws prevent the creation of perfectly reasonable archives. This is particularly problematic in archiving of media resources that are not simply text, but include embedded video, audio, or interactive media.

The current trends in web archiving have yet to reach the level imagined by John Rhodes's "Websites that Heal" in 2002, but the rapid expansion of web materials will require a concurrent expansion in institutions that have to take part in their archival to preserve access and referenced context. As mentioned above, this will require a change in habits, from citation to web design, but with current tools, there are already a wide range of ways librarians can educate themselves about and prevent reference rot in every web-related realm they currently operate in.

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