Reconstructing Websites for the Lazy Webmaster

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ABSTRACT
Backup or preservation of websites is often not considered until after a catastrophic event has occurred. In the face of complete website loss, “lazy” webmasters or concerned third parties may be able to recover some of their website from the Internet Archive. Other pages may also be salvaged from commercial search engine caches. We introduce the concept of “lazy preservation” - digital preservation performed as a result of the normal operations of the Web infrastructure (search engines and caches). We present Warrick, a tool to automate the process of website reconstruction from the Internet Archive, Google, MSN and Yahoo. Using Warrick, we have reconstructed 24 websites of varying sizes and composition to demonstrate the feasibility and limitations of website reconstruction from the public Web infrastructure. To measure Warrick’s window of opportunity, we have profiled the time required for new Web resources to enter and leave search engine caches.

Categories and Subject Descriptors
H.3.5 [Information Storage and Retrieval]: Online Information Services—Web-based services

General Terms
Measurement, Experimentation, Design

Keywords
digital preservation, search engine, cached resources

1. INTRODUCTION

“My old web hosting company lost my site in its entirety (duh!) when a hard drive died on them. Needless to say that I was peeved, but I do notice that it is available to browse on the wayback machine... Does anyone have any ideas if I can download my full site?” - A request for help at archive.org [35]

Sometimes websites are lost due to negligence, sometimes to laziness, and sometimes because the resources to backup a website are just not available. Even when backups are performed, they may not have been performed correctly. When a website is lost due to some calamity, many webmasters will turn to the Internet Archive (IA) “Wayback Machine” for help. The IA performs permanent archiving of all types of Web resources when crawling the Web. Although the IA can sometimes help reconstruct a website, it is strictly a best-effort approach that performs sporadic, incomplete and slow crawls of the Web (the IA repository is at least 6 months out-of-date [22]). Missing content can also be found from search engines (SEs) like Google, MSN and Yahoo that scour the Web looking for content to index and cache. Unfortunately the SEs do not keep web pages long after they have gone missing (404), and they do not preserve canonical copies of all the web resources they cache. We will refer to the IA holdings and the SE caches collectively as web repositories.

We have built Warrick¹, a command-line tool that reconstructs websites by recursively crawling the contents of 4 web repositories (IA, Google, MSN and Yahoo). We used Warrick to reconstruct 24 websites of various sizes and subject matter to measure how well websites can be reconstructed from the 4 web repositories. We measured the time it takes for the SEs to crawl and cache web pages that we have created on .com and .edu websites. In June 2005, we created synthetic web collections consisting of HTML, PDF and images. For 90 days we systematically removed web pages and measured how long they remained cached by the SEs.

2. BACKGROUND AND RELATED WORK

Prior work has focused on 1) web archiving as a means of digital preservation and 2) improving the ability of SEs to index the Web. But no research has been performed that uses the byproduct of commercial SE activity for archiving the Web.

In regards to archiving websites, organizations like the Internet Archive and national libraries are currently engaged in archiving the external (or client’s) view of selected websites [12] and improving that process by building better web crawlers and tools [23]. Systems have been developed to ensure long-term access to Web content within repositories and digital libraries [33].

Numerous systems have been built to archive individual websites and web pages. InfoMonitor archives the server-side components (e.g., CGI scripts and datafiles) and filesystem of a web server [11]. It requires an administrator to configure the system and a separate server with adequate disk space to hold the archives. Other systems like TTAPache [13] and iPROXY [32] archive requested pages from a web server but not the server-side components. TTAPache is an Apache module which archives different versions

¹Warrick is named after a fictional forensic scientist with a penchant for gambling.
of web resources as they are requested from a web server. Users can view archived content through specially formatted URLs. iPROXY is similar to TTApache except that it uses a proxy server and archives requested resources for the client from any number of web servers. A similar approach using a proxy server with a content management system for storing and accessing Web resources was proposed in [16]. Commercial systems like Furl (http://furl.net/) and Spurl.net (http://spurl.net/) also allow users to archive selected web resources that they deem important.

A great deal of research has focused on improving the ability of SEs to crawl and index content. Work in this area focuses on issues related to crawling performance [5, 7, 20], choosing what web pages to crawl [6, 9, 24] choosing when to re-crawl [8, 14, 15], and how to crawl the deep web [28, 31]. Research has been performed showing how to find duplicate Web content [2, 10, 37] and how to measure differences between text documents [4, 36]. Work related to measuring observed web page change rates and their effects on SEs have also been performed [6, 17, 27]. A body of work proposes software that runs on web servers to increase web crawling efficiency [3, 19, 26, 38].

Estimates of SE coverage of the indexable Web have been performed most recently in [18], but no measurement of SE cache sizes or types of files stored in the SE caches has been performed. We are also unaware of any research that documents the crawling and caching behavior of commercial SEs.

3. WEB REPOSITORIES

To limit the implementation complexity, we have focused on what we consider to be the 4 most popular search engines: Google, MSN, and Yahoo. A web resource's TTL in the SE cached is defined as:

\[ \text{TTL}_w = t_r - t_c \]  

where \( t_r \) is the time when the resource is first made available on a web server and \( t_c \) is the time when it is finally purged from a SE cache. A web resource's time-to-live (TTL) on the web server is defined as the number of days until the resource is removed from the server:

\[ \text{TTL}_{ws} = t_v - t_0 \]  

If a SE crawls and caches a resource, it will typically remain cached until the SE performs another crawl and discovers the resource is no longer available on the web server. The resource's TTL in the SE cached is defined as:

\[ \text{TTL}_{c} = t_{cr} - t_{ca} \]
The time-until-removal (TUR), is defined as:

\[
TUR = t_{cr} - t_r
\]  

The \(TTL_{ws}\) and \(TTL_c\) values of a resource may not necessarily overlap. A SE that is trying to maximize the freshness of its index will try to minimize the difference between \(TTL_{ws}\) and \(TTL_c\). A SE that is slow in updating its index, perhaps because it purchases crawling data from a third party, may experience late caching where \(t_r < t_{ca}\). It is also possible to have negative values for \(TUR\) if for some reason a resource is removed from the cache before it has been removed from the web server.

A resource is considered ‘vulnerable’ until it is cached. A vulnerable resource has an undefined \(t_{ca}\) value. A recoverable resource is defined as a resource where \(t_c < t_r\) and \(TTL_c > 0\). A recoverable resource can only be recovered during the \(TTL_c\) period with a probability of \(P_r\) (the observed number of days that a resource is retrievable from the cache divided by \(TTL_c\)). We would like a resource to have a minimal \(t_{ca}\) value to reduce its vulnerability. SEs may also share this goal if they want to index new content as quickly as possible. We would also like a resource to experience large values of \(TUR\) so it can be recovered for many days after its disappearance. SEs on the other hand may want to minimize \(TUR\) in order to purge missing content from their index.

### 4.2 Web Collection Design

We created 4 synthetic web collections with the same number of HTML, PDF and image resources. The web collections were deployed in June 2005 at 4 different websites (1 .com and 3 .edu websites). The .com website (owenbrau.com) was new and had never been crawled before. The .edu websites fmccown, jsmit and mln (all subsites of www.cs.odu.edu) had existed for over 1 year and had been previously crawled by multiple SEs. In order for the web collections to be found by the SEs, we placed links to the root of each web collection from the .edu websites, and we submitted owenbrau’s base URL to Google, MSN and Yahoo 1 month prior to the experiment. For 90 days we systematically removed resources from each collection. We examined the server web logs to determine when resources were crawled, and we queried Google, MSN and Yahoo daily to determine when the resources were cached.

We organized each web collection into a series of update bins or directories which contained a number of HTML pages referencing the same three inline images (GIF, JPG and PNG) and a number of PDF files. An index.html file (with a single inline image) in the root of the web collection pointed to each of the bins. An index.html file in each bin pointed to the HTML pages and PDF files so a web crawler could easily find all the resources. All these files were static and did not change throughout the 90 day period except the index.html files in each bin which were modified when links to deleted web pages were removed.

The number of resources in the web collections were determined by the number of update bins \(B\), the last day that resources were deleted from the collection \(T\) (the terminal day), and the bin \(I\) which contained 3 images per HTML
Table 2: Caching of HTML resources from 4 web collections

| Web collection | % URLs crawled | % URLs cached | $t_{ca}$ | $TT_{ws}/P_{ws}$ | $TT_{UR}$ |
|----------------|----------------|---------------|---------|-----------------|-----------|
| Owenbraun      | 91             | 86            | 41      | 54              | M         |
|                | 92             | 92            | 54      | 86              | M         |
|                | 94             | 94            | 54      | 86              | M         |
|                | 18             | 0             | 47      | 94              | Y         |
| Ave            | 74             | 26            | 50      | 19              | 92        |
|                | 74             | 11            | 35      | 95              | 37        |

* Due to a query error, the MSN results could be higher (up to the percentage crawled).

Figure 3: Number of resources in web collection

Page. Update bins were numbered from 1 to $B$, and resources within each bin $b$ were numbered from 1 to $[T/b]$. Resources were deleted from the web server according to their bin number. Every $n$ days we would delete one HTML page (and associated images for pages in bin 1) and one PDF file from bin $n$. For example, resources in bin 1 were deleted daily, resources in bin 2 were deleted every other day, etc. We also removed the links to the deleted HTML and PDF files from bin $n$'s index.html file.

At any given day $d$ during the experiment (where $d = 0$ is the starting day and $d \leq T$), the total number of resources in the web collection is defined as:

$$Total_{ws}(d) = 2 + \sum_{i=1}^{B} Total_{bins}(i, d)$$

(4)

The total number of HTML, PDF and image files in bin $b$ on any day $d$ is defined as:

$$Total_{w}(b, d) = HTML(b, d) + PDF(b, d) + IMG(b, d)$$

(5)

The total number of resources in each update bin decreases with the bin’s periodicity as shown in Figure 3. The number of HTML, PDF and image files in each bin $b$ on any day $d$ is defined as:

$$HTML(b, d) = [T/b] - [d/b] + 1$$

(6)

$$PDF(b, d) = [T/b] - [d/b]$$

(7)

$$IMG(b, d) = \begin{cases} 
3(HTML(b, d) - 1) & \text{if } b = I \\
0 & \text{if } HTML(b, d) = 1 \\
3 & \text{otherwise} 
\end{cases}$$

(8)

In each of our web collections we created 30 update bins ($B = 30$) that completely decayed by day 90 ($T = 90$), and we chose bin 2 ($I = 2$) to have the supplemental images. So the total number of files in each collection on day 0 was $Total(0) = 954$. We limited the web collections to less than 1000 resources in order to limit the number of daily queries to the SEs. We created a fewer number of images than HTML and PDF pages because we hypothesized that images were not cached as frequently as other resources and the cost of querying for images (number of queries issued per resource) was higher than for HTML and PDF resources.

The $TT_{ws}$ for each resource in the web collection is determined by its bin number $b$, page number $p$, and the web collection terminal day $T$:

$$TT_{ws} = b([T/b] - p + 1)$$

(9)

An example PDF page from one of the web collections is shown in Figure 4. HTML pages look very similar. Each HTML and PDF page contain a unique identifier (UID) at the top of each page that included 4 identifiers: the web collection (e.g., ‘mlnODULPT2’ means the ‘mln’ collection), bin number (e.g., ‘dgrp18’ means bin 18), page number and resource type (e.g., ‘pg18-2-pdf’ means page number 2 from bin 18 and PDF resource). The UID contains spaces to allow for more efficient querying of the SE caches. The text for each page was randomly generated from a standard English dictionary so there would be no keyword skew (e.g., “Bush Iraq”) that might impact crawler behavior. By using random words we avoided creating duplicate pages that a SE may reject. SEs could use natural language processing to determine that the words of each page were random and therefore might punish such pages by refusing to index them, but the SE caching behavior we observed seems to indicate this is not the case.

4.3 Daily SE Queries

In designing our daily SE queries, care was taken perform a minimal number of daily queries to not overburden the SEs. We could have queried the SEs using the URL for each resource, but this might have led to our resources being cached prematurely; it is possible that if a SE is queried for a URL it did not index that it would add the URL to a list of URLs to be crawled at a later date. This is how IA handles missing URLs that are used in users’ queries.

In order to determine which HTML and PDF resources had been cached, we used the UID for each resource to query each SE. We queried the top 100 results of those items matching the resource type (‘PDF’ or ‘HTML’) using the first 2 parts of the UID (e.g., ‘mlnODULPT2 dgrp18’) which uniquely identified the web collection and bin number\(^2\). We then parsed the single result page looking for links to cached versions of the resources. Although we could have queried for the complete UID, this would have unnecessarily increased the load put on the SEs. If there are $w$ web collections with $b$ bins and $t$ types of resources in each bin,\(^2\) MSN only allows limiting the results page to 50 and does not support limiting by resource type. Therefore large bins might require more than 1 query.
4.4 Crawling and Caching Observations

Although the web server logs registered visits from a variety of crawlers, we report only on crawls from Google, Inktomi (Yahoo) and MSN. Alexa Internet (who provides crawls to IA) only accessed our collection once (induced through our use of the Alexa toolbar). A separate IA robot accessed our collection only twice, via the Wayback Machine. After day 40 they began to access our site, and many crawled resources never appeared in the Yahoo cache. There is a lag time of about 30 days between the time an image is crawled and when it appears in the Yahoo cache. From a website reconstruction perspective, Google out-performed MSN and Yahoo in nearly every category. Google cached the highest percentage of HTML resources (76%) and took only 12 days on average to cache new resources from the .edu web collections. On average, Google cached HTML resources for the longest period of time (76 days), and were the slowest to remove cached resources that were deleted from the web server (51 days). Although Yahoo cached more HTML resources and kept the resources cached for a longer period than MSN, the probability of accessing a resource on any given day was only 53% compared to 89% for MSN.

Figure 5 provides an interesting look at the crawling and caching behavior of Google, Yahoo and MSN. These graphs illustrate the crawling and caching of HTML resources from the mln collection; the other 2 .edu collections exhibited similar behavior. The resources are sorted by the mln collection; the other 2 .edu collections showed similar behavior. The resources are sorted by the minimum TTL (in minutes) of the resource. The index.html files which were never removed from the web collection have an infinite TTL ("inf") that the red line indicates the decay of the web collection. On the top row of Figure 5, blue dots indicate resources that were crawled on a particular day. As resources were requested that had been deleted, the web server responded with a 404 (not found) code represented by green dots above the red line. The bottom row of Figure 5 shows the cached HTML resources (blue) resulting from the crawls. Some pages in Yahoo were indexed but not cached (green).

Google was by far the most active of the crawlers and cached more resources than the other two SEs. Google was quick to purge resources from their cache when a crawl revealed the resources were no longer available on the web server. On day 102 many previously purged resources reappeared in the Google cache and stayed for the remainder of our measurements. The other 2 .edu web collections recorded similar behavior where HTML resources reappeared in the Google cache long after being removed. Cached PDF resources did not experience the same reappearance.

Yahoo performed sporadic caching of resources. As shown in Figure 5, resources tended to fluctuate in and out of the Yahoo cache. There is a lag time of about 30 days between Inktomi crawling a resource and the resource appearing in the Yahoo cache, and many crawled resources never appear in the Yahoo cache. Although Inktomi crawled nearly every available HTML resource on day 10, only half of those resources ever became available in the Yahoo cache.

MSN was very slow to crawl the HTML and PDF resources in the update bins. After day 40 they began to...
Figure 5: Crawling (top) and caching (bottom) of HTML resources from the mln web collection
Table 3: Number of queries required to obtain resources from the web repositories

| Web repository | Non-image resource | Image resource |
|----------------|-------------------|---------------|
| Google         | 1                 | 2             |
| MSN            | 2                 | N/A           |
| Yahoo          | 2                 | 2             |
| Internet Archive | ≥ 2          | ≥ 2           |

Figure 6 graphs the observed probability of finding HTML resources from the web collections in at least one SE cache after they have been removed from the web server ($t_r$). The top graph is from the 3.edu collections grouped together, and the bottom graph is from owenbrau. On examination of the.edu web collections, most HTML resources were purged from the SE caches 10 days after $t_r$ as illustrated by the ridge on the left. Some resources continued to be available (mostly from Yahoo) which form the hills in days 20-40. The large plateau on the center-right are those HTML resources that re-appeared in Google’s cache days after being purged. None of the HTML resources from owenbrau appeared in cache until 20-30 days after they were removed, and they remained cached for 40 days before being purged.

We have observed from our measurements that nearly all new HTML and PDF resources that were placed on known websites were crawled and cached by Google several days after they were discovered. Resources on a new website were not cached for months. Yahoo and MSN were 4-5 times slower than Google to acquire new resources, and Yahoo incurs a long transfer delay from Inktomi’s crawls into their cache. Like Google, MSN was quick to remove 404 resources from their cache.

5. WARRICK

5.1 Operation

Warrick is able to reconstruct a website when given a URL pointing to the host page where the site used to exist. The web repositories can be queried with a URL to produce the stored version of the resource in their holdings. For example, we can download Google’s cached version of http://foo.edu/page1.html by so: http://search.google.com/search?q=cache:http://foo.edu/page1.html. If Google has not cached the page, an error page will be generated. Otherwise the cached page can be stripped of any Google-added HTML, and the page can be parsed for links to other resources from the foo.edu domain.

As shown in Table 3, most repositories require 2 queries to obtain a resource because the URL of the stored resource cannot be created automatically like Google’s. MSN, for example, requires an initial query that will produce a web page with the cached URL within it. The cached URL must be extracted from the result page and accessed to find the cached resource. Yahoo and MSN also provide APIs that require 2 queries for obtaining resources without the necessity of page scraping. IA may require more than 2 queries because it will occasionally produce links to stored content that is not retrievable, and additional queries must be performed to check for older versions of the resource.

Table 3: Number of queries required to obtain resources from the web repositories

| Web repository | Non-image resource | Image resource |
|----------------|-------------------|---------------|
| Google         | 1                 | 2             |
| MSN            | 2                 | N/A           |
| Yahoo          | 2                 | 2             |
| Internet Archive | ≥ 2          | ≥ 2           |

Figure 7: Pseudocode for recovering resources from web repositories
times provide a Last-Modified date for the resource), and Google will only provide a cache date for HTML resources. Therefore if a non-HTML resource is returned from all 3 SEs (assuming IA did not have the resource), the MSN version will always be the resource selected.

If the resource has a MIME type of ‘text/html’, Warrick will look for URLs to other resources by examining a variety of tags (e.g., `<A>`, `<IMG>`, `<LINK>`, `<EMBED>`, etc.). The web repositories are queried with each of these URLs until there are no more URLs to be found. There are numerous options to limit how many files are reconstructed and the types of files that should be reconstructed.

All resources are stored to disk in a directory/file that matches the reconstructed URL. For example, the resource with URL http://foo.org/dir1/abc.html would be saved as foo.org/dir1/abc.html. HTML versions of PDFs and other converted types are stored with their original filenames. Warrick provides an option to rename these types of files with an .html extension so they can be viewed in a browser. All links can be made relative and point to the newly renamed files.

Warrick keeps a log of each reconstructed resource that includes the MIME type (‘MISSING’ if the resource could not be found), the web repository the resource was restored from and the date of the resource as indicated by the web repository.

5.2 Cost of Website Reconstruction

Warrick relies on the services provided by the web repositories for reconstructing websites. Warrick “respects” the web repositories in that it issues a limited number of queries per 24 hours and delays before issuing repeated queries. After exceeding a certain number of queries from a particular IP address, some SEs may quit responding to requests (we personally experienced this once). Unfortunately there is no standard way for Warrick to automatically find this limit. Instead we must rely on published standards for whatever public API is released or rely on personal experience. In general, a SE will have a limited number of queries \( P \) that an agent may make on a SE in a time period of \( P \). It may also prefer that an agent wait \( W \) seconds between requests. If the number of queries performed in time \( P \) exceeds \( L \), the agent should cease making queries until a time span of \( P \) has elapsed. If an agent follows these guidelines, the agent is said to “respect” the SE or web repository.

The SEs all provide public APIs that specify a limited number of queries per 24 hours with no \( W \) requirements. Google allows 1000 queries, Yahoo allows 4000, and MSN allows 10,000. Although we currently do not use the Google and MSN APIs, their API limits are good indicators for what they deem reasonable use of their web-based search interfaces. IA does not publish an API with daily query limits, so we chose a daily limit of 1000 queries.

Warrick self-imposes a \( W \) requirement of 1-4 seconds (random) between query rounds (1 round = queries to all web repositories). It will sleep for 24 hours if the number of queries it performs on any web repository exceeds the web repository’s query limit and then pick back up where it left off. Unfortunately files may start to leave a SE cache before being able to complete the reconstruction of a large website. A more urgent reconstruction effort might increase the number of queries per day.

The collective cost incurred by the web repositories for reconstructing a website is the total number of queries they must respond to from Warrick. The query cost \( C_q \) can be defined as the total number of queries needed to pull \( r \) non-image resources from \( n \) web repositories and \( i \) image resources from \( m \) web repositories that house images:

\[
C_q(r, i) = r \sum_{j=1}^{n} Q_r(j) + i \sum_{j=1}^{m} Q_i(j)
\]  

An upper bound for \( Q_r \) is 7 if a non-image resource was found in all 4 web repositories. The lower bound is 2 (canonical version was found in IA). An upper bound for \( Q_i \) is 4 if an image resource was not found until the last web repository. The lower bound is 2 (image was found in the first web repository). The maximum number of queries required to reconstruct a website with 50 HTML files, 50 PDF files, and 50 images would be \( C_q(100, 50) = 900 \) queries, and the minimum number of queries would be 300.
6. WARRICK EVALUATION

6.1 Reconstruction Measurements

A website is a set of interlinked web pages that are made up of one or more web resources (e.g., style sheets, JavaScript, images, etc.), each identified by a URI [39]. Each web page (which is itself a web resource) may link to other web pages if it is an HTML resource, or it may be a self-contained resource like a PDF, MS PowerPoint slide show or image.

We can construct a web graph \( G = (V, E) \) for a website where each resource \( r_i \) is a node \( v_i \), and there exists a directed edge from \( v_i \) to \( v_j \) when there is a hyperlink or reference from \( r_i \) to \( r_j \). This graph may be constructed for any website by downloading the host page (e.g., http://foo.com/) and looking for links or references to other Web resources, a method employed by most web crawlers. The left side of Figure 8 shows a web graph representing some website \( W \) if we began to crawl it beginning at A.

Suppose the website \( W \) was lost and reconstructed forming the website \( W' \) represented in the center of Figure 8. For each resource \( r_i \) in \( W \) we may examine its corresponding resource \( r'_i \) in \( W' \) that shares the same URI and categorize \( r'_i \) as:

1. identical \(- r'_i \) is byte-for-byte identical to \( r_i \)
2. changed \(- r'_i \) is not identical to \( r_i \)
3. missing \(- r'_i \) could not be found in any web repository and does not exist in \( W' \)

We would categorize those resources in \( W' \) that did not share a URL with any resource in \( W \) as:

4. added \(- r'_i \) was not a part of the current website but was recovered due to a reference from \( r'_i \)

Figure 8 shows that resources A, G and E were reconstructed and are identical to their original versions. An older version of B was found (B') that pointed to G, a resource that does not currently exist in W. Since B’ does not reference D, we did not know to recover it. It is possible that G is actually D renamed, but we do not test for this. An older version of C was found, and although it still references F, F could not be found in any web repository.

A measure of change between the original website \( W \) and the reconstructed website \( W' \) can be described using the following difference vector:

\[
\text{difference}(W, W') = \left( \frac{R_{\text{changed}}}{|W|}, \frac{R_{\text{missing}}}{|W|}, \frac{R_{\text{added}}}{|W|} \right)
\]  

(13)

For Figure 8, the difference vector is \((2/6, 1/6, 1/5) = (0.333, 0.167, 0.2)\).

The following bounds apply to the difference vector:

- \((0, 0, 0)\) Best case: a complete reconstruction of a website.
- \((1, 0, 0)\) Every resource of the website was found, but they are all changed.
- \((0, 1, 0)\) Worst case: no resources were found in any web repository.
- \((0, 0, 1)\) Impossible case: It would not be possible to find only added resources if we did not start with a single resource that was either identical or changed.

The difference vector for a reconstructed website can be illustrated as a reconstruction diagram as shown on the right side of Figure 8. The changed, identical and missing resources form the core of the reconstructed website. The dark gray portion of the core grows as the percentage of changed resource increases. The hole in the center of the core grows as the percentage of missing resources increases. The added resources appear as crust around the core. This representation will be used later in Table 4 when we report on the websites we reconstructed in our experiments.

6.2 Website Reconstruction Results

We chose 24 websites covering a variety of topics based on our personal interests and random samples from the Open Directory Project (dmoz.org). Some of the websites we selected are actually subsites, but we will use the term ‘website’ when referring to all of them. We chose 8 small websites (1-149 URIs), 8 medium websites (150-499 URIs) and 8 large websites (500-2000 URIs). We also chose only websites that were crawler friendly (did not use JavaScript to produce dynamic links, did not use Flash exclusively as the main interface, etc.) and did not use the robots exclusion protocol (robots.txt) to stop web crawlers from indexing their websites.

In August 2005 we downloaded the 24 websites using Wget. All files needed to produce each web page were downloaded (HTML, style sheets, external JavaScript files, images, etc.)\(^4\). For simplicity, we restricted the download to only those files that were in and beneath the starting directory. For example, if we downloaded http://foo.edu/abc/*, only URLs matching http://foo.edu/abc/* were downloaded. Immediately after downloading the websites, we ran Warrick to reconstruct all 24 websites. For each website we reconstructed 5 different versions: 4 using each web repository separately, and 1 using all web repositories together.

The results of the aggregate website reconstructions are shown in Table 4 sorted by website size (number of files in the original website). The ‘PR’ column is Google’s PageRank for the root page of each website at the time of the experiments. The PageRank is the importance (0-10 with 10 being the most important) that Google assigns to a web page. MSN and Yahoo do not publicly disclose their ‘importance’ metric. We were unable to find any statistical correlation between percentage of recovered files and PageRank or between recovered files and website size.

For each website the total number of files in the original website is shown along with the total number of files that were recovered and the percentage. The files are also tallied by MIME type. The difference vector for the website accounts for recovered files that were added.

\(^4\)We used Wget 1.10 with the following options: -np, -p, -w 2, -r, -l 0, -e, -t 1.
The ‘Almost identical’ column shows the percentage of text-based resources (e.g., HTML, PDF, PostScript, Word, PowerPoint, Excel) that were almost identical to the originals. The last column shows the reconstruction figure for each website if these almost identical resources are moved from the ‘Changed’ category to ‘Identical’ category. We counted the number of shared fixed-size shingles to determine text document similarity. Shingling (as proposed by Broder et al. [4]) is a popular method for quantifying similarity of text documents when word-order is important [2, 17, 27]. We considered any two documents to be almost identical if they shared at least 75% of their shingles of size 10. Other document similarity metrics that take word order into account could also have been used [36]. We used open-source tools [29] to convert non-HTML resources into text before computing shingles. We did not use any image similarity metrics.

We were able to recover more than 90% of the original files from a quarter of the 24 websites. For 3 quarters of the websites we recovered more than 50% of the files. On average we were able to recover 68% of the website files (median=72%). Of those files recovered, 30% of them on average were not byte-for-byte duplicates. A majority (72%) of the ‘changed’ text-based files were almost identical to the originals (having 75% of their shingles in common). 67% of the 24 websites had obtained additional files when reconstructed which accounted for 7% of the total number of files reconstructed per website.

Figure 9 shows how successful we were at recovering files based on their MIME type. The percentage of resources that were recovered from the 5 different website reconstructions we performed (1 using all 4 web repositories, and 4 using each web repository individually) are shown along with the average number of resources making up the original 24 websites. A majority (92%) of the resources making up the original websites are HTML and images. We were more successful at recovering HTML resources than images; we recovered 100% of the HTML resources for 9 of the websites (38%) using all 4 web repositories. In the case of the individual web repository reconstructions, 3 of the 4 web repositories were individually able to recover a higher percentage of HTML resources than any other resource type. Images and formats with other MIME types were not as likely to be available in the web repositories. Our experiments measuring the caching of images verifies that SEs do not cache images as frequently as they cache text documents.

Figure 10 shows the percentage of each web repository’s contribution in the aggregate reconstructions. The numbers of the x-axis match the numbering of Table 4. Google contributed the most to each website reconstruction, providing on average 44% of the files to each website and failing to contribute to only one website (website 17). MSN was second, providing on average 30% of the files; IA was third with 19%, and Yahoo was last with a 7% contribution rate. Yahoo’s poor contribution rate can be expected for a few reasons. First, they do not consistently provide a datestamp for their resources, and Warrick will always choose a resource with a datestamp over one without it. Second, Yahoo’s solo recovery performance (Figure 9) demonstrated they were the worst at recovering most resources. And finally, as we have seen in our crawling and caching experiments, Yahoo provides very inconsistent access to resources in their cache.

Also MSN cannot be used to recover images; this lowers our chance of aggregate recovery of images even further. PDF and Microsoft Office formats made up a small portion of the websites. We were more successful at recovering PDF resources (85%) with the aggregate reconstructions than MS Office formats (71%).

Figure 10 shows the percentage of each web repository’s contribution in the aggregate reconstructions. The numbers of the x-axis match the numbering of Table 4. Google contributed the most to each website reconstruction, providing on average 44% of the files to each website and failing to contribute to only one website (website 17). MSN was second, providing on average 30% of the files; IA was third with 19%, and Yahoo was last with a 7% contribution rate. Yahoo’s poor contribution rate can be expected for a few reasons. First, they do not consistently provide a datestamp for their resources, and Warrick will always choose a resource with a datestamp over one without it. Second, Yahoo’s solo recovery performance (Figure 9) demonstrated they were the worst at recovering most resources. And finally, as we have seen in our crawling and caching experiments, Yahoo provides very inconsistent access to resources in their cache.

MSN is not usable for recovering images, the second most numerous type of resource in each website. The fact that they contributed 11% more files than IA is due to their high success rate of recovering HTML resources as was shown in Figure 9.

Figure 11 shows the amount of time and the number of queries required to reconstruct all 24 websites. There is al-
Table 4: Results of website reconstructions

| Website                          | PR | MIME type groupings (orig/recovered) | Difference vector ( Changed, Missing, Added) | Recon diag | Almost identical | New recon diag |
|----------------------------------|----|--------------------------------------|-----------------------------------------------|------------|------------------|----------------|
| 1. www.smoky.ccsd.k12.co.us     | 4  | 63/27                                | 20/20                                         | 0.111, 0.571, 0.000 | 100%             |                 |
| 2. www.genesis427.com           | 2  | 65/53                                | 10/10                                         | 0.662, 0.185, 0.000 | 33%              |                 |
| 3. englewood.k12.co.us/schools/clayton | 3 | 68/58                                | 32/29                                         | 0.426, 0.147, 0.000 | N/A              |                 |
| 4. www.harding.edu/hr           | 4  | 73/47                                | 19/19                                         | 0.438, 0.356, 0.145 | 83%              |                 |
| 5. www.raitinvestmenttrust.com  | 4  | 79/65                                | 24/24                                         | 0.089, 0.177, 0.015 | 33%              |                 |
| 6. www.mie2005.net              | 6  | 89/66                                | 16/15                                         | 0.663, 0.258, 0.015 | 89%              |                 |
| 7. otago.settlers.museum        | 5  | 111/48                               | 27/27                                         | 0.171, 0.568, 0.020 | 40%              |                 |
| 8. www.usamriid.army.mil        | 7  | 142/100                              | 38/38                                         | 0.585, 0.296, 0.000 | 50%              |                 |
| 9. searcy.dina.org              | 5  | 162/154                              | 96/95                                         | 0.111, 0.049, 0.078 | 43%              |                 |
| 10. www.cookinclub.com          | 6  | 204/187                              | 67/66                                         | 0.480, 0.083, 0.307 | 100%             |                 |
| 11. www.americancaribbean.com   | 4  | 287/152                              | 60/57                                         | 0.296, 0.470, 0.000 | 100%             |                 |
| 12. www.gltron.org              | 6  | 294/221                              | 20/19                                         | 0.259, 0.248, 0.005 | 90%              |                 |
| 13. privacy.getnetwise.org      | 8  | 305/163                              | 137/137                                       | 0.033, 0.466, 0.201 | 70%              |                 |
| 14. www.mypyramid.gov           | 0  | 344/193                              | 158/154                                       | 0.160, 0.439, 0.000 | 32%              |                 |
| 15. www.digitalpreservation.gov | 8  | 414/378                              | 346/329                                       | 0.097, 0.087, 0.000 | 44%              |                 |
| 16. www.aboutfamouspeople.com   | 6  | 432/430                              | 267/267                                       | 0.653, 0.005, 0.021 | 100%             |                 |
| 17. home.alltel.net/bsprowl     | 0  | 505/112                              | 173/112                                       | 0.012, 0.778, 0.009 | 100%             |                 |
| 18. www.dpconline.org           | 7  | 552/384                              | 236/227                                       | 0.509, 0.304, 0.013 | 66%              |                 |
| 19. www.cs.odu.edu/~pothen       | 5  | 640/435                              | 160/151                                       | 0.402, 0.320, 0.062 | 28%              |                 |
| 20. www.eskimo.com/~scs          | 6  | 719/691                              | 696/669                                       | 0.011, 0.039, 0.001 | 50%              |                 |
| 21. www.financeprofessor.com    | 6  | 817/626                              | 455/404                                       | 0.211, 0.234, 0.011 | 72%              |                 |
| 22. www.fishingcairns.com.au     | 5  | 1152/1070                            | 259/259                                       | 0.466, 0.071, 0.000 | 95%              |                 |
| 23. www.techlocker.com          | 4  | 1216/406                             | 687/149                                       | 0.267, 0.666, 0.175 | 99%              |                 |
| 24. www.kruerdorfmeister.com     | 4  | 1509/128                             | 1298/31                                       | 0.056, 0.915, 0.066 | 50%              |                 |
most a 1:1 ratio of queries to seconds. Although the size of the original websites gets larger along the x-axis, the number of files reconstructed and the number of resources held in each web repository determine how many queries are performed. In none of our reconstructions did we exceed the query limit of any of the web repositories, and so Warrick never had to sleep for 24 hours.

7. FUTURE WORK

We are investigating methods that could be used to insert the server-side components or logic into static web pages in a secure manner so that Warrick may be able to reconstruct the server-side logic of a website.

We are also designing a standard interface that any web repository can implement that would like to share its holdings with Warrick. This will allow new holdings to be added with minimal work.

In our next experiment we are designing “tagging” mechanisms to allow us to track each page as they are crawled. When we find pages inside a cache we will be able to tell which crawler grabbed the page and when. This will allow us to know whether a SE is doing its own crawling or if they are obtaining crawl data from a third party. We are also increasing the variety of resource types in the web collections.

8. CONCLUSIONS

Warrick is not a substitute for digital preservation infrastructure and policy. Web repositories may not crawl orphan pages, protected pages (e.g., robots.txt, password, IP), very large pages, pages deep in a web collection or links influenced by JavaScript, Flash, or session IDs. If a web repository will not or cannot crawl it, Warrick cannot recover it. More significantly, Warrick can only reconstruct the external view of a website as viewed by a web crawler. The server-side components (CGI programs, databases, etc.) cannot be reconstructed from this external view.

We have measured the ability of Google, MSN and Yahoo! to cache 4 synthetic web collections over a period of 4 months. We measured web resources to be vulnerable for as little as 10 days and in the worst case, as long as our 90 day test period. More encouragingly, many HTML resources were recoverable for 20-90 days with TURs ranging from 8-61 days. Google proved to be the most consistent at caching our synthetic web collections.

We have also reconstructed a variety of actual websites from IA and the SEs with varying success. HTML resources were the most numerous (52%) type of resource in our collection of 24 websites and were the most successfully recoverable resource type (80% recoverable). Images were the second most numerous (40%) resource types, but they were less successfully recovered (53%). Here again, Google was the most frequent source (44%), but MSN was a close second (30%), followed by IA (19%) and Yahoo! (7%). The probability of reconstruction success was not correlated with PageRank or the size of the website.

9. REFERENCES

[1] H. Berghel. Responsible web caching. Communications of the ACM, 45(9):15–20, 2002.

[2] K. Bharat and A. Broder. Mirror, mirror on the web: a study of host pairs with replicated content. In Proceedings from WWW ’99, pages 1579–1590, 1999.

[3] O. Brandman, J. Cho, H. Garcia-Molina, and N. Shivakumar. Crawler-friendly web servers. SIGMETRICS Perform. Eval. Rev., 28(2):9–14, 2000.

[4] A. Z. Broder, S. C. Glassman, M. S. Manasse, and G. Zweig. Syntactic clustering of the web. Computer Networks and ISDN Systems, 29(8-13):1157–1166, 1997.

[5] A. Z. Broder, M. Najork, and J. L. Wiener. Efficient url caching for World Wide Web crawling. In Proceedings from WWW ’03, pages 679–689, 2003.

[6] J. Cho and H. Garcia-Molina. The evolution of the web and implications for an incremental crawler. In Proceedings from VLDB ’00, pages 200–209, 2000.

[7] J. Cho and H. Garcia-Molina. Parallel crawlers. In Proceedings from WWW ’02, pages 124–135, 2002.

[8] J. Cho and H. Garcia-Molina. Effective page refresh policies for web crawlers. ACM Trans. Database Syst., 28(4):390–426, 2003.

[9] J. Cho, H. Garcia-Molina, and L. Page. Efficient crawling through url ordering. Computer Networks and ISDN Systems, 30(1-7):161–172, 1998.

[10] J. Cho, N. Shivakumar, and H. Garcia-Molina. Finding replicated web collections. In Proceedings from SIGMOD ’00, pages 355–366, 2000.

[11] B. F. Cooper and H. Garcia-Molina. Infomonitor: Unobtrusively archiving a World Wide Web server. International Journal on Digital Libraries, 5(2):106–119, April 2005.

[12] M. Day. Collecting and preserving the World Wide Web, 2003.

[13] C. E. Dyreson, H. Lin, and Y. Wang. Managing versions of web documents in a transaction-time web server. In Proceedings from WWW ’04, pages 422–432, 2004.

[14] J. E. G. Coffman, Z. Liu, and R. R. Weber. Optimal robot scheduling for web search engines. Journal of Scheduling, 1(1):15–29, 1998.

[15] J. Edwards, K. McCarley, and J. Tomlin. An adaptive model for optimizing performance of an incremental web crawler. In Proceedings from WWW ’01, pages 106–113, 2001.

[16] J. Feise. An approach to persistence of web resources. In Proceedings from HYPERTEXT ’01, pages 215–216, 2001.

[17] D. Fetterly, M. Manasse, M. Najork, and J. Wiener. A large-scale study of the evolution of web pages. In Proceedings from WWW ’03, pages 669–678, 2003.

[18] A. Gulli and A. Signorini. The indexable web is more than 11.5 billion pages. In Proceedings from WWW ’05, pages 902–903, May 2005.

[19] V. Gupta and R. Campbell. Internet search engine freshness by web server help. In Proceedings from SAINT ’04, page 113, 2004.

[20] Y. Hafri and C. Djeraba. High performance crawling system. In Proceedings from MIR ’04, pages 299–306, 2004.

[21] How Do I Keep My Page from Being Cached in Yahoo! Search?, September 2005. http://help.yahoo.com/help/us/ysearch/basics/basics-10.html.

[22] Internet Archive FAQ: How can I get my site included in the Archive? http://www.archive.org/about/faqs.php.
[23] J. L. Marill, A. Boyko, M. Ashenfelder, and L. Graham. Tools and techniques for harvesting the World Wide Web. In Proceedings from JCDL ’04, page 403, 2004.

[24] F. Menczer, G. Pant, P. Srinivasan, and M. E. Ruiz. Evaluating topic-driven web crawlers. In Proceedings from SIGIR ’01, pages 241–249, 2001.

[25] MSN site owner help. September 2005. http://search.msn.com/docs/siteowner.aspx?t=SEARCH_WEBMASTER_REF_RestriXctAccessToSite.htm.

[26] M. L. Nelson, H. Van de Sompel, X. Liu, T. L. Harrison, and N. McFarland. mod_oai: An Apache module for metadata harvesting. In Proceedings from ECDL 2005, 2005.

[27] A. Ntoulas, J. Cho, and C. Olston. What’s new on the Web? The evolution of the web from a search engine perspective. In Proceedings from WWW ’04, pages 1–12, 2004.

[28] A. Ntoulas, P. Zerfos, and J. Cho. Downloading textual hidden web content through keyword queries. In Proceedings from JCDL ’05, pages 100–109, 2005.

[29] J. Ockerbloom. Mediating Among Diverse Data Formats. PhD thesis, Carnegie Mellon University, 1998.

[30] S. Olsen. Court backs thumbnail image linking. CNET News.com, July 2003. http://news.com.com/2100-1025_3-1023629.html.

[31] S. Raghavan and H. Garcia-Molina. Crawling the hidden web. In Proceedings from VLDB ’01, pages 129–138, 2001.

[32] H. C. Rao, Y. Chen, and M. Chen. A proxy-based personal web archiving service. SIGOPS Oper. Syst. Rev., 35(1):61–72, 2001.

[33] V. Reich and D. S. Rosenthal. LOCKSS: A permanent web publishing and access system. D-Lib Magazine, 7(6), 2001.

[34] Remove Cached Pages from Google, September 2005. http://www.google.com/remove.html.

[35] A. Ross. Internet Archive forums: Web forum posting. October 2004. http://www.archive.org/iathreads/post-view.php?id=23121.

[36] N. Shivakumar and H. Garcia-Molina. Scam: A copy detection mechanism for digital documents. In Proceedings from the Conference in Theory and Practice of Digital Libraries ’95, June 1995.

[37] N. Shivakumar and H. Garcia-Molina. Finding near-replicas of documents and servers on the web. In Proceedings from WebDB ’98, pages 204–212, 1999.

[38] P. Thathi, P. Chang, and G. Agha. Crawlets: Agents for high performance web search engines. In Proceedings from MA ’01, volume 2240, 2001.

[39] Web Characterization Terminology and Definition Sheet, W3C Working Draft 24-May-1999, May 1999. http://www.w3.org/1999/05/WCA-terms/.